RELION® PROTECTION AND CONTROL

REX640

Technical Manual

Document ID: 1MRS759142

Issued: 2023-02-07

Revision: F

Open Source Software

This product contains open source software. For license information refer to product documentation at *www.abb.com*.

Warranty

Please inquire about the terms of warranty from your nearest ABB representative.

www.abb.com/mediumvoltage

Disclaimer

The data, examples and diagrams in this manual are included solely for the concept or product description and are not to be deemed as a statement of guaranteed properties. All persons responsible for applying the equipment addressed in this manual must satisfy themselves that each intended application is suitable and acceptable, including that any applicable safety or other operational requirements are complied with. In particular, any risks in applications where a system failure and/or product failure would create a risk for harm to property or persons (including but not limited to personal injuries or death) shall be the sole responsibility of the person or entity applying the equipment, and those so responsible are hereby requested to ensure that all measures are taken to exclude or mitigate such risks.

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In case of discrepancies between the English and any other language version, the wording of the English version shall prevail.

Conformity

This product complies with the directive of the Council of the European Communities on the approximation of the laws of the Member States relating to electromagnetic compatibility (EMC Directive 2014/30/EU) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2014/35/EU). This conformity is the result of tests conducted by the third party testing laboratory Intertek in accordance with the product standard EN 60255-26 for the EMC directive, and with the product standards EN 60255-1 and EN 60255-27 for the low voltage directive. The product is designed in accordance with the international standards of the IEC 60255 series.

Contents

1 Introduction

1.1 This manual

The technical manual contains application and functionality descriptions and lists function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function. The manual can be used as a technical reference during the engineering phase, installation and commissioning phase, and during normal service.

1.2 Intended audience

This manual addresses system engineers and installation and commissioning personnel, who use technical data during engineering, installation and commissioning, and in normal service.

The system engineer must have a thorough knowledge of protection systems, protection equipment, protection functions and the configured functional logic in the protection relays. The installation and commissioning personnel must have a basic knowledge in handling electronic equipment.

1.3 Product documentation

1.3.1 Product documentation set

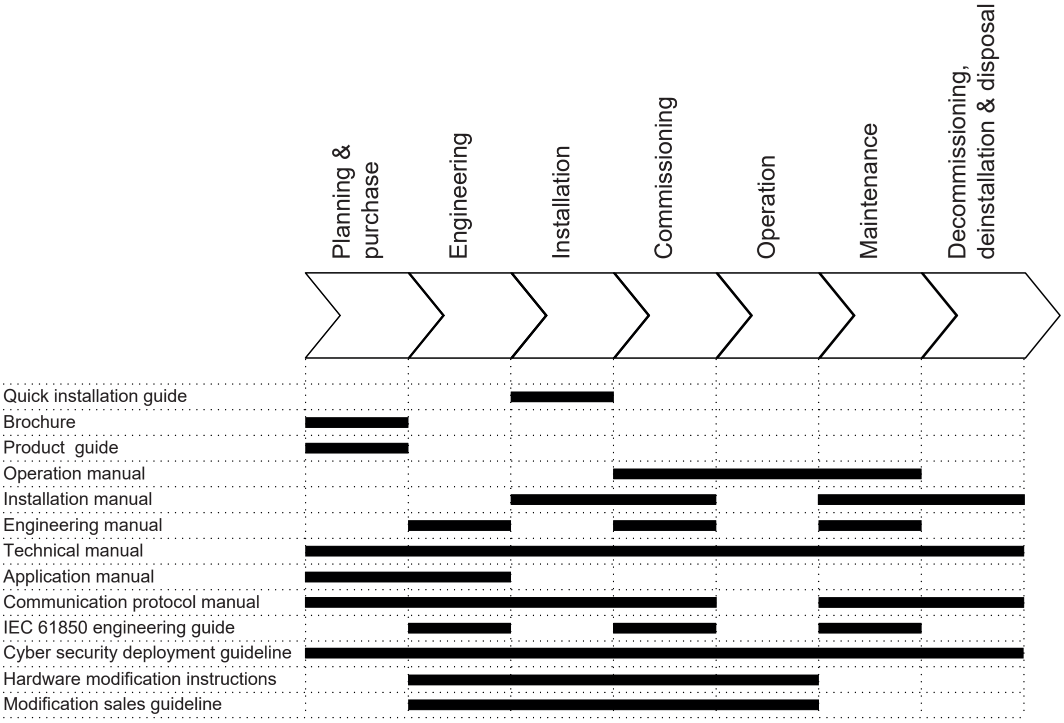


Figure 1: The intended use of documents during the product life cycle

1.3.2 Document revision history

Document revision/ date	Product connectivity level	History
A/2018-12-14	PCL1	First release
B/2019-03-27	PCL1	Content updated
C/2019-08-15	PCL1	Content updated
D/2020-02-13	PCL2	Content updated to correspond to the product connectivity level
E/2020-12-09	PCL3	Content updated to correspond to the product connectivity level
F/2023-02-07	PCL4	Content updated to correspond to the product connectivity level

1.3.3 Related documentation

Name of the document	Document ID
TISSUES Implementation Conformance Statement (TICS) for the IEC 61850 interface in REX640	1MRS759027
Protocol Implementation extra Information for Testing (PIX-IT) for the IEC 61850 interface in REX640	1MRS759030
Protocol Implementation extra Information for Testing (PIX-IT) for the IEC 61850 9–2LE interface in REX640	1MRS759037
Protocol Implementation Conformance Statement (PICS) for the IEC 61850 interface in REX640	1MRS759029
IEC 61850 Ed2 Model Implementation Conformance Statement (MICS) for REX640	1MRS759028

Download the latest documents from the ABB Web site *www.abb.com/mediumvoltage*.

1.4 Symbols and conventions

1.4.1 Symbols

The electrical warning icon indicates the presence of a hazard which could result in electrical shock.

The warning icon indicates the presence of a hazard which could result in personal injury.

The caution icon indicates important information or warning related to the concept discussed in the text. It might indicate the presence of a hazard which could result in corruption of software or damage to equipment or property.

The information icon alerts the reader of important facts and conditions.

The tip icon indicates advice on, for example, how to design your project or how to use a certain function.

Although warning hazards are related to personal injury, it is necessary to understand that under certain operational conditions, operation of damaged equipment may result in degraded process performance leading to personal injury or death. Therefore, comply fully with all warning and caution notices.

1.4.2 Document conventions

A particular convention may not be used in this manual.

- Abbreviations and acronyms are spelled out in the glossary. The glossary also contains definitions of important terms.
- Menu paths are presented in bold.

  Select **Main menu** > **Settings**.
- Parameter names are shown in italics.

  The function can be enabled and disabled with the *Operation* setting
- Parameter values are indicated with quotation marks.

  The corresponding parameter values are "On" and "Off".
- Input/output messages and monitored data names are shown in Courier font.

  When the function starts, the `START` output is set to TRUE.
- Values of quantities are expressed with a number and an SI unit. The corresponding imperial units may be given in parentheses.
- This document assumes that the parameter setting visibility is "Advanced".
- Protective earthing is indicated in figures with the symbol ⏚.

1.4.3 Functions, codes and symbols

Table 1: Functions included in the relay

Function	IEC 61850	IEC 60617	ANSI
Protection			
Distance protection	DSTPDIS	Z<	21P,21N
Local acceleration logic	DSTPLAL	LAL	21LAL
Scheme communication logic	DSOCPSCH	CL	85 21SCHLGC
Current reversal and weak-end infeed logic	CRWPSCH	CLCRW	85 21CREV,WEI
Communication logic for residual overcurrent	RESCPSCH	CLN	85 67G/N SCHLGC
Current reversal and weak-end infeed logic for residual overcurrent	RCRWPSCH	CLCRWN	85 67G/N CREV,WEI
Power swing detection	DSTRPSB	Zpsb	68
Line differential protection with inzone power transformer	LNPLDF	3Id/I>	87L
Binary signal transfer	BSTGAPC	BST	BST
Switch-onto-fault protection	CVPSOF	CVPSOF	SOTF
Three-phase non- directional overcurrent protection, low stage	PHLPTOC	3I>	51P-1
Three-phase non- directional overcurrent protection, high stage	PHHPTOC	3I>>	51P-2
Three-phase non- directional overcurrent protection, instantaneous stage	PHIPTOC	3I>>>	50P
Three-phase directional overcurrent protection, low stage	DPHLPDOC	3I>->	67P/51P-1
Three-phase directional overcurrent protection, high stage	DPHHPDOC	3I>>->	67P/51P-2
Non-directional earth-fault protection, low stage	EFLPTOC	Io>	51G/51N-1
Non-directional earth-fault protection, high stage	EFHPTOC	Io>>	51N-2
Non-directional earth-fault protection, instantaneous stage	EFIPTOC	Io>>>	50G/50N
Directional earth-fault protection, low stage	DEFLPDEF	Io>->	67G/N-1 51G/N-1
Directional earth-fault protection, high stage	DEFHPDEF	Io>>->	67G/N-1 51G/N-2
Three-phase power directional element	DPSRDIR	I1 ->	67P-TC
Neutral power directional element	DNZSRDIR	I2->,Io->	67N-TC
Admittance-based earth-fault protection	EFPADM	Yo>->	21YN
Multifrequency admittance-based earth-fault protection	MFADPSDE	Io>->Y	67NYH
Wattmetric-based earth-fault protection	WPWDE	Po>->	32N
Transient/intermittent earth-fault protection	INTRPTEF	Io>->IEF	67NTEF/NIEF
Harmonics-based earth-fault protection	HAEFPTOC	Io>HA	51NH
Touch voltage based earth-fault current protection	IFPTOC	IF>/UT>	46SNQ/59N
Negative-sequence overcurrent protection	NSPTOC	I2>M	46M

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Phase discontinuity protection	PDNSPTOC	I2/I1>	46PD
Residual overvoltage protection	ROVPTOV	Uo>	59G/59N
Three-phase undervoltage protection	PHPTUV	3U<	27
Three-phase overvoltage variation protection	PHVPTOV	3Urms>	59.S1
Three-phase overvoltage protection	PHPTOV	3U>	59
Positive-sequence overvoltage protection	PSPTOV	U1>	59PS
Positive-sequence undervoltage protection	PSPTUV	U1<	27PS
Negative-sequence overvoltage protection	NSPTOV	U2>	47,59NS
Frequency protection	FRPFRQ	f>/f<,df/dt	81
Three-phase voltage-dependent overcurrent protection	PHPVOC	3I(U)>	51V
Overexcitation protection	OEPVPH	U/f>	24
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR	3Ith>F	49F
Three-phase thermal overload protection, two time constants	T2PTTR	3Ith>T/G/C	49T/G/C
Three-phase overload protection for shunt capacitor banks	COLPTOC	3I>3I<	51,37,86C
Current unbalance protection for shunt capacitor banks	CUBPTOC	dI>C	60N
Three-phase current unbalance protection for shunt capacitor banks	HCUBPTOC	3dI>C	60P
Shunt capacitor bank switching resonance protection, current based	SRCPTOC	TD>	55ITHD
Compensated neutral unbalance voltage protection	CNUPTOV	CNU>	59NU
Directional negative- sequence overcurrent protection	DNSPDOC	I2>->	67Q
Low-voltage ride- through protection	LVRTPTUV	UU	27RT
Voltage vector shift protection	VVSPPAM	VS	78VS
Directional reactive power undervoltage protection	DQPTUV	Q>-> ,3U<	32Q,27
Reverse power/ directional overpower protection	DOPPDPR	P>/Q>	32R/32O
Underpower protection	DUPPDPR	P<	32U
Three-phase under impedance protection	UZPDIS	ZZ	21G
Directional negative sequence impedance protection	DNZPDIS	Z2->	Z2Q
Three-phase under excitation protection	UEXPDIS	X<	40
Third harmonic-based stator earth-fault protection	H3EFPSEF	dUo>/Uo3H	64TN
Rotor earth-fault protection (injection method)	MREFPTOC	Io>R	64R
Generator shaft leakage current	GSLPTOC	I>,GS	38, 51
Thermal overload protection for rotors	RPTTR	3Ith>R	49R
High-impedance or flux-balance based differential protection	MHZPDIF	3dIHi>M	87HIM
Out-of-step protection with double blinders	OOSRPSB	OOS	78PS
Negative-sequence overcurrent protection for machines	MNSPTOC	I2>M	46M

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Loss of phase, undercurrent	PHPTUC	3I<	37
Loss of load supervision	LOFLPTUC	3I<	37
Motor load jam protection	JAMPTOC	Ist>	50TDJAM
Motor start-up supervision	STTPMSU	Is2t n<	49,66,48,50TDLR
Motor start counter	MSCPMRI	n<	66
Phase reversal protection	PREVPTOC	I2>>	46R
Thermal overload protection for motors	MPTTR	3Ith>M	49M
Stabilized and instantaneous differential protection for machines	MPDIF	3dI>M/G	87M/87G
Underpower factor protection	MPUPF	PF<	55U
Stabilized and instantaneous differential protection for two- or three- winding transformers	TR3PTDF	3dI>3W	87T3
Stabilized and instantaneous differential protection for two-winding transformers	TR2PTDF	3dI>T	87T
Numerical stabilized low-impedance restricted earth-fault protection	LREFPNDF	dIoLo>	87NLI
High-impedance based restricted earth- fault protection	HREFPDIF	dIoHi>	87NHI
High-impedance differential protection for phase A	HIAPDIF	dHi_A>	87_A
High-impedance differential protection for phase B	HIBPDIF	dHi_B>	87_B
High-impedance differential protection for phase C	HICPDIF	dHi_C>	87_C
Circuit breaker failure protection	CCBRBRF	3I>/Io>BF	50BF
Three-phase inrush detector	INRPHAR	3I2f>	68HB
Master trip	TRPPTRC	Master Trip	94/86
Arc protection	ARCSARC	ARC	AFD
High-impedance fault detection	PHIZ	HIF	HIZ
Cable Fault Detection	RCFD	CFD	CFD
Fault locator	SCEFRFLO	FLOC	FLOC
Load-shedding and restoration	LSHDPFRQ	UFLS/R	81LSH
Multipurpose protection	MAPGAPC	MAP	MAP
Accidental energization protection	GAEPVOC	U<,I>	50/27
Load blinder	LBRDOB	LB	21LB
Control			
Circuit-breaker control	CBXCBR	I <-> O CB	52
Three-state disconnector control	P3SXSWI	I<->O P3S	29DS/GS
Disconnector control	DCXSWI	I <-> O DCC	29DS
Earthing switch control	ESXSWI	I <-> O ESC	29GS
Three-state disconnector position indication	P3SSXSWI	I<->O P3SS	29DS/GS

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Disconnector position indication	DCSXSWI	I <-> O DC	29DS
Earthing switch position indication	ESSXSWI	I <-> O ES	29GS
Motor controlled earthing switch and disconnector supervision	ESDCSSWI	ESDCCM	29CM
Emergency start-up	ESMGAPC	ESTART	EST,62
Autoreclosing	DARREC	O->I	79
Autosynchronizer for generator breaker	ASGCSYN	AUTOSYNCG	25AUTOSYNCG
Autosynchronizer for network breaker	ASNSCSYN	AUTOSYNC	25AUTOSYNCBT/T
Autosynchronizer co-ordinator	ASCGAPC	AUTOSYNC	25AUTOSYNC
Synchronism and energizing check	SECRSYN	SYNC	25
Tap changer control with voltage regulator	OL5ATCC	COLTC	90V
Transformer data combiner	OLGAPC	OLGAPC	OLGAPC
Petersen coil controller	PASANCR	ANCR	90
High speed bus transfer	HSABTC	I<->O BT	HSBT
Condition monitoring and supervision			
Circuit-breaker condition monitoring	SSCBR	CBCM	52CM
Hot-spot and insulation ageing rate monitoring for transformers	HSARSPTR	3Ihp>T	26/49HS
Trip circuit supervision	TCSSCBR	TCS	TCM
Current circuit supervision	CCSPVC	MCS 3I	CCM
Current circuit supervision for transformers	CTSRCTF	MCS 3I,I2	CCM 3I,I2
Current transformer supervision for high- impedance protection scheme for phase A	HZCCASPVC	MCS I_A	CCM_A
Current transformer supervision for high- impedance protection scheme for phase B	HZCCBSPVC	MCS I_B	CCM_B
Current transformer supervision for high- impedance protection scheme for phase C	HZCCCSPVC	MCS I_C	CCM_C
Fuse failure supervision	SEQSPVC	FUSEF	VCM, 60
Protection communication supervision	PCSITPC	PCS	PCS
Runtime counter for machines and devices	MDSOPT	OPTS	OPTM
Three-phase remanent undervoltage supervision	MSVPR	3U<R	27R
Diesel Generator Monitoring	DGMGAPC	P><,U/f ><	32/40G
Measurement			
Three-phase current measurement	CMMXU	3I	IA, IB, IC
Sequence current measurement	CSMSQI	I1, I2, I0	I1, I2, I0
Residual current measurement	RESCMMXU	Io	IG
Three-phase voltage measurement	VMMXU	3U	VA, VB, VC
Single-phase voltage measurement	VAMMXU	U_A	V_A

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Phase voltage measurement	VPHMMXU	3UL	VL
Residual voltage measurement	RESVMMXU	Uo	VG/VN
Sequence voltage measurement	VSMSQI	U1, U2, U0	V1, V2, V0
Three-phase power and energy measurement	PEMMXU	P, E	P, E
Load profile recorder	LDPRLRC	LOADPROF	LOADPROF
Frequency measurement	FMMXU	f	f
Tap changer position indication	TPOSYLTC	TPOSM	84T
Power quality			
Current total demand, harmonic distortion, DC component (TDD, THD, DC) and individual harmonics	CHMHAI	PQM3IH	PQM ITHD,IDC
Voltage total harmonic distortion, DC component (THD, DC) and individual harmonics	VHMHAI	PQM3VH	PQM VTHD,VDC
Voltage variation	PHQVVR	PQMU	PQMV SWE,SAG,INT
Voltage unbalance	VSQVUB	PQUUB	PQMV UB
Traditional LED indication			
LED indication control	LEDPTRC	LEDPTRC	LEDPTRC
Individual virtual LED control	LED	LED	LED
Logging functions			
Disturbance recorder (common functionality)	RDRE	DR	RDRE
Disturbance recorder, analog channels 1...12	A1RADR	A1RADR	A1RADR
Disturbance recorder, analog channels 13...24	A2RADR	A2RADR	A2RADR
Disturbance recorder, binary channels 1...32	B1RBDR	B1RBDR	B1RBDR
Disturbance recorder, binary channels 33...64	B2RBDR	B2RBDR	B2RBDR
Fault recorder	FLTRFRC	FAULTREC	FR
Other functionality			
Parameter setting groups	PROTECTION	PROTECTION	PROTECTION
Time master supervision	GNRLLTMS	TSYNC	TSYNC
Serial port supervision	SERLCCH	SERLCCH	SERLCCH
IEC 61850-1 MMS	MMSLPRT	MMS	MMS
IEC 61850-1 GOOSE	GSELPRT	GSE	GSE
IEC 60870-5-103 protocol	I3CLPRT	I3C	I3C
IEC 60870-5-104 protocol	I5CLPRT	I5C	I5C
DNP3 protocol	DNPLPRT	DNP 3.0	DNP 3.0
Modbus protocol	MBSLPRT	MBS	MBS
OR gate with two inputs	OR	OR	OR
OR gate with six inputs	OR6	OR6	OR6

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
OR gate with twenty inputs	OR20	OR20	OR20
AND gate with two inputs	AND	AND	AND
AND gate with six inputs	AND6	AND6	AND6
AND gate with twenty inputs	AND20	AND20	AND20
XOR gate with two inputs	XOR	XOR	XOR
NOT gate	NOT	NOT	NOT
Real maximum value selector	MAX3R	MAX3R	MAX3R
Real minimum value selector	MIN3R	MIN3R	MIN3R
Rising edge detector	R_TRIG	R_TRIG	R_TRIG
Falling edge detector	F_TRIG	F_TRIG	F_TRIG
Real switch selector	SWITCHR	SWITCHR	SWITCHR
Integer 32-bit switch selector	SWITCHI32	SWITCHI32	SWITCHI32
SR flip-flop, volatile	SR	SR	SR
RS flip-flop, volatile	RS	RS	RS
Minimum pulse timer, two channels	TPGAPC	TP	62TP
Minimum pulse timer second resolution, two channels	TPSGAPC	TPS	62TPS
Minimum pulse timer minutes resolution, two channels	TPMGAPC	TPM	62TPM
Pulse counter for energy measurement	PCGAPC	PCGAPC	PCGAPC
Pulse timer, eight channels	PTGAPC	PT	62PT
Time delay off, eight channels	TOFGAPC	TOF	62TOF
Time delay on, eight channels	TONGAPC	TON	62TON
Daily timer	DTMGAPC	DTM	DTM
Calendar function	CALGAPC	CAL	CAL
SR flip-flop, eight channels, nonvolatile	SRGAPC	SR	SR
Boolean value event creation	MVGAPC	MV	MV
Integer value event creation	MVI4GAPC	MVI4	MVI4
Analog value event creation with scaling	SCA4GAPC	SCA4	SCA4
Generic control points	SPCGAPC	SPC	SPCG
Generic up-down counter	UDFCNT	UDCNT	UDCNT
Local/Remote control	CONTROL	CONTROL	CONTROL
External HMI wake-up	EIHMI	EIHMI	EIHMI
Real addition	ADDR	ADDR	ADDR
Real subtraction	SUBR	SUBR	SUBR
Real multiplication	MULR	MULR	MULR
Real division	DIVR	DIVR	DIVR

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Real equal comparator	EQR	EQR	EQR
Real not equal comparator	NER	NER	NER
Real greater than or equal comparator	GER	GER	GER
Real less than or equal comparator	LER	LER	LER
Voltage switch	VMSWI	VSWI	VSWI
Current sum	CMSUM	CSUM	CSUM
Current switch	CMSWI	CMSWI	CMSWI
Phase current preprocessing	ILTCTR	ILTCTR	ILTCTR
Residual current preprocessing	RESTCTR	RESTCTR	RESTCTR
Phase and residual voltage preprocessing	UTVTR	UTVTR	UTVTR
Residual current preprocessing, current measured as voltage	RESUTCTR	Io(U)	Io(U)
SMV stream receiver (IEC 61850-9-2LE)	SMVRCV	SMVRCV	SMVRCV
SMV stream sender (IEC 61850-9-2LE)	SMVSENDER	SMVSENDER	SMVSENDER
Redundant Ethernet channel supervison	RCHLCCH	RCHLCCH	RCHLCCH
Ethernet channel supervision	SCHLCCH	SCHLCCH	SCHLCCH
HMI Ethernet channel supervision	HMILCCH	HMILCCH	HMILCCH
Received GOOSE binary information	GOOSERCV_BIN	GOOSERCV_BIN	GOOSERCV_BIN
Received GOOSE double binary information	GOOSERCV_DP	GOOSERCV_DP	GOOSERCV_DP
Received GOOSE measured value information	GOOSERCV_MV	GOOSERCV_MV	GOOSERCV_MV
Received GOOSE 8- bit integer value information	GOOSERCV_INT8	GOOSERCV_INT8	GOOSERCV_INT8
Received GOOSE 32- bit integer value information	GOOSERCV_INT32	GOOSERCV_INT32	GOOSERCV_INT32
Received GOOSE interlocking information	GOOSERCV_INTL	GOOSERCV_INTL	GOOSERCV_INTL
Received GOOSE measured value (phasor) information	GOOSERCV_CMV	GOOSERCV_CMV	GOOSERCV_CMV
Received GOOSE enumerator value information	GOOSERCV_ENUM	GOOSERCV_ENUM	GOOSERCV_ENUM
Bad signal quality	QTY_BAD	QTY_BAD	QTY_BAD
Good signal quality	QTY_GOOD	QTY_GOOD	QTY_GOOD
Received GOOSE Test mode	QTY_GOOSE_TEST	QTY_GOOSE_TEST	QTY_GOOSE_TEST
GOOSE communication quality	QTY_GOOSE_COMM	QTY_GOOSE_COMM	QTY_GOOSE_COMM
GOOSE data health	T_HEALTH	T_HEALTH	T_HEALTH
Fault direction evaluation	T_DIR	T_DIR	T_DIR
Enumerator to boolean conversion	T_TCMD	T_TCMD	T_TCMD
32-bit integer to binary command conversion	T_TCMD_BIN	T_TCMD_BIN	T_TCMD_BIN
Binary command to 32-bit integer conversion	T_BIN_TCMD	T_BIN_TCMD	T_BIN_TCMD
Switching device status decoder - CLOSE position	T_POS_CL	T_POS_CL	T_POS_CL

Table continues on the next page

Function	IEC 61850	IEC 60617	ANSI
Switching device status decoder - OPEN position	T_POS_OP	T_POS_OP	T_POS_OP
Switching device status decoder - OK status	T_POS_OK	T_POS_OK	T_POS_OK
Controllable gate, 8 Channels	GATEGAPC	GATEGAPC	GATEGAPC
Security application	GSAL	GSAL	GSAL
Hotline tag	HLTGAPC	HLTGAPC	HLTGAPC
16 settable 32-bit integer values	SETI32GAPC	SETI32GAPC	SETI32GAPC
16 settable real values	SETRGAPC	SETRGAPC	SETRGAPC
Boolean to integer 32- bit conversion	T_B16_TO_I32	T_B16_TO_I32	T_B16_TO_I32
Integer 32-bit to boolean conversion	T_I32_TO_B16	T_I32_TO_B16	T_I32_TO_B16
Integer 32-bit to real conversion	T_I32_TO_R	T_I32_TO_R	T_I32_TO_R
Real to integer 8-bit conversion	T_R_TO_I8	T_R_TO_I8	T_R_TO_I8
Real to integer 32-bit conversion	T_R_TO_I32	T_R_TO_I32	T_R_TO_I32
Constant FALSE	FALSE	FALSE	FALSE
Constant TRUE	TRUE	TRUE	TRUE

2 REX640 overview

2.1 Overview

REX640 is a powerful all-in-one protection and control relay for use in advanced power distribution and generation applications with unmatched flexibility available during the complete life cycle of the device – from ordering of the device, through testing and commissioning to upgrading the functionality of the modular software and hardware as application requirements change.

The modular design of both hardware and software elements facilitates the coverage of any comprehensive protection application requirement that may arise during the complete life cycle of the relay and substation.

REX640 makes modification and upgrading easy and pushes the limits of what can be achieved with a single device.

2.1.1 PCM600 and relay connectivity package version

- Protection and Control IED Manager PCM600 Ver. 2.12 or later
- REX640 Connectivity Package Ver. 1.3.0 or later

Download connectivity packages from the ABB Web site *www.abb.com/mediumvoltage* or directly with Update Manager in PCM600.

2.2 Relay hardware

The relay includes a Ready LED on the power supply module that indicates the relay's status. In normal situations, the Ready LED has a steady green light. Any other situation that requires the operator's attention is indicated with a flashing light.

The relay has mandatory and optional slots. A mandatory slot always contains a module but an optional slot may be empty, depending on the composition variant ordered.

Table 2: Module slots

Module	Slot A1	Slot A2	Slot B	Slot C	Slot D	Slot E	Slot F	Slot G
ARC1001	o							
COM1001		•						
COM1002		•						
COM1003		•						

Table continues on the next page

Module	Slot A1	Slot A2	Slot B	Slot C	Slot D	Slot E	Slot F	Slot G
COM1004		●						
COM1005		●						
BIO1001			●	o	o			
BIO1002			●	o	o			
BIO1003						o		
BIO1004						o		
RTD1001				o	o			
RTD1002				o	o			
AIM1001						o	●	
AIM1002						o	●	
SIM1901						o	●	
SIM1902						o	●	
PSM1001								●
PSM1002								●
PSM1003								●

● = Mandatory to have one of the allocated modules in the slot

o = Optional to have one of the allocated modules in the slot. The population (order) of the modules in the optional slots depends on the composition variant ordered.

In case the relay and the HMI will be exposed to harsh environmental conditions; like high humidity, chemicals or other corrosive agents, we recommend using the conformal coated versions of both. Contact the nearest ABB sales representative for more information regarding the ordering data.

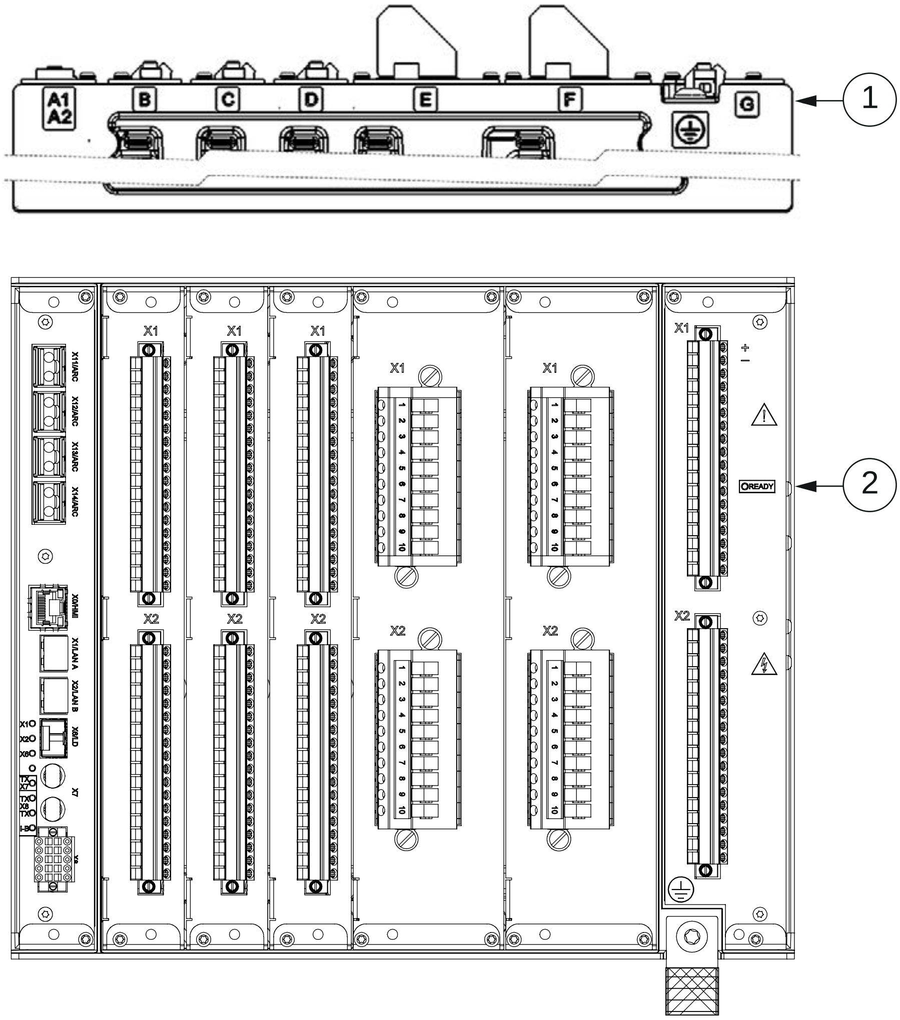


Figure 2: Hardware module slot overview of the REX640 relay

1 Slot markings in enclosure (top and bottom)

2 Ready LED

Table 3: Module description

Module	Description
ARC1001	4 × ARC sensor inputs (lense, loop or mixed)
COM1001	1 × RJ-45 (LHMI port) + 3 × RJ-45 + 1 × LD-SFP [1]
COM1002	1 × RJ-45 (LHMI port) + 2 × LC + 1 × RJ-45 + 1 × LD-SFP
COM1003	1 × RJ-45 (LHMI port) + 3 × LC + 1 × LD-SFP
COM1004	1 × RJ-45 (LHMI port) + 2 × RJ-45 + 1 × LD-SFP + 1 × RS-485/IRIG-B + 1 × FO UART

Table continues on the next page

[1] Line distance/line differential protection communication + binary signal transfer, optical multi-mode or single-mode LC small form-factor pluggable transceiver (SFP)

Module	Description
COM1005	1 × RJ-45 (LHMI port) + 2 × LC + 1 × LD-SFP + 1 × RS-485/IRIG-B + 1 × FO UART
BIO1001/ BIO1003	14 × BI + 8 × SO
BIO1002/ BIO1004	6 × SPO + 2 × SPO (TCS) + 9 × BI
RTD1001	10 × RTD channels + 2 × mA channels (input/output)
RTD1002	3 × RTD channels + 6 × mA channels (input/output) + 12 x BI
AIM1001	4 × CT + 1 × CT (sensitive, for residual current only) + 5 × VT
AIM1002	6 × CT + 4 × VT
SIM1901	3 × combi sensor inputs (RJ-45) + 1 × CT (sensitive, for residual current only) + 1 × VT
SIM1902	3 × combi sensor inputs (RJ-45) + 1 × CT (sensitive, for residual current only) + 1 × VT
PSM1001	24...60 VDC, 3 × PO (TCS) + 2 × PO + 3 × SO + 2 × SSO
PSM1002	48...250 VDC / 100...240 VAC, 3 × PO (TCS) + 2 × PO + 3 × SO + 2 × SSO
PSM1003	110/125 VDC (77...150 VDC), 3 × PO (TCS) + 2 × PO + 3 × SO + 2 × SSO

PO = Power Output
SPO = Static Power Output
SO = Signal Output
SSO = Static Signal Output

The relay has a nonvolatile memory which does not need any periodical maintenance. The nonvolatile memory stores all events, recordings and logs to a memory which retains data if the relay loses its auxiliary supply.

2.3 Local HMI

The LHMI is used for setting, monitoring and controlling the protection relay and the related process. It comprises a 7-inch color screen with capacitive touch sensing and a Home button at the bottom of the LHMI.

The LHMI must be paired with the protection relay to enable all the functionalities in it. See the operation manual for the pairing procedure.

The LHMI is an accessory for the relay which is fully operational even without the LHMI.

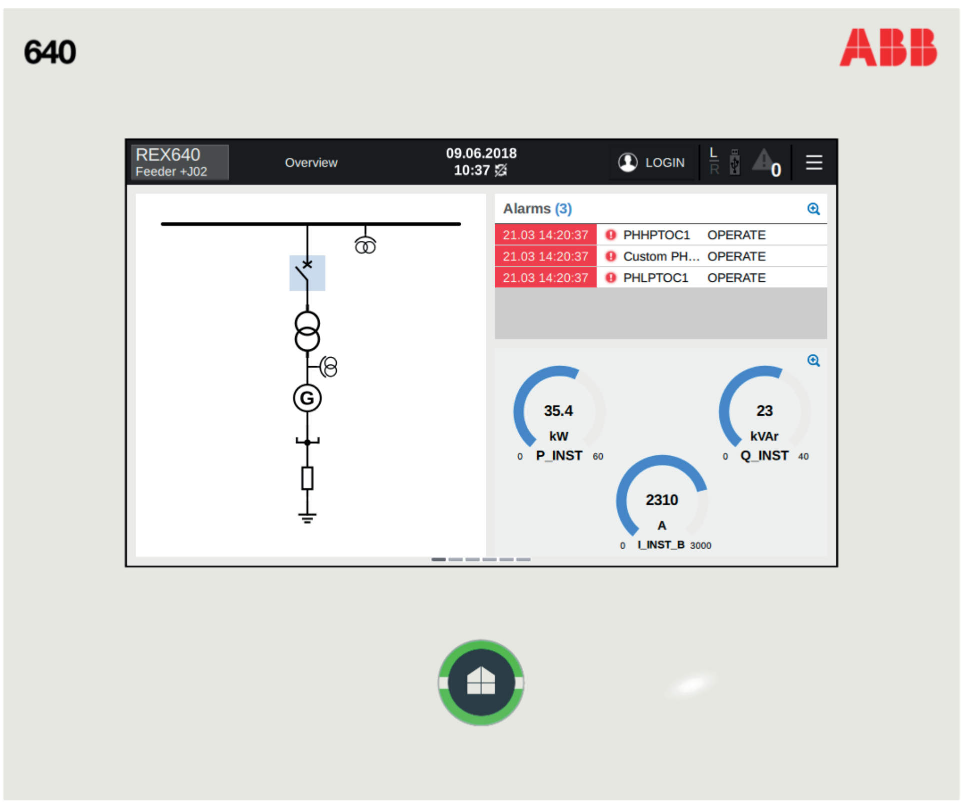


Figure 3: Example of a local HMI page

The LHMI presents pages in two categories.

- Operator pages are typically required as a part of an operator's normal activities, such as a single-line diagram, controls, measurements, events or alarms
- Engineer pages are specifically designed pages supporting relay parametrization, troubleshooting, testing and commissioning activities

The Operator pages can be scrolled either by pressing the Home button or by swiping the actual pages. The Engineer pages are accessible by tapping the menu button in the menu bar on the top of the LHMI display.

The Home button indicates the relay's status at a glance. In normal situations, the Home button shows a steady green light. Any other situation that requires the operator's attention is indicated with a flashing light, a red light or a combination of these.

Table 4: Power supply module Ready LED and local HMI Home button LED

State	Power supply module Ready LED	LHMI Home button	Alarm acknowledged
Relay under normal operation and LHMI connected	Steady green	Steady green	N/A
Relay's IRF activated, but communicates with LHMI	High frequency blinking green [1]	High frequency blinking red [1]	N/A

Table continues on the next page

[1] High frequency = 3 Hz

State	Power supply module Ready LED	LHMI Home button	Alarm acknowledged
Communication lost between Relay and LHMI, but no IRF	Steady green	High frequency blinking green [1]	N/A
LHMI not running normally or in start-up initialization phase	Steady green	High frequency blinking green [1]	N/A
Process related alarm active	Steady green	Low frequency blinking red [2]	No
Process related alarm active	Steady green	Steady red	Yes
Process related alarm has been active earlier, but is not any more active.	Steady green	Low frequency blinking red [2]	No
Process related alarm has been active earlier, but is not any more active.	Steady green	Steady green	Yes
Relay set to Test Mode	Low frequency blinking green [2]	High frequency blinking green [2]	No

The Operator pages can be used as such or customized according to the project's requirements using Graphical Display Editor in PCM600. The Engineer pages are fixed and cannot be customized.

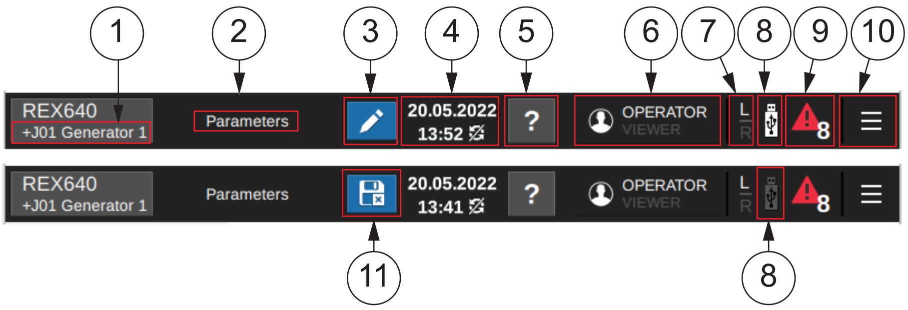


Figure 4: Menu bar elements

1	Bay name for the relay
2	Page name
3	Edit mode active (parameter editing)
4	Date, time and time synchronization status
5	Page help (visible if help is available for the page)
6	Login button/logged in user indication
7	Local/remote indication
8	USB memory not connected/connected (visible only if USB port is enabled)
9	Number of active alarms
10	Menu button for Engineer pages
11	Store or reject changed parameters indication

[2] Low frequency = 1 Hz

Table 5: Local HMI default pages

Page category	Pages	Subpages
Operator pages	Overview	Alarms
	Events	
	Fault Records	
	Timeline	
	Measurements	Phasors Load Profile Records
Engineer pages	Parameters	
	Testing and Commissioning	Force Functions Force Outputs Simulate Inputs View I/O Send Events Secondary Injection Monitoring Protection Measurement Direction Coil Controller Commissioning [3] View GOOSE sending View GOOSE receiving View SMV sending View SMV receiving
	Relay Status	Monitoring
	Clear	
	Disturbance Records	
	Alarms	
	Device Information	
	USB Actions	

[3] Available with the Petersen coil control application package

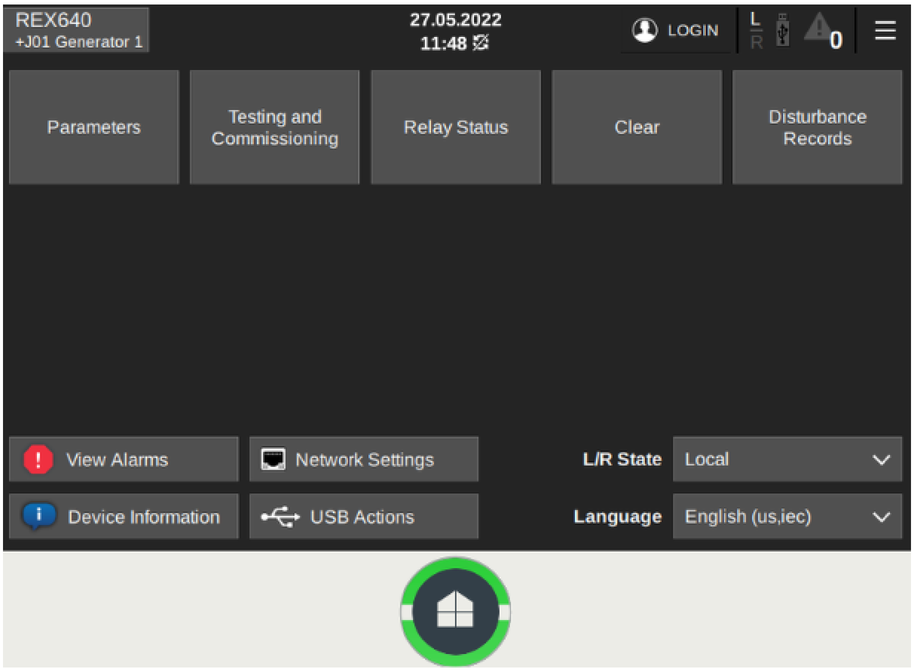


Figure 5: Engineer pages menu

2.4 Switchgear HMI

The SHMI is used for setting, monitoring and controlling up to 20 REX640 protection relays and the related processes. It comprises a 7-inch color screen with capacitive touch sensing and a Home button at the bottom of the SHMI. All features of standard HMI are also available in the SHMI.

The SHMI is an accessory for the relay which is fully operational even without the SHMI.

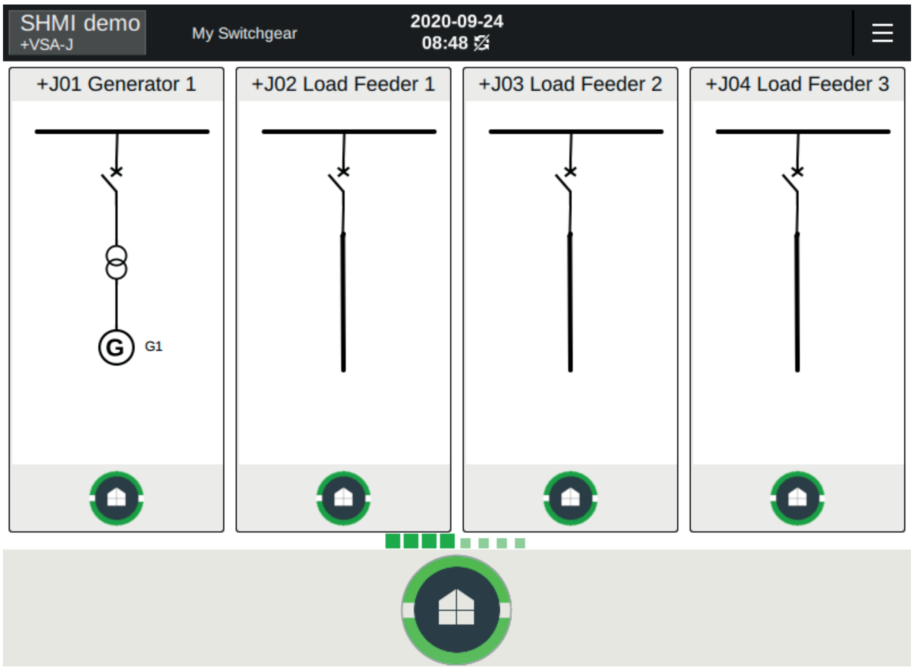


Figure 6: Example of a switchgear HMI navigation page

The SHMI has a navigation page which presents the physical switchgear lineup installation and indicates the status of each REX640 within the system. The area presenting a single switchgear bay has a small user-configurable bay overview section and a virtual Home button showing the status of the connected relay. By tapping the selected bay overview area, the SHMI connects with the related REX640 and works as normal LHMI for that relay.

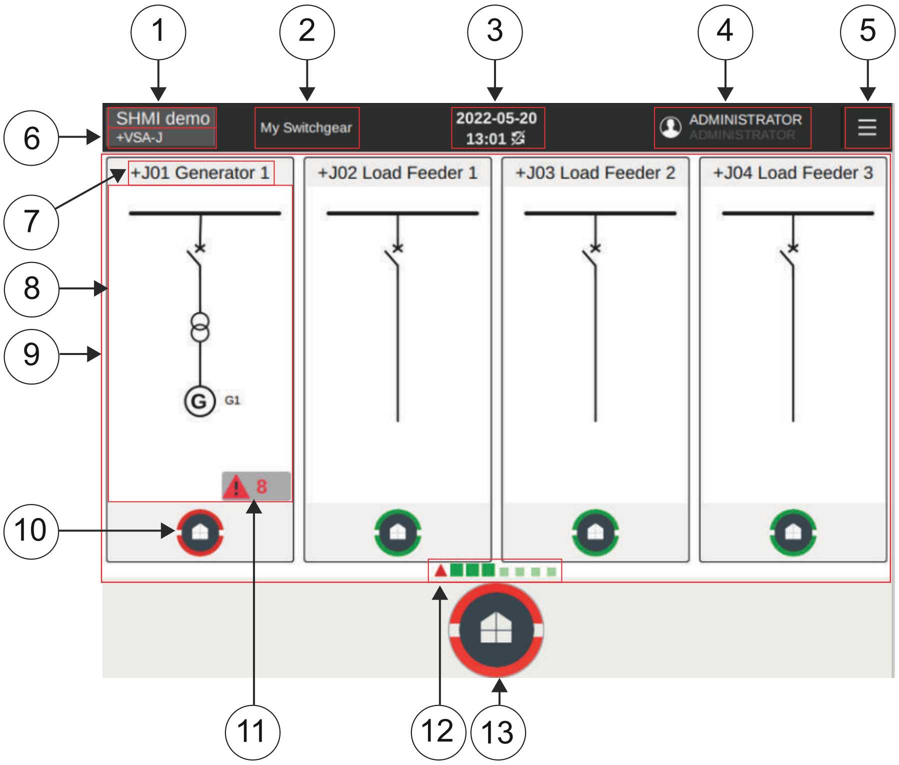


Figure 7: Navigation page elements

1	User-defined substation name
2	User-defined name for the switchgear or sub-part of switchgear lineup controlled by the SHMI
3	Date, time and time synchronization status
4	Logout button and authentication status
5	Menu button
6	User-defined voltage level name
7	User defined bay name and voltage level extension
8	Bay overview area showing static or dynamic information for a bay and functioning as a navigation point to launch the HMI view for the respective relay, user-defined content
9	SHMI navigation page
10	Virtual Home button representing the status of the respective relay's physical Home button
11	Number of active alarms
12	Panel lineup overview showing the current status of all connected relays and the current position of navigation page
13	SHMI's physical Home button

2.4.1 Bay overview area

Bay overview area consists either of a static picture or a dynamic SLD. They are configured with Graphical Display Editor in PCM600. One relay can have two overview pages.

Static picture may be, for example, a drawing or a photo of switchgear lineup. Maximum size of the picture is 186 × 320 px.

SLD does not support control operations. The following features are available.

- Static symbols such as connections, measurement devices, transformers and reactors
- Dynamic status for switching devices, but no control operations
- Dynamic and static text objects
  - Boolean state text
  - Integer state text
  - Label (translation not supported)
  - Numeric value
  - String value
- Custom symbols
- Busbar coloring

2.4.2 Physical and virtual Home buttons

On the SHMI navigation page, the virtual Home button shows the status of each relay as it would be shown with the physical Home button on a normal LHMI panel. In normal situations, the virtual Home button shows a steady green light. All other situations in which the relay requires operator’s attention are indicated with a flashing light, a red light or a combination of these.

SHMI’s physical Home button has two operation modes.

- On the SHMI navigation page, the Home button indicates the combined status of all connected relays. If multiple relays have different statuses, the Home button shows the indication with the highest priority.
- On the HMI view, the Home button indicates the status of the respective relay as described in *Figure 3*.

2.4.3 Navigation

Navigation page is the default view for the SHMI. The navigation page shows bay overviews areas which are lined up to represent the actual panel installations. The navigation page can be scrolled by swiping the screen horizontally or by pressing the physical Home button to move the page from left to right one bay overview at a time.

Bay overview area is the configured view for one relay. It may show static or dynamic information but all control operations are disabled. The whole bay overview area works as a navigation point to the relay’s HMI view. Tapping this area opens the HMI view of the respective relay.

Panel lineup overview shows the position of the navigation page by highlighting the visible bay overviews. It also shows the status of all connected relays and helps in identifying which relay requires operator's attention when the bay overview is not visible on the navigation page.

When the HMI view is opened for a relay, the SHMI works exactly like a normal HMI. All the same features are available, and the Home button switches between the configured home pages and indicates the alarm status for the respective relay.

Navigation area on the top left corner of the HMI view is used to navigate back to the SHMI's navigation page. The navigation area shows the bay name on the button to identify which relay's HMI is open.

2.5 Physical ports

The relay communication module has a dedicated port where the LHMI is connected using an RJ-45 connector and a CAT 6 S/FTP galvanic cable. The HMI can be connected to the relay also via station communication network if a longer distance is required between the relay and the HMI. For more information, see the installation manual.

Additionally, the HMI contains one Ethernet service port with an RJ-45 connector and one USB port. The service port can be used for the PCM600 connection or for WHMI connection. Data transfer to a USB stick is enabled via the USB port. By default the USB port is disabled and has to be taken into use with a specific parameter.

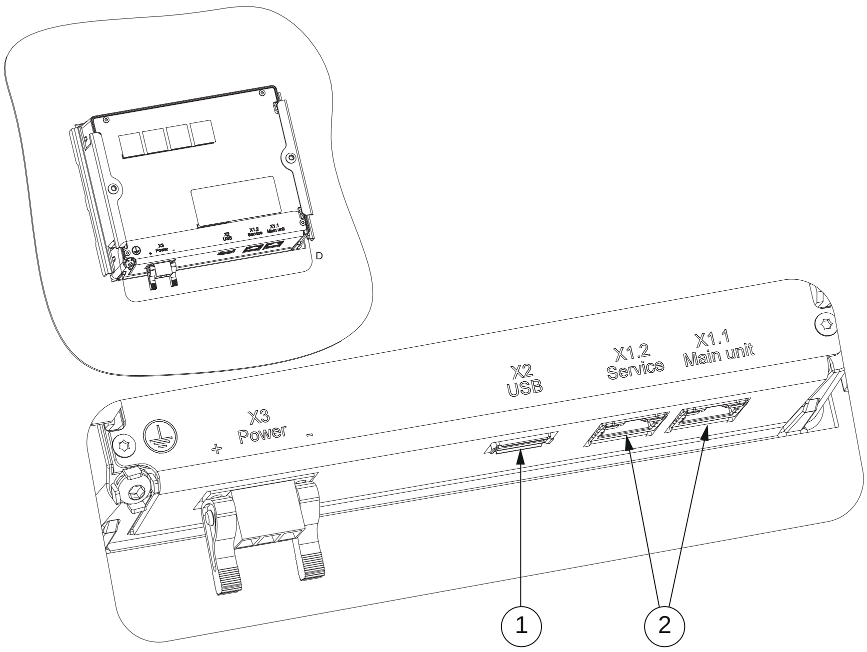


Figure 8: Local HMI connectors

1 USB port

2 RJ-45 ports

2.6 Web HMI

The WHMI allows secure access to the protection relay via a Web browser. The WHMI is verified with Google Chrome, Mozilla Firefox and Microsoft Edge.

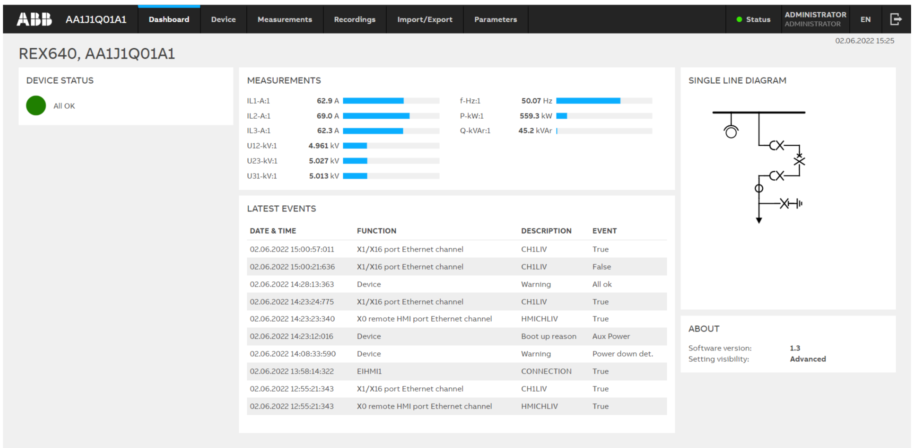


Figure 9: Example view of the Web HMI

WHMI offers several functions. The menu tree structure on the WHMI is almost identical to the one on the LHMI.

Table 6: Web HMI main groups and submenus

Main groups	Submenus	Description
Dashboard		Used to see an overview of the protection relay including status, measurements, single-line diagram and latest events
Device	Monitoring Information Self-supervision Single Line Diagram Clear Change Password About	Used to navigate to monitoring, information, self-supervision, single-line diagram or clear pages
Measurements	Measurements Phasor Diagrams	Used to navigate to the measurements or phasor diagrams
Recordings	Events Disturbance records Fault records Load Profile Record Alarm List	Used to view the events, disturbance records, fault records, load profile records and alarms
Import/Export	Report Summary Import/Export Set-tings Parameter List	Used to export a parameter list or a report summary, and to import and export settings

Table continues on the next page

Main groups	Submenus	Description
Parameters		Used to view the menu tree structure for the protection relay's setting parameters
Language selection		Used to change the language
Logout		Used to end the session

The WHMI can be accessed locally and remotely.

- Locally by connecting the laptop to the protection relay
- Remotely over LAN/WAN

2.7 User authorization

The user management for the protection relay can be handled in two possible ways. Only one user management way can be enabled in the protection relay at a time.

For more information, see the cyber security deployment guideline.

2.7.1 Local user account management

Four factory default user accounts (VIEWER, OPERATOR, ENGINEER and ADMINISTRATOR) have been predefined for the LHMI and the WHMI, each with different rights and default passwords. The roles for these user accounts are the same as the username. Additional user accounts can be added for the protection relay.

IED Users in PCM600 is used to manage the user accounts. Each protection relay supports eight fixed roles and 50 user accounts belonging to any one of these roles. Each user account can be mapped to a maximum of eight roles.

The factory default passwords can be changed with Administrator user rights or by the users themselves. Relay user passwords can be changed using the LHMI, IED Users in PCM600 or the WHMI. Only Administrator can create user accounts and update the roles-to-rights mapping. Administrator can also reset the passwords of the users.

User authorization is disabled by default for the LHMI and can be enabled with the *Local override* parameter via the menu path **Configuration** > **Authorization** > **Passwords**. WHMI always requires authentication. Changes in user management settings do not cause the protection relay to reboot. The changes are taken into use immediately after committing the changed settings.

2.7.2 Central account management

The user accounts and roles can be created and authenticated centrally in a CAM server. CAM needs to be activated in the protection relay from Account Management in PCM600.

A CAM server can be an Active Directory (AD) server such as Windows AD. There can also be a secondary or redundant CAM server configured which can act as a backup CAM server if the primary CAM server is not accessible.

The protection relay is the CAM client and can maintain its own replica database of the user accounts and roles configured in the CAM server. This CAM replica database acts as a backup authentication mechanism if primary and secondary CAM servers are not accessible from the protection relay.

Each protection relay supports eight roles and 50 user accounts in the CAM replica database. Each user account can be mapped to a maximum of eight roles.

For more information on user management and security logging, see the cyber security deployment guideline.

For user authorization for PCM600, see the PCM600 documentation.

2.8 Station communication

Operational information and controls are available through a wide range of communication protocols including IEC 61850 Edition 2, IEC 61850-9-2 LE, IEC 60870-5-103, IEC 60870-5-104, Modbus® and DNP3. Full communication capabilities, for example, horizontal communication between the relays, are only enabled by IEC 61850.

The relay provides the possibility for a second IP address and a second subnetwork when the communication modules with three Ethernet ports (COM1001...1003) are used. However, only one IP network can be used as the default route. Using two IP addresses, communication networks can be separated based on the dominant user's needs. For example, one IP address can serve the dispatchers and the other one can serve the service engineers' needs.

The IEC 61850 protocol is a core part of the relay as the protection and control application is fully based on standard modelling. The relay supports Edition 2 and Edition 1 versions of the standard. With Edition 2 support, the relay has the latest functionality modelling for substation applications and the best interoperability for modern substations. The relay supports flexible product naming (FPN) facilitating the mapping of relay's IEC 61850 data model to a customer defined IEC 61850 data model.

2.9 Modification Sales

Modification Sales is a concept that provides modification support for already delivered relays. Under Modification Sales it is possible to modify both the hardware and software capabilities of the existing relay. The same options are available as when a new relay variant is configured and ordered from the factory: it is possible to add new hardware modules into empty slots, change the type of the existing modules within the slots or add software functions by adding application and, if necessary, add-on packages. If it is needed to use the possibilities provided by the Modification Sales concept, please contact your local ABB unit.

3 Basic functions

3.1 General parameters

3.1.1 Authorization settings

Table 7: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Remote Update	0=Disable 1=Enable			0=Disable	Remote update
Thumbprint				0	ClientThumb Print
Remote override	0=False 1=True			1=True	Disable authority
Local override	0=False 1=True			1=True	Disable authority
Clear AD userlist	0=False 1=True			0=False	Clear Active Directory user list
FTP write access	0=Off 1=On			1=On	FTP write access
MMS write access	0=Off 1=On			1=On	MMS write access
HTTPS write access	0=Off 1=On			1=On	HTTPS write access
FTP write access	0=Off 1=On			1=On	FTP write access
MMS write access	0=Off 1=On			1=On	MMS write access
HTTPS write access	0=Off 1=On			1=On	HTTPS write access
FTP write access	0=Off 1=On			1=On	FTP write access
MMS write access	0=Off 1=On			1=On	MMS write access

3.1.2 Binary input settings

Table 8: Binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Slot specific threshold	0=False 1=True			0=False	Use slot specific binary input voltage threshold
Slot specific hysteresis	0=False 1=True			0=False	Use slot specific binary input voltage hysteresis
Input threshold voltage	16...176	Vdc	2	16	Global binary input threshold for all slots
Input threshold hysteresis	10...50	%	2	10	Global binary input hysteresis for all slots
Input osc. level	2...50	events/s	1	30	Binary input oscillation suppression threshold
Input osc. hyst	2...50	events/s	1	10	Binary input oscillation suppression hysteresis

3.1.3 Network1 address settings

Table 9: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.2.10	IP address for Network1
Subnet mask				255.255.255.0	Subnet mask for Network1
Default gateway				192.168.2.1	Default gateway for Network1
Mac address				XX-XX-XX-XX-XX-XX	Mac address for Network1

3.1.4 Network2 address settings

Table 10: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Enable	0=False 1=True			0=False	Enable Network2 IP address
IP address				192.168.3.10	IP address for Network2
Subnet mask				255.255.255.0	Subnet mask for Network2
Default gateway				0.0.0.0	Default gateway for Network2 (only inuse if NW1 GW = 0.0.0.0)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for Network2

3.1.5 HMI port address settings

Table 11: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP address				192.168.0.254	IP address for front port (fixed)
Mac address				XX-XX-XX-XX-XX-XX	Mac address for front port

3.1.6 System settings

Table 12: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Rated frequency	1=50Hz 2=60Hz			1=50Hz	Rated frequency of the network
Phase rotation	1=ABC 2=ACB			1=ABC	Phase rotation order
Blocking mode	1=Freeze timer 2=Block all 3=Block OPERATE output			1=Freeze timer	Behaviour for function BLOCK inputs
Bay name				REX640	Bay name in system
IDMT Sat point	10...50	I/I>	1	50	Overcurrent IDMT saturation point
Frequency adaptivity	0=Disable 1=Enable			0=Disable	Enabling frequency adaptivity
SMV Max Delay	0=2/2 ms 1=3/3 ms 2=5/4 ms 3=6/5 ms 4=7/6 ms			1=3/3 ms	SMV Maximum allowed delay
Test mode selection	1=Local 2=Local+Remote, maintenance 3=Local+Remote, all levels 4=Binary input			1=Local	Authority for remote activation of test mode

3.1.7 HMI Settings

Table 13: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
FB naming convention	1=IEC61850 2=IEC60617 3=ANSI			1=IEC61850	FB naming convention used in IED
Backlight timeout[1]	1...60	min	1	3	LHMI backlight timeout
Web HMI mode	0=Off 1=On			0=Off	Web HMI functionality
HMI timeout	1...60	min	1	3	HMI login timeout
SLD symbol format	1=IEC 2=ANSI			1=IEC	Single Line Diagram symbol format
Setting visibility	1=Basic 2=Advanced			2=Advanced	Setting visibility for HMI
User defined name	0=Disabled 1=Enabled			false	Configuration of User defined name

3.1.8 HMI control settings

Confirmation dialog

If the parameter *Breaker operation* in **Configuration** > **Control** > **HMI** is set to "After confirmation", a confirmation dialog box opens after tapping the control button. The confirmation dialog box has a progress bar indicating the *Select timeout* set for the controllable object. If the *Control mode* setting of a control function is set to "sbo-with-enhanced-security", the confirmation dialog box always opens regardless of the *Breaker operation* setting value.

Delayed close

If the parameter *Close delay* mode in **Configuration** > **Control** > **LHMI** is set to "In use", a timer is started after tapping the close button and accepting the possible confirmation dialog. Close operation is performed only after the timer reaches zero. Remaining time is displayed on top of close button, user can cancel the operation during countdown by tapping the Cancel button. The delay can be configured by *Close delay* in **Configuration** > **Control** > **LHMI**.

Table 14: HMI control settings

Parameter	Values	Unit	Step	Default	Description
Close delay mode	1=In use 2=Not in use			2=Not in use	Delayed operation when closing circuit breakers, disconnec-

Table continues on the next page

[1] SHMI has separate backlight timeout setting that is used while in switchgear view. The SHMI setting can be accessed from SHMI settings page, that is available while in SHMI's switchgear page.

Parameter	Values	Unit	Step	Default	Description
					tors and earthing switches from HMI
Close delay	5…900	s	1	60	Operation delay for *Close delay* mode
Breaker operation	0=After confirmation 1=Without confirmation			0=After confirmation	Enable or disable confirmation dialog before operating circuit breakers, disconnectors and earthing switches from HMI

3.1.9 IEC 103 Settings

Table 15: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Selects if this protocol instance is enabled or disabled
Serial port	1=COM 1 2=COM 2			1=COM 1	COM port
Address	1...255		1	1	Unit address
Start delay	0...20	char	1	4	Start frame delay in chars
End delay	0...20	char	1	4	End frame delay in chars
DevFunType	0...255		1	9	Device Function Type
UsrFunType	0...255		1	10	Function type for User Class 2 Frame
UsrInfNo	0...255		1	230	Information Number for User Class2 Frame
Class1Priority	0=Ev High 1=Ev/DR Equal 2=DR High			0=Ev High	Class 1 data sending priority relationship between Events and Disturbance Recorder data.
Class2Interval	0...86400	s	1	0	Interval in seconds to send class 2 response
Frame1InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			6=Private frame 6	Active Class2 Frame 1
Frame2InUse	-1=Not in use			-1=Not in use	Active Class2 Frame 2

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7				
Frame3InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			-1=Not in use	Active Class2 Frame 3
Frame4InUse	-1=Not in use 0=User frame 1=Standard frame 1 2=Standard frame 2 3=Standard frame 3 4=Standard frame 4 5=Standard frame 5 6=Private frame 6 7=Private frame 7			-1=Not in use	Active Class2 Frame 4
Class1OvInd	0=No indication 1=Both edges 2=Rising edge			2=Rising edge	Overflow Indication
Class1OvFType	0...255		1	10	Function Type for Class 1 overflow indication
Class1OvInfNo	0...255		1	255	Information Number for Class 1 overflow indication
Class1OvBackOff	0...500		1	500	Backoff Range for Class1 buffer
GI Optimize	0=Standard behaviour 1=Skip spontaneous 2=Only overflown 3=Combined			0=Standard behaviour	Optimize GI traffic
DR Notification	0=False 1=True			0=False	Disturbance Recorder spontaneous indications enabled/disabled

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Block Monitoring	0=Not in use 1=Discard events 2=Keep events			0=Not in use	Blocking of Monitoring Direction
EC_FRZ	0=False 1=True			0=False	Control point for freezing energy counters
Prtl Customization	0...2147483647		1	0	Customization parameter. Please, refer to the protocol manual.

3.1.10 IEC 103 Monitored data

Table 16: Monitored data

Name	Type	Values (Range)	Unit	Description
Customization Mode	Enum	0=Off/Normal 1=By Parameter 2=By File		Protocol Customization Mode
Reset counters	BOOLEAN	0=False 1=True		Reset counters
Received frames	INT32	-1...2147483646		Received frames
Checksum errors	INT32	-1...2147483646		Checksum errors
Transmitted frames	INT32	-1...2147483646		Transmitted frames

3.1.11 IEC 101-104 General settings

Table 17: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Selects if this protocol instance is enabled or disabled
Port	3=IEC104 - Ethernet			3=IEC104 - Ethernet	Port selection
Mapping select	1...2		1	1	Mapping select
ClientIP				0.0.0.0	IP address of the client
TCP Port	0...65535		1	2404	Server TCP port
Device Address	1...65535		1	1	Device address
ASDU Address	1...65535		1	1	Common address of ASDU
Link Mode	0=Balanced 1=Unbalanced			0=Balanced	Link mode setting
COT Length	1...2		1	1	Cause of transmission length
IOA Length	1...3		1	2	Information Object Address length
Link Address Length	1...2		1	1	Link Address Length
ASDU Address Length	1...2		1	1	ASDU Address Length

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Single Char Resp	0=False 1=True			0=False	Single character response enabled/disabled
Show Bad Time	0=False 1=True			1=True	Enable/disable bad time quality indication in events
Time Format	1=Full 56bit			1=Full 56bit	Time stamp format 3 or 7 octet
Time Zone	0=Local 1=UTC			1=UTC	Selects between UTC/Local time
Overflow Mode	0=Oldest+indication 1=Keep newest			0=Oldest+indication	Event buffer overflow handling mechanism
OvInd IOA	0...16777215		1	60000	Overflow indication address for interrogated data
OvInd NoGI IOA	0...16777215		1	60000	Overflow indication address for non-interrogated data
Selection Timeout	1...65	s	1	30	Selection timeout for control SBO operations
Counter Reporting	0=Read by master 1=Spontaneous			0=Read by master	Counter reporting after freeze
Freeze mode	0=Not in use 1=Freeze only 2=Freeze and Reset			0=Not in use	Freezing mode for externally triggered integrated totals
TX window (k)	1...20		1	12	IEC60870-5-104 transmit window (k)
RX window (w)	1...20		1	8	IEC60870-5-104 receive window (w)
TX timeout (t1)	1...2147483647	ms	1	30000	IEC60870-5-104 transmit timeout (t1)
RX timeout (t2)	1...2147483647	ms	1	10000	IEC60870-5-104 receive timeout (t1)
Test interval (t3)	0...2147483647	ms	1	20000	IEC60870-5-104 link test interval (t3) - 0: Disables the transmission of test frames
Cyclical Period	1...604800	s	1	10	Cyclical period in seconds
IT_FRZ	0=False 1=True			0=False	Control point for freezing integrated totals
Command delay	0...65535	ms	1	5000	Maximum delay for timestamped commands in milliseconds.
Prtl Customization	0...2147483647		1	0	Customization parameter. Please, refer to the protocol manual.

3.1.12 IEC 101-104 Secure settings

Table 18: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Protocol Security Mode	1=App. authentication 2=TLS and appl. auth. 0=Off			0=Off	Protocol Security Mode - 0: Off; 1: Aplication authentication; 2: TLS and Aplication authentication
Reply timeout	100...120000	ms	1	2000	Reply timeout
Exp Sesn key Chg Intv	0...14400	s	1	1800	Expected Session key change interval - Value zero will indicate that interval is not used
Exp Sesn key Chg Cnt	2...10000000		1	4000	Expected session key change count
Max Sesn key Stat Cnt	1...255		1	5	Maximum session key status count
Sec Stat Cnt Grp	1=Group 1 2=Group 2 3=Group 3 4=Group 4			4=Group 4	Secure statistics counter group
Sec Stat Cnt IOA	1...65535		1	61000	Information object address for secure statistics counters

3.1.13 IEC 101-104 Secure statistics thresholds settings

Table 19: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Unexpected Msgs	1...65535		1	3	Security statistics threshold for unexpected messages
Auth failures	1...65535		1	5	Security statistics threshold for authorization failures
Authn failures	1...65535		1	5	Security statistics threshold for authentication failures
Reply timeouts	1...65535		1	3	Security statistics threshold for reply timeouts
Rekeys Authn failure	1...65535		1	3	Security statistics threshold for rekeys due to authentication failure
Total Msgs Tx	1...65535		1	100	Security statistics threshold for total messages sent
Total Msgs Rx	1...65535		1	100	Security statistics threshold for total messages received
Total Crit Msgs Rx	1...65535		1	100	Security statistics threshold for total critical messages received
Discarded Msgs	1...65535		1	10	Security statistics threshold discarded messages

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Error Msgs Tx	1...65535		1	10	Security statistics threshold error messages sent
Error Msgs Rx	1...65535		1	10	Security statistics threshold error messages received
Successful Authn	1...65535		1	100	Security statistics threshold for successful authentications
Sesn key Chg	1...65535		1	10	Security statistics threshold for session key changes
Failed Sesn key Chgs	1...65535		1	5	Security statistics threshold for failed session key changes
Upd key Chgs	1...65535		1	1	Security statistics threshold for update key changes
Failed Upd key Chgs	1...65535		1	1	Security statistics threshold for failed update key changes

3.1.14 IEC 101-104 Monitored data

Table 20: Monitored data

Name	Type	Values (Range)	Unit	Description
Customization Mode	Enum	0=Off/Normal 1=By Parameter 2=By File		Protocol Customization Mode
Reset counters	BOOLEAN	0=False 1=True		Reset counters
Received frames	INT32	-1...2147483646		Received frames
Transmitted frames	INT32	-1...2147483646		Transmitted frames
Physical errors	INT32	-1...2147483646		Physical layer errors
Link errors	INT32	-1...2147483646		Link layer errors
Transport errors	INT32	-1...2147483646		Transport layer errors
CnReject no sockets	INT32	-1...2147483646		Number of rejected connections due to no sockets available
CnReject unregistered	INT32	-1...2147483646		Connection rejected due to unregistered client

3.1.15 IEC 101-104 Secure monitored data

Table 21: Monitored data

Name	Type	Values (Range)	Unit	Description
Unexp Msgs Cnt	INT32	0...2147483646		Security statistics counter for unexpected messages
Auth Fail Cnt	INT32	0...2147483646		Security statistics counter for authorization failures
Authn Fail Cnt	INT32	0...2147483646		Security statistics counter for authentication failures
Reply timeouts Cnt	INT32	0...2147483646		Security statistics counter for reply timeouts
Rekey Authn Fail Cnt	INT32	0...2147483646		Security statistics counter for rekeys due to authentication failure
Total Msgs Tx	INT32	0...2147483646		Security statistics counter for total messages sent
Total Msgs Rx	INT32	0...2147483646		Security statistics counter for total messages received
Critical Msgs Rx Cnt	INT32	0...2147483646		Security statistics counter for critical messages received
Discarded Msgs Cnt	INT32	0...2147483646		Security statistics counter for discarded messages
Err Msgs Tx Cnt	INT32	0...2147483646		Security statistics counter error messages sent
Err Msgs Rx Cnt	INT32	0...2147483646		Security statistics counter error messages received
Successful Authn Cnt	INT32	0...2147483646		Security statistics counter for successful authentications
Session Key Chg Cnt	INT32	0...2147483646		Security statistics counter for session key changes
Fail Ses Key Chg Cnt	INT32	0...2147483646		Security statistics counter for failed session key changes
Upd Key Chgs Cnt	INT32	0...2147483646		Security statistics counter update key changes
Fail Upd Key Chgs Cnt	INT32	0...2147483646		Security statistics counter for failed update key changes

3.1.16 IEC 61850-8-1 MMS settings

Table 22: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Unit mode	1=Primary 0=Nominal 2=Primary-Nominal			0=Nominal	IEC 61850-8-1 unit mode
MMS	0=Off 1=On			1=On	MMS communication mode
MMS	0=Off			1=On	MMS communication mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=On				
MMS	0=Off 1=On			1=On	MMS communication mode

3.1.17 MODBUS Settings

Table 23: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Enable or disable this protocol instance
Port	1=COM 1 2=COM 2 3=Ethernet - TCP 1			3=Ethernet - TCP 1	Port selection for this protocol instance. Select between serial and Ethernet based communication.
Mapping selection	1...2		1	1	Chooses which mapping scheme will be used for this protocol instance.
Address	1...254		1	1	Unit address
Link mode	1=RTU 2=ASCII			1=RTU	Selects between ASCII and RTU mode. For TCP, this should always be RTU.
TCP port	1...65535		1	502	Defines the listening port for the Modbus TCP server. Default = 502.
Parity	0=none 1=odd 2=even			2=even	Parity for the serial connection.
Start delay	0...20		1	4	Start delay in character times for serial connection
End delay	0...20		1	4	End delay in character times for serial connections
CRC order	0=Hi-Lo 1=Lo-Hi			0=Hi-Lo	Selects between normal or swapped byte order for checksum for serial connection. Default: Hi-Lo.
Client IP				0.0.0.0	Sets the IP address of the client. If set to zero, connection from any client is accepted.
Write authority	0=Read only 1=Disable 0x write 2=Full access			2=Full access	Selects the control authority scheme
Time format	0=UTC 1=Local			1=Local	Selects between UTC and local time for events and timestamps.

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Event ID selection	0=Address 1=UID			0=Address	Selects whether the events are reported using the MB address or the UID number.
Event buffering	0=Keep oldest 1=Keep newest			0=Keep oldest	Selects whether the oldest or newest events are kept in the case of event buffer overflow.
Event backoff	1...500		1	200	Defines how many events have to be read after event buffer overflow to allow new events to be buffered. Applicable in "Keep oldest" mode only.
ControlStructPWd 1				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 2				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 3				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 4				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 5				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 6				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 7				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
ControlStructPWd 8				****	Password for control operations using Control Struct mechanism, which is available on 4x memory area.
Prtl Customization	0...2147483647		1	0	Customization parameter. Please, refer to the protocol manual.

3.1.18 MODBUS Monitored data

Table 24: Monitored data

Name	Type	Values (Range)	Unit	Description
Customization Mode	Enum	0=Off/Normal 1=By Parameter 2=By File		Protocol Customization Mode
Reset counters	BOOLEAN	0=False 1=True		Reset counters
Received frames	INT32	-1...2147483646		Number of received frames
Transmitted frames	INT32	-1...2147483646		Number of transmitted frames
Transmitted exc A	INT32	-1...2147483646		Number of transmitted exception responses 01 and 02
Transmitted exc B	INT32	-1...2147483646		Number of transmitted exception responses 03
Checksum errors	INT32	-1...2147483646		Number of checksum errors
CnReject no sockets	INT32	-1...2147483646		Number of rejected connections due to no sockets available
CnReject unregistered	INT32	-1...2147483646		Connection rejected due to unregistered client

3.1.19 DNP 3.0 Settings

Table 25: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			5=off	Operation Off / On
Port	1=COM 1 2=COM 2 3=Ethernet - TCP 1 4=Ethernet TCP+UDP 1 5=Ethernet - UDP 1			3=Ethernet - TCP 1	Communication interface selection
Unit address	0...65519		1	1	DNP unit address
Master address	0...65519		1	3	DNP master and UR address
Mapping select	1...2		1	1	Mapping select
ClientIP				0.0.0.0	IP address of client
TCP port	20000...65535		1	20000	TCP Port used on ethernet communication
UDP Rx Port	1...65535		1	20000	UDP Port for accepting data from client/master
UDP Tx Port Ini	1...65535		1	20000	UDP Port for initial NULL response to client/master

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
UDP Tx Port	0...65535		1	0	UDP Destination Port for client/master
Client control authority	0=No clients 1=Reg. clients 2=All clients			2=All clients	0=no client controls allowed; 1=Controls allowed by registered clients; 2=Controls allowed by all clients
Link keep-alive	0...1000000	s	1	0	Link keep-alive interval for DNP
Validate master addr	1=Disable 2=Enable			1=Disable	Validate master address on receive
Self address	1=Disable 2=Enable			2=Enable	Support self address query function
Need time interval	0...65535	min	1	30	Period to set IIN need time bit
Time format	0=UTC 1=Local			1=Local	UTC or local. Coordinate with master.
CROB select timeout	1...65535	s	1	10	Control Relay Output Block select timeout
Data link confirm	0=Never 1=Only Multiframe 2=Always			0=Never	Data link confirm mode
Data link confirm TO	100...65535	ms	1	3000	Data link confirm timeout
Data link retries	0...65535		1	3	Data link retries count
Data link Rx to Tx delay	0...255	ms	1	0	Turnaround transmission delay
Data link inter char delay	0...20	char	1	4	Inter character delay for incoming messages
App layer confirm	1=Disable 2=Enable			1=Disable	Application layer confirm mode
App/UR confirm TO	100...65535	ms	1	5000	Application layer confirm and UR timeout
App layer fragment	256...2048	bytes	1	2048	Application layer fragment size
UR mode	1=Disable 2=Enable			1=Disable	Unsolicited responses mode
UR retries	0...65535		1	3	Unsolicited retries before switching to UR offline mode
UR retry delay	0...65535	ms	1	5000	Additional delay kept after App/UR confirm TO before sending new unsolicited retry
UR offline interval	0...65535	min	1	15	Unsolicited offline interval
UR Class 1 Min events	0...999		1	2	Min number of class 1 events to generate UR
UR Class 1 TO	0...65535	ms	1	50	Max holding time for class 1 events to generate UR

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
UR Class 2 Min events	0...999		1	2	Min number of class 2 events to generate UR
UR Class 2 TO	0...65535	ms	1	50	Max holding time for class 2 events to generate UR
UR Class 3 Min events	0...999		1	2	Min number of class 3 events to generate UR
UR Class 3 TO	0...65535	ms	1	50	Max holding time for class 3 events to generate UR
Legacy master UR	1=Disable 2=Enable			1=Disable	Legacy DNP master unsolicited mode support. When enabled relay does not send initial unsolicited message.
Legacy master SBO	1=Disable 2=Enable			1=Disable	Legacy DNP Master SBO sequence number relax enable
Default Var Obj 01	1=1:BI 2=2:BI&status			1=1:BI	1=BI; 2=BI with status.
Default Var Obj 02	1=1:BI event 2=2:BI event&time			2=2:BI event&time	1=BI event; 2=BI event with time.
Default Var Obj 03	1=1:DBI 2=2:DBI&status			1=1:DBI	1=DBI; 2=DBI with status.
Default Var Obj 04	1=1:DBI event 2=2:DBI event&time			2=2:DBI event&time	1=DBI event; 2=DBI event with time.
Default Var Obj 20	1=1:32bit Cnt 2=2:16bit Cnt 5=5:32bit Cnt noflag 6=6:16bit Cnt noflag			2=2:16bit Cnt	1=32 bit counter; 2=16 bit counter; 5=32 bit counter without flag; 6=16 bit counter without flag.
Default Var Obj 21	1=1:32bit FrzCnt 2=2:16bit FrzCnt 5=5:32bit FrzCnt&time 6=6:16bit FrzCnt&time 9=9:32bit FrzCnt noflag 10=10:16bit FrzCnt noflag			6=6:16bit FrzCnt&time	1=32 bit frz counter; 2=16 bit frz counter; 5=32 bit frz counter with time; 6=16 bit frz counter with time; 9=32 bit frz counter without flag;10=16 bit frz counter without flag.
Default Var Obj 22	1=1:32bit Cnt evt 2=2:16bit Cnt evt 5=5:32bit Cnt evt&time 6=6:16bit Cnt evt&time			6=6:16bit Cnt evt&time	1=32 bit counter event; 2=16 bit counter event; 5=32 bit counter event with time; 6=16 bit counter event with time.
Default Var Obj 23	1=1:32bit FrzCnt evt 2=2:16bit FrzCnt evt 5=5:32bit FrzCnt evt&time			6=6:16bit FrzCnt evt&time	1=32 bit frz counter event; 2=16 bit frz counter event; 5=32 bit frz counter event with time;

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	6=6:16bit FrzCnt evt&time				6=16 bit frz counter event with time.
Default Var Obj 30	1=1:32bit AI 2=2:16bit AI 3=3:32bit AI noflag 4=4:16bit AI noflag 5=5:AI float 6=6:AI double			5=5:AI float	1=32 bit AI; 2=16 bit AI; 3=32 bit AI without flag; 4=16 bit AI without flag; 5=AI float; 6=AI double.
Default Var Obj 32	1=1:32bit AI evt 2=2:16bit AI evt 3=3:32bit AI evt&time 4=4:16bit AI evt&time 5=5: float AI evt 6=6:double AI evt 7=7:float AI evt&time 8=8:double AI evt&time			7=7:float AI evt&time	1=32 bit AI event; 2=16 bit AI event; 3=32 bit AI event with time; 4=16 bit AI event with time; 5=float AI event; 6=double AI event; 7=float AI event with time; 8=double AI event with time.
Default Var Obj 40	1=1:32bit AO 2=2:16bit AO 3=3:AO float 4=4:AO double			2=2:16bit AO	1=32 bit AO; 2=16 bit AO; 3=AO float; 4=AO double.
Default Var Obj 42	1=1:32bit AO evt 2=2:16bit AO evt 3=3:32bit AO evt&time 4=4:16bit AO evt&time 5=5:float AO evt 6=6:double AO evt 7=7:float AO evt&time 8=8:double AO evt&time			4=4:16bit AO evt&time	1=32 bit AO event; 2=16 bit AO event; 3=32 bit AO event with time; 4=16 bit AO event with time; 5=float AO event; 6=double AO event; 7=float AO event with time; 8=double AO event with time.
An In Evt Mod	0=0:SOE 1=1:Most Recent			0=0:SOE	Analog Input Event Mode - 0: Sequence of Events, 1: Most Recent
Prtl Customization	0...2147483647		1	0	Customization parameter. Please, refer to the protocol manual.

3.1.20 DNP 3.0 Secure settings

Table 26: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Protocol Security Mode	1=App. authentication			0=Off	Protocol Security Mode - 0: Off; 1: Aplication authentication; 2: TLS and

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=TLS and appl. auth. 0=Off				Aplication authentication
Aggressive mode enable	1=Disable 2=Enable			1=Disable	Aggressove mode - 1: disable; 2: enable
Reply timeout	100...120000	ms	1	2000	Reply timeout
Exp Sesn key Chg Intv	0...14400	s	1	1800	Expected Session key change interval - Value zero will indicate that interval is not used
Exp Sesn key Chg Cnt	2...10000000		1	4000	Expected session key change count
Max Sesn key Stat Cnt	1...255		1	5	Maximum session key status count
Max Authn Fail Thres	1...65535		1	5	Maximum authentication failures threshold
Max Reply Tm Thres	1...65535		1	3	Maximum reply timeouts threshold
Max Authn Rekey Thres	1...65535		1	3	Maximum authentication rekeys threshold
Max Err Msg Tx Thres	1...65335		1	10	Maximum error messages sent threshold
Event Class Obj 122	1=1 2=2 3=3 4=1&2 5=1&3 6=2&3 7=1&2&3			1=1	Event Class for Obj 122
Default Var Obj 122	1=32bit SecStat evt 2=32bit SecStat evt&time			1=32bit SecStat evt	1=32bit Secure Statistics event; 2=32bit Secure Statistics event with time
Clear User List	0=False 1=True			0=False	Clear DNP Secure authentication User List

3.1.21 DNP 3.0 Secure statistics thresholds settings

Table 27: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Unexpected Msgs	1...65535		1	3	Security statistics threshold for unexpected messages
Auth failures	1...65535		1	5	Security statistics threshold for authorization failures
Authn failures	1...65535		1	5	Security statistics threshold for authentication failures

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Reply timeouts	1...65535		1	3	Security statistics threshold for reply timeouts
Rekeys Authn fail-ure	1...65535		1	3	Security statistics threshold for re-keys due to authen-tication failure
Total Msgs Tx	1...65535		1	100	Security statistics threshold for total messages sent
Total Msgs Rx	1...65535		1	100	Security statistics threshold for total messages received
Total Crit Msgs Rx	1...65535		1	100	Security statistics threshold for total critical messages received
Discarded Msgs	1...65535		1	10	Security statistics threshold discar-ded messages
Error Msgs Tx	1...65535		1	10	Security statistics threshold error messages sent
Error Msgs Rx	1...65535		1	10	Security statistics threshold error messages received
Successful Authn	1...65535		1	100	Security statistics threshold for suc-cessful authentica-tions
Sesn key Chg	1...65535		1	10	Security statistics threshold for ses-sion key changes
Failed Sesn key Chgs	1...65535		1	5	Security statistics threshold for failed session key changes
Upd key Chgs	1...65535		1	1	Security statistics threshold for up-date key changes
Failed Upd key Chgs	1...65535		1	1	Security statistics threshold for failed update key changes

3.1.22 DNP 3.0 Monitored data

Table 28: Monitored data

Name	Type	Values (Range)	Unit	Description
Customization Mode	Enum	0=Off/Normal 1=By Parameter 2=By File		Protocol Customization Mode
Reset counters	BOOLEAN	0=False 1=True		Reset counters
Received frames	INT32	-1...2147483646		Received frames
Transmitted frames	INT32	-1...2147483646		Transmitted frames
Physical errors	INT32	-1...2147483646		Physical layer errors
Link errors	INT32	-1...2147483646		Link layer errors
Transport errors	INT32	-1...2147483646		Transport layer errors
Mapping errors	INT32	-1...2147483646		Mapping errors

3.1.23 DNP 3.0 Secure monitored data

Table 29: Monitored data

Name	Type	Values (Range)	Unit	Description
Unexp Msgs Cnt	INT32	0...2147483646		Security statistics counter for unexpected messages
Auth Fail Cnt	INT32	0...2147483646		Security statistics counter for authorization failures
Authn Fail Cnt	INT32	0...2147483646		Security statistics counter for authentication failures
Reply timeouts Cnt	INT32	0...2147483646		Security statistics counter for reply timeouts
Rekey Authn Fail Cnt	INT32	0...2147483646		Security statistics counter for rekeys due to authentication failure
Total Msgs Tx	INT32	0...2147483646		Security statistics counter for total messages sent
Total Msgs Rx	INT32	0...2147483646		Security statistics counter for total messages received
Critical Msgs Rx Cnt	INT32	0...2147483646		Security statistics counter for critical messages received
Discarded Msgs Cnt	INT32	0...2147483646		Security statistics counter for discarded messages
Err Msgs Tx Cnt	INT32	0...2147483646		Security statistics counter error messages sent
Err Msgs Rx Cnt	INT32	0...2147483646		Security statistics counter error messages received
Successful Authn Cnt	INT32	0...2147483646		Security statistics counter for successful authentications
Session Key Chg Cnt	INT32	0...2147483646		Security statistics counter for session key changes
Fail Ses Key Chg Cnt	INT32	0...2147483646		Security statistics counter for failed session key changes
Upd Key Chgs Cnt	INT32	0...2147483646		Security statistics counter update key changes
Fail Upd Key Chgs Cnt	INT32	0...2147483646		Security statistics counter for failed update key changes

3.1.24 COM1 Settings

Table 30: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake			1=RS485 2Wire	Serial mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=RS232 with hand-shake				
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate

3.1.25 COM1 Monitored data

Table 31: Monitored data

Name	Type	Values (Range)	Unit	Description
Characters received	INT32	-1...2147483646		Characters received
Frames received	INT32	-1...2147483646		Number of successfully received frames
Frames discarded	INT32	-1...2147483646		Number of discarded frames
Frames transmitted	INT32	-1...2147483646		Number of transmitted frames
CD lost	INT32	-1...2147483646		CD lost
Collision	INT32	-1...2147483646		Collision
CTS Timeout	INT32	-1...2147483646		CTS Timeout
Transmission timeout	INT32	-1...2147483646		Transmission timeout
Parity errors	INT32	-1...2147483646		Number of parity errors
Overrun errors	INT32	-1...2147483646		Number of overrun errors
Framing errors	INT32	-1...2147483646		Number of framing errors
Reset counters	BOOLEAN	0=False 1=True		Resets counters

3.1.26 COM2 Settings

Table 32: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no hand-shake 4=RS232 with hand-shake			1=RS485 2Wire	Serial mode
Fiber mode	0=No fiber			0=No fiber	Fiber mode (light ON/OFF = idle)

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Fiber light ON loop 2=Fiber light OFF loop 3=Fiber light ON star 4=Fiber light OFF star				
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate

3.1.27 COM2 Monitored data

Table 33: Monitored data

Name	Type	Values (Range)	Unit	Description
Characters received	INT32	-1...2147483646		Characters received
Frames received	INT32	-1...2147483646		Number of successfully received frames
Frames discarded	INT32	-1...2147483646		Number of discarded frames
Frames transmitted	INT32	-1...2147483646		Number of transmitted frames
CD lost	INT32	-1...2147483646		CD lost
Collision	INT32	-1...2147483646		Collision
CTS Timeout	INT32	-1...2147483646		CTS Timeout
Transmission timeout	INT32	-1...2147483646		Transmission timeout
Parity errors	INT32	-1...2147483646		Number of parity errors
Overrun errors	INT32	-1...2147483646		Number of overrun errors
Framing errors	INT32	-1...2147483646		Number of framing errors
Reset counters	BOOLEAN	0=False 1=True		Resets counters

3.1.28 IO modules settings

Table 34: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Slot specific threshold	0=False			0=False	Use slot specific binary input voltage threshold

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=True				
Slot specific hysteresis	0=False 1=True			0=False	Use slot specific binary input voltage hysteresis
Input threshold voltage	16...176	Vdc	2	16	Global binary input threshold for all slots
Input threshold hysteresis	10...50	%	2	10	Global binary input hysteresis for all slots
Input osc. level	2...50	events/s	1	30	Binary input oscillation suppression threshold
Input osc. hyst	2...50	events/s	1	10	Binary input oscillation suppression hysteresis

3.2 Communication

The protection relay supports a range of communication protocols including IEC 61850, IEC 61850-9-2 LE, IEC 60870-5-103, IEC 60870-5-104, Modbus® and DNP3. Profibus DPV1 communication protocol is supported by using the protocol converter SPA-ZC 302. Operational information and controls are available through these protocols. However, some communication functionality, for example, horizontal communication between the protection relays, is only enabled by the IEC 61850 communication protocol.

One full IEC 61850-9-2 LE stream containing both voltages and currents can be sent. Receiving of up to four SMV streams is supported with a total of maximum 16 channels. The channels are freely configurable with the possibility to engineer SMV stream redundancy using the voltage and current switch functions with either another SMV stream or local measurements. The SMV stream quality along with other Application Configuration logic can be used for switching between measurement sources.

The IEC 61850 communication implementation supports all monitoring and control functions. Additionally, parameter settings, disturbance recordings and fault records can be accessed using the IEC 61850 protocol. Disturbance recordings are available to any Ethernet-based application in the IEC 60255-24 standard COMTRADE file format. The protection relay can send and receive binary signals from other devices (so-called horizontal communication) using the IEC 61850-8-1 GOOSE profile, where the highest performance class with a total transmission time of 3 ms is supported. Furthermore, the protection relay supports sending and receiving of analog values using GOOSE messaging. The protection relay meets the GOOSE performance requirements for tripping applications in distribution substations, as defined by the IEC 61850 standard.

The protection relay can support five simultaneous clients. If PCM600 reserves one client connection, only four client connections are left, for example, for IEC 61850 and Modbus.

All communication connectors are placed on integrated optional communication modules. The protection relay can be connected to Ethernet-based communication systems via the RJ-45 connector (100Base-TX) or the fiber-optic LC connector (100Base-FX).

The LHMI has two RJ-45 connectors. One is for connecting the LHMI to the protection relay main unit and the second is a service port which is used for connecting the LHMI and a computer. This computer can be, for example, a laptop with the PCM600 engineering tool or a browser for WHMI.

An optional serial interface is available for RS-485 communication.

3.2.1 Ethernet addresses for HMI

There is a DHCP server available at X0 port that can provide an IP address and a netmask for one client. The service port on the LHMI has a DHCP server that can also serve one client. To use WHMI or PCM600, a PC can be connected either directly to X0 port or to the LHMI's service port. In both cases, the PC can use the DHCP client to receive the IP address automatically.

If the LHMI is connected to the relay through the station network, the service port still offers the DHCP server even if the LHMI's main unit port uses a static address. The LHMI device functions as a router between the PC and the protection relay.

Main unit's X0 port IP address can also be changed to avoid conflicts with other network addresses. Parameter is located under Configuration/Communication/Ethernet/HMI address. Subnet mask for X0 IP address is always 255.255.255.0 and cannot be changed.

3.2.2 Self-healing Ethernet ring

The protection relay supports a self-healing ring solution for small installations. For the correct operation of self-healing ring topology, the network topology must be a ring. It is essential that the external switches in the network support the RSTP protocol and that it is enabled in the switches. Otherwise, connecting the ring topology can cause problems to the network.

The protection relay itself does not support link-down detection or RSTP. The ring recovery process is based on the aging of the MAC addresses and the link-up/linkdown events can cause temporary breaks in communication. For a better performance of the self-healing ring, it is recommended that the external switch furthest from the protection relay loop is assigned as the root switch (bridge priority = 0) and the bridge priority increases towards the protection relay ring. The end links of the protection relay loop can be attached to the same external switch or to two adjacent external switches. If two adjacent external switches are connected to the relay loop, the point-to-point Ethernet link connecting these two switches should be prioritized by setting higher RSTP priority (lower setting value for port priority). This ensures that most of the network traffic that is not meant for the relays flows between the Ethernet switches.

The self-healing ring solution supports the connection of up to 30 protection relays. However, the HSR or PRP network is recommended to ensure redundant and proper functionality.

Self-healing is not recommended for time-critical applications using IEC 61850-9-2 and PTP due to longer recovery time. Instead, HSR/PRP is recommended to ensure reliable performance.

3.2.3 Ethernet redundancy

IEC 61850 specifies a network redundancy scheme that improves the system availability for substation communication. It is based on two complementary protocols defined in the IEC 62439-3:2012 standard: parallel redundancy protocol PRP and high-availability seamless redundancy HSR protocol. Both protocols rely on the duplication of all transmitted information via two Ethernet ports for one logical network connection. Therefore, both are able to overcome the failure of a link or switch with a zero-switchover time, thus fulfilling the most demanding real-time application requirements for the substation automation.

Ethernet network redundancy can be achieved using HSR or PRP and it is applied to all services using the Ethernet/TCP network.

PRP specifies that each device is connected in parallel to two local area networks. HSR applies the PRP principle to rings and to the rings of rings to achieve cost-effective redundancy. Thus, each device incorporates a switch element that forwards frames from port to port.

IEC 62439-3:2012 cancels and replaces the first edition published in 2010. These standard versions are also referred to as IEC 62439-3 Edition 1 and IEC 62439-3 Edition 2. The protection relay supports IEC 62439-3:2016 (Edition 3) and IEC 62439-3:2012 and it is not compatible with IEC 62439-3:2010.

PRP

Each PRP node, called a double attached node with PRP (DAN), is attached to two independent LANs operated in parallel. These parallel networks in PRP are called LAN A and LAN B. The networks are completely separated to ensure failure independence, and they can have different topologies. Both networks operate in parallel, thus providing zero-time recovery and continuous checking of redundancy to avoid communication failures. Non-PRP nodes, called single attached nodes (SANs), are either attached to one network only (and can therefore communicate only with DANs and SANs attached to the same network), or are attached through a redundancy box, a device that behaves like a DAN.

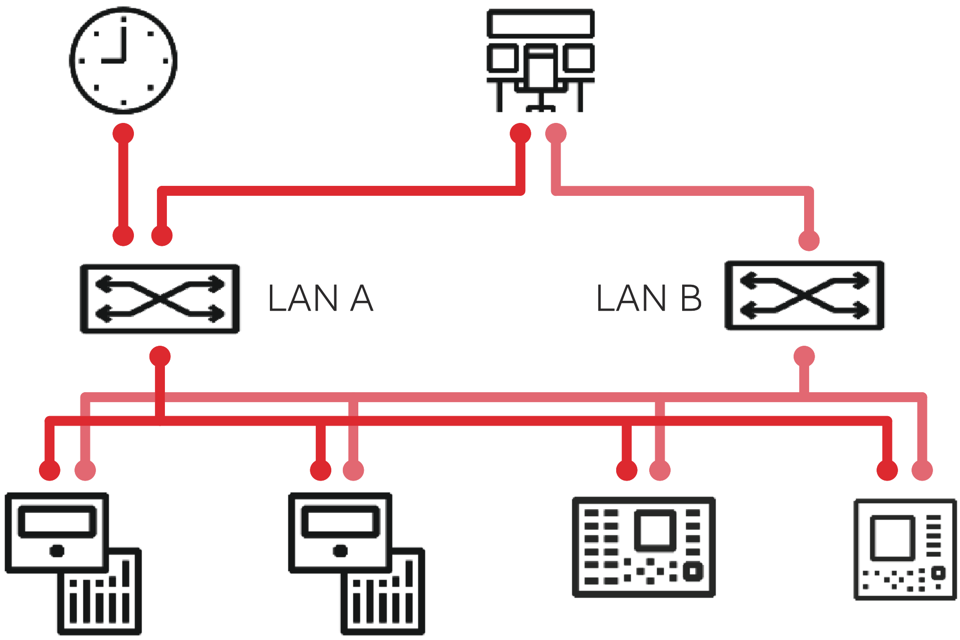


Figure 10: Parallel redundancy protocol solution

In case a laptop or a PC workstation is connected as a non-PRP node to one of the PRP networks, LAN A or LAN B, it is recommended to use a redundancy box device or an Ethernet switch with similar functionality between the PRP network and SAN to remove additional PRP information from the Ethernet frames. In some cases, default PC workstation adapters are not able to handle the maximum-length Ethernet frames with the PRP trailer.

There are different alternative ways to connect a laptop or a workstation as SAN to a PRP network.

- Via an external redundancy box (RedBox) or a switch capable of connecting to PRP and normal networks
- By connecting the node directly to LAN A or LAN B as SAN
- By connecting the node to the protection relay's interlink port

HSR

HSR applies the PRP principle of parallel operation to a single ring, treating the two directions as two virtual LANs. For each frame sent, a node, DAN, sends two frames, one over each port. Both frames circulate in opposite directions over the ring and each node forwards the frames it receives, from one port to the other. When the originating node receives a frame sent to itself, it discards that to avoid loops; therefore, no ring protocol is needed. Individually attached nodes, SANs, such as laptops and printers, must be attached through a “redundancy box” that acts as a ring element. For example, a REX640 protection relay with HSR support can be used as a redundancy box.

Each protection relay has a 50-µs store-and-forward delay. To fulfil the performance requirements for fast horizontal communication for protection applications using GOOSE and SMV, the ring size is limited to 30 protection relays.

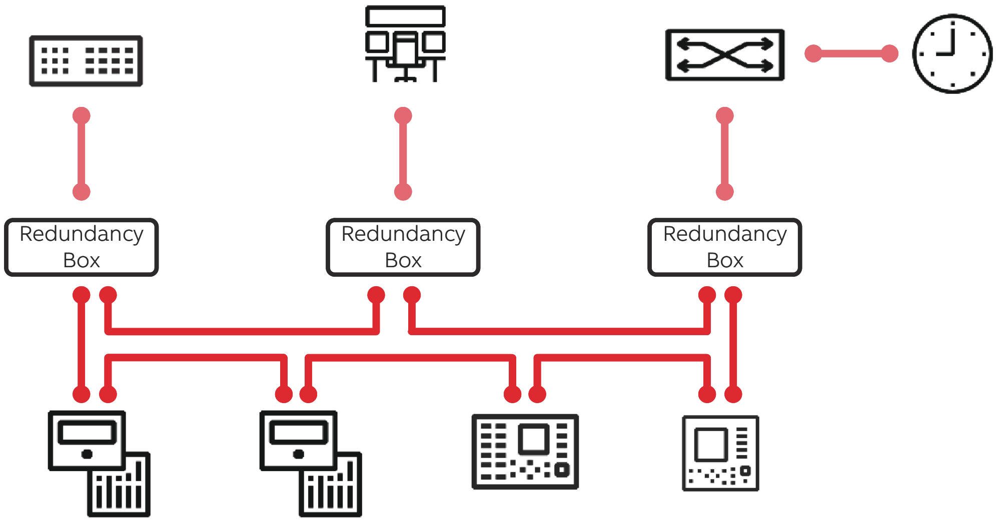


Figure 11: High-availability seamless redundancy solution

3.2.3.1 Interlink port

In the relay redundant COM module, the port without LAN-A/LAN-B tag is so called interlink-port. This port can be used to connect a device directly to the relay. Mainly this port should be used to connect a single point-to-point device, such as RIO600. Although it is possible, it not recommended to connect big amount of devices behind the interlink port, thus making the relay act as a hub between two network segments. The relay should preferrably act as a network end-device, and not as a hub for network traffic.

3.2.4 Process bus

Process bus IEC 61850-9-2 defines the transmission of Sampled Measured Values within the substation automation system. International Users Group created a guideline IEC 61850-9-2 LE that defines an application profile of IEC 61850-9-2 to facilitate implementation and enable interoperability. Process bus is used for distributing process data from the primary circuit to all process bus compatible devices in the local network in a real-time manner. The data can then be processed by any protection relay to perform different protection, automation and control functions.

Redundant SMV streams are also supported by using the voltage (VMSWI) and current (CMSWI) function blocks. Automatic switching to the backup SMV stream can be configured in Application Configuration using SMV quality and/or other logic.

UniGear Digital switchgear concept relies on the process bus together with current and voltage sensors. The process bus enables several advantages for the UniGear Digital like simplicity with reduced wiring, flexibility with data availability to all devices, improved diagnostics and longer maintenance cycles.

With process bus the galvanic interpanel wiring for sharing busbar voltage value can be replaced with Ethernet communication. Transmitting measurement samples over process bus brings also higher error detection because the signal transmission is automatically supervised. Additional contribution to the higher availability is the possibility to use redundant Ethernet network for transmitting SMV signals.

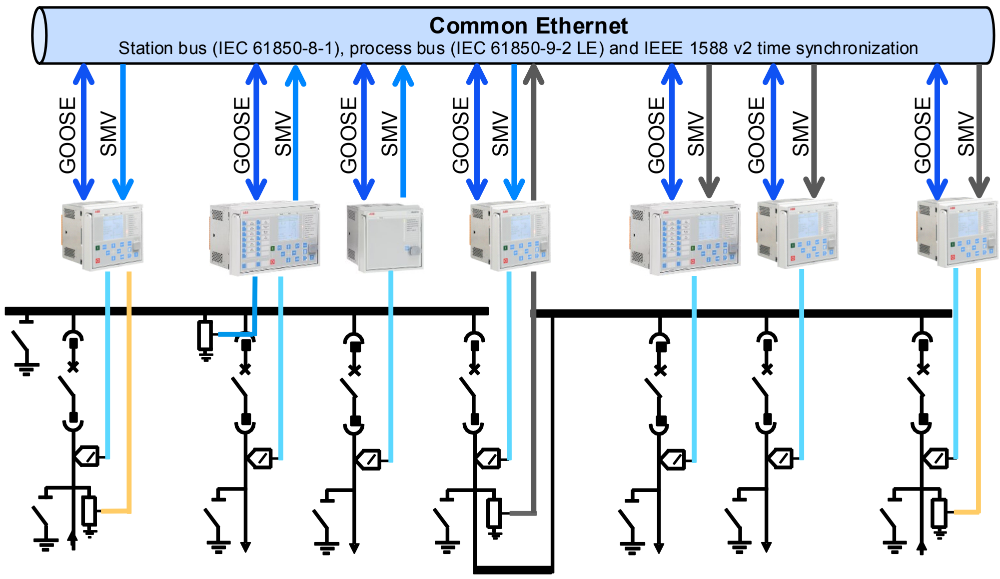


Figure 12: Process bus application of voltage sharing and synchrocheck

REX640 supports IEC 61850 process bus with sampled values of analog currents and voltages. The measured values are transferred as sampled values using the IEC 61850-9-2 LE protocol which uses the same physical Ethernet network as the IEC 61850-8-1 station bus. One example application is sharing the measured busbar voltage from one or several REX640 relays with the other REX640 relays. This can be done even for a double busbar switchgear installation using automatic 9-2 stream selection based on the bus disconnectors' physical position.

REX640 protection relays with process bus based applications use IEEE 1588 v2 Precision Time Protocol (PTP) according to IEEE C37.238-2011 or IEC 61850-9-3 profiles for high accuracy time synchronization. With IEEE 1588 v2, the cabling infrastructure requirement is reduced by allowing time synchronization information to be transported over the same Ethernet network as the data communications.

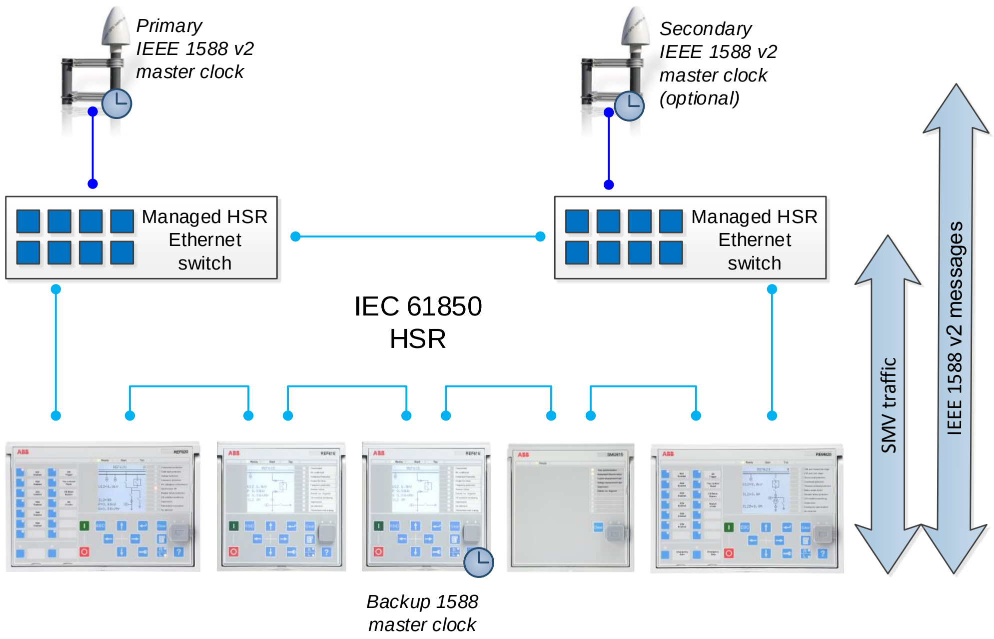


Figure 13: Example network topology with process bus, redundancy and IEEE 1588 v2 time synchronization

3.2.5 Secure communication

The protection relay supports secure communication for WHMI and file transfer protocol using Transport Layer Security protocol. The WHMI must be connected from a Web browser using the HTTPS protocol. File transfer client must use explicit FTPS.

3.2.6 Communication services control

3.2.6.1 Ethernet ports

The protection relay allows the use of a secondary IP address for the station ports on the communication modules COM1001...COM1003. This secondary IP network is assigned to a single Ethernet port and can be used to make separate networks for different communication protocols or, for example, a separate service network for configuration purposes. Multicast station/bus communication, such as IEC 61850-9-2 LE sampled values and GOOSE, is only supported on the Network 1 interface. The parameters for setting the secondary IP network are located under **Configuration** > **Communication** > **Ethernet** > **Network 2 address**.

Table 35: Secondary IP address parameters

Parameter	Options	Description
Configuration/Communication/Ethernet/Network 2 address/ Enable	False (default)	Network 2 disabled
	TRUE	Network 2 enabled
Configuration/Communication/Ethernet/Network 2 address/IP address	0.0.0.0	IP address for Network 2
Configuration/Communication/Ethernet/Network 2 address/IP address	0.0.0.0	Subnet address for Network 2
Configuration/Communication/Ethernet/Network 2 address/MAC address	xx-xx-xx-xx-xx-xx	MAC address for Network 2

The IP address for Network 2 is disabled by default settings, and all Ethernet ports are assigned to the same IP address used in the Network 1 address menu **Configuration** > **Communication** > **Ethernet** > **Network 1**. If Network 2 is taken into use by the setting Enable="True" (requires reboot), the interlink port X3 of the COM module is assigned to this second network, using the IP address and subnet parameters in the Network 2 address menu **Configuration** > **Communication** > **Ethernet** > **Network 2 address**.

If the Network 2 interface is enabled, PTP time synchronization and SMV/GOOSE multicast are disabled for that port.

The secondary IP setting must not collide with the primary Network 1 IP address or LHMI IP address, otherwise the secondary IP address is not taken into use.

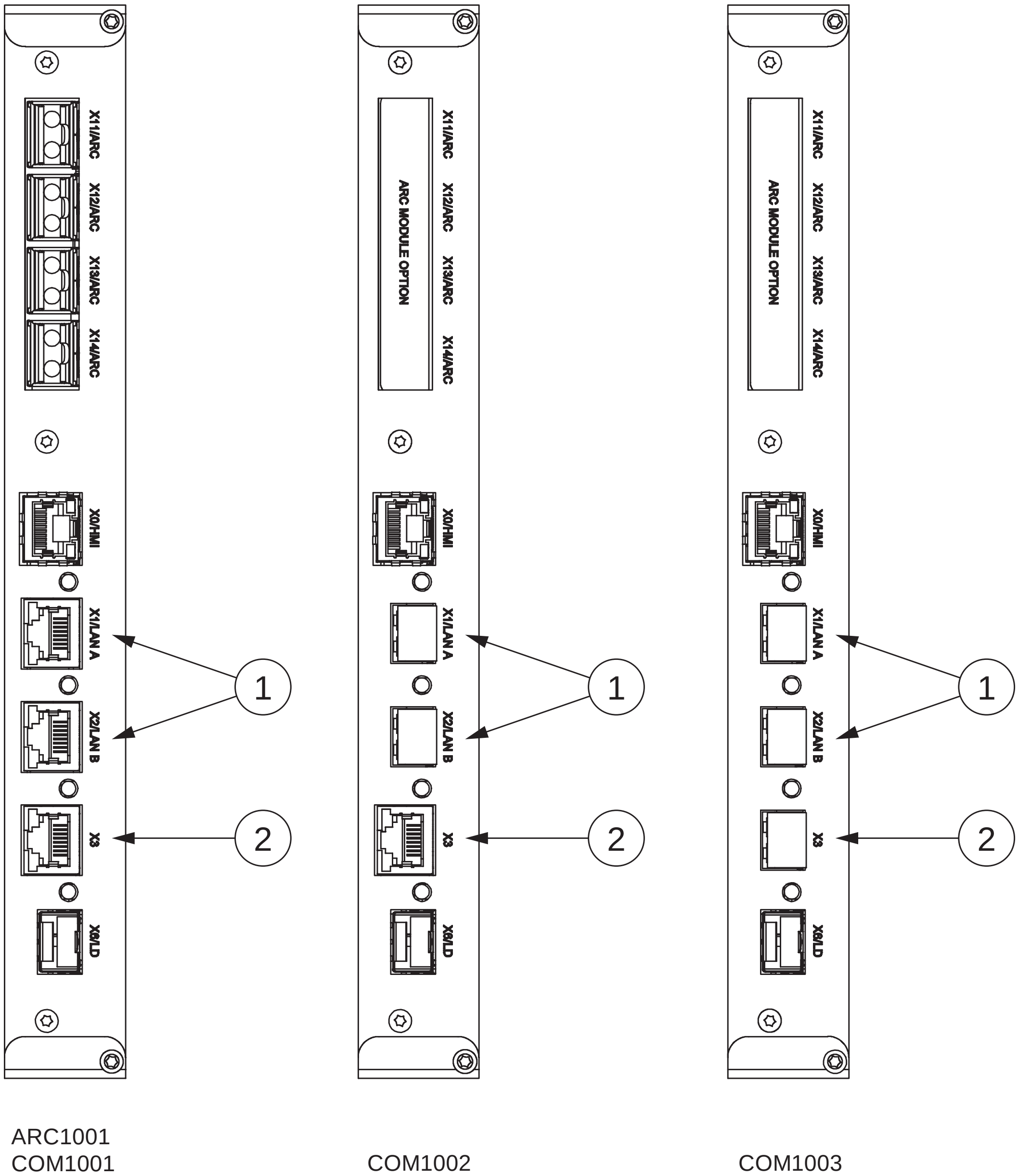


Figure 14: Ethernet modes with Network 1 and Network 2

1 Network 1

2 Network 1 / Network 2

3.2.6.2 Protocol control

It is possible to allow or block different protocols for different network interfaces in the protection relay using the parameters in **Configuration** > **Communication** > **Protocols** > **Network1**, **Configuration** > **Communication** > **Protocols** > **Network2** and **Configuration** > **Communication** > **Protocols** > **HMI Port**.

All protocols are allowed for each network by default, and can be separately disabled.

Table 36: Protocol control in the protection relay

Parameter	Options	Description
Configuration/Communication/Proto-cols/Network1/FTP	Off	Denies FTP and FTPS
	On	Allows FTP and FTPS
	Secure (Default)	Allows FTPS only
Configuration/Communication/Proto-cols/Network2/FTP	Off	Denies FTP and FTPS
	On	Allows FTP and FTPS
	Secure (Default)	Allows FTPS only
Configuration/Communication/Proto-cols/HMI Port/FTP	Off	Denies FTP and FTPS
	On	Allows FTP and FTPS
	Secure (Default)	Allows FTPS only
Configuration/Communication/Proto-cols/Network1/HTTPS	Off	Denies HTTPS
	On (Default)	Allows HTTPS
Configuration/Communication/Proto-cols/Network2/HTTPS	Off	Denies HTTPS
	On (Default)	Allows HTTPS
Configuration/Communication/Proto-cols/Network1/MMS	Off	Denies IEC 61850 MMS
	On (Default)	Allows IEC 61850 MMS
Configuration/Communication/Proto-cols/Network2/MMS	Off	Denies IEC 61850 MMS
	On (Default)	Allows IEC 61850 MMS
Configuration/Communication/Proto-cols/HMI Port/MMS	Off	Denies IEC 61850 MMS
	On (Default)	Allows IEC 61850 MMS
Configuration/Communication/Proto-cols/Network1/DNP	Off	Denies DNP3
	On (Default)	Allows DNP3
Configuration/Communication/Proto-cols/Network2/DNP	Off	Denies DNP3
	On (Default)	Allows DNP3
Configuration/Communication/Proto-cols/Network1/Modbus	Off	Denies Modbus
	On (Default)	Allows Modbus
Configuration/Communication/Proto-cols/Network2/Modbus	Off	Denies Modbus
	On (Default)	Allows Modbus
Configuration/Communication/Proto-cols/Network1/ IEC-60870-5-104	Off	Denies IEC 60870-5-104
	On (Default)	Allows IEC 60870-5-104
Configuration/Communication/Proto-cols/Network2/ IEC-60870-5-104	Off	Denies IEC 60870-5-104
	On (Default)	Allows IEC 60870-5-104

3.2.6.3 Protocol write access rights

Write access rights are configurable for FTP, MMS, and HTTPS protocols in **Configuration** > **Authorization**. The write access parameters are used to narrow down services that allow setting changes on different network interfaces. Disabling the FTP and IEC 61850 MMS write access on Network 1 and 2 prevents the user from updating the configuration to the protection relay from PCM600. Disabling the HTTPS write access prevents the user from writing setting changes from WHMI.

Table 37: Protocol write access in the protection relay

Parameter	Options	Description
Configuration/Authorization/Network1/FTP write access	Off	FTP write access denied for Network 1
	On (Default)	FTP write access allowed for Network 1
Configuration/Authorization/Network1/MMS write access	Off	IEC 61850 MMS write access denied for Network 1
	On (Default)	IEC 61850 MMS write access allowed for Network 1
Configuration/Authorization/Network1/HTTPS write access	Off	HTTPS write access denied for Network 1
	On (Default)	HTTPS write access allowed for Network 1
Configuration/Authorization/Network2/FTP write access	Off	FTP write access denied for Network 2
	On (Default)	FTP write access allowed for Network 2
Configuration/Authorization/Network2/MMS write access	Off	IEC 61850 MMS write access denied for Network 2
	On (Default)	IEC 61850 MMS write access allowed for Network 2
Configuration/Authorization/Network2/HTTPS write access	Off	HTTPS write access denied for Network 2
	On (Default)	HTTPS write access allowed for Network 2
Configuration/Authorization/HMI/FTP write access	Off	FTP write access denied for the HMI port
	On (Default)	FTP write access allowed for the HMI port
Configuration/Authorization/HMI/MMS write access	Off	IEC 61850 MMS write access denied for the HMI port
	On (Default)	IEC 61850 MMS write access allowed for the HMI port

PCM600 is using FTP or FTPS protocol to communicate with the protection relay. If the FTP write access is disabled for a network PCM600 functionality is limited to support read operations only from Disturbance handling, Event viewer and Parameter Setting.

Enabling Network 2 IP address requires additional configuration in PCM600 to define IEC 61580 subnetworks. This configuration is done via Ethernet Configuration and IEC 61850 Configuration in PCM600.

3.2.7 Serial port supervision SERLCCH

3.2.7.1 Function block

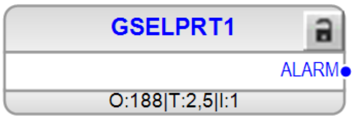


Figure 15: Function block

3.2.7.2 Functionality

The function block represents the IEC61850 GOOSE communication monitoring and diagnostics in the relay. Function block includes the GOOSE diagnostic counters that can be accessed via HMI, and `ALARM` output.

`ALARM` output indicates if overall GOOSE communication status is good or not. If `ALARM` output status is “False”, all GOOSE inputs are receiving data within the timeout limits. If the output is “True”, there is an issue (e.g. timeout or decoding), with one or more of GOOSE inputs in the relay.

For more information on the GOOSE configuration and monitoring refer to the IEC61850 engineering manual.

3.2.8 Serial port supervision SERLCCH

3.2.8.1 Function block

Figure 16: Function block

3.2.8.2 Functionality

The serial port supervision function SERLCCH represents one serial communication port driver. Depending on the hardware configuration, the protection relay can be equipped with two UART-based serial communication ports. The communication ports can be both galvanic (RS-485) or one port could be fiber-optic. The protection relay uses the ports for serial communication protocol links.

Serial communication drivers are identified in the device configuration as COM1 and COM2, which correspond to function blocks SERLCCH1 and SERLCCH2, respectively. Each COM port driver has its own setting parameters on the HMI under **Configuration** > **Communication** > **COMn (n=1,2)**.

Output `LNKxLIV` is active (TRUE) whenever characters are received on the serial interface. Output `CHxLIV` is active (TRUE) while complete link frames are received. Both outputs go to FALSE state after 15 seconds of inactivity on the port.

3.2.9 Assigning of a serial communication protocol to a COM serial port

The settings of the serial communication protocol instance include a setting parameter, called either *Port* or *Serial port*, which is used to select the COM1 or COM2 setting.

Since not all serial protocol standards allow changes in link parameters, all link setting parameters are not found in the COMn settings. Additional link setting parameters are found in the setting parameter list of the used serial protocol.

3.2.10 Physical locations of the serial channels

The physical location of the COM1 and COM2 drivers depends on the link mode used which, in turn, depends on the used communication hardware option. Serial channels can be found on communication boards COM1004...COM1005.

- X7 is the fiber-optic interface. Only driver COM2 can be configured into fiber-optic mode.
- X8 is the RS-485/IRIG-B interface. Both drivers COM1 and COM2 can be configured to this interface: COM1 and COM2 can act as two RS-485 2-wire links or, alternatively, COM1 can act as one single RS-485 4-wire link. Both ports are galvanically isolated serial communication ports.

Table 38: Connector X8 signals

Pin No	Pin name	Description	Alternative
1	GND	EARTH	
2	GNDC	GND connected to earth via 1nF capaci-tor	
3	NC		
4	IRIG-B -	ISOL2_GND	
5	IRIG-B +		
6	ISOL_GND	RS485 GND	
7	RS485 B1/-	2-wire - , COM1	4-wire TX pair, COM1
8	RS485 A1/+	2-wire + , COM1	4-wire TX pair, COM1
9	RS485 B2/-	2-wire - , COM2	4-wire RX pair, COM1
10	RS485 A2/+	2-wire + , COM2	4-wire RX pair, COM1

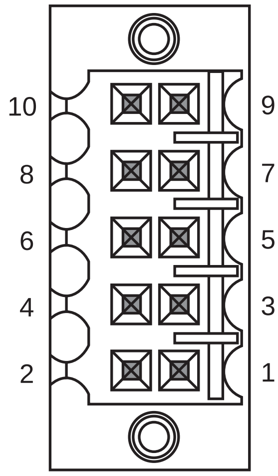


Figure 17: X8 connector pinout for socket on communication board

Table 39: LED configuration (COM1004...COM1005)

LED	Description
X1	X1 LANA
X2	X2 LANB
X6	X6 LD
X7 TX	FO-UART
X8 TX	RS-485/COM2
X8 TX	RS-485/COM1
IRIG-B	IRIG-B

3.2.11 RS-485 bias and termination settings

A 6 x DIP switch is located on the COM1004...COM1005 cards. The COM card needs to be pulled out from the relay case to access the switch. See *Figure 18* for the location of the switch. RS-485 biasing and termination settings are possible through this switch. If the switch is in “OFF” position, bias and termination are disabled and in “ON” position, they are enabled.

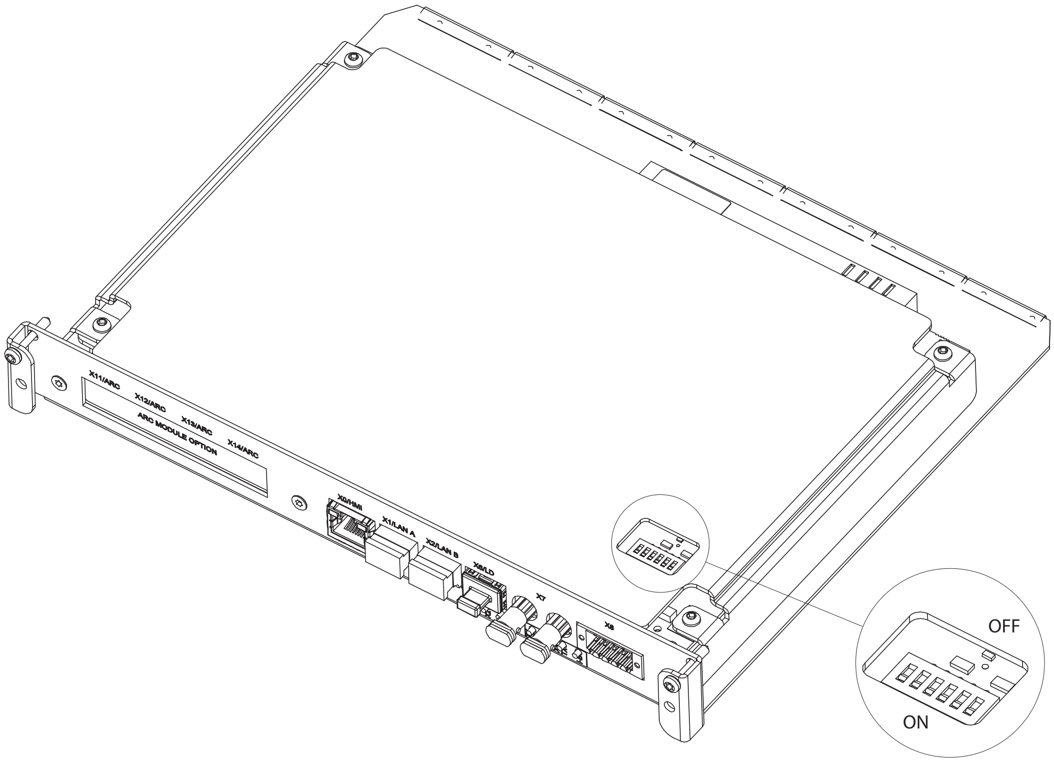


Figure 18: DIP switches on the COM1004...COM1005 cards

Table 40: Bias and termination DIP switch

Switch	Signal	X8 pin	Type
1	RS485_A1/+	8	Bias
2	RS485_A1/+ RS485_B1/-		Bus termination
3	RS485_B1/-	7	Bias
4	RS485_A2/+	10	Bias
5	RS485_A2/+ RS485_B2/-		Bus termination
6	RS485_B2/-	9	Bias

3.2.12 Serial link diagnostics and monitoring

Serial communication diagnostics and monitoring is divided between the serial link driver and the serial communication protocol. The lower-level physical and protocol-independent aspects of the UART-based serial communication are monitored in the serial link driver. Diagnostic counters and monitoring values are located on the HMI under **Monitoring** > **Communication** > **COMn** (n= 1,2,…).

Depending on the communication protocol, the serial driver software receives single characters or complete protocol frames, based on the frame start/stop characters or on link frame timing.

Table 41: Setting parameters

Parameter	Description
Fiber mode	Defines the fiber-optic mode used. Setting "No fiber" is the same as galvanic mode.
Serial mode	Used for galvanic RS-485 modes 2- or 4-wire. This setting is relevant only if Fiber mode is set to "No fiber".
Baudrate	Communication speed used.

Table 42: Diagnostic counters and indications

Counters	Description
Characters received	Counts all incoming non-erroneous characters. This counter operates regardless of whether the serial driver is set to detect a whole protocol link frame or just separate characters.
Frames received	Counts all protocol-specific non-erroneous frames received. Protocol-specific frames can be based on timing (for example, Modbus RTU) or on special start and stop characters (for example, Modbus ASCII).
Frames discarded	Counts all protocol-specific erroneous frames received. If the driver detects an error while receiving a frame, the whole frame is automatically discarded. This also means that the protocol in question never receives a faulty link frame from the driver. When this counter is incremented, one of the detailed error counters (Parity, Overrun, Framing) can also be incremented.
Frames transmitted	Counts all protocol-specific frames transmitted from the COM channel.
Collisions	Counts the number of transmission collisions that have occurred. Used in RS-485 mode by some protocols where transmissions could collide with reception. For example, DNP3 unsolicited reporting mode.
Parity errors	Counts the number of parity errors detected in characters received.
Overrun errors	Counts the number of overrun errors detected in characters received.
Framing errors	Counts the number of framing errors detected in characters received.
Link status	In write direction: By writing value 1 to this parameter, all the diagnostic counters are reset to 0.
Link status	In monitoring direction: If the driver instance is in use by any communication protocol, the monitoring value shows value 1. Otherwise, the value is 0.

3.2.13 Modbus protocol MBSLPRT

3.2.13.1 Function block

Figure 19: Function block

3.2.13.2 Functionality

The function block represents a Modbus server protocol instance in the protection relay. Function block settings include communication interface assignment for the instance, that is, Ethernet/TCP or serial.

A Modbus server protocol instance is activated if the function block instance is added to the application configuration. The setting *Operation* should be "On" and setting *Port* should have the communication interface assignment.

The STATUS output of the function block is active if Modbus client requests have been received on the communication interface within 15 seconds.

By default no Modbus data is mapped to the protocol interface. Protocol data has to be created using Communication Management in PCM600. There are two mapping sets, “Mapping 1” and “Mapping 2”, and either can be used. Setting parameter *Mapping selection* points to the mapping set used. Several Modbus protocol instances can point to the same mapping set.

For more information on the Modbus server protocol, see the Modbus communication protocol manual.

3.2.14 DNP3 protocol DNPLPRT

3.2.14.1 Function block

Figure 20: Function block

3.2.14.2 Functionality

The function block represents one DNP3 server protocol instance in the protection relay. Function block settings include communication interface assignment for the instance, that is, Ethernet/TCP(+UDP) or serial.

Over Ethernet/TCP, the protocol optionally supports secure authentication with symmetric keys. The implementation follows the IEC 62351-5 security standard specification as well as the descriptions in DNP3 standard part 7, IP-networking chapter "Secure authentication".

A DNP3 server protocol instance is activated if the function block instance is added to the application configuration. The setting *Operation* should be "On" and setting *Port* should have the communication interface assignment.

The STATUS output of the function block is active if DNP3 client requests or DNP3 supervision messages have been received on the communication interface within an interval defined by the link keep-alive parameter.

By default no DNP3 data is mapped to the protocol interface. Protocol data has to be created using Communication Management in PCM600. There are two mapping sets, “Mapping 1” and “Mapping 2”, and either can be used. Setting parameter *Mapping selection* points to the mapping set used. Several DNP3 protocol instances can point to the same mapping set.

For more information on the DNP3 server protocol, see the DNP3 communication protocol manual.

3.2.15 IEC 60870-5-103 protocol I3CLPRT

3.2.15.1 Function block

Figure 21: Function block

3.2.15.2 Functionality

The function block represents one IEC 60870-5-103 server protocol instance in the protection relay. Function block settings include communication interface assignment for the instance, that is, serial communication port 1 or 2.

An IEC 60870-5-103 server protocol instance is activated if the function block instance is added to the application configuration. The setting *Operation* should be "On" and setting *Serial port* should have the communication interface assignment.

The STATUS output of the function block is active if IEC 60870-5-103 client requests have been received on the communication interface within 15 seconds.

The function block input EC_FRZ relates to possible ASDU 205 (mostly energy) counters defined in the protection relay. Activation of the EC_FRZ input freezes and captures the current ASDU 205 counter values and sends them to the IEC 60870-5-103 client. Several options for the activation exist.

1. EC_FRZ object exists as a control object in the IEC 60870-5-103 data model, and can be written from the client.
2. EC_FRZ physical input can be activated from an internal or external timer application signal.

By default most IEC 60870-5-103 data is pre-mapped to the protocol interface. However, protocol data can be deleted, added and modified using Communication Management in PCM600.

For more information on the IEC 60870-5-103 server protocol, see the IEC 60870-5-103 communication protocol manual.

3.2.16 IEC 60870-5-104 protocol I5CLPRT

3.2.16.1 Function block

Figure 22: Function block

3.2.16.2 Functionality

The function block represents one IEC 60870-5-104 TCP/IP server protocol instance in the protection relay.

An IEC 60870-5-104 server protocol instance is activated if the function block instance is added to the application configuration. The setting *Operation* should be "On".

The protocol optionally supports secure authentication version with symmetric keys. The implementation follows the IEC 62351-5 security standard specification and the descriptions in the pro-tocol standard part IEC 60870-5-7 “Transmission procedures, extension for secure communica-tion”. **Functionality is limited to single user mode only**.

The `STATUS` output of the function block is active if IEC 60870-5-104 client activity is noticed on the communication interface within 15 seconds.

The function block input `IT_FRZ` relates to the IEC 610870-5-104 integration totals counter objects defined in the protection relay. The `IT_FRZ` input can be configured for external counter freezing.

By default no IEC 60870-5-104 data objects are mapped to the protocol instance. Protocol data can be added and modified using Communication Management in PCM600.

For more information on the IEC 60870-5-104 server protocol, see the IEC 60870-5-104 communication protocol manual.

3.3 Self-supervision

The protection relay's extensive self-supervision system continuously supervises the relay’s software, hardware and certain external circuits. It handles the run-time fault situation and informs the user about a fault via the LHMI, the relay's main unit power module Ready LED and through the communication channels. The target of the self-supervision is to safeguard the relay’s reliability by increasing both dependability and security. The dependability can be described as the relay’s ability to operate when required. The security can be described as the relay scheme’s ability to refrain from operating when not required. The dependability is increased by letting the system operators know about the problem, giving them a chance to take the necessary actions as soon as possible. The security is increased by preventing the relay from making false decisions, such as issuing false control commands.

There are two types of fault indications.

- Internal faults
- Warnings

Warnings are indications of less severe situations which can also be caused by external reasons, for example, in case the RTD sensor measurement circuit is not complete.

On the LHMI, the self-supervision status is available as an advanced page under Relay Status page. The self-supervision status is indicated with Internal Fault, Warning and All OK LEDs. In normal operation, All OK LED is lit. The selfsupervision also controls the status of IRF output relay. The IRF output relay is energized under normal conditions and de-energized under internal fault conditions.

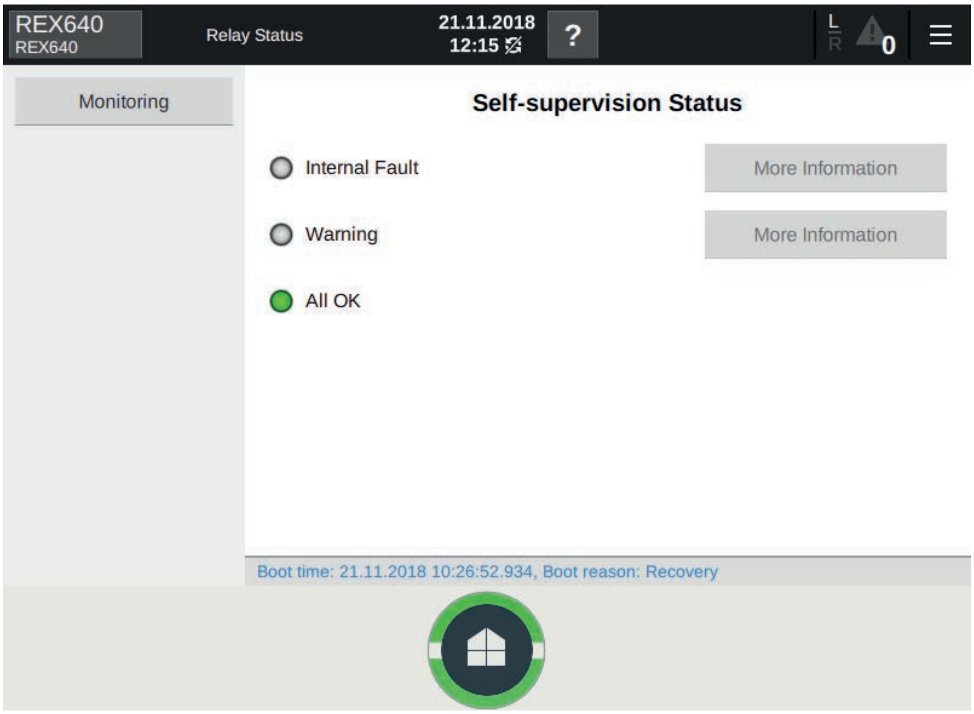


Figure 23: Relay self-supervision status on local HMI

On the WHMI, the self-supervision status is available under Device menu. The top right LED indicates the relay status.

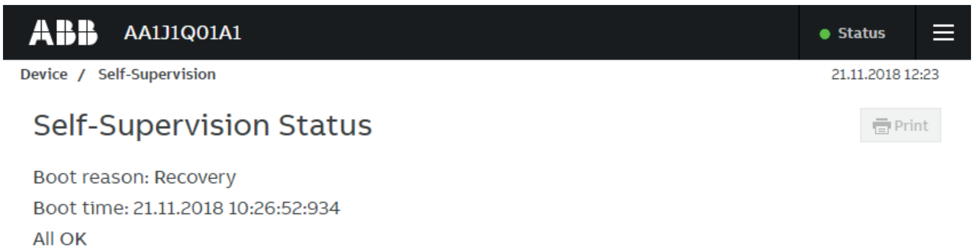


Figure 24: Relay self-supervision status on Web HMI

In addition, the last boot reason and time are shown on both LHMI and WHMI.

3.3.1 Internal faults

When an internal relay fault is detected, the relay protection operation is disabled, the self-supervision output relay is de-energized, and the change-over contact is released. In the main unit, the main indication of an internal fault is a flashing green Ready LED behind the power module, and on the HMI, a rapidly flashing red Home button.

Different actions are taken depending on the severity of the internal fault. In case of a temporary fault, the protection relay tries to recover from the situation by restarting. The restart procedure includes two stages; when the relay detects a fault, it restarts itself in a few seconds after the fault occurrence. If the relay did not recover after the first restart, or the fault reoccurs during the next 60 minutes, the second restart is delayed for 10 minutes. In case of a permanent fault, the protection relay stays in the internal fault mode. All output relays are de-energized and contacts are released for the internal fault. The protection relay continues to perform internal tests during the fault situation. If the internal fault disappears, the fault indication LEDs stop flashing and the protection relay returns to the normal service state.

One possible cause for an internal fault situation is a so-called soft error. The soft error is a probabilistic phenomenon which is rare in a single device, statistically not happening more often than once in a relay’s lifetime. No hardware failures are expected and a full recovery from the soft error is possible by a self-supervision controlled restart of the relay.

The self-supervision signal output operates on the closed-circuit principle. Under normal conditions, the IRF output relay is energized and the contact gap 3-5 is closed. If the auxiliary power supply fails or an internal fault is detected, the IRF output relay is de-energized and the contact gap 3-5 opens.

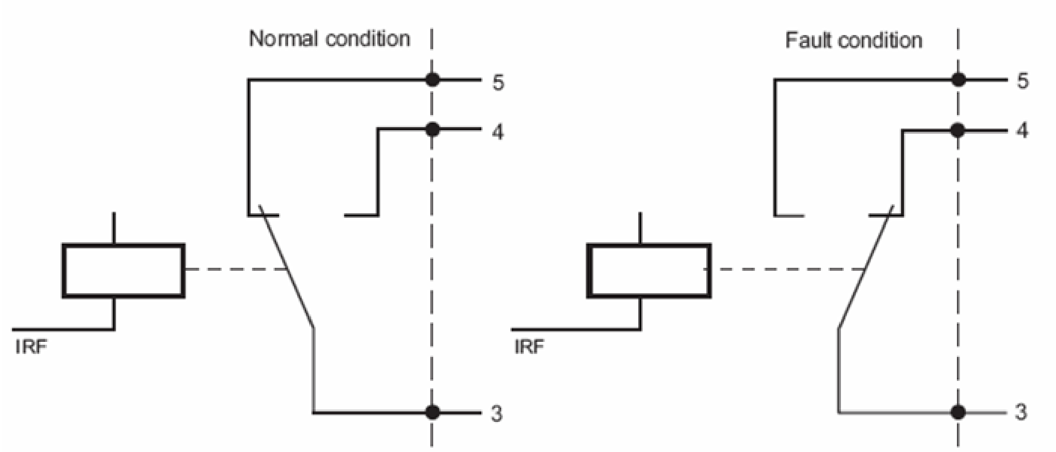


Figure 25: Output contact

The internal fault code indicates the type of internal relay fault. When a fault appears, the code must be recorded so that it can be reported to ABB customer service.

More details about the active internal fault are found on the Relay Status page. On the LHMI, the internal fault state is indicated with a red LED. More information about the fault and recovery options can be accessed by tapping More Information.

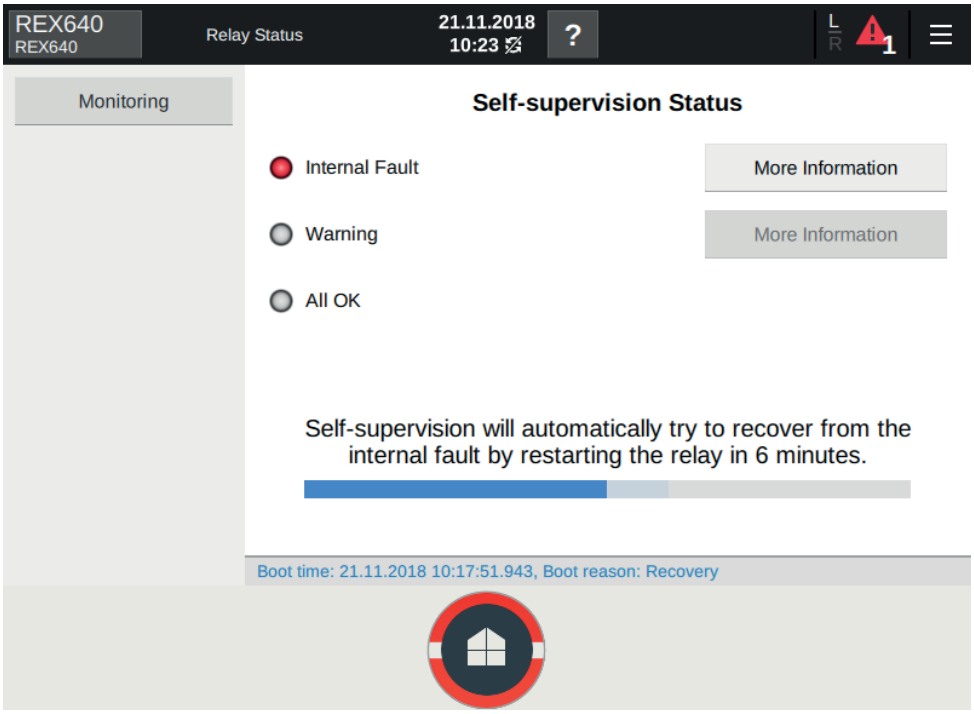


Figure 26: Internal fault state indicated with red LED

More Information shows all active faults and the corresponding fault codes. In addition, a recovery procedure is described.

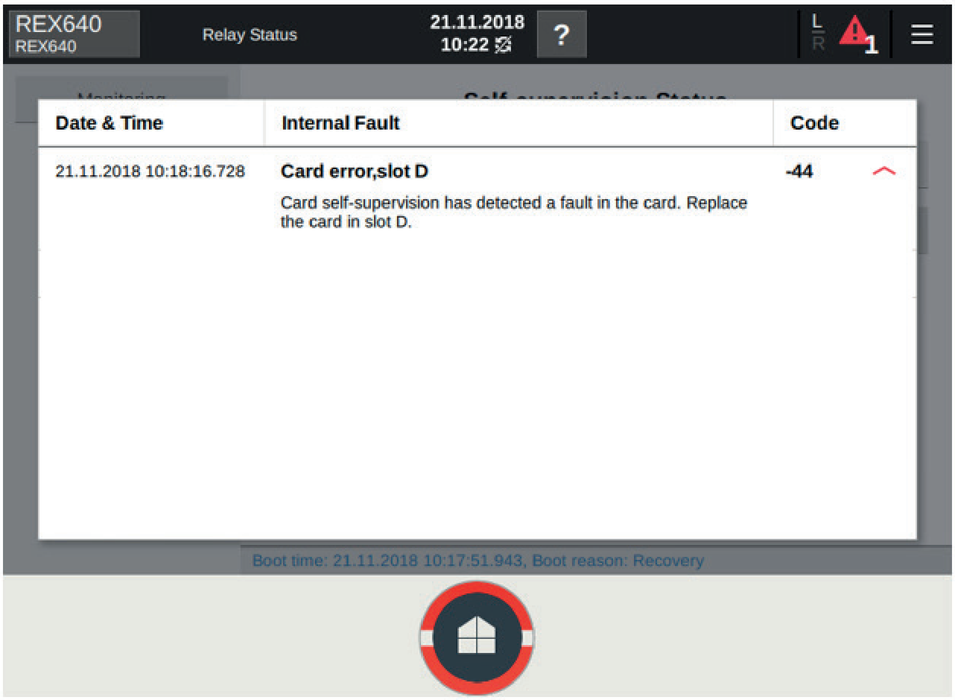


Figure 27: More information about the fault

On the WHMI, internal fault information is shown under Self-Supervision Status.

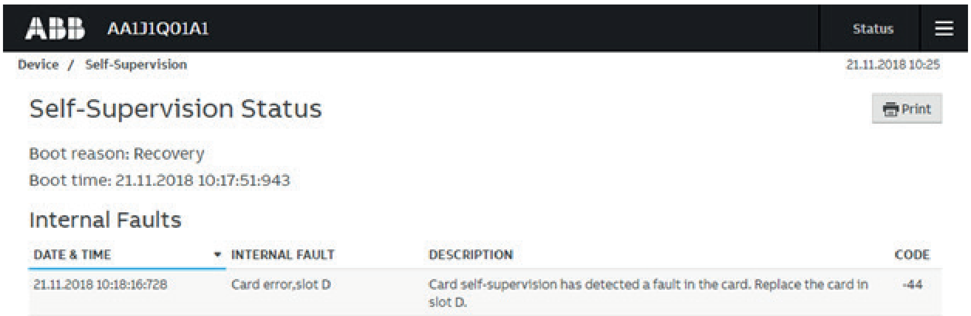


Figure 28: Internal fault information on Web HMI

Table 43: Internal fault indications and codes

Fault indication	Fault code	Additional information	Fast self-recovery attempt	Slow 10min self-recovery (# of attempts)	Immediate IRF-mode	Action in permanent fault state
Internal Fault System error	2	Start up error: HW/SW mismatch	No	No	Yes	If relay SW has just been updated, redo it. If not recovered, contact your nearest ABB representative to check the next possible corrective action.
Internal Fault System error	2	Start up or runtime error: Data bus error, CPU module	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault System error	2	Start up error: SCL file missing	No	No	Yes	Do factory restore or rewrite configuration using PCM600.
Internal Fault System error	2	Start up error: Missing order number	No	No	Yes	Do factory restore. If not recovered, contact your nearest ABB representative to check the next possible corrective action.
Internal Fault System error	2	Start up error: FPGA HW error, CPU module	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault System error	2	Start up error: FPGA image corrupted, CPU module	Yes	Yes (3)	No	Restart the relay or if relay SW has just been updated, redo it. If recovered by restarting, continue relay normal operation. If not recovered by restarting or redoing SW update, replace the relay, most probably hardware failure in CPU module.
Internal Fault System error	2	Runtime error: CPU internal fault	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restart-

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt	Slow 10min self-recovery (# of attempts)	Immediate IRF-mode	Action in permanent fault state
						ing, replace the relay, most probably hardware failure in CPU module.
Internal Fault System error	2	Start up error: Card init fault	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recovered by restarting, check for example relay's Information menu to see which card(s) are not shown correctly and replace it (them).
Internal Fault File system error	7	Start up error or runtime error: file system error	Yes	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault Test	8	Internal fault test activated manually by the user.	No	No	-	Just check the "Internal fault test" -setting parameter position, if relay is in test mode
Internal Fault SW watchdog error	10	Start up error: Watchdog reset has occurred too many times within an hour. Note! This is different indication than Warning code 10: Watchdog reset	No	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay.
Internal Fault LHMI module	79	Start up error: EEPROM error in LHMI module. The fault indication may not be seen on the LHMI during the fault.	No	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, check LHMI connection cable and connection to be proberly fixed. If then not recovered by restarting, exchange the LHMI module.
Internal Fault LHMI module	79	Runtime error: LHMI LCD error. The fault indication may not be seen on the LHMI during the fault.	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, check LHMI connection cable and connection to be proberly fixed. If then not recovered by restarting, exchange the LHMI module.
Internal Fault RAM error	80	Runtime error: Error in the RAM memory on the CPU module.	No	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault ROM error	81	Runtime error: Error in the ROM memory on the CPU module.	Yes	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt	Slow 10min self-recovery (# of attempts)	Immediate IRF-mode	Action in permanent fault state
Internal Fault EEPROM error	82	Start up error: Error in the EEPROM memory on the CPU module.	No	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault EEPROM error	82	Start up error: CRC check failure in the EEPROM memory on boot-up on the CPU module.	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault FPGA error	83	Runtime error: Error in the FPGA on the CPU module.	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault RTC error	84	Start up error: Error in the RTC on the CPU module.	Yes	No	Yes	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, replace the relay, most probably hardware failure in CPU module.
Internal Fault COM card error	116	Runtime error: Error in the COM card.	Yes	Yes (3)	No	Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the communication module in slot X000.
Internal Fault SO-relay(s), Slot C	-10	Runtime error: Faulty Signal Output relay(s) in card located in slot C.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot C.
Internal Fault SO-relay(s), Slot E	-11	Runtime error: Faulty Signal Output relay(s) in card located in slot E.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot E.
Internal Fault SO-relay(s), Slot A2	-12	Runtime error: Faulty Signal Output relay(s) in card located in slot A2.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot A2.
Internal Fault SO-relay(s), Slot B	-13	Runtime error: Faulty Signal Output relay(s) in card located in slot B.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot B.

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt	Slow 10min self-recovery (# of attempts)	Immediate IRF-mode	Action in permanent fault state
Internal Fault SO-relay(s), Slot D	-14	Runtime error: Faulty Signal Output relay(s) in card located in slot D.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot D.
Internal Fault SO-relay(s), Slot F	-15	Runtime error: Faulty Signal Output relay(s) in card located in slot F.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot F.
Internal Fault SO-relay(s), Slot G	-16	Runtime error: Faulty Signal Output relay(s) in card located in slot G.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot G.
Internal Fault SO-relay(s), Slot A1	-17	Runtime error: Faulty Signal Output relay(s) in card located in slot A1.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot A1.
Internal Fault PO-relay(s), Slot C	-20	Runtime error: Faulty Power Output relay(s) in card located in slot C.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot C.
Internal Fault PO-relay(s), Slot E	-21	Runtime error: Faulty Power Output relay(s) in card located in slot E.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot E.
Internal Fault PO-relay(s), Slot A2	-22	Runtime error: Faulty Power Output relay(s) in card located in slot A2.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot A2.
Internal Fault PO-relay(s), Slot B	-23	Runtime error: Faulty Power Output relay(s) in card located in slot B	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot B.
Internal Fault PO-relay(s), Slot D	-24	Runtime error: Faulty Power Output relay(s) in card located in slot D.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot D.

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt	Slow 10min self-recovery (# of attempts)	Immediate IRF-mode	Action in permanent fault state
Internal Fault PO-relay(s), Slot F	-25	Runtime error: Faulty Power Output relay(s) in card located in slot F.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot F.
Internal Fault PO-relay(s), Slot G	-26	Runtime error: Faulty Power Output relay(s) in card located in slot G.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot G.
Internal Fault PO-relay(s), Slot A1	-27	Runtime error: Faulty Power Output relay(s) in card located in slot A1.	Yes	Yes (3)	No	Check wirings. Restart the relay. If recovered by restarting, continue relay normal operation. If not recover by restarting, exchange the hardware module in slot A1.
Internal Fault Conf. error, Slot C	-30	Start up error: Card in slot C is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot C is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the hardware module in slot C.
Internal Fault Conf. error, Slot E	-31	Start up error: Card in slot E is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot E is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the hardware module in slot E.
Internal Fault Conf. error, Slot A2	-32	Start up error: Card in slot A2 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the communication card in slot A2 is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the communication module in slot A2.
Internal Fault Conf. error, Slot B	-33	Start up error: Card in slot B is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot B is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the hardware module in slot B.
Internal Fault Conf. error, Slot D	-34	Start up error: Card in slot D is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot D is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Ex-

Table continues on the next page

Fault indication	Fault code	Additional information	Fast self-recovery attempt	Slow 10min self-recovery (# of attempts)	Immediate IRF-mode	Action in permanent fault state
						change the hardware module in slot D.
Internal Fault Conf. error, Slot F	-35	Start up error: Card in slot F is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot F is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the hardware module in slot F.
Internal Fault Conf. error, Slot G	-36	Start up error: Card in slot G is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot G is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the hardware module in slot G.
Internal Fault Conf. error, Slot A1	-37	Start up error: Card in slot A1 is wrong type, is missing, does not belong to original configuration or card firmware is faulty.	No	No	Yes	Check that the card in slot A1 is proper type and properly installed. Then restart the relay. If does not then recover by restarting, it is hardware module failure most likely in question. Exchange the hardware module in slot A1.
Internal Fault Card error, Slot C	-40	Card in slot C is faulty.	Yes	No	Yes	Exchange the hardware module in slot C.
Internal Fault Card error, Slot E	-41	Card in slot E is faulty.	Yes	No	Yes	Exchange the hardware module in slot E.
Internal Fault Card error, Slot A2	-42	Card in slot A2 is faulty.	Yes	No	Yes	Exchange the communication module in slot A2.
Internal Fault Card error, Slot B	-43	Card in slot B is faulty.	Yes	No	Yes	Exchange the hardware module in slot B.
Internal Fault Card error, Slot D	-44	Card in slot D is faulty.	Yes	No	Yes	Exchange the hardware module in slot D.
Internal Fault Card error, Slot F	-45	Card in slot F is faulty.	Yes	No	Yes	Exchange the hardware module in slot F.
Internal Fault Card error, Slot G	-46	Card in slot G is faulty.	Yes	No	Yes	Exchange the hardware module in slot G.
Internal Fault Card error, Slot A1	-47	Card in slot A1 is faulty.	Yes	No	Yes	Exchange the hardware module in slot A1.
Internal Fault 640-Prod. License error	-62	Runtime error: Product license error, license file is not found or is wrong	No	No	Yes	If SW update under Modification Sales has been carried out, redo the update. If not recovered, contact your nearest ABB representative to check the next possible corrective action.

3.3.2 Warnings

In case of a warning, the protection relay continues to operate except for those protection functions affected by the fault. The main unit status LED remains lit as during normal operation. If the device warning event is configured as alarms, the LHMI Home button flashes red.

If a warning appears, record the name and code so that it can be provided to ABB customer service. See the operation manual for more information on reading internal log files from the relay.

On the LHMI, an active warning is indicated with a yellow LED. More information about the warning and recovery options can be accessed by tapping More Information.

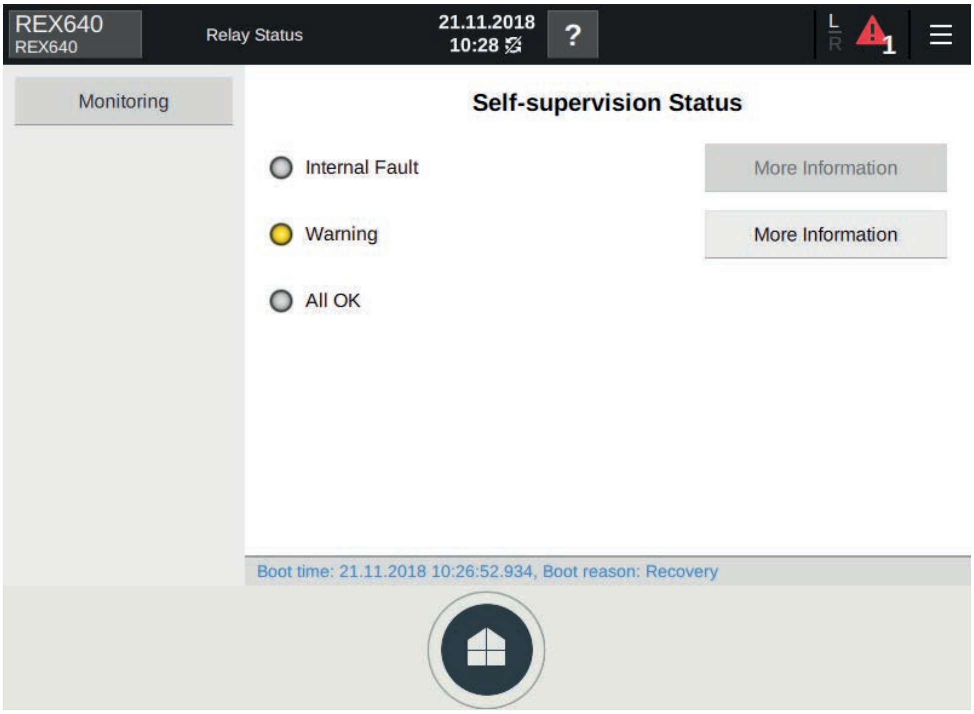


Figure 29: Active warning on local HMI

More information shows all active warnings and corresponding fault codes. In addition, a recovery procedure is described.

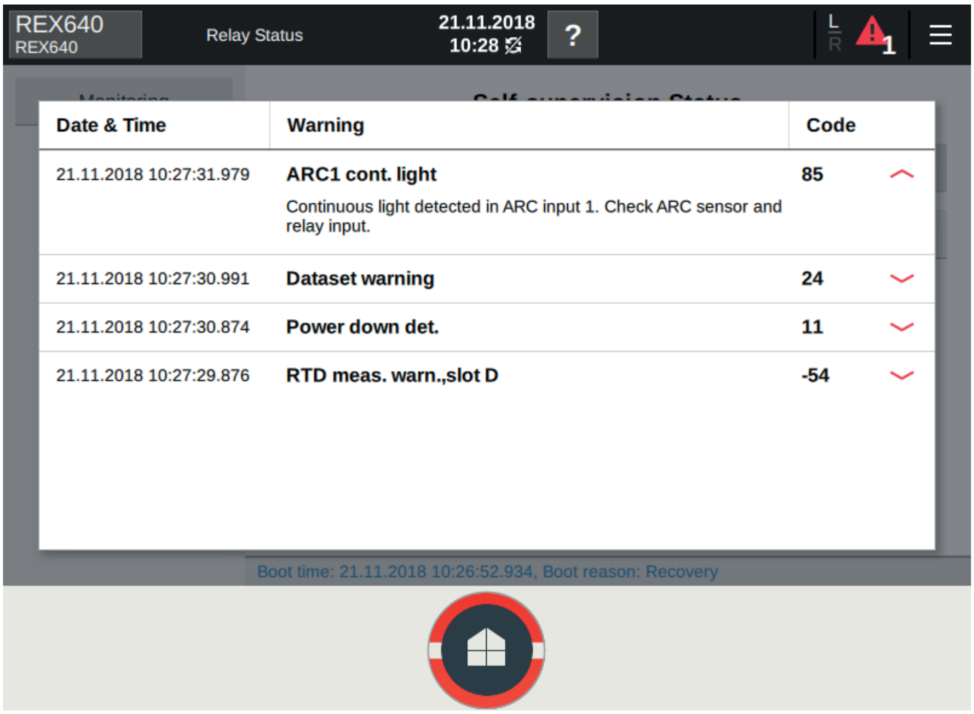


Figure 30: More information about the warning

The warning alarm is only displayed when configured in PCM600 event filtering.

Table 44: Warning indications and codes

Warning indication	Warning code	Additional information
Watchdog reset	10	A watchdog reset has occurred.
Power down det.	11	The auxiliary supply voltage has dropped too low.
DNP3 warning	22	Error in the DNP3 communication.
Dataset warning	24	Error in the Data set(s).
Report cont. warning	25	Error in the Report control block(s).
GOOSE contr. warning	26	Error in the GOOSE control block(s).
SCL config warning	27	Error in the SCL configuration file or the file is missing.
Logic warning	28	
SMT logic warning	29	
GOOSE input warning	30	
ACT warning	31	Analog channel configuration warning.
GOOSE rec. warning	32	
AFL warning	33	
SMV warning	34	Error in the SMV configuration.

Table continues on the next page

Warning indication	Warning code	Additional information
Comm. channel down	35	Redundant Ethernet (HSR/ PRP) communication interrupted.
Settings mismatch	36	Mismatch between parameter settings and application configuration.
Protection comm.	50	Error in protection communication.
ARC1 cont. light	85	A continuous light has been detected on the ARC light input 1.
ARC2 cont. light	86	A continuous light has been detected on the ARC light input 2.
ARC3 cont. light	87	A continuous light has been detected on the ARC light input 3.
ARC4 cont. light	88	A continuous light has been detected on the ARC light input 4.
RTD meas. warn.,slot D	–54	Abnormal signal from sensor(s) received in slot D.
RTD meas. warn.,slot C	–50	Abnormal signal from sensor(s) received in slot C.
mA output warn.,slot D	–24	Temporary error occurred in RTD module located in slot D.
mA output warn.,slot C	–20	Temporary error occurred in RTD module located in slot C.

3.3.3 Power supply module Ready LED and HMI Home button LED

Both power supply module Ready LED and LHMI Home button LED visualize the self-supervision state of the relay. *Table 45* shows how these states are indicated.

Table 45: Power supply module Ready LED and local HMI Home button LED

State	Power supply module Ready LED	LHMI Home button	Alarm acknowledged
Relay under normal operation and LHMI connected	Steady green	Steady green	N/A
Relay’s IRF activated, but communicates with LHMI	HF blinking green	HF blinking red	N/A
Communication lost between Relay and LHMI, but no IRF	Steady green	HF blinking green	N/A
LHMI not running normally or in start-up initialization phase	Steady green	HF blinking green	N/A
Process related alarm active	Steady green	LF blinking red	No
Process related alarm active	Steady green	Steady red	Yes
Process related alarm has been active earlier, but is not any more active	Steady green	LF blinking red	No

Table continues on the next page

State	Power supply module Ready LED	LHMI Home button	Alarm acknowledged
Process related alarm has been active earlier, but is not any more active	Steady green	Steady green	Yes
Relay set to Test Mode	LF blinking green	LF blinking green	No

The physical SHMI Home button has two operation modes.

- On the SHMI's navigation page, the Home button indicates the combined status of all connected relays. If multiple relays have different statuses, the Home button shows the indication with the highest priority.
- On the HMI view, the Home button indicates the status of the respective relay as described in *Table 45*.

3.3.4 Fail-safe principle for relay protection

The relay behavior during an internal fault situation has to be considered when engineering trip circuits under the fail-safe principle. The considerations discussed and examples given are mainly based on the need of protection scheme reliability.

The reliability need can be divided into two subparts: dependability and security. The dependability can be described as the protection scheme's ability to operate when required. The security can be described as the protection scheme's ability to refrain from operating when not required. The protection scheme fail-safe principle is typically related to satisfying these two performance criteria. Depending on the requirements set to the electricity distribution process, one of the criteria may get more attention than the other. However, in some industrial electricity distribution networks, the main (productization) process is so dependent on reliable electricity supply that both criteria are addressed equally.

The examples presented focus on the relay's protection role in the fail-safe circuitry using traditional hardwiring. If communication between the relays, or to an upper level system, is a part of the fail-safe functionality, it must be also be a part of the circuitry.

3.3.4.1 Motor feeder

The target is to prevent the motor from running uncontrollably and to secure the emergency stop circuit functionality.

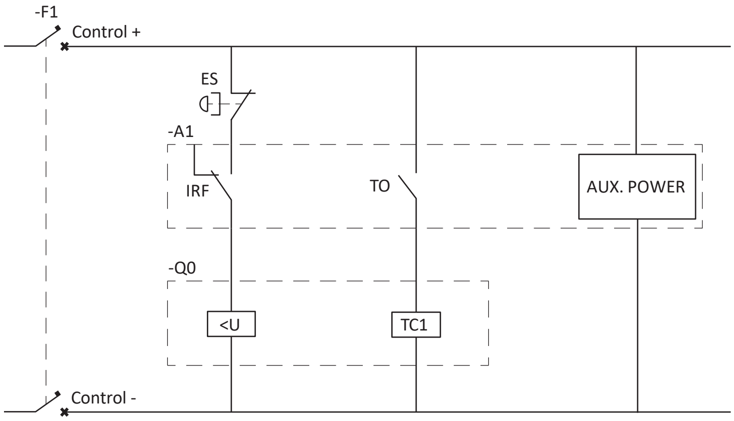


Figure 31: Motor feeder fail-safe trip circuit principle, example 1

A1	Protection relay
ES	Emergency stop
Q0	Circuit breaker (CB)
TO	Protection relay trip output
IRF	Internal relay fault indication
<U	CB undervoltage trip coil
TC1	CB trip coil 1
DCS	Distributed process control system
F1	Miniature circuit breaker

In example 1, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. In case of a temporary internal relay fault, the circuit breaker is immediately tripped before the relay recovers from the situation. In case the IRF output relay is directly connected to the undervoltage trip coil circuit, the output’s performance figures (make and break values) must be checked.

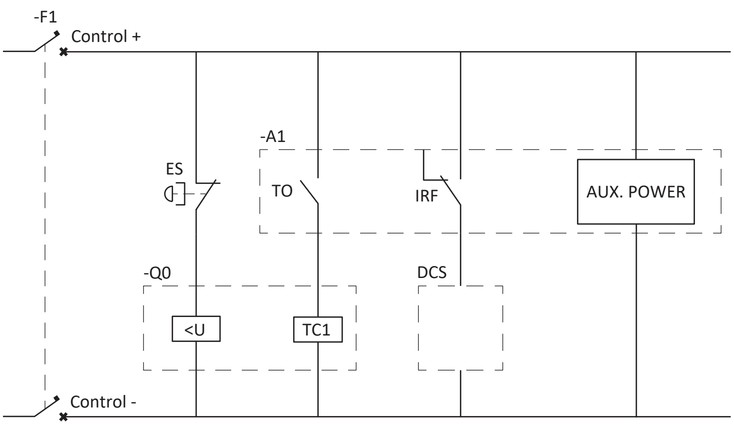


Figure 32: Motor feeder fail-safe trip circuit principle, example 2

A1	Protection relay
ES	Emergency stop
Q0	Circuit breaker (CB)

Table continues on the next page

TO	Protection relay trip output
IRF	Internal relay fault indication
<U	CB undervoltage trip coil
TC1	CB trip coil 1
DCS	Distributed process control system
F1	Miniature circuit breaker

In example 2, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. In case of internal relay fault, the necessary actions must be initiated by the process operators or by the control system.

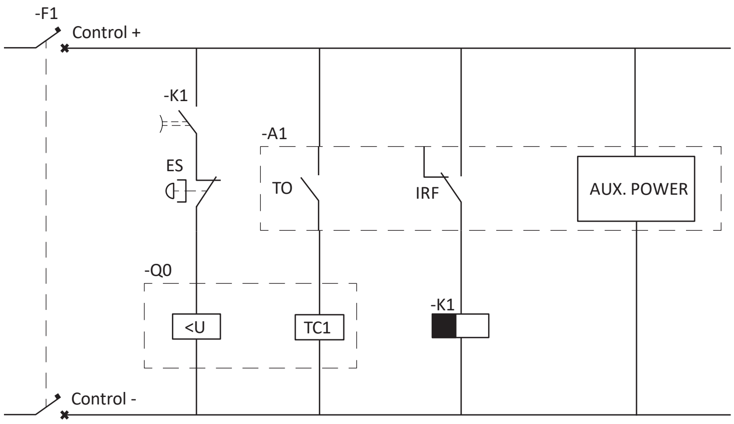


Figure 33: Motor feeder fail-safe trip circuit principle, example 3

A1	Protection relay
ES	Emergency stop
Q0	Circuit breaker (CB)
TO	Protection relay trip output
IRF	Internal relay fault indication
<U	CB undervoltage trip coil
TC1	CB trip coil 1
K1	OFF delay time relay
F1	Miniature circuit breaker

In example 3, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. In case of internal relay fault, the circuit breaker is tripped via an undervoltage coil after a preset time delay. The additional time delay allows the relay to recover from the internal fault situation without tripping the circuit breaker.

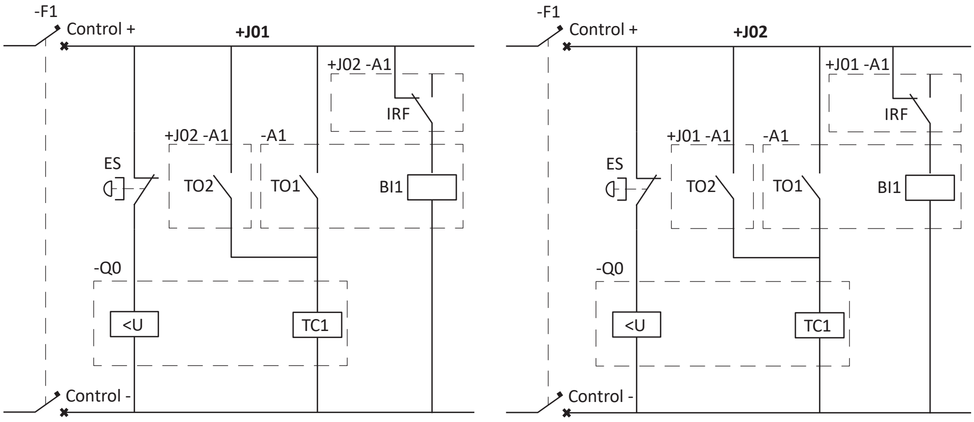


Figure 34: Motor feeder fail-safe trip circuit principle, example 4

J01	Feeder #1 panel
J02	Feeder #2 panel
ES	Emergency stop
Q0	Circuit breaker
TO1	Relay trip output #1
TO2	Relay trip output #2
IRF	Relay internal fault indication
BI1	Relay binary input #1
<U	CB undervoltage trip coil
TC1	CB trip coil 1
F1	Miniature circuit breaker

In example 4, the fail-safe approach aims at securing motor shutdown via an emergency switch and in case the control voltage disappears. The adjacent panels provide backup for each other in internal relay fault situations. In case of an internal relay fault, the situation is noticed by the relay in the adjacent panel and the circuit breaker in the panel with the faulty relay is tripped after a preset time delay. The additional time delay allows the relay to recover from the internal fault situation without tripping the circuit breaker.

3.3.4.2 Other critical feeders

The examples given for motor feeders can be applied for other types of feeders as well. The following examples are for critical feeders in which the protection system dependability, security or both are the drivers.

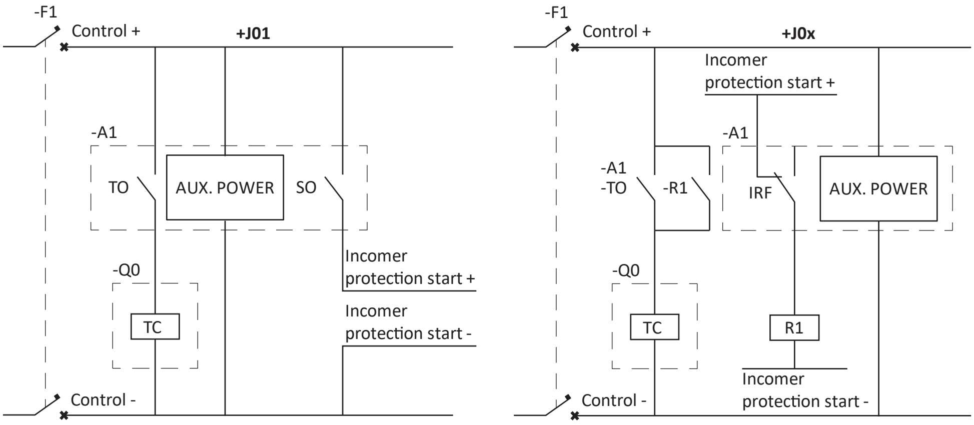


Figure 35: Redundant protection fail-safe principle, example 1

J01	Incomer feeder panel
J0x	Load feeder panels
Q0	Circuit breaker (CB)
TO	Relay trip output
SO	Relay start output
A1	Protection relay
R1	Auxiliary relay
TC	CB trip coil
F1	Miniature circuit breaker

In example 1, the fail-safe approach aims at securing circuit breaker tripping even if a relay fails. The incomer panel relay indicates the start of selected protection functions. This start signal is distributed to all load feeder panels. If a relay in the load feeder panel indicates an IRF status, the start signal of the incomer panel relay results in circuit breaker tripping. This approach offers basic protection for a load feeder while the actual protection relay performs a self-supervision controlled restart sequence.

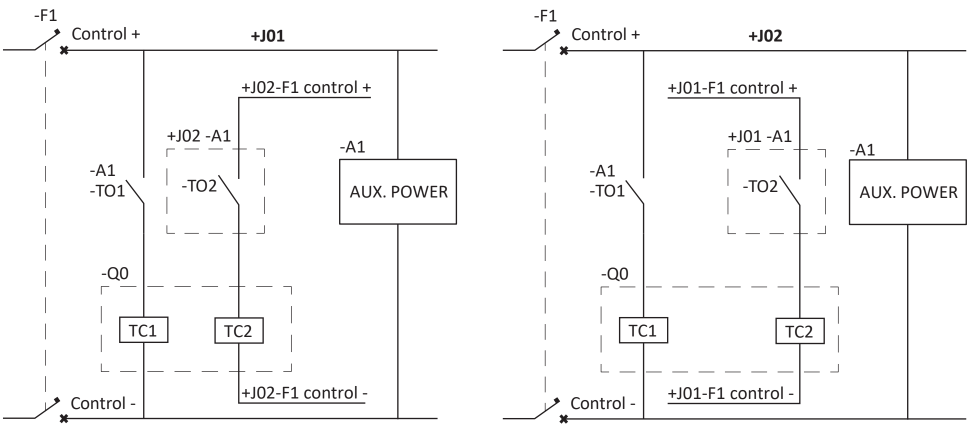


Figure 36: Redundant protection fail-safe principle, example 2

J01 Feeder #1 panel
J02 Feeder #2 panel
Q0 Circuit breaker (CB)
TO1 Relay trip output #1
TO2 Relay trip output #2
A1 Protection relay
TC1 CB trip coil 1
TC2 CB trip coil 2
F1 Miniature circuit breaker

In example 2, the fail-safe approach aims at securing circuit breaker tripping even if a relay fails. A relay in a panel measures also the adjacent panel's currents (and voltages) and receives the necessary primary device's position information. In other words, the relay in a panel functions as a backup relay for the adjacent panel. This approach allows service continuation while the failed relay is waiting for spare parts or a complete replacement. The backup protection features provided by the adjacent panel's relay do not necessarily fully match the features available in the main relay.

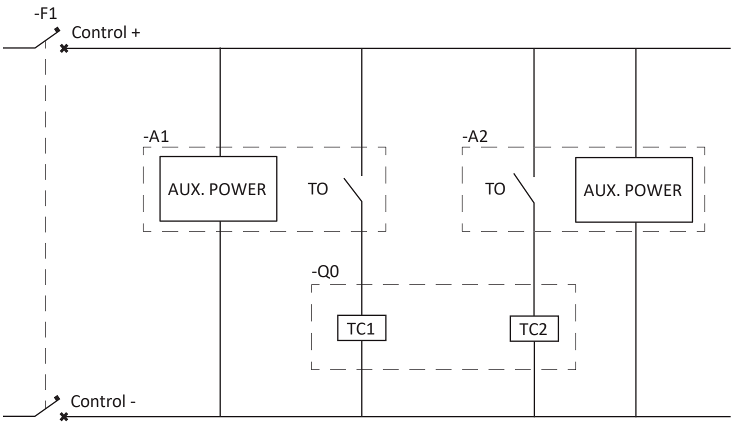


Figure 37: Redundant protection fail-safe principle, example 3

Q0 Circuit breaker (CB)
A1 Protection relay #1
A2 Protection relay #2
TO Protection relay trip output
TC1 CB trip coil 1
TC2 CB trip coil 2
F1 Miniature circuit breaker

In example 3, the fail-safe approach aims at securing circuit breaker tripping even if one of the redundant relays fails. The scheme is often referred to as the 1-outof- 2 approach. This approach allows service continuation while the failed relay is waiting for spare parts or a complete replacement. The redundancy in this example covers relays and circuit breaker tripping coils but it can be expanded to auxiliary power supplies (two station batteries and isolated distribution), cabling, circuit breaker failure protection, and so on. Another variant of this approach is to have a main relay and a backup relay instead of two fully redundant relays. The backup relay does not have all the features of the main relay, mainly containing a minimum acceptable set of protection functions.

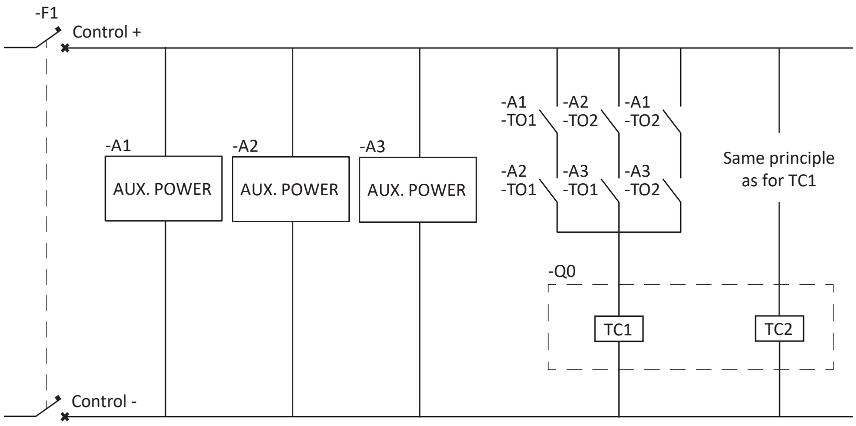


Figure 38: Redundant protection fail-safe principle, example 4

Q0	Circuit breaker (CB)
A1	Protection relay #1
A2	Protection relay #2
A3	Protection relay #3
TO#	Protection relay trip output
TC1	CB trip coil 1
TC2	CB trip coil 2
F1	Miniature circuit breaker

In example 4, the fail-safe approach aims at securing circuit breaker tripping even if one of the redundant relays fails and, in addition, no single relay alone can cause the circuit breaker tripping. The scheme is often referred to as the 2-out-of-3 approach. This approach allows service continuation while the failed relay is waiting for spare parts or a complete replacement. The redundancy in this example covers relays and circuit breaker tripping coils but it can be expanded to auxiliary power supplies (two station batteries and isolated distribution), cabling, circuit breaker failure protection, and so on. All three relays are similar with the same protection functions. This principle is used in cases where the primary process requires absolute dependability and security from the supplying feeder protection.

3.4 LED indication control LEDPTRC

3.4.1 Function block

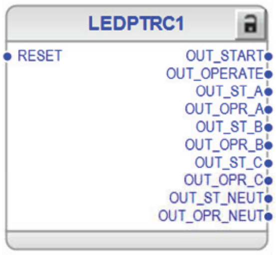


Figure 39: Function block

3.4.2 Functionality

The protection relay includes a global conditioning function LEDPTRC that is used to control the virtual Start and Trip indication LEDs.

LED indication control should never be used for tripping purposes. There is a separate trip logic function TRPPTRC available in the relay configuration.

LED indication control is preconfigured in a such way that all the protection function general start and operate signals are combined with this function (available as output signals `OUT_START` and `OUT_OPERATE`). These signals are internally connected to Device Status on WHMI Dashboard and the Device Status widget on the LHMI if the widget has been instantiated in the LHMI engineering phase. LEDPTRC collects and combines phase information from different protection functions (available as output signals `OUT_ST_A /_B /_C` and `OUT_OPR_A /_B /_C`). There is also combined earth fault information collected from all the earth-fault functions available in the relay configuration (available as output signals `OUT_ST_NEUT` and `OUT_OPR_NEUT`).

3.5 Individual virtual LED control LED

3.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
Individual virtual LED control	LED	LED	LED

3.5.2 Function block

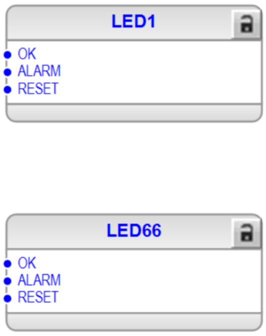


Figure 40: Function block

3.5.3 Functionality

The virtual, programmable LEDs are visible on the Programmable LEDs page in LHMI and on the WHMI dashboard.

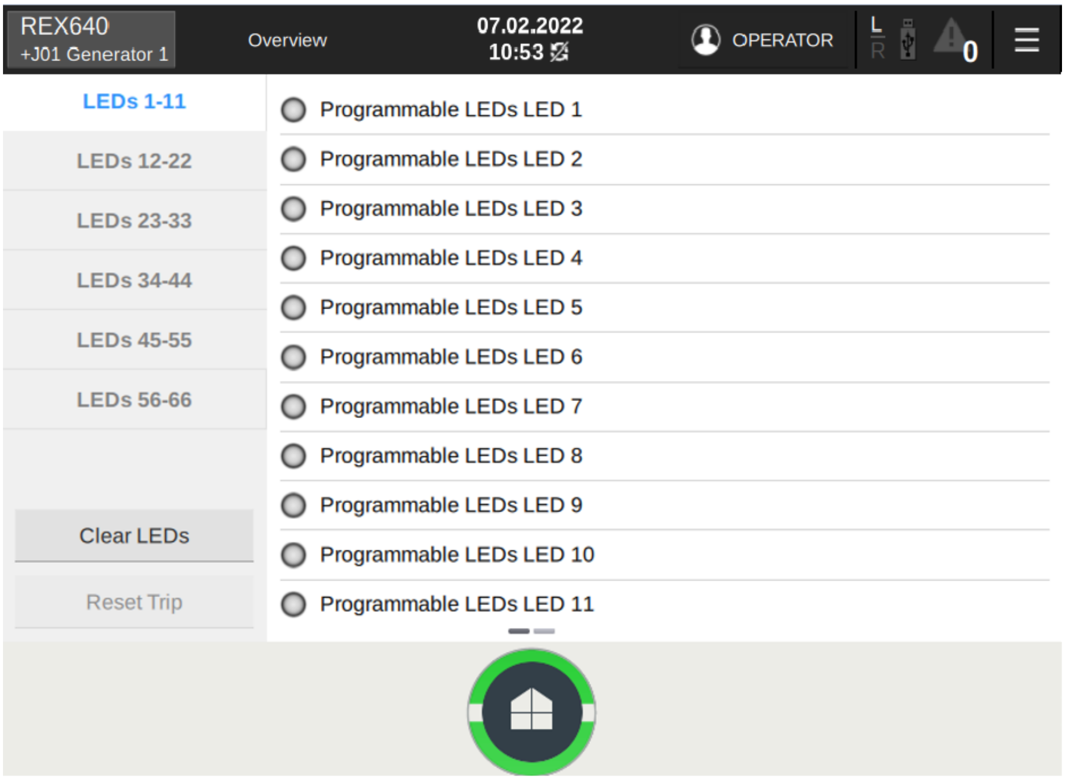


Figure 41: Programmable LEDs page in LHMI

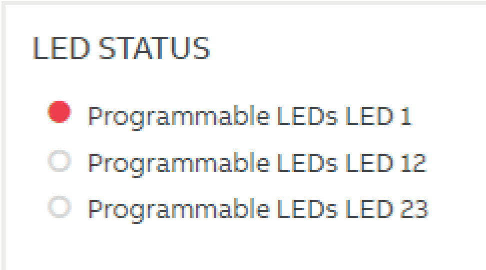


Figure 42: Programmable LEDs status in WHMI

Programmable LEDs are available only when at least one LED has been instantiated and the `OK` or `ALARM` signal is connected in Application Configuration in PCM600.

All the programmable LEDs on the protection relay's HMI have two colors, green and red. For each LED, the different colors are individually controllable.

Each LED has two control inputs, `ALARM` and `OK`. The color setting is common for all the LEDs. It is controlled with the *Alarm colour* setting, the default value being "Red". The `OK` input corresponds to the color that is available, with the default value being "Green".

Changing the *Alarm colour* setting to "Green" changes the color behavior of the `OK` inputs to red.

The `ALARM` input has a higher priority than the `OK` input. When a LED is in the alarming state, a bell symbol is shown on the LHMI next to the title of the Programmable LEDs page.

Each LED is seen in Application Configuration as an individual function block. Each LED has a user-editable description text for event description. The state ("None", "OK", "Alarm") of each LED can also be read under a common monitored data view for programmable LEDs.

The LED status also provides a means for resetting the individual LED via communication. The LED can also be reset from configuration with the `RESET` input.

The resetting and clearing function for all LEDs is available at the left side of the Programmable LEDs page and under the **Clear** menu.

The menu structure for the programmable LEDs is presented in *Figure 43*. The common color selection setting *Alarm colour* for all `ALARM` inputs is in the **General** menu, while the LED-specific settings are under the LED-specific menu nodes.

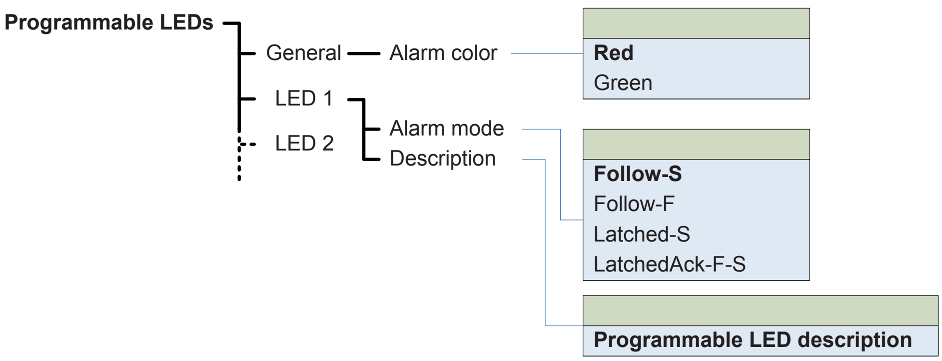


Figure 43: Menu structure

Alarm mode alternatives

The ALARM input behavior can be selected with the alarm mode settings from the alternatives "Follow-S", "Follow-F", "Latched-S" and "LatchedAck-F-S". The OK input behavior is always according to "Follow-S". The alarm input latched modes can be cleared with the reset input in the application logic.

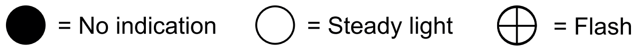


Figure 44: Symbols used in the sequence diagrams

"Follow-S": Follow Signal, ON

In this mode ALARM follows the input signal value, Non-latched.

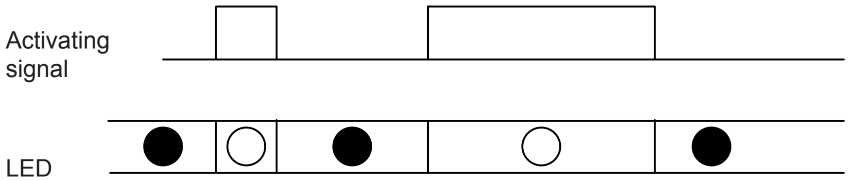


Figure 45: Operating sequence "Follow-S"

"Follow-F": Follow Signal, Flashing

Similar to "Follow-S", but instead the LED is flashing when the input is active, Non-latched.

"Latched-S": Latched, ON

This mode is a latched function. At the activation of the input signal, the alarm shows a steady light. After acknowledgement by the local operator pressing any key on the keypad, the alarm disappears.

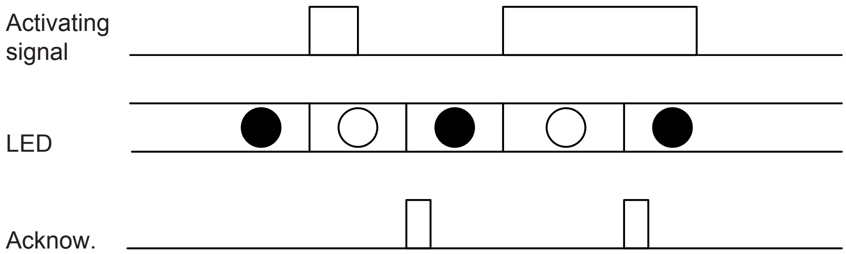


Figure 46: Operating sequence "Latched-S"

"LatchedAck-F-S": Latched, Flashing-ON

This mode is a latched function. At the activation of the input signal, the alarm starts flashing. After acknowledgement, the alarm disappears if the signal is not present and gives a steady light if the signal is present.

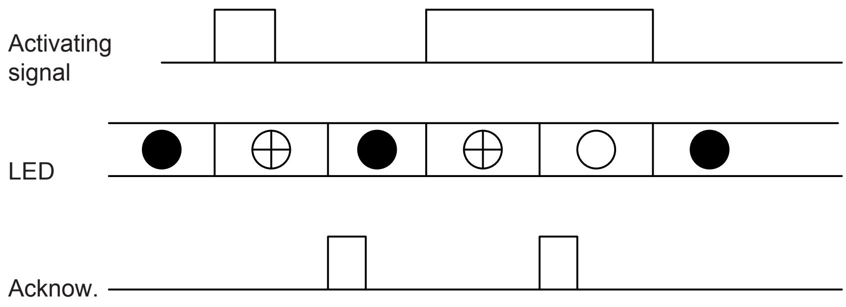


Figure 47: Operating sequence "LatchedAck-F-S"

3.5.4 Signals

Table 46: Input signals for LEDs 1...66

Name	Type	Default	Description
OK	BOOLEAN	0=False	Ok input for the LED
ALARM	BOOLEAN	0=False	Alarm input for the LED
RESET	BOOLEAN	0=False	Reset input for the LED

3.5.5 Settings

Table 47: Settings for LEDs 1...66

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm colour	1=Green 2=Red			2=Red	Colour for the alarm state of the LED
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for the programmable LED

3.5.6 Monitored data

Table 48: Monitored data for LEDs 1...66

Name	Type	Values (Range)	Unit	Description
Programmable LED n [1]	Enum	0=None 1=Ok 3=Alarm		Status of the programmable LED

[1] n = 1...66

Table 49: IEC 61850 mapping

LED instance in Application Configuration	Mapping in IEC 61850 data model (ALARM and OK signals)
LED1...LED11	LEDGGIO1.Alm1...LEDGGIO1.Alm11
	LEDGGIO1.Ind1...LEDGGIO1.Ind11
LED12...LED22	LEDGGIO2.Alm1...LEDGGIO2.Alm11
	LEDGGIO2.Ind1...LEDGGIO2.Ind11
LED23....LED33	LEDGGIO3.Alm1...LEDGGIO3.Alm11
	LEDGGIO3.Ind1...LEDGGIO3.Ind11
LED34...LED44	LEDGGIO4.Alm1...LEDGGIO4.Alm11
	LEDGGIO4.Ind1...LEDGGIO4.Ind11
LED45...LED55	LEDGGIO5.Alm1...LEDGGIO5.Alm11
	LEDGGIO5.Ind1...LEDGGIO5.Ind11
LED56....LED66	LEDGGIO6.Alm1...LEDGGIO6.Alm11
	LEDGGIO6.Ind1...LEDGGIO6.Ind11

3.6 Time synchronization

3.6.1 Time master supervision GNRLLTMS

3.6.1.1 Function block

Figure 48: Function block

3.6.1.2 Functionality

The protection relay has a disciplined RTC in hardware with a resolution of one nanosecond. The clock can be either free-running or synchronized to an external source. The RTC is used to time-stamp events, recorded data, disturbance recordings, sampled measured values and various other system services.

The protection relay supports SNTP, IRIG-B, IEEE 1588 v2, DNP3, Modbus, IEC 60870-5-101/104, IEC 60870-5-103 and line differential communication to synchronize the RTC. IEEE 1588 v2 with a GNSS grandmaster clock and IRIG-B provide the accuracy of ±1 µs. The accuracy is ±1 ms with SNTP.

Real-time clock at power off

During power off, the system time is kept in a separate capacitor-backed RTC. This RTC provides a millisecond resolution and digital temperature compensation for the crystal oscillator. Typical accuracy is 5 ppm which means the time may drift maximum 0.5 seconds per day. This RTC runs on a stored charge in a supercapacitor at least for 48 hours. After the capacitor has been discharged, the time is lost.

Real-time clock at power-up

At startup, the initial system time is recovered from the capacitor-backed RTC or set to 01-01-2010 if the RTC time was lost. The clock is free-running until the selected synchronization source becomes available. The first synchronization message sets the time to an accurate value and later synchronization messages additionally discipline the clock so that the time drift between synchronization messages is minimized. If the synchronization source is lost, the drift can be 0.25 ppm if the external clock source was a high-quality clock and the surrounding temperature is constant.

The setting *Synch source* determines the method for synchronizing the RTC. If it is set to "None", the clock is free-running and the settings *Date* and *Time* can be used to set the time manually. In this mode the typical accuracy is 5 ppm and the time may drift maximum 0.5 seconds per day.

Other setting values activate a communication protocol that provides the time synchronization. Only one synchronization method can be active at a time. Both IEEE 1588 v2 and SNTP provide time master backup functionality.

Connect at least one measurement channel in Application Configuration in PCM600 either from the hardware (AIM or SIM) or from SMVRCV to ensure that the time system works correctly.

Line differential communication

When using line differential communication between the protection relays, the time synchronization messages can be received from the other line end protection relay within the protection telegrams. The protection relay begins to synchronize its RTC with the remote end protection relay's time if the "Line differential" time synchronization source is selected. This does not affect the protection synchronization used in the line differential protection or the selection of the remote end protection relay's time synchronization method. It is expected that the remote end protection relay has another time synchronization source activated and therefore operates as a time gateway. Line differential time synchronization is available only for X6 port.

GNRLLTMS supervision functionality depends on the synchronization source. This means that the GNRLLTMS supervision signal values and their combinations have different meanings depending on the used synchronization source.

SNTP

The relay can use one of two SNTP servers, the primary or the secondary server. The primary server is mainly in use, whereas the secondary server is used if the primary server cannot be reached or a KoD response is received. While using the secondary SNTP server, the relay tries to switch back to the primary server on every third SNTP request attempt. If both SNTP servers are offline, event time stamps have the time invalid status.

If one SNTP server is used, it is recommended to set *IP SNTP secondary* as "0.0.0.0". This disables the server redundancy scheme and prevents the IED from attempting to access a non-existing secondary server.

The time is requested from the SNTP server every 60 seconds. Supported SNTP versions are 3 and 4. SNTP requires a high-performance server to meet the performance expectations.

IEEE 1588v2

The protection relay's 1588 precision time protocol synchronization complies with the IEEE C37.238-2011 and IEC 61850-9-3 profiles, which are interoperable with IEEE 1588 v2. The protection relay is an ordinary clock which can operate either in slave-only and slave or master mode. According to the supported profiles, the frame format used is IEEE 802.3 Ethernet frames with 0x88F7 Ethertype as the communication service and the delay mechanism is P2P. For both profiles, the TLVs required are included in the announce frame (IEEE C37.238-2011: Organization extension and Alternate time offset indicator TLVs, IEC 61850-9-3: Alternate time offset indicator TLV).

Time synchronization with IEEE 1588 v2 creates many possible scenarios since it is a dynamic synchronization method whereby the current master is determined with the BMC algorithm. GNRLLTMS outputs reflect this status. When IEEE 1588 v2 is used as a time synchronization source, the device stores the grandmasters in priority order according to the BMC algorithm. When the grandmaster clock is lost, an alarm and a warning are activated based on the stored grandmasters' list. The alarm is activated when there are no clocks with capabilities equivalent to primary or secondary grandmaster clocks. The warning is activated when a primary grandmaster clock is not available. The grandmaster list can be Section 3 1MRS759142 E Basic functions 132 REX640 Technical Manual cleared using the *Clear clock* list setting, for example, if the grandmaster clocks need to be replaced. The setting af-fects only the alarm and warning states.

If the current master is not within the 1 µs accuracy, ALARM is set to TRUE. If the current master is not the saved primary master, WARNING is set to TRUE. The EXTCLKMSTR output indicates if the ordinary clock is a slave to an external master.

Since the list is updated via the current primary master in the network, it is possible to lower the current grandmaster's priority to a point where another clock takes the role and the priority value in the list for the original master is no longer updated. This means that there is a discrepancy between the list and the device. Consequently, the GNRLLTMS warning status becomes TRUE as the saved primary master is no longer considered connected. The list logic can be reset to clear the clock list.

When IEEE 1588 v2 time synchronization is used, the recommended maximum num-ber of network hops from the grandmaster is 15 to ensure that the total inaccuracy stays within 1 µs. The grandmaster and each switch on the path must comply with the performance requirements set by the selected profile.

The protection relay is an ordinary clock which can operate either in slave-only and slave or master mode.

IRIG-B

IRIG-B time synchronization requires IRIG-B format B00x and IRIG-B time code extensions according to IEEE Std C37.118.1TM-2011. The extensions are defined by Annex D.

The synchronization time in IRIG-B can be either UTC time or local time. As no reboot is necessary, the time synchronization starts immediately after the IRIG-B synchronization source is selected and the IRIG-B signal source is connected. GNRLLTMS signals reflect the signal status from the IRIG-B master.

IRIG-B time synchronization requires a COM module with an `IRIG-B` input.

DNP3, Modbus, IEC 60870-5-101/104 and IEC 60870-5-103

For legacy protocols as synchronization source, a timeout can be set by *Time Syn Src Tmm* (minutes). This setting defines the maximum interval required by the protocol master sending the time synchronization commands. If a time synchronization command has not been received from the protocol master during this period, bad synchronization status is raised for the protection relay.

Legacy protocols as time synchronization sources do not offer the best accuracy. For better accuracy PTP, SNTP or IRIG-B time synchronization is recommended.

3.6.1.3 Signals

Table 50: GNRLLTMS Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status for clock synchronization Always FALSE with *Synch source* set to "None".
WARNING	BOOLEAN	Warning status for clock synchronization Always FALSE with *Synch source* set to "None".
EXTCLKMSTR	BOOLEAN	Status of the protection relay's clock synchronization Always FALSE with *Synch source* set to "None".

Table 51: SNTP Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status for clock synchronization TRUE if the connection to both primary and secondary SNTP servers has been lost. FALSE if the connection to the secondary SNTP server is detected.
WARNING	BOOLEAN	Warning status for clock synchronization TRUE if the connection to SNTP primary server has been lost. Otherwise FALSE.
EXTCLKMSTR	BOOLEAN	Status of the protection relay's clock synchronization. TRUE if the protection relay has been synchronized by an SNTP server.

Name	Type	Description
		FALSE if the clock has not been synchronized by an SNTP server.

Table 52: IEEE 1588v2 Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status for clock synchronization. TRUE if the current master's accuracy is not within 1µs or priority1 is bigger than that of first secondary's. Also TRUE if the external master was lost and the protection relay itself acts as a master. Otherwise FALSE.
WARNING	BOOLEAN	Warning status for clock synchronization. TRUE if a previously connected and stored primary master has been lost. Otherwise FALSE.
EXTCLKMSTR	BOOLEAN	Status of the protection relay's clock synchronization. TRUE if the protection relay has been synchronized by an external master. FALSE if the clock has not been synchronized by an external master.

Table 53: IRIG-B Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status for clock synchronization. TRUE if the signal has been lost for a minute. Otherwise FALSE.
WARNING	BOOLEAN	Warning status for clock synchronization. TRUE if the signal connection is lost. FALSE if the relay is synchronized to an IRIG-B master.
EXTCLKMSTR	BOOLEAN	Status of the protection relay's clock synchronization. TRUE if the protection relay has been synchronized to an IRIG-B master. Otherwise FALSE.

Table 54: DNP3, Modbus, IEC 60870-5-101/104 and IEC 60870-5-103 Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status for clock synchronization. TRUE if the clock has not been synchronized by the master.

Table continues on the next page

Name	Type	Description
		FALSE if the clock has been synchronized by the master.
WARNING	BOOLEAN	Warning status for clock synchronization. TRUE if the clock has not been synchronized by the master. FALSE if the clock has been synchronized by the master.
EXTCLKMSTR	BOOLEAN	Status of the protection relay's clock synchronization. TRUE if the protection relay has been synchronized by an external master. FALSE if the clock has not been synchronized by an external master.

Table 55: Line differential Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm status for clock synchronization. TRUE if the LD connection has been lost.
WARNING	BOOLEAN	Warning status for clock synchronization. TRUE if the LD connection has been lost.
EXTCLKMSTR	BOOLEAN	Status of the protection relay's clock synchronization. TRUE if the clock has been synchronized to the LD partner.

3.6.1.4 Settings

Time format settings

Table 56: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Time format	1=24H:MM:SS:MS 2=12H:MM:SS:MS			1=24H:MM:SS:MS	Time format
Date format	1=DD.MM.YYYY 2=DD/MM/YYYY 3=DD-MM-YYYY 4=MM.DD.YYYY 5=MM/DD/YYYY 6=YYYY-MM-DD 7=YYYY-DD-MM 8=YYYY/DD/MM			1=DD.MM.YYYY	Date format

Time settings

Table 57: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Synch source	0=None 1=SNTP 2=Modbus 3=IEEE 1588 5=IRIG-B 9=DNP 17=IEC60870-5-103			1=SNTP	Time synchronization source
PTP Profile	1=IEEE C37.238-2011 2=IEC 61850-9-3			1=IEEE C37.238-2011	Profile Selection for the Precision Time Protocol
PTP domain ID	0...255		1	0	The domain is identified by an integer, the domainNumber, in the range of 0 to 255.
PTP priority 1	0...255		1	128	PTP priority 1, in the range of 0 to 255.
PTP priority 2	0...255		1	128	PTP priority 2, in the range of 0 to 255.
PTP Slave-only	0=False 1=True			0=False	If true, the IED cannot become a clock master
Time master mode	1=Master with finite holdover 2=Master with infinite holdover			1=Master with finite holdover	Device Time Master Mode
Clear clock list	0=False 1=True			0=False	Clears the stored master clock list
Time Syn Src Tmm	1...65535	min	1	3	Time synchronization timeout for legacy protocols as clock source (Modbus, IEC103, IEC101, IEC104 and DNP)

Table 58: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Date				0	Date
Time				0	Time
Local time offset	-840...840	min	1	0	Local time offset in minutes

Table 59: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP SNTP primary				192.168.2.166	IP address for SNTP primary server
IP SNTP secondary				192.168.2.165	IP address for SNTP secondary server

Table 60: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
DST in use	0=False 1=True			1=True	DST in use setting
DST on time (hours)	0...23	h		2	Daylight saving time on, time (hh)
DST on time (minutes)	0...59	min		0	Daylight saving time on, time (mm)
DST on date (day)	1...31			1	Daylight saving time on, date (dd:mm)
DST on date (month)	1=January 2=February 3=March 4=April 5=May 6=June 7=July 8=August 9=September 10=October 11=November 12=December			5=May	Daylight saving time on, date (dd:mm)
DST on day (weekday)	0=reserved 1=Monday 2=Tuesday 3=Wednesday 4=Thursday 5=Friday 6=Saturday 7=Sunday			0=reserved	Daylight saving time on, day of week
DST off time (hours)	0...23	h		2	Daylight saving time off, time (hh)
DST off time (minutes)	0...59	min		0	Daylight saving time off, time (mm)
DST off date (day)	1...31			25	Daylight saving time off, date (dd:mm)
DST off date (month)	1=January 2=February 3=March 4=April 5=May 6=June 7=July 8=August 9=September 10=October 11=November 12=December			9=September	Daylight saving time off, date (dd:mm)
DST off day (weekday)	0=reserved 1=Monday			0=reserved	Daylight saving time off, day of week

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Tuesday 3=Wednesday 4=Thursday 5=Friday 6=Saturday 7=Sunday				
DST offset	-720...720	min	1	60	Daylight saving time offset

3.6.1.5 Monitored data

Table 61: Monitored data

Name	Type	Values (Range)	Unit	Description
Synch source	Enum	0=Not defined 1=SNTP primary 2=SNTP secondary 4=IEEE 1588 master 5=IEEE 1588 slave 7=IRIG-B 8=DNP 3.0 9=Modbus 17=IEC 60870-5-103 21=Line differential 99=Free running		Time synchronization source
Synch status	Bool	0=Down 1=Up		Time synchronization status
Synch accuracy	Int	0...128		Time synchronization accuracy. Number of the significant bits in fraction of second.
PTP gm identity	String			PTP grand master clock identity according PTP standard
PTP gm time Src	Enum	1=Atomic clock 2=GPS 3=Terrestrial radio 4=PTP 5=NTP 6=Hand set 7=Other 8=Internal oscil.		PTP grand master clock source type
PTP gm accuracy	Enum	1=25 ns 2=100 ns 3=250 ns 4=1 us 5=2.5 us 6=10 us 7=25 us 8=100 us 9=250 us 10=1 ms		PTP grand master accuracy according PTP standard

Name	Type	Values (Range)	Unit	Description
		11=2.5 ms 12=10 ms 13=25 ms 14=100 ms 15=250 ms 16=1 s 17=10 s 18=more than 10 s		

3.7 Generic protection control PROTECTION

3.7.1 Function block

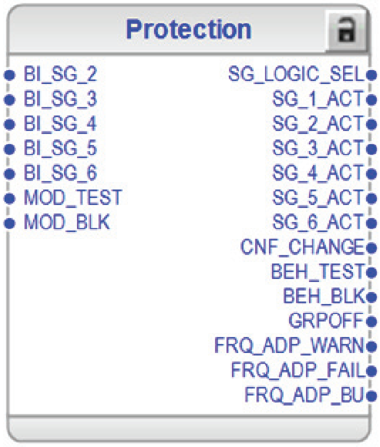


Figure 49: Function block

3.7.2 Functionality

3.7.2.1 Setting group control

The protection relay supports six setting groups. Each setting group contains parameters categorized as group settings inside application functions. The customer can change the active setting group at run time.

The active setting group can be changed by a parameter or via binary inputs depending on the mode selected with the **Configuration** > **Setting Group** > **SG operation mode** setting.

The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected. The setting group selection is not dependent on the SG_x_ACT outputs.

Table 62: Optional operation modes for setting group selection

SG operation mode	Description
Operator (Default)	Setting group can be changed with the setting Settings/Setting group/Active group. Value of the SG_LOGIC_SEL output is FALSE.
Logic mode 1	Setting group can be changed with binary inputs (BI_SG_2...BI_SG_6). The highest TRUE binary input defines the active setting group. Value of the SG_LOGIC_SEL output is TRUE.
Logic mode 2	Setting group can be changed with binary inputs where BI_SG_4 is used for selecting setting groups 1–3 or 4–6. When binary input BI_SG_4 is FALSE, setting groups 1–3 are selected with binary inputs BI_SG_2 and BI_SG_3. When binary input BI_SG_4 is TRUE, setting groups 4–6 are selected with binary inputs BI_SG_5 and BI_SG_6. Value of the SG_LOGIC_SEL output is TRUE.

For example, six setting groups can be controlled with three binary inputs. *SG operation mode* is set to "Logic mode 2" and inputs BI_SG_2 and BI_SG_5 are connected together the same way as inputs BI_SG_3 and BI_SG_6.

Table 63: SG operation mode = "Logic mode 1"

Input					
BI_SG_2	**BI_SG_3**	**BI_SG_4**	**BI_SG_5**	**BI_SG_6**	**Active group**
FALSE	FALSE	FALSE	FALSE	FALSE	1
TRUE	FALSE	FALSE	FALSE	FALSE	2
any	TRUE	FALSE	FALSE	FALSE	3
any	any	TRUE	FALSE	FALSE	4
any	any	any	TRUE	FALSE	5
any	any	any	any	TRUE	6

Table 64: SG operation mode = "Logic mode 2"

Input					
BI_SG_2	**BI_SG_3**	**BI_SG_4**	**BI_SG_5**	**BI_SG_6**	**Active group**
FALSE	FALSE	FALSE	any	any	1
TRUE	FALSE	FALSE	any	any	2
any	TRUE	FALSE	any	any	3
any	any	TRUE	FALSE	FALSE	4
any	any	TRUE	TRUE	FALSE	5
any	any	TRUE	any	TRUE	6

Setting group 1 can be copied to any other or all groups from HMI (Copy group 1).

3.7.2.2 Test mode

The function has two outputs, BEH_TST and BEH_BLK, which are activated in test mode according to *Table 65*.

Table 65: Test mode

Test mode	Description	Protection BEH_BLK	Protection BEH_TST
Normal mode	Normal operation	FALSE	FALSE
IED blocked	Protection works as in “Normal mode” but the ACT configuration can be used to block physical outputs to process. Control function commands are blocked.	TRUE	FALSE
IED test	Protection works as in “Normal mode” but protection functions work in parallel with test parameters.	FALSE	TRUE
IED test and blocked	Protection works as in “Normal mode” but protection functions work in parallel with the test parameter. The ACT configuration can be used to block physical outputs to process. Control function command is blocked.	TRUE	TRUE

For more information, see the Test mode section in this manual.

3.7.2.3 Frequency adaptivity

The FRQ_ADP_WARN output is active when full adaptation to the actual frequency is not reached or guaranteed. The FRQ_ADP_FAIL output is active when no frequency source has sufficient amplitude and the nominal frequency window size is used in measurements. The FRQ_ADP_BU output is active when the backup adaptivity frequency source is active.

When switching from the main frequency source to the backup frequency source, there is an interval of 200 ms where the last known frequency is used to determine the measurement window size. During this period, FRQ_ADP_WARN is activated. This also happens when no frequency source has sufficient amplitude and the last frequency is held for 3 s before activating output FRQ_ADP_FAIL.

3.7.2.4 Special function block outputs

The function block has a few outputs dedicated for special purposes.

Table 66: Special function block outputs

Output	Description
CNF_CHANGE	Any setting change in the protection relay activates this output for a short period of time (100...200 ms).
GRPOFF	Some application function blocks do now allow unconnected analog inputs. In such a case, GRPOFF must be connected to such an input.
DEV_WARN	A protection relay's internal warning activates this output. For more information, see Warnings under the Self-supervision section.

3.7.3 Signals

Table 67: PROTECTION Input signals

Name	Type	Default	Description
BI_SG2	BOOLEAN	0	Setting group 2 is active
BI_SG3	BOOLEAN	0	Setting group 3 is active
BI_SG4	BOOLEAN	0	Setting group 4 is active
BI_SG5	BOOLEAN	0	Setting group 5 is active
BI_SG6	BOOLEAN	0	Setting group 6 is active
MOD_TEST	BOOLEAN	0	Activation of test mode
MOD_BLK	BOOLEAN	0	Block test mode

Table 68: PROTECTION Output signals

Name	Type	Description
SG_LOGIC_SEL	BOOLEAN	Logic selection for setting group
SG_1_ACT	BOOLEAN	Setting group 1 is active
SG_2_ACT	BOOLEAN	Setting group 2 is active
SG_3_ACT	BOOLEAN	Setting group 3 is active
SG_4_ACT	BOOLEAN	Setting group 4 is active
SG_5_ACT	BOOLEAN	Setting group 5 is active
SG_6_ACT	BOOLEAN	Setting group 6 is active
CNF_CHANGE	BOOLEAN	Active after any setting change
BEH_TEST	BOOLEAN	Logical device LD0 test status
BEH_BLK	BOOLEAN	Logical device LD0 block status

Table continues on the next page

Name	Type	Description
GRPOFF	Group signal	Group off signal for function blocks
DEV_WARN	BOOLEAN	Protection relay internal warning
FRQ_ADP_WARN	BOOLEAN	Frequency adaptivity warning
FRQ_ADP_FAIL	BOOLEAN	Frequency adaptivity status fail
FRQ_ADP_BU	BOOLEAN	Main frequency adaptivity source

3.7.4 Settings

Table 69: PROTECTION Settings

Parameter	Values (Range)	Unit	Step	Default	Description
SG operation mode	1=Operator 2=Logic mode 1 3=Logic mode 2			1=Operator	Operation mode for setting group change

3.8 Local/Remote control CONTROL

3.8.1 Function block

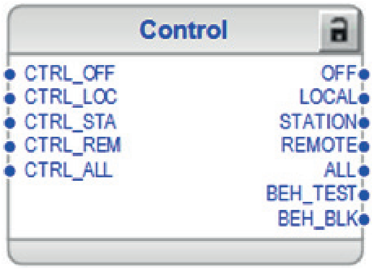


Figure 50: Function block

3.8.2 Functionality

Local/Remote control is by default realized through the R/L button on the front panel. The control via binary input can be enabled by setting the value of the *LR control* setting to "Binary input". The binary input control requires that the CONTROL function is instantiated in the product configuration.

Local/Remote control supports multilevel access for control operations in substations according to the IEC 61850 standard. Multilevel control access with separate station control access level is not supported by other protocols than IEC 61850.

The actual Local/Remote control state is evaluated by the priority scheme on the function block inputs. If more than one input is active, the input with the highest priority is selected. The priority order is “off”, “local”, “station”, “remote”, “all”.

The actual state is reflected on the CONTROL function outputs. Only one output is active at a time.

Table 70: Truth table for CONTROL

Input					Output
CTRL_OFF	**CTRL_LOC**	**CTRL_STA**	**CTRL_REM**	**CTRL_ALL**	
TRUE	N/A	N/A	N/A	N/A	OFF = TRUE
FALSE	TRUE	N/A	N/A	N/A	LOCAL = TRUE
FALSE	FALSE	TRUE	N/A	N/A	STATION = TRUE
FALSE	FALSE	FALSE	TRUE	TRUE	REMOTE = TRUE
FALSE	FALSE	FALSE	FALSE	TRUE	ALL = TRUE
FALSE	FALSE	FALSE	FALSE	FALSE	OFF = TRUE

3.8.3 L/R control access

Four different Local/Remote control access scenarios are possible depending on the selected station authority level: “L,R”, “L,R,L+R”, “L,S,R” and “L, S, S+R, L+S, L+S+R”. If control commands need to be allowed from multiple levels, multilevel access can be used. Multilevel access is possible only by using the station authority levels “L,R,L+R” and “L, S, S+R, L+S, L+S+R”. Multilevel access status is available from IEC 61850 data object CTRL.LLN0.MltLev.

Control access selection is made with R/L button or CONTROL function block and IEC 61850 data object CTRL.LLN0.LocSta. When writing CTRL.LLN0.LocSta IEC 61850 data object, IEC 61850 command originator category station must be used by the client, and remote IEC 61850 control access must be allowed by the relay station authority. CTRL.LLN0.LocSta data object value is retained in the nonvolatile memory. The present control status can be monitored in the HMI or PCM600 via **Monitoring** > **Control command** with the *LR state* parameter or from the IEC 61850 data object CTRL.LLN0. LocKeyHMI.

IEC 61850 command originator category is always set by the IEC 61850 client. The relay supports station and remote IEC 61850 command originator categories, depending on the selected station authority level.

3.8.4 Station authority level “L,R"

Relay default station authority level is “L,R”. In this scenario only local or remote control access is allowed. Control access with IEC61850 command originator category station is interpreted as remote access. There is no multilevel access

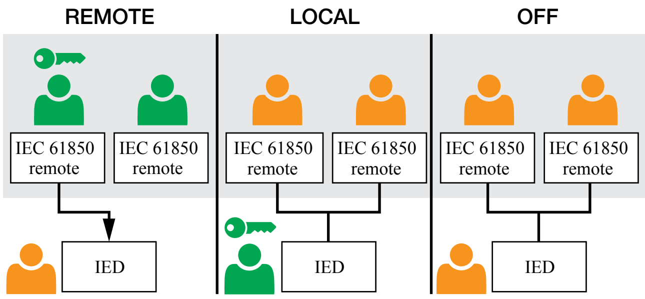


Figure 51: Station authority is "L,R"

When station authority level "L,R" is used, control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block inputs `CTRL_STA` and `CTRL_ALL` are not applicable for this station authority level.

Table 71: Station authority level "L,R" using R/L button

L/R control		L/R control status		Control access	
R/L button	CTRL.LLN0.LocSta	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKey HMI	Local user	IEC 61850 client [1]
Local	N/A	FALSE	1	x	
Remote	N/A	FALSE	2		x
Off	N/A	FALSE	0		

Table 72: Station authority "L,R" using CONTROL function block

L/R control		L/R control status		Control access	
Control FB input	CTRL.LLN0.LocSta	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKey HMI	Local user	IEC 61850 client [2]
CTRL_OFF	N/A	FALSE	0		
CTRL_LOC	N/A	FALSE	1	x	
CTRL_STA	N/A	FALSE	0		
CTRL_REM	N/A	FALSE	2		x
CTRL_ALL	N/A	FALSE	0		

[1] Client IEC 61850 command originator category check is not performed.
[2] Client IEC 61850 command originator category check is not performed.

3.8.5 Station authority level "L,R,L+R"

Station authority level "L,R, L+R" adds multilevel access support. Control access can also be simultaneously permitted from local or remote location. Simultaneous local or remote control operation is not allowed as one client and location at time can access controllable objects and they remain reserved until the previously started control operation is first completed by the client. Control access with IEC61850 originator category station is interpreted as remote access.

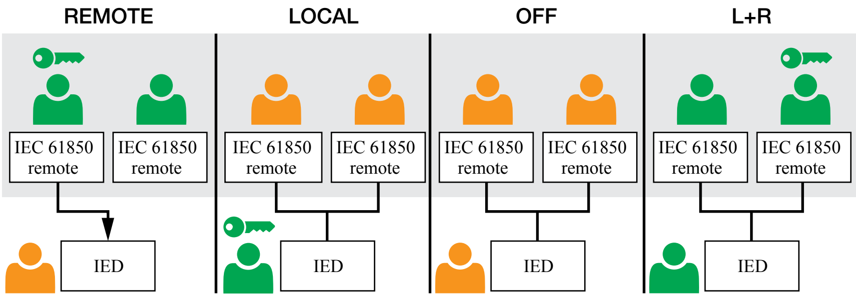


Figure 52: Station authority is "L,R,L+R"

When station authority level "L,R, L+R" is used, the control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input `CTRL_STA` are not applicable for this station authority level.

Table 73: Station authority level "L,R,L+R" using R/L button

L/R Control		L/R Control status		Control access	
R/L button	**CTRL.LLN0.LocSta**	**CTRL.LLN0.MltLev**	**L/R state CTRL.LLN0.LocKey HMI**	**Local user**	**IEC 61850 client[1]**
Local	N/A	FALSE	1	x	
Remote	N/A	FALSE	2		x
Local + Remote	N/A	TRUE	4	x	x
Off	N/A	FALSE	0		

Table 74: Station authority "L,R,L+R" using CONTROL function block

L/R Control		L/R Control status		Control access	
Control FB input	**CTRL.LLN0.LocSta**	**CTRL.LLN0.MltLev**	**L/R state CTRL.LLN0.LocKey HMI**	**Local user**	**IEC 61850 client[2]**
CTRL_OFF	N/A	FALSE	0		
CTRL_LOC	N/A	FALSE	1	x	
CTRL_STA	N/A	FALSE	0		
CTRL_REM	N/A	FALSE	2		x
CTRL_ALL	N/A	TRUE	4	x	x

1 Client IEC 61850 command originator category check is not performed.
2 Client IEC 61850 command originator category check is not performed.

3.8.6 Station authority level "L,S,R"

Station authority level "L,S,R" adds station control access. In this level IEC 61850 command originator category validation is performed to distinguish control commands with IEC 61850 command originator category set to “Remote” or “Station”. There is no multilevel access.

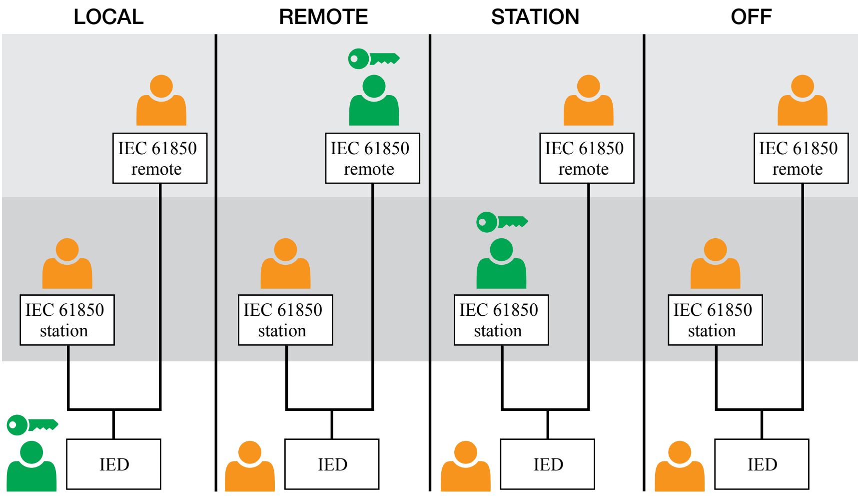


Figure 53: Station authority is “"L,S,R"

When the station authority level “L,S,R” is used, the control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input CTRL_STA are applicable for this station authority level.

Station control access can be reserved by using R/L button or CONTROL function block together with IEC 61850 data object CTRL.LLN0.LocSta

Table 75: Station authority level “L,S,R” using R/L button

L/R Control		L/R Control status		Control access		
R/L button	**CTRL.LLN0.LocSta**[1]	**CTRL.LLN0.MltLev**	**L/R state CTRL.LLN0.LocKeyHMI**	**Local user**	**IEC 61850 client**[2]	**IEC 61850 client**[3]
Local	FALSE	FALSE	1	x		
Remote	FALSE	FALSE	2		x	
Remote	TRUE	FALSE	3			x
Off	FALSE	FALSE	0			

1 Station client reserves the control operating by writing controllable point LocSta.
2 Client IEC 61850 command originator category is remote.
3 Client IEC 61850 command originator category is station.

Table 76: Station authority level “L,S,R” using CONTROL function block

L/R Control		L/R Control status		Control access		
R/L button	CTRL.LLN0.LocSta[4]	CTRL.LLN0.MltLev	L/R state CTRL.LLN0.LocKeyHMI	Local user	IEC 61850 client[5]	IEC 61850 client[6]
CTRL_OFF	FALSE	FALSE	0			
CTRL_LOC	FALSE	FALSE	1	x		
CTRL_STA	TRUE	FALSE	3			
CTRL_REM[7]	TRUE	FALSE	3			x
CTRL_REM	FALSE	FALSE	2		x	
CTRL_ALL	FALSE	FALSE	0			

3.8.7 Station authority level “L,S,S+R,L+S,L+S+R”

Station authority level "L,S,S+R,L+S,L+S+R" adds station control access together with several different multilevel access scenarios. Control access can also be simultaneously permitted from local, station or remote location. Simultaneous local, station or remote control operation is not allowed as one client and location at time can access controllable objects and they remain reserved until the previously started control operation is first completed by the client.

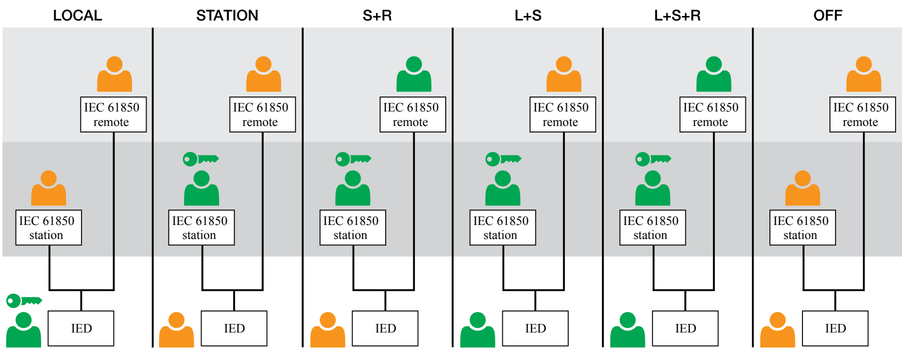


Figure 54: Station authority is “L,S,S+R,L+S,L+S+R”

When station authority level “L,S,S+R,L+S,L+S+R” is used, control access can be selected using R/L button or CONTROL function block. IEC 61850 data object CTRL.LLN0.LocSta and CONTROL function block input `CTRL_STA` are applicable for this station authority level.

“Station” and “Local + Station” control access can be reserved by using R/L button or CONTROL function block in combination with IEC 61850 data object CTRL.LLN0.LocSta.

4 Station client reserves the control operating by writing controllable point LocSta.
5 Client IEC 61850 command originator category is remote.
6 Client IEC 61850 command originator category is station.
7 CTRL_STA unconnected in application configuration. Station client reserves the control operating by writing controllable point LocSta.

Table 77: Station authority level "L,S,S+R,L+S,L+S+R" using R/L button

L/R Control		L/R Control status		Control access		
R/L button	**CTRL.LLN0.LocSta**[1]	**CTRL.LLN0.MltLev**	**L/R state CTRL.LLN0.LocKeyHMI**	**Local user**	**IEC 61850 client**[2]	**IEC 61850 client**[3]
Local	FALSE	FALSE	1	x		
Remote	FALSE	TRUE	7		x	x
Remote	TRUE	FALSE	3			x
Local + Remote	FALSE	TRUE	6	x	x	x
Local + Remote	TRUE	TRUE	5	x		x
Off	FALSE	FALSE	0			

Table 78: Station authority level "L,S,S+R,L+S,L+S+R" using CONTROL function block

L/R Control		L/R Control status		Control access		
R/L button	**CTRL.LLN0.LocSta**[4]	**CTRL.LLN0.MltLev**	**L/R state CTRL.LLN0.LocKeyHMI**	**Local user**	**IEC 61850 client**[5]	**IEC 61850 client**[6]
CTRL_OFF	FALSE	FALSE	0			
CTRL_LOC	FALSE	FALSE	1	x		
CTRL_STA	FALSE	FALSE	3			x
CTRL_REM [7]	TRUE	TRUE	3			x
CTRL_REM	FALSE	TRUE	7		x	x
CTRL_ALL	FALSE	TRUE	6	x	x	x
CTRL_ALL [7]	TRUE	TRUE	5	x		x

3.8.8 Control mode

The function has two outputs `BEH_TST` and `BEH_BLK` which are activated in test mode according to *Table 79*.

Table 79: Control mode

Control mode	Description	Control BEH_BLK
On	Normal operation	FALSE
Blocked	Control function commands blocked	TRUE
Off	Control functions disabled	FALSE

For more information, see the Test mode chapter in this manual.

[1] Station client reserves the control operating by writing controllable point LocSta.
[2] Client IEC 61850 command originator category is remote.
[3] Client IEC 61850 command originator category is station.
[4] Station client reserves the control operating by writing controllable point LocSta.
[5] Client IEC 61850 command originator category is remote.
[6] Client IEC 61850 command originator category is station.
[7] CTRL_STA unconnected in application configuration. Station client reserves the control operating by writing controllable point LocSta.

3.8.9 Signals

Table 80: CONTROL Input signals

Name	Type	Default	Description
CTRL_OFF	BOOLEAN	0	Control input OFF
CTRL_LOC	BOOLEAN	0	Control input Local
CTRL_STA	BOOLEAN	0	Control input Station
CTRL_REM	BOOLEAN	0	Control input Remote
CTRL_ALL	BOOLEAN	0	Control input All

Table 81: CONTROL Output signals

Name	Type	Description
OFF	BOOLEAN	Control output OFF
LOCAL	BOOLEAN	Control output Local
STATION	BOOLEAN	Control output Station
REMOTE	BOOLEAN	Control output Remote
ALL	BOOLEAN	Control output All
BEH_BLK	BOOLEAN	Logical device CTRL block status
BEH_TST	BOOLEAN	Logical device CTRL test status

3.8.10 Settings

Table 82: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
LR control	1=LR key 2=Binary input			1=LR key	LR control through LR key or binary input
Station authority	1=L,R 2=L,S,R 3=L,R,L+R 4=L,S,S+R,L+S,L +S+R			1=L,R	Control command originator category usage
Control mode	1=On 2=Blocked 5=Off			1=On	Enabling and disabling control

3.8.11 Monitored data

Table 83: Monitored data

Name	Type	Values (Range)	Unit	Description
Command response	Enum	0=No commands 1=Select open 2=Select close 3=Operate open 4=Operate close 5=Direct open 6=Direct close 7=Cancel 8=Position reached 9=Position timeout 10=Object status only 11=Object direct 12=Object select 13=RL local allowed 14=RL remote allowed 15=RL off 16=Function off 17=Function blocked 8=Command progress 19=Select timeout 20=Missing authority 21=Close not enabled 22=Open not enabled 23=Internal fault 24=Already close 25=Wrong client 26=RL station allowed 27=RL change 28=Abortion by trip 29=Reed not closed 30=Motor blocked 31=Motor wrong direction		Latest command response
LR state	Enum	0=Off 1=Local 2=Remote 3=Station 4=L+R 5=L+S 6=L+S+R 7=S+R		LR state monitoring

3.9 Fault recorder FLTRFRC (ANSI FR)

3.9.1 Function block

Figure 55: Function block

3.9.2 Functionality

The protection relay has the capacity to store the records of the latest 128 fault events. Fault records include fundamental or RMS current values. The records enable the user to analyze recent power system events. Each fault record (FLTRFRC) is marked with an up-counting fault number and a time stamp that is taken from the beginning of the fault.

The fault recording period begins from the start event of any protection function connected to the START input and ends if any protection function connected to the OPERATE input trips or the start is restored before the operate event. If a start is restored without an operate event, the start duration shows the protection function that has started first. The TRIG input can be used to start the fault recording period with, for example, binary input.

If *Start duration* has the value "100%", it indicates that a protection function has operated during the fault; if none of the protection functions has operated, *Start duration* always shows values less than 100%.

The fault recorded data *Protection* (rec. set 1 or rec. set 2) and *Start duration* are from the same protection function. The fault recorded data operate time shows the time of the actual fault period. This value is the time difference between the activation of the internal start and operate signals. The actual operate time also includes the starting time and the delay of the output relay. The fault recorded data Breaker clear time is the time difference between the internal operate signal and the activation of the CB_CLRD input.

If some functions in the relay application are sensitive to start frequently, it might be advisable to set the setting parameter Trig mode to "From operate". Then only faults that cause an operate event trigger a new fault recording.

The fault-related current, voltage, frequency, angle values, shot pointer and the active setting group number are taken from the moment of the operate event, or from the beginning of the fault if only a start event occurs during the fault. The maximum current value collects the maximum fault currents during the fault. If frequency cannot be measured, nominal frequency is used for frequency and zero for frequency gradient and validity is set accordingly.

The measuring mode for phase current and residual current values can be selected with the *A measurement mode* setting parameter.

For a detailed description of the measurement modes, see *Chapter 11.6 Measurement modes* in this manual.

3.9.3 Analog channel configuration

FLTRFRC has twelve analog group inputs which must be properly configured. All inputs can be connected to GRPOFF.

Table 84: Analog inputs

Input	Description
I3P1 [1]	Three-phase currents
I3P2 [1]	Three-phase currents
I3P3 [1]	Three-phase currents
IRES1 [1]	Residual current (measured or calculated)
IRES2 [1]	Residual current (measured or calculated)
IRES3 [1]	Residual current (measured or calculated)
U3P1 [1]	Three-phase voltages
U3P2 [1]	Three-phase voltages
U3P3 [1]	Three-phase voltages
URES1 [1]	Residual voltage (measured or calculated)
URES2 [1]	Residual voltage (measured or calculated)
URES3 [1]	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

[1] Can be connected to GRPOFF

Table 85: Special conditions

Condition	Description
URES1 connected to the calculated residual voltage	The function requires that all three voltage channels are connected to UTVTR. Setting *VT connection* must be "Wye" in that particular UTVTR.
URES2 connected to the calculated residual voltage	The function requires that all three voltage channels are connected to UTVTR. Setting *VT connection* must be "Wye" in that particular UTVTR.
URES3 connected to the calculated residual voltage	The function requires that all three voltage channels are connected to UTVTR. Setting *VT connection* must be "Wye" in that particular UTVTR.

3.9.4 Signals

3.9.4.1 FLTRFRC Input signals

Table 86: FLTRFRC Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
I3P3	SIGNAL	-	Three-phase currents 3
IRES1	SIGNAL	-	Residual current 1
IRES2	SIGNAL	-	Residual current 2
IRES3	SIGNAL	-	Residual current 3
U3P1	SIGNAL	-	Three-phase voltages 1
U3P2	SIGNAL	-	Three-phase voltages 2
U3P3	SIGNAL	-	Three-phase voltages 3
URES1	SIGNAL	-	Residual voltage 1
URES2	SIGNAL	-	Residual voltage 2
URES3	SIGNAL	-	Residual voltage 3

3.9.5 Settings

3.9.5.1 FLTRFRC Settings

Table 87: FLTRFRC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Trig mode	0=From all faults 1=From operate 2=From only start			0=From all faults	Triggering mode

Table 88: FLTRFRC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
A measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode phase currents and residual current

3.9.6 Monitored data

3.9.6.1 FLTRFRC Monitored data

Table 89: FLTRFRC Monitored data

Name	Type	Values (Range)	Unit	Description
Fault number	INT32	0...999999		Fault record number
Time and date	Timestamp			Fault record time stamp
Protection (rec. set 1)	Enum	0=None 1=PHLPTOC1 2=PHLPTOC2 6=PHHPTOC1 7=PHHPTOC2 8=PHHPTOC3 9=PHHPTOC4 12=PHIPTOC1 13=PHIPTOC2 17=EFLPTOC1 18=EFLPTOC2 19=EFLPTOC3 22=EFHPTOC1 23=EFHPTOC2 24=EFHPTOC3 25=EFHPTOC4 30=EFIPTOC1 31=EFIPTOC2 32=EFIPTOC3 35=NSPTOC1 36=NSPTOC2 -7=INTRPTEF1 -5=STTPMSU1 -3=JAMPTOC1		Protection function (rec. set1)

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		41=PDNSPTOC1 44=T1PTTR1 46=T2PTTR1 48=MPTTR1 50=DEFLPDEF1 51=DEFLPDEF2 53=DEFHPDEF1 56=EFPADM1 57=EFPADM2 58=EFPADM3 59=FRPFRQ1 60=FRPFRQ2 61=FRPFRQ3 62=FRPFRQ4 63=FRPFRQ5 64=FRPFRQ6 65=LSHDPFRQ1 66=LSHDPFRQ2 67=LSHDPFRQ3 68=LSHDPFRQ4 69=LSHDPFRQ5 71=DPHLPDOC1 72=DPHLPDOC2 74=DPHHPDOC1 77=MAPGAPC1 78=MAPGAPC2 79=MAPGAPC3 85=MNSPTOC1 86=MNSPTOC2 88=LOFLPTUC1 90=TR2PTDF1 91=LNPLDF1 92=LREFPNDF1 94=MPDIF1 96=HREFPDIF1 100=ROVPTOV1 101=ROVPTOV2 102=ROVPTOV3 104=PHPTOV1 105=PHPTOV2 106=PHPTOV3 108=PHPTUV1 109=PHPTUV2 110=PHPTUV3 112=NSPTOV1 113=NSPTOV2 116=PSPTUV1 118=ARCSARC1 119=ARCSARC2 120=ARCSARC3		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-96=SPHIPTOC1 -93=SPHLPTOC2 -92=SPHLPTOC1 -89=SPHHPTOC2 -88=SPHHPTOC1 -87=SPHPTUV4 -86=SPHPTUV3 -85=SPHPTUV2 -84=SPHPTUV1 -83=SPHPTOV4 -82=SPHPTOV3 -81=SPHPTOV2 -80=SPHPTOV1 -25=OEPVPH4 -24=OEPVPH3 -23=OEPVPH2 -22=OEPVPH1 -19=PSPTOV2 -18=PSPTOV1 -15=PREVPTOC1 -12=PHPTUC2 -11=PHPTUC1 -9=PHIZ1 5=PHLTPTOC1 20=EFLPTOC4 26=EFHPTOC5 27=EFHPTOC6 37=NSPTOC3 38=NSPTOC4 45=T1PTTR2 54=DEFHPDEF2 75=DPHHPDOC2 89=LOFLPTUC2 103=ROVPTOV4 117=PSPTUV2 -13=PHPTUC3 3=PHLPTOC3 10=PHHPTOC5 11=PHHPTOC6 28=EFHPTOC7 29=EFHPTOC8 107=PHPTOV4 111=PHPTUV4 114=NSPTOV3 115=NSPTOV4 -30=PHDSTPDIS1 -29=TR3PTDF1 -28=HICPDIF1 -27=HIBPDIF1 -26=HIAPDIF1		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-32=LSHDPFRQ8 -31=LSHDPFRQ7 70=LSHDPFRQ6 80=MAPGAPC4 81=MAPGAPC5 82=MAPGAPC6 83=MAPGAPC7 -102=MAPGAPC12 -101=MAPGAPC11 -100=MAPGAPC10 -99=MAPGAPC9 -98=RESCPSCH1 -57=FDEFLPDEF2 -56=FDEFLPDEF1 -54=FEFLPTOC1 -53=FDPHLPDOC2 -52=FDPHLPDOC1 -50=FPHLPTOC1 -47=FRPFRQ8 -46=FRPFRQ7 -45=MAPGAPC24 -44=MAPGAPC23 -43=MAPGAPC22 -42=MAPGAPC21 -41=MAPGAPC20 -40=MAPGAPC19 -37=HAEFPTOC1 -35=WPWDE3 -34=WPWDE2 -33=WPWDE1 52=DEFLPDEF3 84=MAPGAPC8 93=LREFPNDF2 97=HREFPDIF2 -117=XDEFLPDEF2 -116=XDEFLPDEF1 -115=SDPHLPDOC2 -114=SDPHLPDOC1 -113=XNSPTOC2 -112=XNSPTOC1 -111=XEFIPTOC2 -110=XEFHPTOC4 -109=XEFHPTOC3 -108=XEFLPTOC3 -107=XEFLPTOC2 -66=DQPTUV1 -65=VVSPPAM1 -64=PHPVOC1 -63=H3EFPSEF1 -60=HCUBPTOC1		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-59=CUBPTOC1 -72=DOPPDPR1 -69=DUPPDPR1 -61=COLPTOC1 -106=MAPGAPC16 -105=MAPGAPC15 -104=MAPGAPC14 -103=MAPGAPC13 -76=MAPGAPC18 -75=MAPGAPC17 -62=SRCPTOC1 -74=DOPPDPR3 -73=DOPPDPR2 -70=DUPPDPR2 -58=UZPDIS1 -36=UEXPDIS1 14=MFADPSDE1 -10=LVRTPTUV1 -8=LVRTPTUV2 -6=LVRTPTUV3 -122=DPH3LPDOC1 -121=DPH3HPDOC2 -120=DPH3HPDOC1 -119=PH3LPTOC2 -118=PH3LPTOC1 -79=PH3HPTOC2 -78=PH3HPTOC1 -77=PH3IPTOC1 -127=PHAPTUV1 -124=PHAPTOV1 -123=DPH3LPDOC2 -68=PHPVOC2 -67=DQPTUV2 -39=UEXPDIS2 98=MHZPDIF1 -4=MREFPTOC1 -16=MPUPF1 -14=OOSRPSB1 121=PSPTUV3 122=PSPTOV3 123=PHVPTOV1 39=DNSPDOC1 40=DNSPDOC2 -126=PHCPTOV1 -125=PHBPTOV1 -97=HIAPDIF3 -95=HICPDIF3 -94=HICPDIF2 -91=HIBPDIF3 -90=HIBPDIF2		

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-71=HIAPDIF2 -55=FRPFRQ12 -51=FRPFRQ11 -49=FRPFRQ10 -48=FRPFRQ9 -38=DSTPDIS1 -21=CUBPTOC3 -20=CUBPTOC2 -17=MPUPF2 -2=PHCPTUV1 -1=PHBPTUV1 4=PHIPTOC3 15=MFADPSDE2 16=MFADPSDE3 73=DPHLPDOC3 76=DPHHPDOC3 95=HCUBPTOC2 99=MREFPTOC2 124=PSPTUV4 125=PSPTOV4 127=JAMPTOC2 21=DEFHPDEF4 33=DPHHPDOC4 34=DPHLPDOC4 47=DEFLPDEF4 55=DEFHPDEF3		
Protection (rec. set 2)	Enum	0=None 1=External 2=IFPTOC1 3=IFPTOC2 4=IFPTOC3		Protection function (rec. set 2)
Start duration	FLOAT32	0.00...100.00	%	Maximum start duration of all stages during the fault
Operate time	FLOAT32	0.000...999999.999	s	Operate time
Breaker clear time	FLOAT32	0.000...3.000	s	Breaker clear time
Fault distance	FLOAT32	0.00...3000.00	pu	Distance to fault measured in pu
Fault resistance	FLOAT32	0.00...3000.00	ohm	Fault resistance
Fault reactance	FLOAT32	0.00...3000.00	ohm	Fault reactance
Active group	INT32	1...6		Active setting group
Shot pointer	INT32	1...7		Autoreclosing shot pointer value
Max diff current IL1:1	FLOAT32	0.000...80.000	pu	Maximum phase A differential current (1)
Max diff current IL2:1	FLOAT32	0.000...80.000	pu	Maximum phase B differential current (1)
Max diff current IL3:1	FLOAT32	0.000...80.000	pu	Maximum phase C differential current (1)
Diff current IL1:1	FLOAT32	0.000...80.000	pu	Differential current phase A (1)
Diff current IL2:1	FLOAT32	0.000...80.000	pu	Differential current phase B (1)

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Diff current IL3:1	FLOAT32	0.000...80.000	pu	Differential current phase C (1)
Max bias current IL1:1	FLOAT32	0.000...50.000	pu	Maximum phase A bias current: (1)
Max bias current IL2:1	FLOAT32	0.000...50.000	pu	Maximum phase B bias current (1)
Max bias current IL3:1	FLOAT32	0.000...50.000	pu	Maximum phase C bias current (1)
Bias current IL1:1	FLOAT32	0.000...50.000	pu	Bias current phase A (1)
Bias current IL2:1	FLOAT32	0.000...50.000	pu	Bias current phase B (1)
Bias current IL3:1	FLOAT32	0.000...50.000	pu	Bias current phase C (1)
Diff current Io:1	FLOAT32	0.000...80.000	pu	Differential current residual (1)
Bias current Io:1	FLOAT32	0.000...50.000	pu	Bias current residual (1)
Max current IL1:1	FLOAT32	0.000...50.000	xIn	Maximum phase A current (1)
Max current IL2:1	FLOAT32	0.000...50.000	xIn	Maximum phase B current (1)
Max current IL3:1	FLOAT32	0.000...50.000	xIn	Maximum phase C current (1)
Max current Io:1	FLOAT32	0.000...50.000	xIn	Maximum residual current (1)
Current IL1:1	FLOAT32	0.000...50.000	xIn	Phase A current (1)
Current IL2:1	FLOAT32	0.000...50.000	xIn	Phase B current (1)
Current IL3:1	FLOAT32	0.000...50.000	xIn	Phase C current (1)
Current Io:1	FLOAT32	0.000...50.000	xIn	Residual current (1)
Current Io-Calc:1	FLOAT32	0.000...50.000	xIn	Calculated residual current (1)
Current Ps-Seq:1	FLOAT32	0.000...50.000	xIn	Positive sequence current (1)
Current Ng-Seq:1	FLOAT32	0.000...50.000	xIn	Negative sequence current (1)
Max current IL1:2	FLOAT32	0.000...50.000	xIn	Maximum phase A current (2)
Max current IL2:2	FLOAT32	0.000...50.000	xIn	Maximum phase B current (2)
Max current IL3:2	FLOAT32	0.000...50.000	xIn	Maximum phase C current (2)
Max current Io:2	FLOAT32	0.000...50.000	xIn	Maximum residual current (2)
Current IL1:2	FLOAT32	0.000...50.000	xIn	Phase A current (2)
Current IL2:2	FLOAT32	0.000...50.000	xIn	Phase B current (2)
Current IL3:2	FLOAT32	0.000...50.000	xIn	Phase C current (2)
Current Io:2	FLOAT32	0.000...50.000	xIn	Residual current (2)
Current Io-Calc:2	FLOAT32	0.000...50.000	xIn	Calculated residual current (2)
Current Ps-Seq:2	FLOAT32	0.000...50.000	xIn	Positive sequence current (2)
Current Ng-Seq:2	FLOAT32	0.000...50.000	xIn	Negative sequence current (2)
Max current IL1:3	FLOAT32	0.000...50.000	xIn	Maximum phase A current (3)
Max current IL2:3	FLOAT32	0.000...50.000	xIn	Maximum phase B current (3)
Max current IL3:3	FLOAT32	0.000...50.000	xIn	Maximum phase C current (3)
Max current Io:3	FLOAT32	0.000...50.000	xIn	Maximum residual current (3)
Current IL1:3	FLOAT32	0.000...50.000	xIn	Phase A current (3)

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Current IL2:3	FLOAT32	0.000...50.000	xIn	Phase B current (3)
Current IL3:3	FLOAT32	0.000...50.000	xIn	Phase C current (3)
Current Io:3	FLOAT32	0.000...50.000	xIn	Residual current (3)
Current Io-Calc:3	FLOAT32	0.000...50.000	xIn	Calculated residual current (3)
Current Ps-Seq:3	FLOAT32	0.000...50.000	xIn	Positive sequence current (3)
Current Ng-Seq:3	FLOAT32	0.000...50.000	xIn	Negative sequence current (3)
Voltage UL1:1	FLOAT32	0.000...4.000	xUn	Phase A voltage
Voltage UL2:1	FLOAT32	0.000...4.000	xUn	Phase B voltage
Voltage UL3:1	FLOAT32	0.000...4.000	xUn	Phase C voltage
Voltage U12:1	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage
Voltage U23:1	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage
Voltage U31:1	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage
Voltage Uo:1	FLOAT32	0.000...4.000	xUn	Residual voltage
Voltage Zro-Seq:1	FLOAT32	0.000...4.000	xUn	Zero sequence voltage
Voltage Ps-Seq:1	FLOAT32	0.000...4.000	xUn	Positive sequence voltage
Voltage Ng-Seq:1	FLOAT32	0.000...4.000	xUn	Negative sequence voltage
Voltage UL1:2	FLOAT32	0.000...4.000	xUn	Phase A voltage (2)
Voltage UL2:2	FLOAT32	0.000...4.000	xUn	Phase B voltage (2)
Voltage UL3:2	FLOAT32	0.000...4.000	xUn	Phase B voltage (2)
Voltage U12:2	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage (2)
Voltage U23:2	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage (2)
Voltage U31:2	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage (2)
Voltage Uo:2	FLOAT32	0.000...4.000	xUn	Residual voltage (2)
Voltage Zro-Seq:2	FLOAT32	0.000...4.000	xUn	Zero sequence voltage (2)
Voltage Ps-Seq:2	FLOAT32	0.000...4.000	xUn	Positive sequence voltage (2)
Voltage Ng-Seq:2	FLOAT32	0.000...4.000	xUn	Negative sequence voltage (2)
Voltage UL1:3	FLOAT32	0.000...4.000	xUn	Phase A voltage (3)
Voltage UL2:3	FLOAT32	0.000...4.000	xUn	Phase B voltage (3)
Voltage UL3:3	FLOAT32	0.000...4.000	xUn	Phase C voltage (3)
Voltage UL12:3	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage (3)
Voltage UL23:3	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage (3)
Voltage UL31:3	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage (3)
Voltage Uo:3	FLOAT32	0.000...4.000	xUn	Residual voltage (3)
Voltage Zro-Seq:3	FLOAT32	0.000...4.000	xUn	Zero sequence voltage (3)
Voltage Ps-Seq:3	FLOAT32	0.000...4.000	xUn	Positive sequence voltage (3)
Voltage Ng-Seq:3	FLOAT32	0.000...4.000	xUn	Negative sequence voltage (3)
PTTR thermal level	FLOAT32	0.00...99.99		PTTR calculated temperature of the protec-

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
				ted object relative to the operate level
PDNSPTOC1 rat. I2/I1	FLOAT32	0.00...999.99	%	PDNSPTOC1 ratio I2/I1
Frequency:1	FLOAT32	0.00...80.00	Hz	Frequency (1)
Frequency gradient:1	FLOAT32	-10.00...10.00	Hz/s	Frequency gradient (1)
Frequency:2	FLOAT32	0.00...80.00	Hz	Frequency (2)
Frequency gradient:2	FLOAT32	-10.00...10.00	Hz/s	Frequency gradient (2)
Frequency:3	FLOAT32	0.00...80.00	Hz	Frequency (3)
Frequency gradient:3	FLOAT32	-10.00...10.00	Hz/s	Frequency gradient (3)
Conductance Yo	FLOAT32	-1000.00...1000.00	mS	Conductance Yo
Susceptance Yo	FLOAT32	-1000.00...1000.00	mS	Susceptance Yo
Angle Uo:1 - Io:1	FLOAT32	-180.00...180.00	deg	Angle residual voltage (1) - residual current (1)
Angle U23:1- IL1:1	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage (1) - phase A current (1)
Angle U31:1 - IL2:1	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage (1) - phase B current (1)
Angle U12:1 - IL3:1	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage (1) - phase C current (1)
Angle Uo:2 - Io:2	FLOAT32	-180.00...180.00	deg	Angle residual voltage (2) - residual current (2)
Angle U23:2 - IL1:2	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage (2) - phase A current (2)
Angle U31:2 - IL2:2	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage (2) - phase B current (2)
Angle U12:2 - IL3:2	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage (2) - phase C current (2)
Angle Uo:3 - Io:3	FLOAT32	-180.00...180.00	deg	Angle residual voltage (3) - residual current (3)
Angle U23:3 - IL1:3	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage (3) - phase A current (3)
Angle U31:3 - IL2:3	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage (3) - phase B current (3)
Angle U12:3 - IL3:3	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage (3) - phase C current (3)

The recorded differential and bias currents as well as the maximum differential and bias currents are provided by LNPLDF1, MPDIF1, TR2PTDF1 or TR3PTDF1. If the configuration contains more than one of these functions, only the currents from the function first found on the list are recorded.

3.10 Nonvolatile memory

The relay does not include any battery backup power. If the auxiliary power is lost, critical information such as relay configuration and settings, events, disturbance recordings and other critical data are saved to the relay's nonvolatile memory. The relay's real-time clock keeps running via a 48-hour capacitor backup.

- Up to 1024 events are stored. The stored events are visible in HMI and Event viewer tool in PCM600.
- Recorded data
  - Fault records (up to 128)
  - Maximum demands
- Circuit breaker condition monitoring
- Latched alarm and trip LEDs' statuses
- Trip circuit lockout
- Counter values

3.11 Analog measurement channels

The maximum number of physical analog measurement channels is 20. This can be achieved with two analog input modules. The protection relay also supports up to 16 SMV channels in four separate 9-2 streams. In addition to the local or 9-2 channels, a certain number of numerical channels is always calculated from physical measurements. This number also depends on the connection type of the TVTR function block.

Table 90: TVTR/TCTR connection types and numerical channels

Connection type	Function block	Physical channels	Numerical channels
ULx × 1	ULxTVTR	1	0
URES	ULxTVTR	1	0
ULx × 2 (Wye/Delta)	ULxTVTR	2	4
ULx × 2 + URES (Wye/ Delta)	ULxTVTR	3	4
ULx × 3 (Delta)	ULxTVTR	3	3
ULx × 3 (Wye)	ULxTVTR	3	4
ILx × 3	ILxTCTR	3	1
IRES	RESxTCTR	1	0
ILx × 6	CMSUM	6	4

The maximum number of measurement channels is 64. This can be calculated by adding physical and numerical channels together.

In REX640 relays, the UTVTR functions automatically calculate missing signals if enough information is available. If measured Uo is needed for calculations but it is not provided, it is assumed to be zero. *Table 91* shows possible voltage connections and outcome of the UTVTR function. A three-phase current connection in the ILTCTR function always provides a calculated Io channel.

Table 91: Calculated voltages for different connection types

Voltage connection	Phase-to-phase voltages (Ph-Ph)	Phase-to-neutral voltages (Ph-n)	Residual voltage Uo
3 × ph-n	yes, calculated	yes	yes, calculated
3 × ph-n + Uo	yes, calculated	yes	yes
2 × ph-n	yes, calculated [1]	yes, missing ph-n calculated [1]	no
2 × ph-n + Uo	yes, calculated	yes, missing ph-n calculated	yes
3 × ph-ph	yes	yes, calculated [1]	no
3 × ph-ph + Uo	yes	yes, calculated	yes
2 × ph-ph	yes, missing ph-ph calculated	yes, calculated [1]	no
2 × ph-ph + Uo	yes, missing ph-ph calculated	yes, calculated	yes

3.12 Sensor inputs for currents and voltages

This chapter gives short examples on how to define the correct parameters for sensor measurement interfaces.

Sensors can have correction factors, measured and verified by the sensor manufacturer, to increase the measurement accuracy. Correction factors are recommended to be set to the relay. Two types of correction factors are available for voltage and current (Rogowski) sensors. The Amplitude correction factor is named *Amplitude corr. A(B/C)* and Angle correction factor is named *Angle corr A(B/C)*. These correction factors can be found on the Sensor's rating plate and/or sensor routine test protocol. If the correction factors are not available, contact the sensor manufacturer for more information.

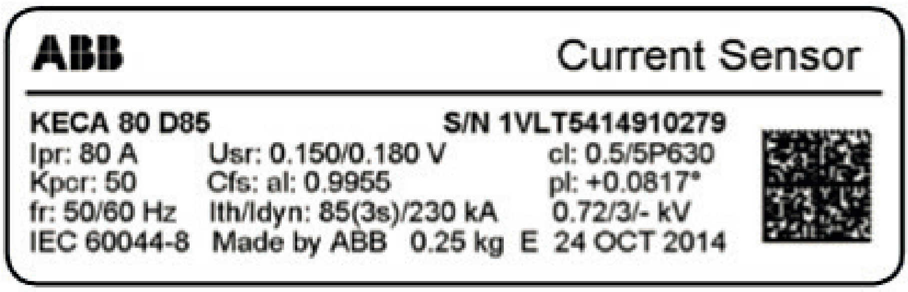


Figure 56: Example of ABB Rogowski current sensor KECA 80 D85 rating plate

Current (Rogowski) sensor setting example

In this example, an 80 A/0.150 V at 50 Hz (0.180 V at 60 Hz) sensor, such as the example shown in *Figure 56*, is used in a 50 Hz electrical network. The application has a 150 A nominal current (In) corresponding to the protected object's nominal current. The application nominal current is set to Rogowski

[1] Uo assumed zero.

sensor setting *Primary current*. Taken from the sensor's technical data, this example sensor can be used with up to 4000 A application nominal current. As the Rogowski sensor is linear and does not saturate, the 80 A/0.150 V at 50 Hz sensor also works as a 150 A/0.28125 V at 50 Hz sensor. When defining another primary value for the sensor, also the nominal voltage has to be redefined to maintain the same transformation ratio. However, the setting in the protection relay (*Rated Secondary Value*) is not in V but in mV/Hz, which makes the same setting *Rated Secondary Value* valid for both 50 and 60 Hz nominal frequency.

$$RSV = \frac{\frac{I_n}{I_{pr}} \times K_r}{f_n}$$

(Equation 1)

RSV	*Rated Secondary Value* in mV/Hz
I_n	Application nominal current
I_{pr}	Sensor-rated primary current
f_n	Network nominal frequency
K_r	Sensor-rated voltage at the rated current in mV

In this example, the value is as calculated using the equation.

$$\frac{\frac{150A}{80A} \times 150mV}{50Hz} = 5.625\frac{mV}{Hz}$$

(Equation 2)

With this information, the protection relay's current (Rogowski) sensor settings can be set.

Table 92: Example setting values for current (Rogowski) sensor

Setting	Value
Primary current	150 A
Rated secondary value	5.625 mV/Hz

When considering setting values for current sensor interfaces and for protection functions utilizing these measurements, it should be noted that the sensor measurement inputs in the relay have limits for linear behavior. When this limit is exceeded, the input starts to saturate. The saturation is reflected to the protection functions connected to the sensor inputs. To ensure that the related protection functions operate correctly, the start value setting for protection functions utilizing either instantaneous or definite minimum time characteristics must not exceed the linear measurement range. Furthermore, the effect on protection functions utilizing inverse time characteristics should be considered. The upper limit of the linear measurement range depends on the selected application nominal current and the type of the current sensor used. *Table 93* shows the limits for an 80A/150mV 50Hz sensor.

Table 93: Application nominal current relation to the upper limit of linear measurement range

Application nominal current (I_n)	Rated secondary value with 80A / 0.150 V at 50 Hz (0.180 V at 60 Hz)	Upper limit of linear measurement range
40...800 A	1.500...30.000 mV/Hz	60 × I_n
800...1250 A	30.000...46.875 mV/Hz	60...40 × I_n
1250...2500 A	46.875...93.750 mV/Hz	40...20 × I_n
2500...4000 A	93.750...150.000 mV/Hz	20...12.5 × I_n

Table 93 shows the upper limits of the linear measurement range based on a certain range in application nominal current. The linear measurement limit for a given application nominal current can be derived from the values stated in the table with a simple proportion equation. For example, the upper limit for linear measurement for 3000 A application nominal current would be 17.5 xIn.

It can also be calculated from *Table 93* that with the stated sensor the relay input can linearly measure up to 50 kA (RMS) short circuit currents.

Rogowski sensor and overcurrent protection setting evaluation example

A 20 kV utility substation with a single busbar switchgear rated up to 40 kA shortcircuit currents has one incomer and 20 outgoing feeder relays using 80 A/0.150 V at 50 Hz Rogowski current sensors with rating plate values similar to *Figure 56*. For the incomer panel, electrical system designer has evaluated the application nominal current to be 1250 A. Customer specification for these protection relays defines normal instantaneous and time-delayed overcurrent and earth-fault protection functions. Overcurrent protection requires functions to be settable up to 20 xIn.

The sensor setting *Primary current* is set to be the same as the evaluated application nominal current 1250 A. According to the sensor's technical data, the application nominal current matches the sensor's capability which is up to 4000 A.

The setting *Rated secondary value* is calculated by using *Equation 1*.

$$\frac{\frac{1250A}{80A}\cdot 150mV}{50Hz} = 46.875\frac{mV}{Hz}$$

(Equation 3)

From *Table 93* it is seen that with the 1250 A application nominal current value, the maximum setting for overcurrent protection is 40 xIn. This covers the customer specification requirements for overcurrent settings of up to 20 xIn.

Voltage sensor setting example

The voltage sensor is based on the resistive divider or capacitive divider principle. Therefore, the voltage is linear throughout the whole measuring range. The output signal is a voltage, directly proportional to the primary voltage. For the voltage sensor, all parameters are readable directly from its rating plate and/or sensor routine test protocol, and conversions are not needed.

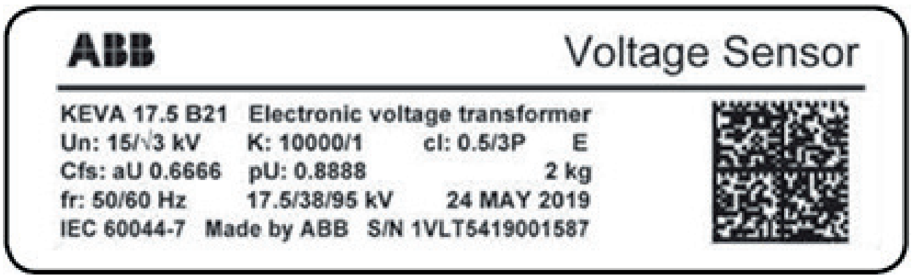


Figure 57: Example of ABB voltage sensor KEVA 17.5 B21 rating plate

In this example the system phase-to-phase voltage rating is 10 kV. Thus, the *Primary voltage* parameter is set to 10 kV. For protection relays with sensor measurement support, the *Voltage input type* is set to "Voltage sensor". The VT connection parameter is set to the "WYE" type. The division ratio for ABB voltage sensors is most often 10000:1. Thus, the *Division ratio* parameter is usually set to "10000". The primary voltage is proportionally divided by this division ratio.

Table 94: Example setting values for voltage sensor

Setting	Value
Primary voltage	10 kV
VT connection	Wye
Voltage input type	3=Voltage sensor
Division ratio	10000

3.13 Binary inputs

The binary inputs are mainly assembled in groups of three inputs that have one common connection. The binary inputs are bipolar so the common connection can be tied to ground or to supply voltage. Input groups are isolated from each other and from the secondary side. In addition, there can be groups with only one input. For more information, see *Chapter 13.1 Module diagrams* in this manual.

In harsh industrial environments binary inputs are exposed to contamination. This causes a thin film of insulating sulfidation, oxidation, or contaminates on the surface of the contacts. Film must be removed to establish circuit continuity. Binary inputs have an oxide-burn feature to create a high wetting current impulse to burn off oxidation layer when the threshold is reached. Input wetting current is reduced to a steady-state current when oxide-burn is completed.

In BIO1001 and BIO1003 modules oxide-burn feature can be disabled only on binary input 14 to use it as pulse counter input. The pulse counter input is enabled by setting the parameter *Input 14 counter-mode* in **Configuration** > **I/O modules** > **Slot #** > **Input filtering**. When enabled, the pulse counter input has dedicated *Input* *counter threshold voltage* and *Input counter threshold hysteresis* settings. Oxide-burn feature cannot be disabled in BIO1002 & BIO1004.

In RTD1002 module wetting current can be adjusted by setting the parameter *Input oxide burn A* in **Configuration** > **I/O modules** > **Slot #** > **Input filtering**. This parameter is common for all binary inputs in the module.

3.13.1 Binary input threshold voltage

The parameter *Input threshold voltage* is used to set the threshold level of the binary inputs. *Input threshold voltage* determines the voltage level for the activation of the inputs. The threshold can be set for every module or slot specifically depending on the *Slot specific threshold* setting.

Table 95: Input threshold voltage parameters

Parameter	Values	Default
Slot specific threshold	0=False 1=True	0=False
Input threshold voltage	16...176 V	16 V

3.13.2 Threshold hysteresis

Threshold hysteresis is used to determine the deactivation threshold for the binary inputs in case of voltage drops in the auxiliary voltage supply. Threshold hysteresis value determines how low the deactivation voltage is compared to the activation voltage as a percentage. Hysteresis can be set for every module or slot specifically depending on the *Slot specific hysteresis* setting.

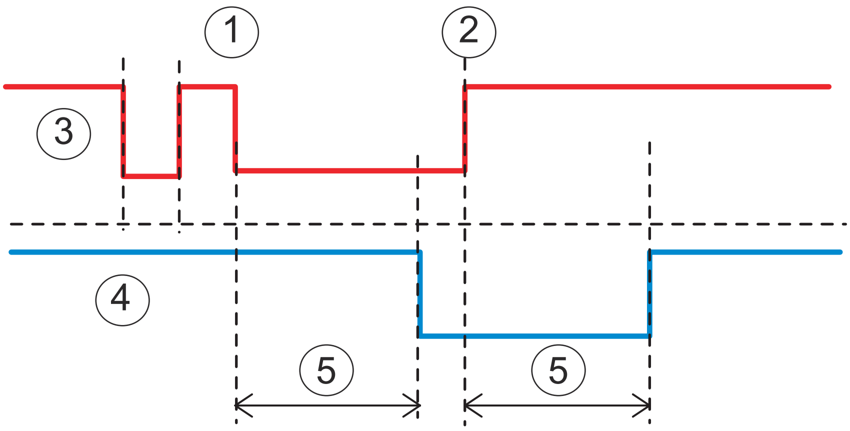
Binary inputs always deactivate when the voltage level drops below 14 V.

Table 96: Threshold hysteresis parameters

Parameter	Values	Default
Slot specific hysteresis	0=False 1=True	0=False
Input threshold hysteresis	10...50 %	10 %

3.13.3 Binary input filter time

The filter time eliminates debounces and short disturbances on a binary input. The filter time is set for each binary input of the protection relay.



1 t_0
2 t_1
3 Input signal
4 Filtered input signal
5 Filter time

Figure 58: Binary input filtering

At the beginning, the input signal is at the high state, the short low state is filtered and no input state change is detected. The low state starting from the time t_0 exceeds the filter time, which means that the change in the input state is detected and the time tag attached to the input change is t_0. The high state starting from t_1 is detected and the time tag t_1 is attached.

Each binary input has a filter time parameter *"Input # filter"*, where # is the number of the binary input of the module in question (for example *"Input 1 filter"*).

Table 97: Input filter parameter values

Parameter	Values	Default
Input # filter time	5...1000 ms	5 ms

3.13.4 Binary input inversion

The parameter *Input # invert* is used to invert a binary input.

Table 98: Binary input states

Control voltage	Input # invert	State of binary input
No	0	FALSE (0)
Yes	0	TRUE (1)
No	1	TRUE (1)
Yes	1	FALSE (0)

When a binary input is inverted, the state of the input is TRUE (1) when no control voltage is applied to its terminals. Accordingly, the input state is FALSE (0) when a control voltage is applied to the terminals of the binary input.

3.13.5 Oscillation suppression

Oscillation suppression is used to reduce the load from the system when a binary input starts oscillating. A binary input is regarded as oscillating if the number of valid state changes (= number of events after filtering) during one second is equal to or greater than the set oscillation level value. During oscillation, the binary input is blocked (the status is invalid) and an event is generated. The state of the input will not change when it is blocked, that is, its state depends on the condition before blocking.

The binary input is regarded as non-oscillating if the number of valid state changes during one second is less than the set oscillation level value minus the set oscillation hysteresis value. Note that the oscillation hysteresis must be set lower than the oscillation level to enable the input to be restored from oscillation. When the input returns to a non-oscillating state, the binary input is deblocked (the status is valid) and an event is generated.

Table 99: Oscillation parameters

Parameter	Value	Default
Input osc. level	2...50 events/s	30 events/s
Input osc. hyst	2...50 events/s	10 events/s

3.14 Binary outputs

The protection relay provides a number of binary outputs used for tripping, executing local or remote control actions of a breaker or a disconnector, and for connecting the protection relay to external annunciation equipment for indicating, signalling and recording.

Power output contacts are used when the current rating requirements of the contacts are high, for example, for controlling a breaker, such as energizing the breaker trip and closing coils.

The contacts used for external signalling, recording and indicating, the signal outputs, need to adjust to smaller currents, but they can require a minimum current (burden) to ensure a guaranteed operation.

The protection relay provides both power output and signal output contacts. To guarantee proper operation, the type of the contacts used are chosen based on the operating and reset time, continuous current rating, make and carry for short time, breaking rate and minimum connected burden. A combination of series or parallel contacts can also be used for special applications. When appropriate, a signal output can also be used to energize an external trip relay, which in turn can be confiugred to energize the breaker trip or close coils.

Using an external trip relay can require an external trip circuit supervision relay. It can also require wiring a separate trip relay contact back to the protection relay for breaker failure protection function.

All contacts are freely programmable, except the internal fault output IRF.

3.14.1 Power output contacts

Power output contacts are normally used for energizing the breaker closing coil and trip coil, external high burden lockout or trip relays.

3.14.1.1 Dual single-pole power outputs POSP1 and POSP2

Dual (series-connected) single-pole (normally open/form A) power output contacts POSP1 and POSP2 are rated for continuous current of 8 A. The contacts are normally used for closing circuit breakers and energizing high burden trip relays. They can be arranged to trip the circuit breakers when the trip circuit supervision is not available or when external trip circuit supervision relay is provided.

The power outputs are included in the power supply module in slot G.

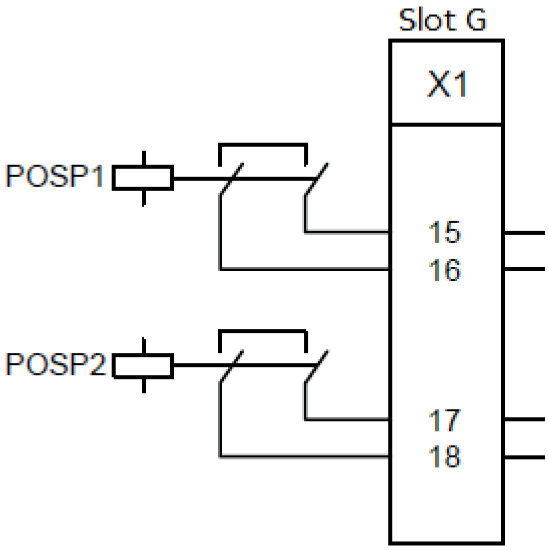


Figure 59: Dual single-pole power outputs in power supply module

3.14.1.2 Double-pole power outputs PODP1, PODP2 and PODP3 with trip circuit supervision

The power outputs PODP1, PODP2 and PODP3 are double-pole normally open/ form A power outputs with trip circuit supervision. The trip circuit supervision hardware includes constant current generator to provide trip circuit supervision (TCS) current and TCS input that can be connected to the TCS function with Application Configuration in PCM600. See Trip circuit supervision TCSSCBR function for TCS connections.

When the two poles of the contacts are connected in series, they have the same technical specification as POSP1/POSP2 for breaking duty. Contacts PODP1, PODP2 and PODP3 are usually used for energizing the breaker trip coils.

The power outputs are included in the power supply module in slot G.

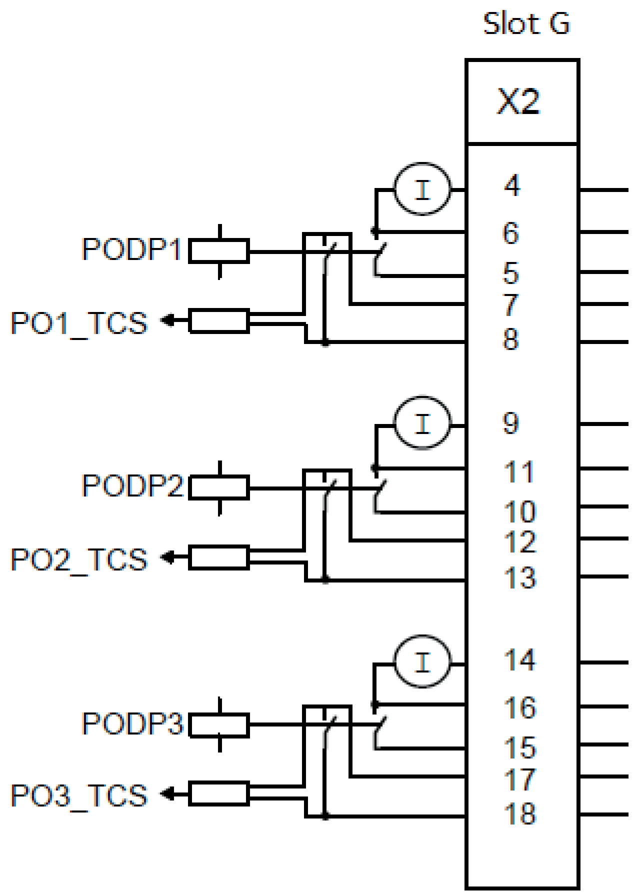


Figure 60: Double-pole power outputs with trip circuit supervision in power supply module

3.14.1.3 Static power outputs SPO1...SPO8

The outputs are normally used in applications that require fast relay output contact activation time to achieve fast opening of a breaker, such as, arc-protection or breaker failure protection, where fast operation is required either to minimize fault effects to the equipment or to avoid a fault to expand to a larger area. With the static power outputs, the total time from the application to the relay output contact activation is 4...6 ms shorter than when using output contacts with conventional mechanical output relays.

SPO5 and SPO7 are equipped with constant current generator to provide trip circuit supervision (TCS) current. SPO6 and SPO8 are equipped with TCS input that can be connected to the TCS function with Application Configuration in PCM600. See Trip circuit supervision TCSSCBR function for TCS connections.

The static power outputs are included in BIO1002 and BIO1004 modules.

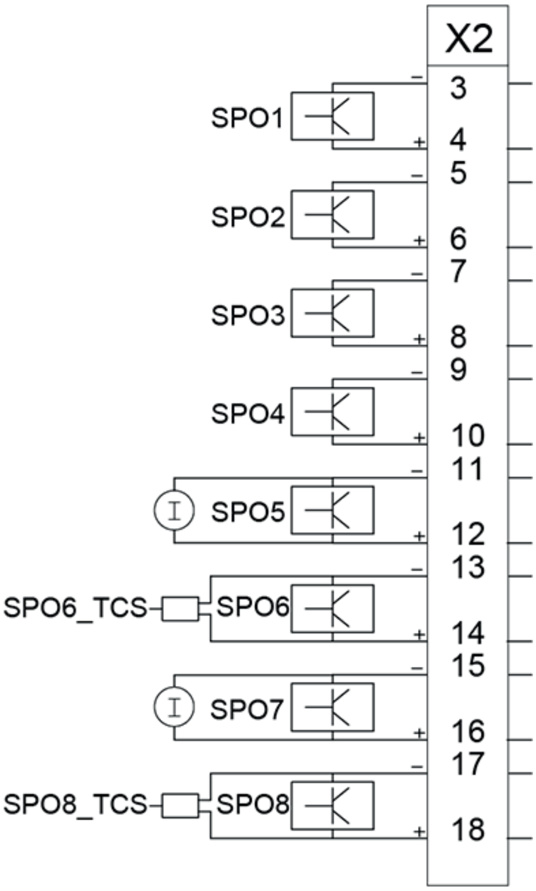


Figure 61: Static power outputs SPO1...SPO8

3.14.2 Signal output contacts

Signal output contacts are single-pole, single (normally open/form A or change-over/form C) signal output contacts (SO1, SO2,...) or parallel connected dual contacts.

The signal output contacts are used for energizing, for example, external low burden trip relays, auxiliary relays, annunciators and LEDs.

A single signal contact is rated for a continuous current of 5 A. It has a make and carry for 0.5 seconds at 15 A.

When two contacts are connected in parallel, the relay is of a different design. It has the make and carry rating of 30 A for 0.5 seconds. This can be applied for energizing breaker close coil and tripping coil. Due to the limited breaking capacity, a breaker auxiliary contact can be required to break the circuit.

Static signal outputs (SSO1, SSO2) are light-duty fast binary signal outputs and can also be used as pulse outputs.

Figure 62: Signal outputs in power supply module

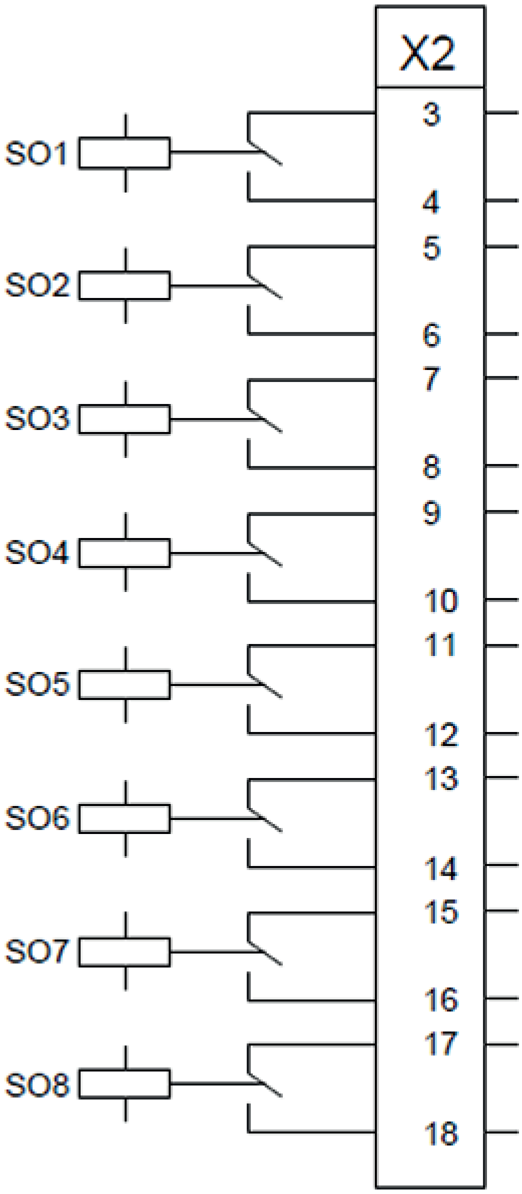


Figure 63: Signal outputs in BIO1001 and BIO1003 modules

3.14.2.1 Internal fault signal output IRF

The internal fault signal output (change-over/form C) IRF is a single contact included in the power supply module of the protection relay in slot G.

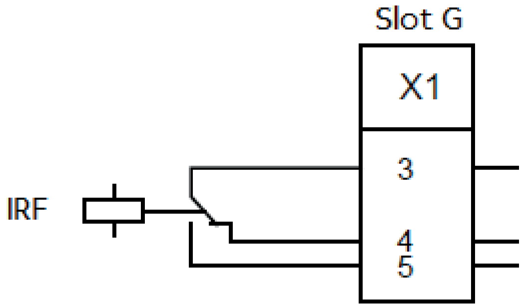


Figure 64: Internal fault signal output IRF

3.15 RTD/mA inputs/mA outputs

3.15.1 Function blocks

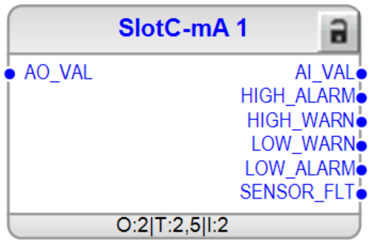


Figure 65: Function block for mA channel

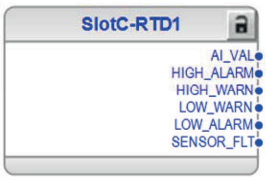


Figure 66: Function block for RTD channel

3.15.2 Functionality

The Slot#-mA#/RTD# function is an interface function between the relay's mA/RTD hardware channels. The function is split into separate function blocks for each hardware channel.

The mA function block works as an interface for the mA current channel. The channel can be defined either as a measuring input or a controllable output.

The RTD function block works as an interface for the RTD measuring channel that supports various types of RTD sensors.

Both function blocks have limit supervision alarm outputs and an output for sensor fault.

3.15.3 Operation principle

The operation of Slot#-mA#/RTD# can be described with a module diagram that illustrates a single input-output combination of the actual function block. All the modules in the diagram are explained in the next sections.

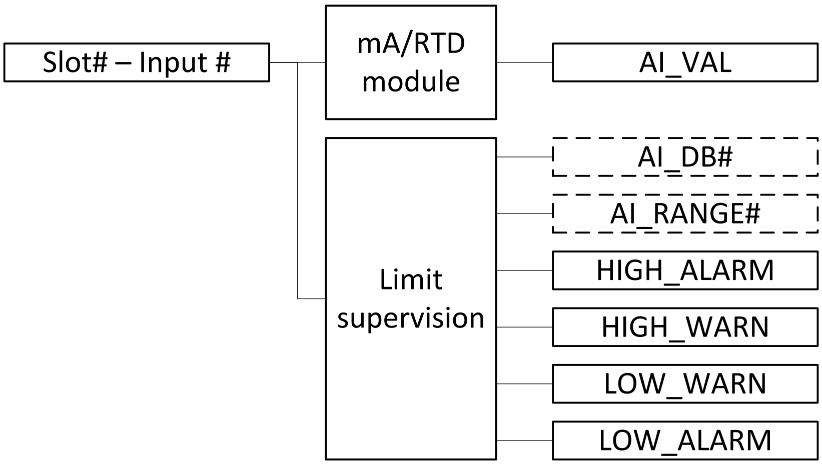


Figure 67: Functional module diagram for input mode

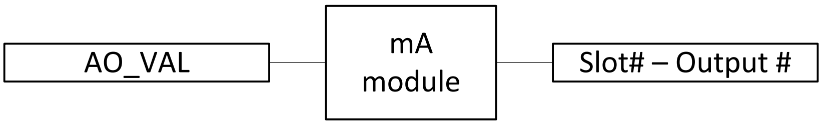


Figure 68: Functional module diagram for output mode

mA modules

mA current channels are used for input current measurement or output current control in the range of -20…20 mA (DC current). The channels are configured for particular input or output signal types by using channel-specific settings. When Input 1 is activated with setting "-20…20mA", the Output 1 mode is blocked. If Output 2 mode is activated with setting "-20…20mA", the Input 2 mode is blocked. When a channel is configured as an output, the alarm outputs are deactivated.

RTD modules

RTD channels are used for resistance measurements and they are only input channels. The inputs are configured for a particular input signal type by using the channel-specific *Input mode* setting. The default mode for each channel is "Not in use" which means that the channel is not sampled and the output value quality is set accordingly.

All the channels are independent mA/RTD channels with separated protection, filtering, reference, A/D-conversion and isolation. Thus, the RTD group is isolated from mA channels.

The RTD inputs measure resistance in the range of 0...4000 Ω. All inputs are calibrated and the calibration factors are stored on the module in nonvolatile memory. The calibration circuitry monitors the RTD channels continuously and reports the circuitry break of any channel.

The RTD inputs have separate setting values for value update interval. The settings are: "No delay", "10 ms delay", "50 ms delay" and "100 ms delay". Between the update intervals the RTD input constantly returns the last valid value before updating to the new value after the interval time expires.

3.15.3.1 Input mode

Table 100: Analog input modes for the mA inputs

Input mode	Description
Not in use	Default selection when the corresponding input is not used.
–20...20 mA	The analog input covers the range of –20...20 mA. The input can be used in a narrower range by setting *Input minimum* and *Input maximum*. Settings *Value minimum* and *Value maximum* are used to scale the output within the appropriate range. The output unit is selected with the set *Value unit*.

Table 101: Analog input modes for the RTD inputs

Input mode	Description
Not in use	Default selection when the corresponding input is not used.
Resistance	Freely settable resistance input. *Input minimum* and *Input maximum* define the resistive input range. The corresponding output can be scaled based on *Value minimum* and *Value maximum*. The output unit is selected with the set *Value unit*.
Pt 100	The input is expected to be the selected temperature sensor. The set *Value unit* should be set to degrees Celsius. The expected input range is –40...200°C. However, the output can be scaled to a narrower output range by setting *Value minimum* and *Value maximum*.
Pt 250	
Ni 100	
Ni 120	
Ni 250	

Selection of value unit format

Each input has an independent *Value unit* setting that is used to select the unit for the channel value representation. The default value for the *Value unit* setting is "Dimensionless". The *Input minimum*, *Input maximum*, *Value maximum* and *Value minimum* settings have to be adjusted according to the input channel and if *Value unit* is changed.

When the RTD channel input is used for the temperature sensor type, the *Value unit* setting needs to be changed to "Degrees Celsius". When *Value unit* is set to "Degrees Celsius", linear scaling is not applied but the default range (–40…200°C) can be decreased with the *Value maximum* and *Value minimum* settings..

When the DC milliampere signal is connected to the mA channel and the application requires a linear scaling of the input range, the *Value unit* setting value has to be set to "Dimensionless" so that the input range can be linearly scaled with the settings Input minimum and Input maximum to *Value minimum* and *Value maximum*. When milliampere is used as a value unit, *Value unit* has to be "Ampere". When *Value unit* is set to "Ampere", the default range (–20…20 mA) can be decreased with the *Value maximum* and *Value minimum* settings.

When a resistance type signal is connected to the RTD channel and the application requires a linear scaling of the input range, the *Value unit* setting value has to be set to "Dimensionless" so that the input range can be linearly scaled with the settings *Input minimum* and *Input maximum* to *Value minimum* and *Value maximum*. When resistance is used as a value unit, *Value unit* has to be "Ohm". When *Value unit* is set to "Ohm", the default range (0…4000 Ω) can be decreased with the *Value maximum* and *Value minimum* settings.

RTD temperature vs. resistance

The resistance values of temperature sensors at specified temperatures are given in *Table 102*.

Table 102: Temperature vs. resistance

Temp °C	Platinum TCR 0.00385		Nickel TCR 0.00618		
	Pt 100	Pt 250	Ni 100	Ni 120	Ni 250
–40	84.28	210.70	79.13	94.96	197.83
–30	88.22	220.56	84.15	100.97	210.36
–20	92.16	230.40	89.30	107.16	223.24
–10	96.09	240.21	94.58	113.50	236.45
0	100.00	250.00	100.00	120.00	250.00
10	103.90	259.76	105.55	126.66	263.88
20	107.79	269.48	111.24	133.48	278.09
30	111.67	279.18	117.06	140.47	292.64
40	115.54	288.85	123.01	147.61	307.53
50	119.40	298.49	129.11	154.93	322.76
60	123.24	308.10	135.34	162.41	338.35
70	127.08	317.69	141.72	170.06	354.30
80	130.90	327.24	148.25	177.90	370.63
90	134.71	336.77	154.93	185.92	387.34
100	138.51	346.26	161.78	194.13	404.45
110	142.29	355.73	168.79	202.55	421.97
120	146.07	365.17	175.97	211.17	439.93
130	149.83	374.58	183.33	220.00	458.34
140	153.58	383.96	190.89	229.06	477.22
150	157.33	393.31	198.63	238.36	496.59
160	161.05	402.64	206.59	247.91	516.47
170	164.77	411.93	214.76	257.71	536.89
180	168.48	421.20	223.15	267.78	557.88
190	172.17	430.43	231.78	278.14	579.46
200	175.86	439.64	240.66	288.79	601.65

Self-supervision

Each input contains functionality to monitor the input measurement chain. The circuitry monitors the RTD channels continuously and reports a circuitry break of any enabled input channel. If the measured input value is outside the limits, the minimum/maximum value is shown in the corresponding output. The quality of the corresponding output is set accordingly, and the fault is reported at SENSOR_FLT to indicate misbehavior in the mA/RTD input.

Table 103: Limits for the mA/RTD inputs

mA/RTD input	Limit value
RTD temperature, high	> 200°C
RTD temperature, low	< –40°C
mA current, high	> 24 mA
mA current, low	< –24 mA
Resistance, high	> 4000 Ω
Resistance, low	Not defined [1]

When necessary, the valid measuring range may be narrower than the default of the selected measuring range. A narrower range can be defined with the *Value minimum* and *Value maximum* settings.

RTD input supervision

RTD sensor currents are measured continuously at a fixed rate. The delay between the RTD current/connectivity checks is about 10s at a maximum (if all 10 RTD channels are active). If the RTD current is not within ±5% of the expected current, the measurement is considered to be invalid, and the channel is discarded until a valid current is obtained.

The expected currents are 1 mA for RTD sensors and 0.21 mA for pure resistance. While the quality of the invalid input is set accordingly, a warning is also provided on the **Relay Status** page of LHMI/WHMI. The invalid signal is deactivated as soon as the corresponding input signal is within the valid range.

Delay for SENSOR_FLT activation depends on the connected sensor type, amount of connected channels and RTD module type. The maximum delay is 10 seconds.

mA input supervision

The current limit for mA input supervision is defined by parameter *Sensor fault level*. Value must be below *Input minimum* parameter. SENSOR_FLT is activated, and measurement quality is set bad when measured current is below set limit. The supervision is disabled if *Sensor fault level* is set to 0 mA.

3.15.3.2 Output mode

A measurement value from another function, mA input or RTD input can be represented by the mA output. The mA output scaling principle is otherwise similar

[1] Low limit is not defined for the resistance input. In practice the low limit is 0 because the resistance cannot be negative.

to the input scaling but there is also a possibility to use up to four different knee points. To be able to cover a wide range of input units, the input settings used for scaling are dimensionless. The output range of the mA output is selected with parameters *Value maximum* and *Value minimum* and the selected number of knee points with parameter *Num of knee points*. Depending on the amount of *Num of knee points*, the knee point settings *Input knee point 1-4* and *Value knee point 1-4* are visible.

Table 104: Analog output modes for the mA outputs

Output mode	Description
Not in use	Default selection when the corresponding output is not used.
–20...20 mA	Analog output can operate in the range of –20...20 mA. The output can be used in a narrower range by setting *Value minimum* and *Value maximum*.

3.15.4 Application

The general function block can be used in REX640 relays that are equipped with an RTD/analog module.

The function can be applied to various applications, for example, to measure temperature, pressure or flow.

3.15.4.1 Input scaling

Each mA/RTD input can be scaled linearly by constructing a separate scaling curve for each input. The curve consists of two points where the x-axis of the curve illustrates a range selected for the input and the y-axis is the scaled absolute value of the input. The input scaling is enabled only when mA or resistance input is used.

When the scaling is enabled, the settings *Value maximum* and *Value minimum* affect the scaled range. The range of the scaled input is defined with the settings *Input minimum* and *Input maximum*.

Scaling example 1

The function is used with a Pt100 temperature sensor. Predefined scaling can be selected when *Input mode* is set to "Pt100".

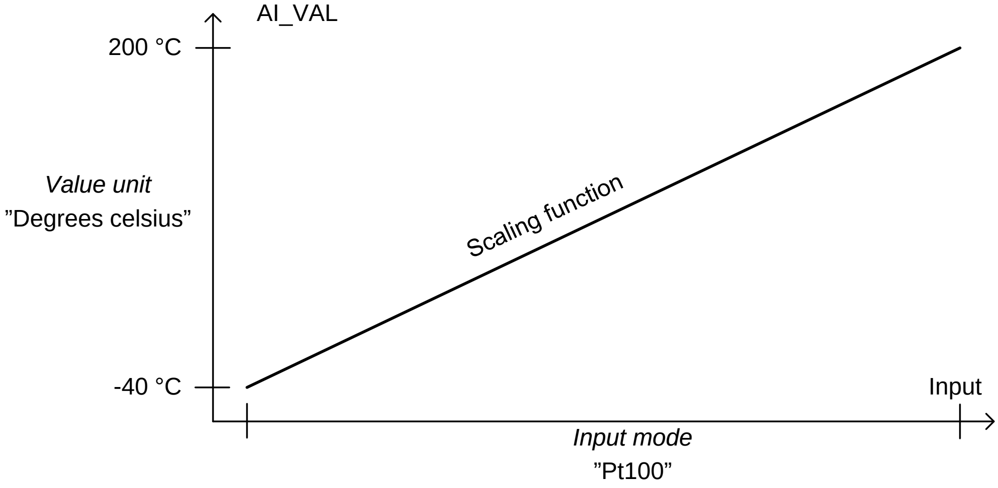


Figure 69: Pt100 scaling function

Scaling example 2

Input mode is set to –20...20 mA that is used for tap position information fed from the tap changer. The tap positions are between –36...36. Thus, the scaling setting *Value minimum* is set to "–36" and *Value maximum* is set to "36". These settings apply the input scaling to the output. In the tap position case, the *Value unit* should be set to "Dimensionless".

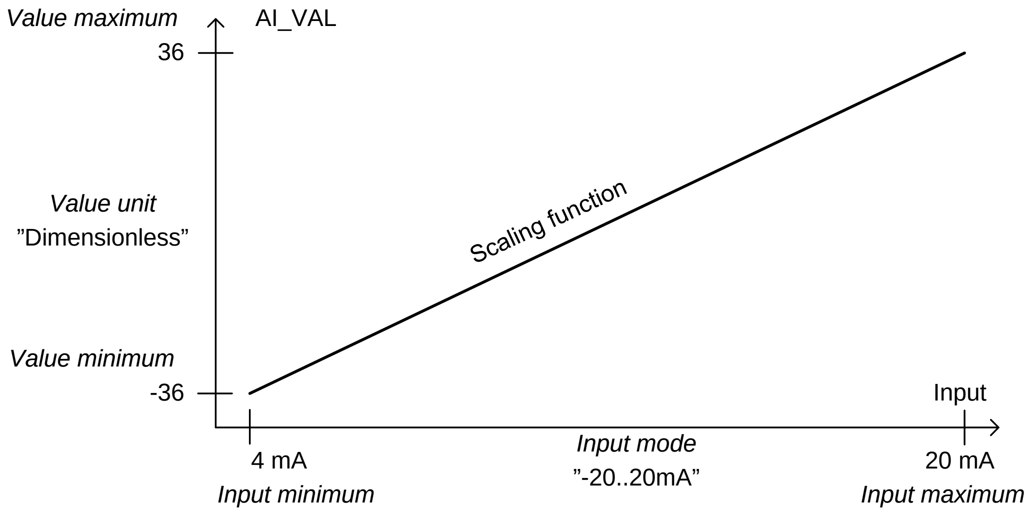


Figure 70: Tap changer position from mA input

Scaling example 3

When *Input mode* is set to "Resistance", the output can be scaled as desired. For example, the desired function output is a ratio in a function of resistance. If the input resistance varies between 100...1600 ohms, *Input minimum* is set to "100" and *Input maximum* is set to "1600". As the wanted output should be in percents, the setting *Value unit* is set to "Dimensionless". When *Input mode* is set to "Resistance", output scaling is enabled. Thus, *Value minimum* is set to "0" and *Value maximum* is set to "100". These settings allow the input values to be scaled as a ratio of the resistance range.

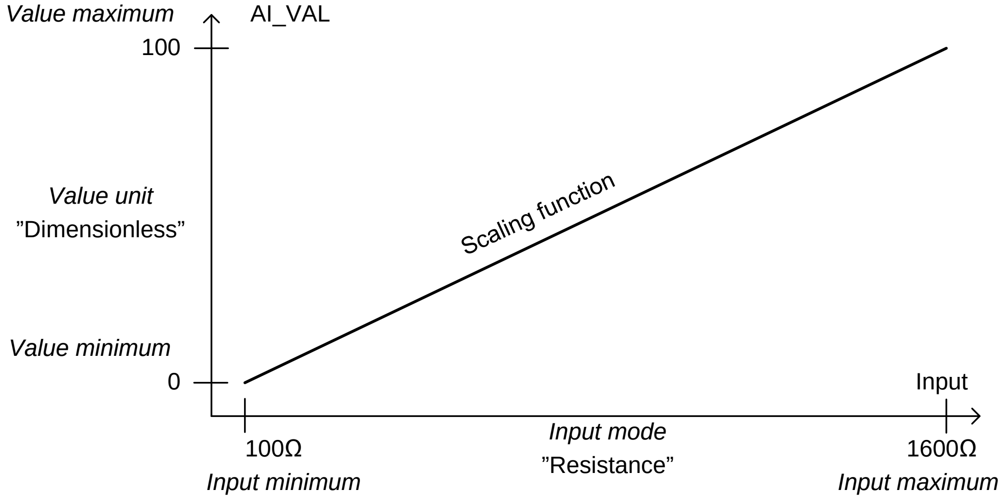


Figure 71: Output as a ratio of the resistance range

The output scaling function:

$$k = \frac{Input\ maximum - Input\ minimum}{Value\ maximum - Value\ minimum}$$

(Equation 4)

$$f = -k \cdot Value\ minimum + Input\ minimum$$

(Equation 5)

$$AI\_VAL = \frac{Input - f}{k}$$

(Equation 6)

3.15.4.2 Limit value supervision

All the measurement inputs have individual limit supervision modules that operate similarly as in the measurement functions. The measured values are compared against their set value limits. The limit supervision outputs are HIGH_ALARM, HIGH_WARN, LOW_WARN and LOW_ALARM.

When an output is scaled, *Value maximum* and *Value minimum* are the range limits to which the output value is limited or scaled. Hysteresis is added to the range limit values so that the output value is allowed to slightly exceed or go below the limit value before being treated as out of range.

The pre-defined hysteresis values are set based on the set *Value unit*.

Table 105: Pre-defined hysteresis values based on Value unit

Value unit	Hysteresis
Dimensionless	Based on the scaling function [1]
Ampere	0.1 mA

Table continues on the next page

Value unit	Hysteresis
Degrees Celsius	0.5°C
Ohm	2 Ω

$$Hysteresis \cdot \left| \frac{Value\ maximum - Value\ minimum}{Input\ maximum - Input\ minimum} \right|$$

(Equation 7)

Example

Ampere input –20…20 mA is scaled to tap position information 0...36. The actual hysteresis for limit supervision is 0.18.

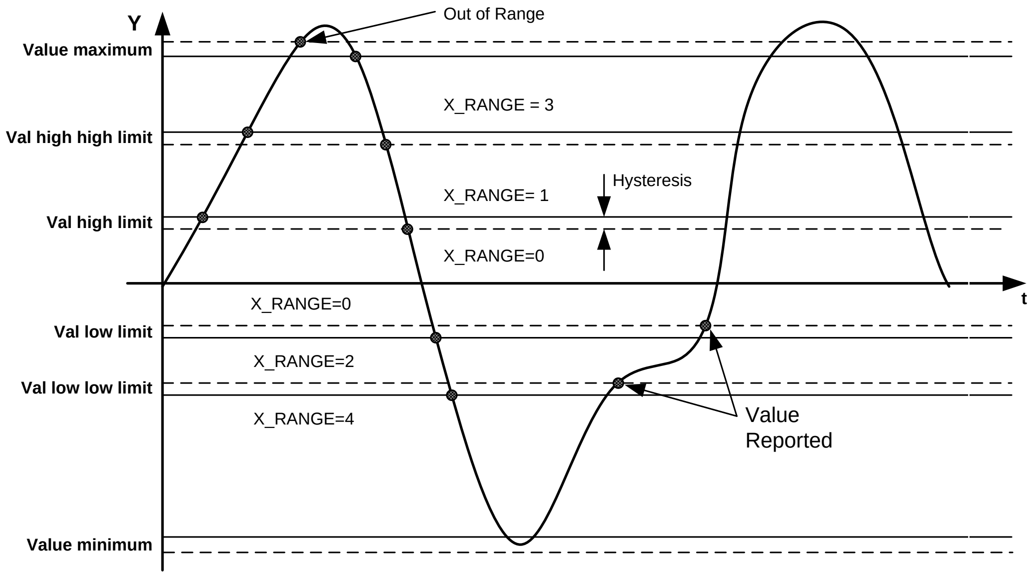


Figure 72: Limit value supervision

3.15.4.3 Deadband supervision

This is the same functionality as in measurement functions.

3.15.4.4 Output scaling

The mA outputs are scaled linearly by constructing linear scaling curves for each output.

Value maximum and *Value minimum* affect the scaled output range. The range of the scaled input is defined with the settings *Input minimum* and *Input maximum*. Depending on setting *Num of knee points*, the output can be scaled with up to five

[1] When the input is scaled to the "Dimensionless" output, the additional hysteresis is added the initial table value.

linear curves. The knee points are defined by parameters *Input knee point 1-4* and *Value knee point 1-4*.

Example 1: VMMXU1 to mA output

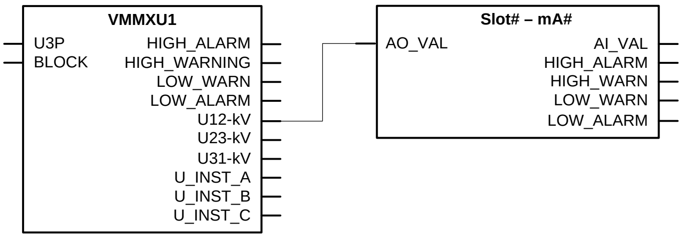


Figure 73: Application example for VMMXU1 to mA output

The measured phase-to-phase voltage from VMMXU is connected to AO_VAL. *Input maximum* value is set to "24" (kV) and *Input minimum* value is set to "18" (kV). The input unit is not significant as long as the value range is in the same scale. *Value maximum* is set to "20" mA and *Value minimum* to "4" mA. *Num of knee points* is set to "0".

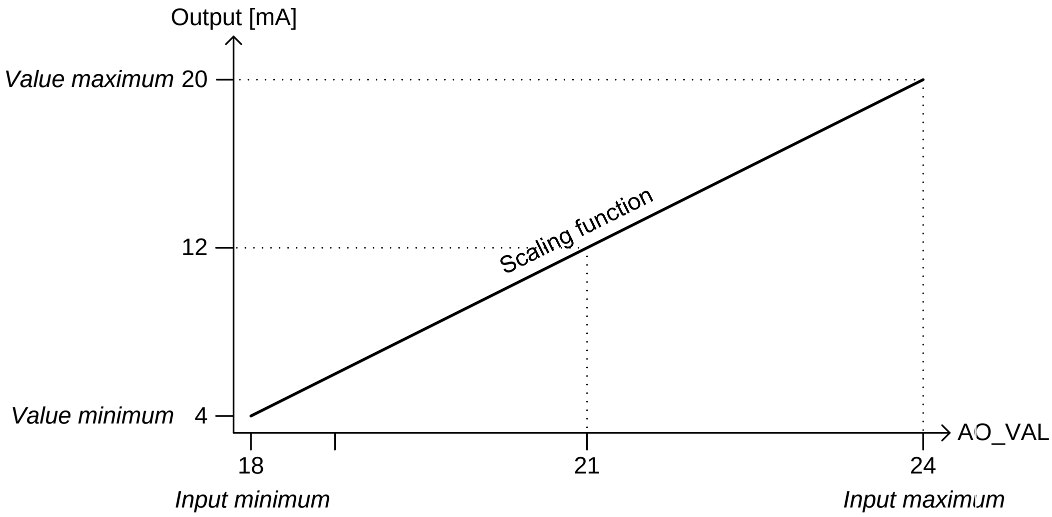


Figure 74: Scaling of AO_VAL to mA output

Example 2: mA input to mA output

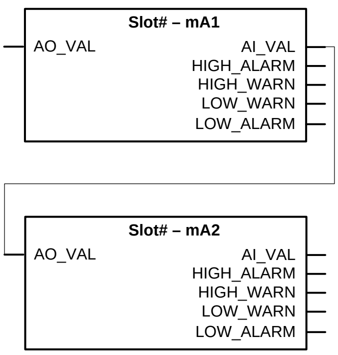


Figure 75: Application example for mA input to mA output

mA current is measured at channel 1. `AI_VAL` from measuring channel 1 is connected to `AO_VAL` of output channel 2. *Input maximum* is set to "20" (mA) and *Input minimum* to "–20" (mA). *Value maximum* is set to "20" mA and *Value minimum* is set to "0" mA. *Num of knee points* is set to "2".

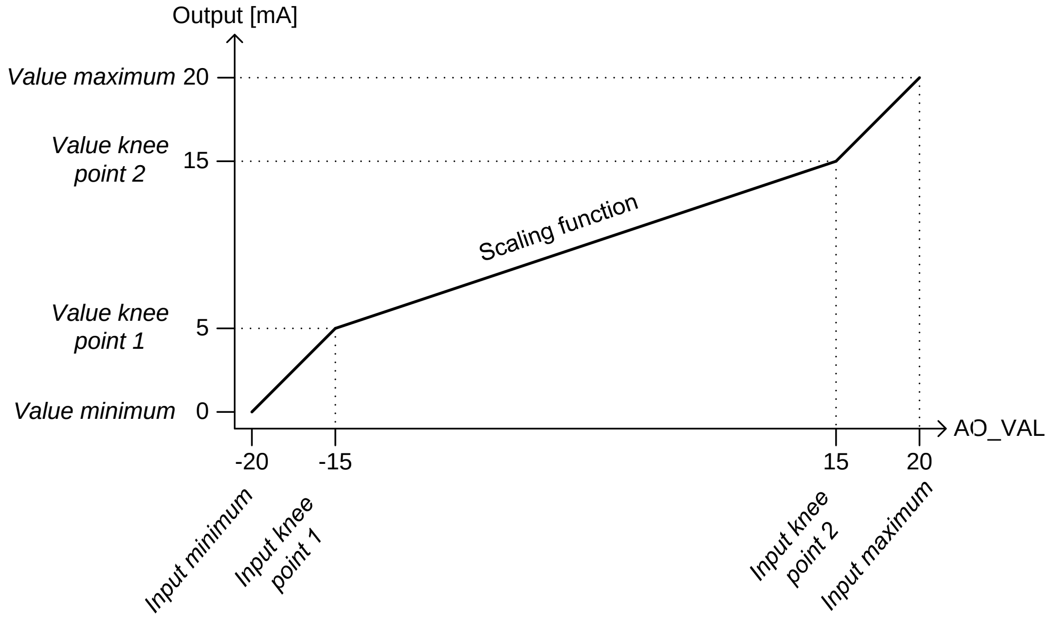


Figure 76: Scaling of AO_VAL to mA output with two knee points

Example 3: RTD input to mA output

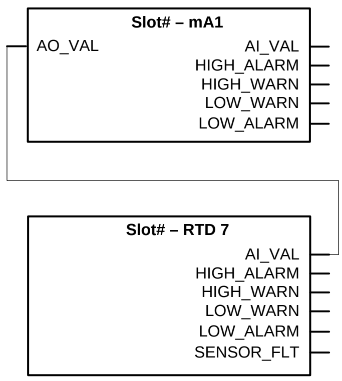


Figure 77: Application example for RTD input to mA output

Tap position is measured by the RTD channel 7. `AI_VAL` from channel 7 is connected to `AO_VAL` of channel 1. *Input maximum* is set to "160" (ohm) and *Input minimum* to "10" (ohm). *Value maximum* is set to "20" mA and *Value minimum* is set to "4" mA. *Num of knee points* is set to "4".

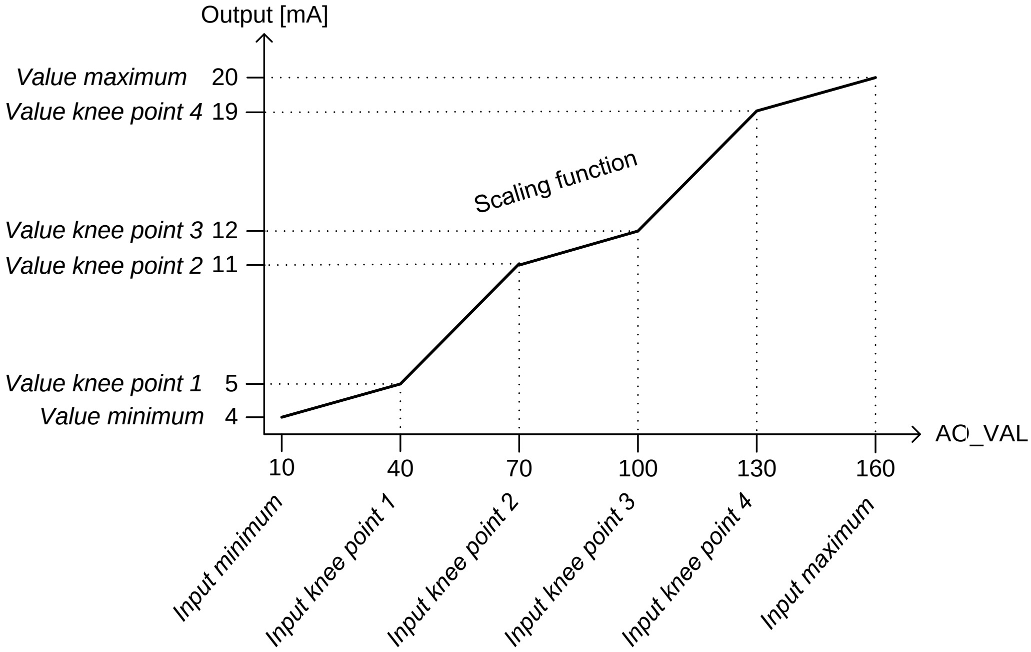


Figure 78: Scaling of AO_VAL to mA output with four knee points

Incorrect knee point values against the minimum and maximum values and a too narrow interval between the knee point values can cause inaccuracy to the output scaling function. Use increasing linearity and a value interval >1.0 for most accurate results.

3.15.5 RTD/mA input/mA output connection

RTD inputs can be used with a 2-wire or 3-wire connection with common ground. When using the 3-wire connection, it is important that all three wires connecting the sensor are symmetrical, that is, the wires are of the same type and length. Thus the wire resistance is automatically compensated.

RTD/mA card variants

The available variants of RTD cards are 10RTD/2mA and 3RTD/6mA. The features are similar in both cards.

10RTD/2mA card

This card accepts two milliampere inputs and ten inputs from the RTD sensors. The inputs `1` and `2` are used for current measurement, whereas inputs from `3` to `12` are used for resistance type of measurements.

3RTD/6mA card

This card accepts six milliampere inputs and three inputs from the RTD sensors. The inputs from `1` to `6` are used for current measurement, whereas inputs from `7` to `9` are used for resistance type of measurements.

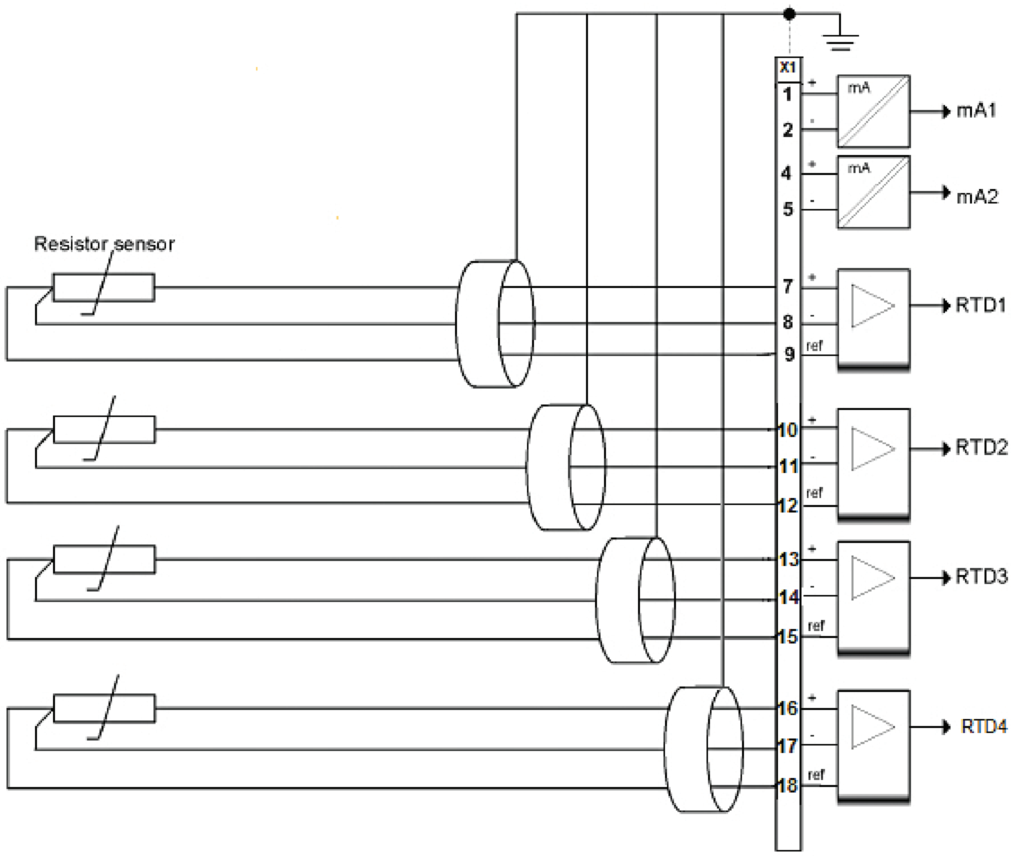


Figure 79: Four RTD/resistance sensors connected according to the 3-wire connection for 10RTD/2mA card

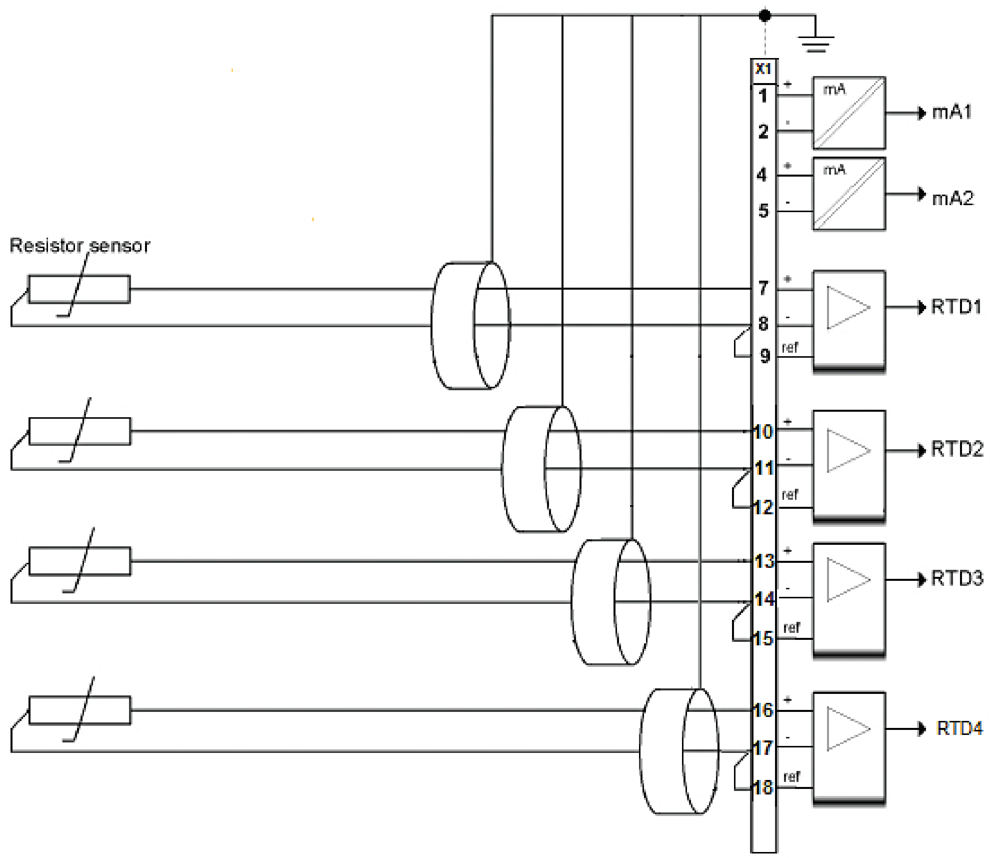


Figure 80: Four RTD/resistance sensors connected according to the 2-wire connection for 10RTD/2mA card

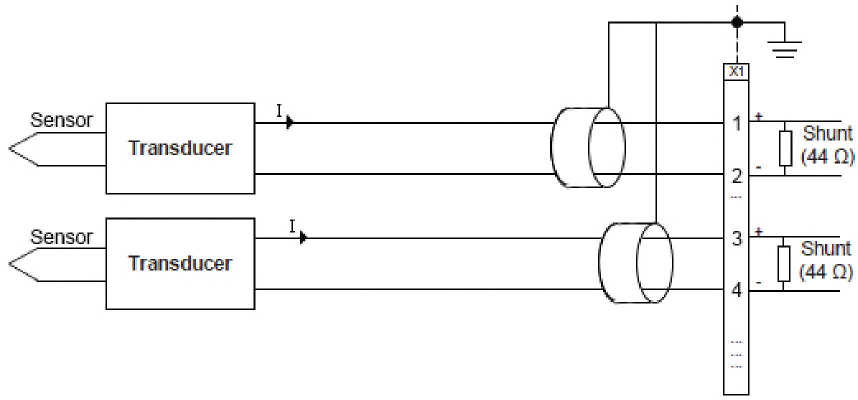


Figure 81: mA channels working as mA inputs

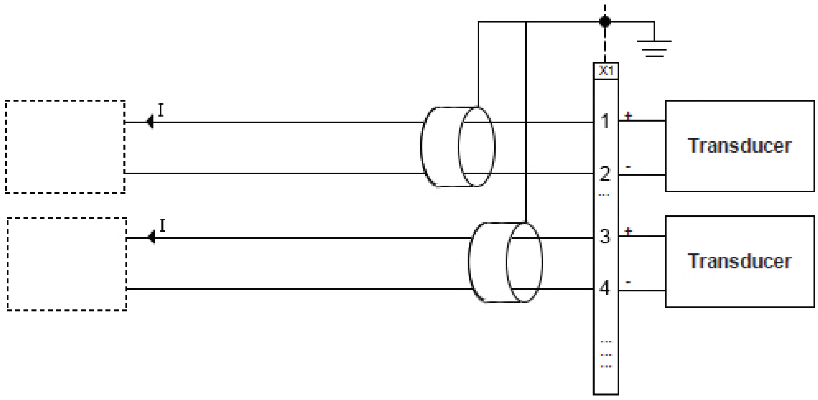


Figure 82: mA channels working as mA outputs

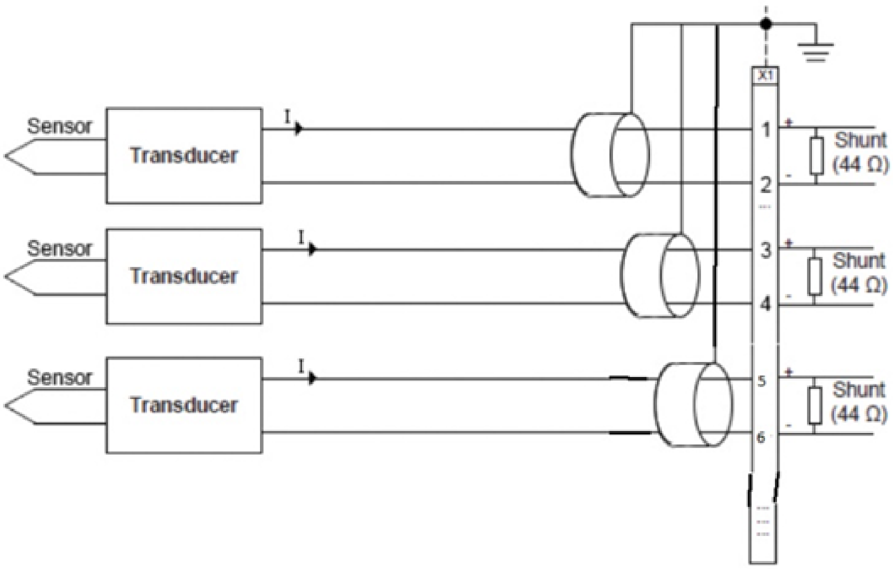


Figure 83: mA channels working as mA inputs

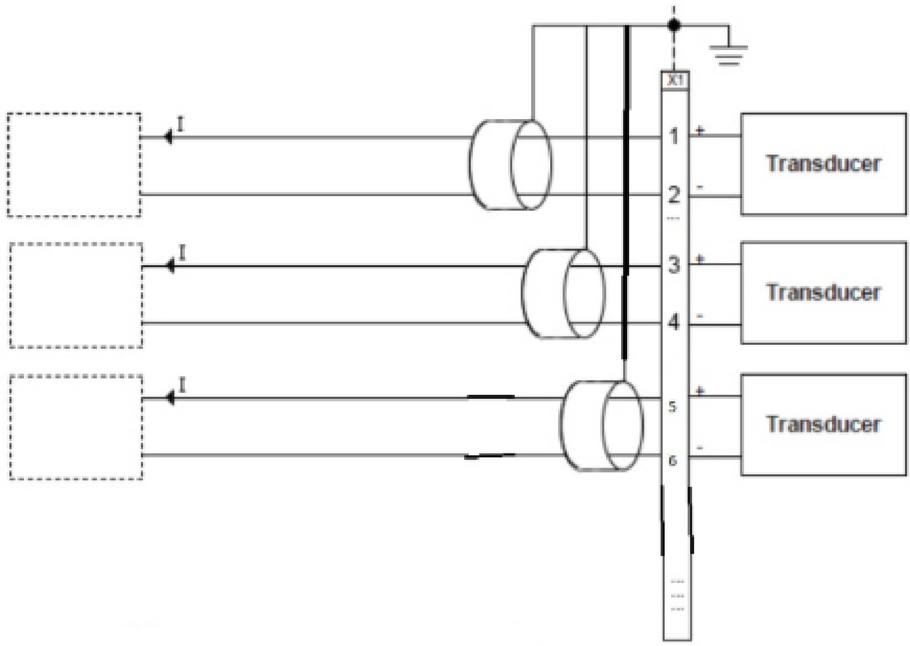


Figure 84: mA channels working as mA outputs

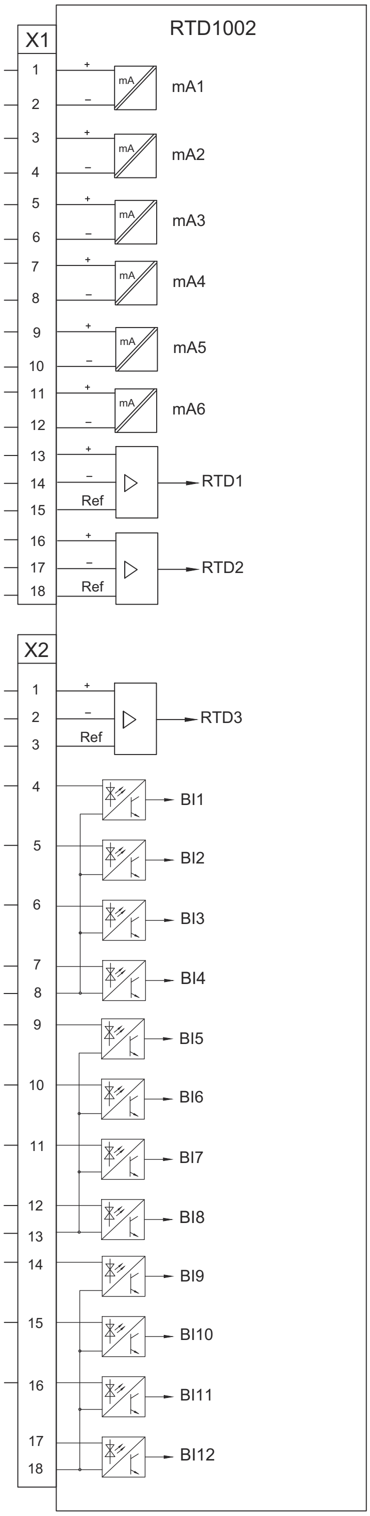


Figure 85: RTD1002 module

3.15.6 Signals

Table 106: mA Input signals

Name	Type	Default	Description
AO_VAL	FLOAT32	0	mA output, instantaneous value

Table 107: mA Output signals

Name	Type	Description
AI_VAL	FLOAT32	mA input, instantaneous value

Table 108: RTD Output signals

Name	Type	Description
AI_VAL	FLOAT32	RTD input, instantaneous value
SENSOR_FLT	BOOLEAN	Sensor fault

Table 109: Common outputs for each function block

Name	Type	Description
HIGH_ALARM	BOOLEAN	General high alarm
HIGH_WARN	BOOLEAN	General high warning
LOW_WARN	BOOLEAN	General low warning
LOW_ALARM	BOOLEAN	General low alarm

3.15.7 Settings

Table 110: Input-specific settings for mA

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 5=0..20mA			1=Not in use	Analogue input mode
Input maximum	–20...20	mA			Maximum analogue input value for mA or resistance scaling
Input minimum	–20...20	mA			Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	–10000.0...10000.0			10000	Maximum output value for scaling and supervision
Value minimum	–10000.0...10000.0			–10000	Minimum output value for scaling and supervision
Val high high limit	–10000.0...10000.0			10000	Output value high alarm limit for supervision
Value high limit	–10000.0...10000.0			10000	Output value high warning limit for supervision

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Value low limit	–10000.0...10000.0			–10000	Output value low warning limit for supervision
Value low low limit	–10000.0...10000.0			–10000	Output value low alarm limit for supervision
Value deadband	100...100000			1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)
Sensor fault level	0…3	mA		0	Below this current level sensor fault is activated

Table 111: Input-specific settings for RTD

Parameter	Values (Range)	Unit	Step	Default	Description
Input mode	1=Not in use 2=Resistance 10=Pt100 11=Pt250 20=Ni100 21=Ni120 22=Ni250 30=Cu10			1=Not in use	Analogue input mode
Input maximum	0...4000	Ω			Maximum analogue input value for mA or resistance scaling
Input minimum	0...4000	Ω			Minimum analogue input value for mA or resistance scaling
Value unit	1=Dimensionless 5=Ampere 23=Degrees celsius 30=Ohm			1=Dimensionless	Selected unit for output value format
Value maximum	–10000.0...10000.0			10000	Maximum output value for scaling and supervision
Value minimum	–10000.0...10000.0			–10000	Minimum output value for scaling and supervision
Val high high limit	–10000.0...10000.0			10000	Output value high alarm limit for supervision
Value high limit	–10000.0...10000.0			10000	Output value high warning limit for supervision
Value low limit	–10000.0...10000.0			–10000	Output value low warning limit for supervision
Value low low limit	–10000.0...10000.0			–10000	Output value low alarm limit for supervision
Value deadband	100...100000			1000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)
Update interval	0=No delay 1=10 ms 2=50 ms 3=100 ms			0	Value update interval

Table 112: Output-specific settings for mA

Parameter	Values (Range)	Unit	Step	Default	Description
Output mode	1=Not in use			1=Not in use	Analog output mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	6=0...20mA				
Num of knee points	0...4			0	Number of knee points in scaling
Input maximum	–10000.0...10000.0			10000.0	Maximum analog input value for mA scaling
Input knee point 4	–10000.0...10000.0			0.0	Input knee point value 4 for scal-ing
Input knee point 3	–10000.0...10000.0			0.0	Input knee point value 3 for scal-ing
Input knee point 2	–10000.0...10000.0			0.0	Input knee point value 2 for scal-ing
Input knee point 1	–10000.0...10000.0			0.0	Input knee point value 1 for scal-ing
Input minimum	–10000.0...10000.0			–10000.0	Minimum analog input value for mA scaling
Value maximum	–20.0...20.0	mA		20	Maximum analog output value for mA output
Value knee point 4	–20.0...20.0	mA		0	Knee point value 4 for output scaling
Value knee point 3	–20.0...20.0	mA		0	Knee point value 3 for output scaling
Value knee point 2	–20.0...20.0	mA		0	Knee point value 2 for output scaling
Value knee point 1	–20.0...20.0	mA		0	Knee point value 1 for output scaling
Value minimum	–20.0...20.0	mA		–20	Minimum analog output value for mA output

3.15.8 Monitored data

Table 113: mA Monitored data

IEC name	Type	Values (Range)	Unit	Description
AI_RANGE	Enum			mA input, range
AI_DB	FLOAT32			mA input, reported value

Table 114: RTD Monitored data

IEC name	Type	Values (Range)	Unit	Description
AI_RANGE	Enum			RTD input, range
AI_DB	FLOAT32			RTD input, reported value

3.16 SMV function blocks

SMV function blocks are used in the process bus applications with the IEC 61850-9-2 LE protocol. Function blocks represent the sending of the sampled measured values of analog currents and voltages and the receiving of the sampled values of analog currents and voltages.

3.16.1 SMV stream sender (IEC 61850-9-2LE) SMVSENDER

3.16.1.1 Function block

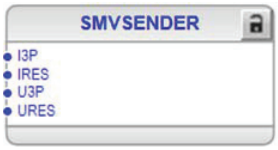


Figure 86: Function block

3.16.1.2 Functionality

The SMV stream sender (IEC 61850-9-2LE) function SMVSENDER is used for activating the SMV sending functionality. It adds/removes the sampled value control block and the related data set into/from the sending device's configuration. It has only input signals.

SMVSENDER can be disabled with the *Operation* setting value “off”. Toggling SMVSENDER “on” or “off” can be done from the LHMI. When disabled, the sending of the sample values is disabled.

3.16.1.3 Settings

Table 115: SMVSENDER Settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation

3.16.2 SMV stream receiver (IEC 61850-9-2LE) SMVRCV

3.16.2.1 Function block

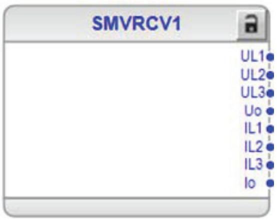


Figure 87: Function block

3.16.2.2 Functionality

The SMV stream receiver (IEC 61850-9-2LE) function SMVRCV is used for connecting SMV channels to the application.

3.16.2.3 Signals

Table 116: SMVRCV Output signals

Name	Type	Description
UL1	INT32-UL1	IEC61850-9-2 phase 1 voltage
UL2	INT32-UL2	IEC61850-9-2 phase 2 voltage
UL3	INT32-UL3	IEC61850-9-2 phase 3 voltage
U0	INT32-Uo	IEC61850-9-2 residual voltage
IL1	INT32-IL1	IEC61850-9-2 phase 1 current
IL2	INT32-IL2	IEC61850-9-2 phase 2 current
IL3	INT32-IL3	IEC61850-9-2 phase 3 current
I0	INT32-I0	IEC61850-9-2 residual current

3.17 Preprocessing blocks

3.17.1 Phase current preprocessing ILTCTR

3.17.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase current preprocessing	ILTCTR	ILTCTR	ILTCTR

3.17.1.2 Function block

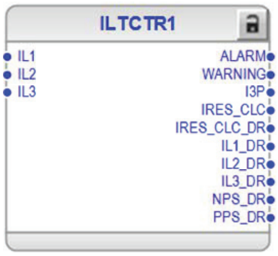


Figure 88: Function block

3.17.1.3 Functionality

The phase current preprocessing function ILTCTR is used for setting up the three phase current measurement channels. The input channels for ILTCTR are either physical hardware or IEC 61850-9-2 sampled value channels. The output `I3P` channel of ILTCTR can be connected to different applications which require 3 phase current and positive- and negative-sequence current. The output `IRES_CLC` can be connected to functions using the calculated residual current.

The current transducer selection can be made by setting *Current input type* to "Current trafo" for conventional CT or to "Current sensor" for current sensor type.

The sensor's or the CT's primary rated current can be set using *Primary current* setting. The setting *Secondary current* defines the nominal current of the CT's secondary winding. This is used as a reference to scale the measurements accordingly. These settings also affect the scaling of the calculated residual current.

Current magnitude correction of an external CT can be made using settings *Amplitude Corr A*, *Amplitude Corr B* and *Amplitude Corr C*.

Current angle correction of an external CT can be made using settings *Angle Corr A*, *Angle Corr B* and *Angle Corr C*.

Rated secondary Val setting defines the ratio for sensor use. This value multiplied by the *Rated frequency* setting (under **Configuration** > **System**) gives the sensor's nominal voltage corresponding to the sensors' primary rated current.

Reverse polarity setting is used to reverse the polarity of phase CTs.

The WARNING output in the receiver is activated if the synchronization accuracy of the sender or the receiver is worse than 4 µs. The output remains on for 10 seconds after the synchronization accuracy returns within limits.

The ALARM in the receiver is activated if the synchronization accuracy of the sender or the receiver is not within tolerances. The output is held on for 10 seconds after the synchronization accuracy returns within limits. If the effect on protection is negligible, the WARNING or ALARM output is not activated.

The *SMV Max Delay* setting defines how long the receiver waits for the SMV frames before activating the ALARM output. This setting can be accessed via **Configuration** > **System**. Waiting for the SMV frames delays the local measurements of the receiver to keep them correctly time aligned. The *SMV Max Delay* values include sampling, processing and network delay.

Frequency adaptive measurements for a three-phase current can be activated with the setting *Frequency adaptivity*. Three selections are provided.

Table 117: Frequency adaptivity setting for three-phase current measurement

Setting value	Description
Disable	Frequency adaptive measurements are disabled for this ILTCTR. Measurements are fixed to nominal frequency defined with **Configuration** > **System** > **Rated frequency**.
Enable	Frequency adaptive measurements are enabled. In this case, the estimated network frequency is defined by another preprocessing block.
Backup frequency source	Frequency adaptive measurements are enabled. If the main frequency source cannot determine the network frequency, the currents of the preprocessing block determine the network frequency.

All three phases must be always connected.

ILTCTR setting *Frequency adaptivity* is visible only if the system setting **Configuration** > **System** > **Frequency adaptivity** is set to "Enable".

3.17.1.4 Signals

ILTCTR Input signals

Table 118: ILTCTR Input signals

Name	Type	Default	Description
IL1	SIGNAL	-	Analog input
IL2	SIGNAL	-	Analog input
IL3	SIGNAL	-	Analog input

ILTCTR Output signals

Table 119: ILTCTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning
I3P	SIGNAL	Three-phase currents
IRES_CLC	SIGNAL	Residual current, calculated
IRES_CLC_DR	SIGNAL	Residual current, calculated, for disturbance recorder
IL1_DR	SIGNAL	Phase current IL1 for disturbance recorder
IL2_DR	SIGNAL	Phase current IL2 for disturbance recorder
IL3_DR	SIGNAL	Phase current IL3 for disturbance recorder
NPS_DR	SIGNAL	Negative sequence current for disturbance recorder
PPS_DR	SIGNAL	Positive sequence current for disturbance recorder

3.17.1.5 Settings

ILTCTR Settings

Table 120: ILTCTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Current input type	2=Current trafo 4=Current sensor			2=Current trafo	Type of the current input
Primary current	1.0...15000.0	A	0.1	100.0	Rated primary current
Secondary current	2=1A 3=5A			2=1A	Rated secondary current
Rated secondary Val	1.000...150.000	mV/Hz	0.001	3.000	Rated Secondary Value (RSV) ratio
Amplitude Corr A	0.9000...1.1000		0.0001	1.0000	Phase A amplitude correction factor
Amplitude Corr B	0.9000...1.1000		0.0001	1.0000	Phase B amplitude correction factor
Amplitude Corr C	0.9000...1.1000		0.0001	1.0000	Phase C amplitude correction factor
Angle Corr A	-8.0000...8.0000	deg	0.0001	0.0000	Phase A angle correction factor
Angle Corr B	-8.0000...8.0000	deg	0.0001	0.0000	Phase B angle correction factor
Angle Corr C	-8.0000...8.0000	deg	0.0001	0.0000	Phase C angle correction factor

Table 121: ILTCTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the phase CTs
Frequency adaptivity	0=Disable 1=Enable 3=Backup frequency source			0=Disable	Frequency adaptivity selection

3.17.1.6 Monitored data

Monitored data is available in three locations.

- **Monitoring** > **I/O status** > **Analog inputs**
- **Monitoring** > **IED status** > **SMV traffic**
- **Monitoring** > **IED status** > **SMV accuracy**

3.17.2 Residual current preprocessing RESTCTR

3.17.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual current preprocessing	RESTCTR	RESTCTR	RESTCTR

3.17.2.2 Function block

Figure 89: Function block

3.17.2.3 Functionality

The residual current preprocessing function RESTCTR is used for setting up the residual current measurement channels. Input channels for RESTCTR are either physical hardware or IEC 61850-9-2 sampled value channels. The output `IRES_MEAS` channel of RESTCTR can be connected to different applications which require measured residual current.

The current transducer selection can be made by setting *Current input type* to "Current trafo" for conventional CT or to "Current sensor" for current sensor type.

The residual CTs' primary rated current can be set using *Primary current* setting. The setting *Secondary current* defines the nominal current of the CT's secondary winding. This is used as a reference to scale measurements accordingly.

Residual current magnitude correction of an external CT can be made using the *Amplitude Corr* setting.

Residual current angle correction of an external CT can be made using the *Angle correction setting*.

Rated secondary Val (RSV) setting in combination with *Primary current* setting defines the ratio for sensor use. See *Chapter 3.12 Sensor inputs for currents and voltages* in this manual for further details.

Rated secondary Val should be set to same value in all RESTCTR instances which are configured to sensor measurement.

The *Reverse polarity* setting is used to reverse the polarity of the residual CT.

The WARNING output in the receiver is activated if the synchronization accuracy of the sender or the receiver is worse than 4 μs. The output is held on for 10 seconds after the synchronization accuracy returns within limits.

The ALARM in the receiver is activated if the synchronization accuracy of the sender or the receiver is not within tolerances. The output is held on for 10 seconds after the synchronization accuracy returns within limits. If the effect on protection is negligible, the WARNING or ALARM outputs are not activated.

The *SMV Max Delay* setting defines how long the receiver waits for the SMV frames before activating the ALARM output. This setting can be accessed via **Configuration** > **System**. Waiting for the SMV frames also delays the local measurements of the receiver to keep them correctly time aligned. The *SMV Max Delay* values include sampling, processing and network delay.

Frequency adaptive measurements for residual current can be activated with the setting *Frequency adaptivity*. Two selections are provided.

Table 122: Frequency adaptivity setting for residual current measurement

Setting value	Description
Disable	Frequency adaptive measurements are disabled for this RESTCTR. Measurements are fixed to nominal frequency defined with **Configuration** > **System** > **Rated frequency**.
Enable	Frequency adaptive measurements are enabled. In this case, the estimated network frequency is defined by another preprocessing block.

RESTCTR setting *Frequency adaptivity* is visible only if system setting **Configuration** > **System** > **Frequency adaptivity** is set to "Enable".

3.17.2.4 Signals

RESTCTR Input signals

Table 123: RESTCTR Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current

RESTCTR Output signals

Table 124: RESTCTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning
IRES_MEAS	SIGNAL	Residual current, measured
IRES_MEAS_DR	SIGNAL	Residual current, measured, for disturbance recorder

3.17.2.5 Settings

RESTCTR Settings

Table 125: RESTCTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Current input type	2=Current trafo 4=Current sensor			2=Current trafo	Type of the current input
Primary current	1.0...15000.0	A	0.1	100.0	Primary current
Secondary current	1=0.2A 2=1A 3=5A			2=1A	Secondary current
Rated secondary Val	1.000...150.000	mV/Hz	0.001	3.000	Rated Secondary Value (RSV) ratio
Amplitude Corr	0.9000...1.1000		0.0001	1.0000	Amplitude correction
Angle correction	-8.0000...8.0000	deg	0.0001	0.0000	Angle correction factor

Table 126: RESTCTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the residual CT
Frequency adaptivity	0=Disable 1=Enable			0=Disable	Frequency adaptivity selection

3.17.2.6 Monitored data

Monitored data is available in three locations.

- **Monitoring** > **I/O status** > **Analog inputs**
- **Monitoring** > **IED status** > **SMV traffic**
- **Monitoring** > **IED status** > **SMV accuracy**

3.17.3 Phase and residual voltage preprocessing UTVTR

3.17.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase and residual voltage preprocessing	UTVTR	UTVTR	UTVTR

3.17.3.2 Function block

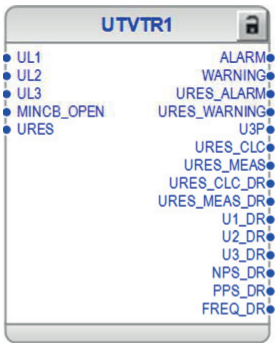


Figure 90: Function block

3.17.3.3 Functionality

The phase and residual voltage preprocessing function UTVTR is used for setting up the three phase voltage measurement channels and residual voltage measurement. The input channels for UTVTR are either physical hardware or IEC 61850-9-2 sampled value channels.

The output channel `U3P` of UTVTR can be connected to different applications which require phase voltage, positive and negative sequence.

Outputs `URES_MEAS` and `URES_CLC` can be connected to different applications which require measured residual voltage or calculated residual voltage (from phase voltages), respectively.

If only two phase-to-earth/phase-to-phase voltages are available, then the third phase-to-earth/phase-to-phase voltage can be calculated without `URES` input connected (assumed to be zero in that case). Positive- and negative-sequence components are also calculated using these voltages. The accuracy of the calculated phase-to-earth values is affected if the actual residual voltage is not zero.

If an application function requires only the frequency value, output `U3P` of UTVTR still needs to be connected since the frequency is calculated from the voltage.

The voltage transducer selection can be made by setting *Voltage input type* to "Voltage trafo" for conventional VT or to "Voltage sensor" for voltage sensor type.

The sensor's or the VTs' primary rated voltage can be set using *Primary voltage* setting. The setting *Secondary voltage* defines the nominal voltage of the VT's secondary winding. This is used as a reference to scale the measurements accordingly.

Division ratio setting defines the ratio for sensor use.

The division ratio for ABB voltage sensors is typically 10000:1. Thus, the Division ratio setting is usually set to "10000". For more information on Division ratio, see *Chapter 3.12 Sensor inputs for currents and voltages*.

The Voltage (Uo) residual voltage settings are also used for scaling the calculated residual voltage in comparison to the measured residual voltage.

The Voltage (Uo) settings must be set for output URES_MEAS and URES_CLC scaling. If the residual voltage is not connected to UTVTR, Voltage (Uo) settings must be set only for the calculated residual voltage URES_CLC scaling.

If the residual voltage is not connected to UTVTR, the **Voltage (Uo)** > **Primary voltage** cannot be set smaller than 1/√3 times **Voltage (3U)** > **Primary voltage**.

Voltage magnitude correction can be made using settings *Amplitude Corr A*, *Amplitude Corr B* and *Amplitude Corr C* for an external three-phase VT and *Amplitude Corr* setting for an external residual VT.

Voltage angle correction can be made using settings *Angle Corr A*, *Angle Corr B* and *Angle Corr C* for an external three-phase VT and *Angle correction* setting for an external residual VT.

The VT connection can be set using *VT connection*. For three phase-to-earth voltage measurements, *VT connection* can be set to "Wye", and for three phase-to-phase voltage measurements, *VT connection* can be set to "Delta".

The MINCB_OPEN input signal is connected through a relay binary input to the NC auxiliary contact of the MCB protecting the VT secondary circuit. The MINCB_OPEN signal receives information about the MCB open state. When MINCB_OPEN is active, the outputs ALARM and WARNING are activated.

The MCB open state does not affect IEC 61850-9-2 sampled value quality information.

The WARNING and URES_WARNING outputs in the receiver are activated if the synchronization accuracy of the sender or the receiver is worse than 4 µs. The outputs remain on for 10 seconds after the synchronization accuracy returns within limits.

ALARM and URES_ALARM in the receiver are activated if the synchronization accuracy of the sender or the receiver is not within tolerances. The outputs remain on for 10 seconds after the synchronization accuracy returns within limits. If the effect on protection is negligible, the WARNING, URES_WARNING, ALARM or URES_ALARM outputs are not activated.

The *SMV Max Delay* setting defines how long the receiver waits for the SMV frames before activating the ALARM and URES_ALARM outputs. This setting can be accessed via **Configuration** > **System**. Waiting for the SMV frames delays the local measurements of the receiver to keep them correctly time aligned. The *SMV Max Delay* values include sampling, processing and network delay.

Outputs WARNING and URES_WARNING are always internally active whenever outputs ALARM and URES_ALARM, respectively, are active.

The receiver activates the WARNING, URES_WARNING, ALARM and URES_ALARM outputs if any of the quality bits, except for the derived bit, is activated. When the receiver is in the test mode, it accepts SMV frames with test bit without activating the WARNING, URES_WARNING, ALARM and URES_ALARM outputs.

Frequency adaptive measurements for three-phase voltages can be activated with the setting *Frequency adaptivity*. Four selections are provided.

Table 127: Frequency adaptivity setting for three-phase voltage measurement

Setting value	Description
Disable	Frequency adaptive measurements are disabled for this UTVTR. Measurements are fixed to nominal frequency defined with **Configuration** > **System** > **Rated frequency**.
Enable	Frequency adaptive measurements are enabled. In this case, the estimated network frequency is defined by another preprocessing block.
Main frequency source	Frequency adaptive measurements are enabled and other preprocessing blocks follow the network frequency defined by this preprocessing block.
Backup frequency source	Frequency adaptive measurements are enabled. If the main frequency source cannot determine the network frequency, the voltages of this preprocessing block determine the network frequency.

All three phases must to be connected if the main or backup frequency source is selected.

Frequency adaptive measurements for residual voltage can be activated with the setting *Frequency adaptivity*. Two selections are provided.

Table 128: Frequency adaptivity setting for residual voltage measurement

Setting value	Description
Disable	Frequency adaptive measurements are disabled for this UTVTR. Measurements are fixed to nominal frequency defined with **Configuration** > **System** > **Rated frequency**.
Enable	Frequency adaptive measurements are enabled. In this case, the estimated network frequency is defined by another preprocessing block.

UTVTR setting *Frequency adaptivity* is visible only if system setting **Configuration** > **System** > **Frequency adaptivity** is set to "Enable".

3.17.3.4 Residual voltage scaling

Calculated U_0 is scaled to the same level as measured U_0. The scaling is determined by the ratio of ULTVTR primary voltage and RESTVTR primary voltage within one UTVTR instance. The assumption is open-delta U_0 measurement type.

Typical markings of an open-delta U_0 transformer in a 20 kV network can be: **20kV/ sqrt(3) :100V/sqrt(3) :100V/3**. In case of a solid earth fault, this transformer gives 100 V output which corresponds to 11.547 kV. If ULTVTR primary voltage is set to 20 kV and RESTVTR primary voltage is set to 11.547 kV when this transformer is used, URES_CLC and URES_MEAS output equal amplitude.

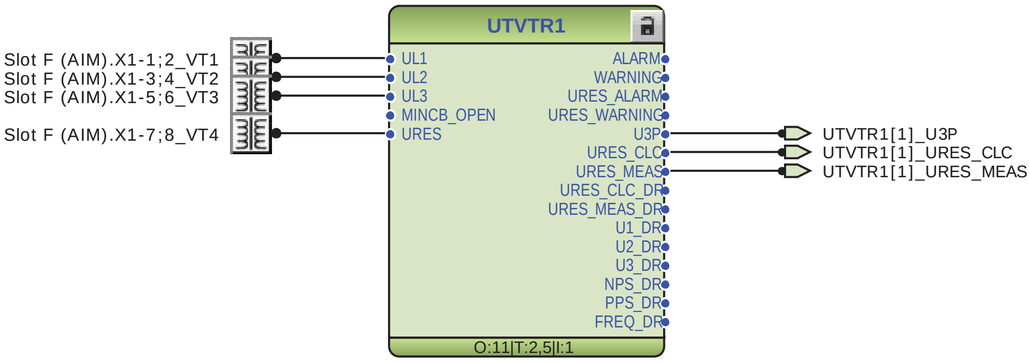


Figure 91: UTVTR1 configured with both measured and calculated U0

The VT connection mode must be "WYE".

In this case, ROVPTOV1 and ROVPTOV2 in *Figure 92* can both use the same U_0 reference level in their settings. URES_CLC and URES_MEAS in *Figure 91* are scaled to the same level.

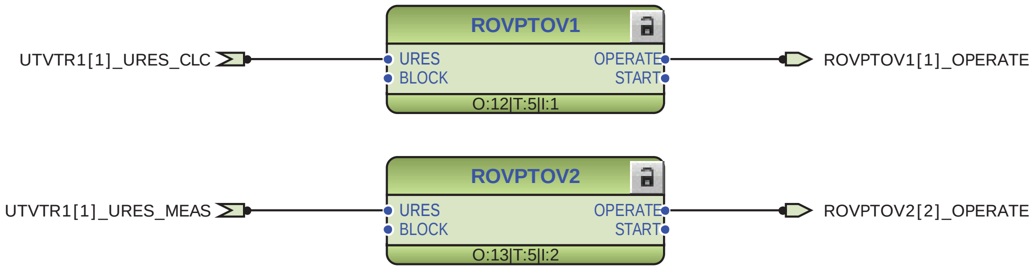


Figure 92: Two ROVPTOV instances, one using calculated U0 and the other measured U0

3.17.3.5 Signals

UTVTR Input signals

Table 129: UTVTR Input signals

Name	Type	Default	Description
UL1	SIGNAL	-	Analog input
UL2	SIGNAL	-	Analog input
UL3	SIGNAL	-	Analog input
URES	SIGNAL	-	Residual voltage
MINCB_OPEN	BOOLEAN	0=False	Active when external MCB opens protected voltage circuit

UTVTR Output signals

Table 130: UTVTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning
URES_ALARM	BOOLEAN	Alarm
URES_WARNING	BOOLEAN	Warning
U3P	SIGNAL	Three-phase voltages
URES_CLC	SIGNAL	Residual voltage, calculated
URES_MEAS	SIGNAL	Residual voltage, measured
URES_CLC_DR	SIGNAL	Residual voltage, calculated, for disturbance recorder
URES_MEAS_DR	SIGNAL	Residual voltage, measured, for disturbance recorder
U1_DR	SIGNAL	Phase voltage U1 for disturb-ance recorder
U2_DR	SIGNAL	Phase voltage U2 for disturb-ance recorder
U3_DR	SIGNAL	Phase voltage U3 for disturb-ance recorder
NPS_DR	SIGNAL	Negative sequence current for disturbance recorder
PPS_DR	SIGNAL	Positive sequence current for disturbance recorder
FREQ_DR	SIGNAL	Measured frequency for dis-turbance recorder

3.17.3.6 UTVTR Settings

Table 131: UTVTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage input type	1=Voltage trafo 3=Voltage sensor			1=Voltage trafo	Type of the voltage input
Primary voltage	0.100...800.000	kV	0.001	20.000	Primary rated phase-to-phase voltage
Secondary voltage	57...416	V	1	100	Secondary rated phase-to-phase voltage
Division ratio	1000...20000		1	10000	Voltage sensor divi-sion ratio
VT connection	1=Wye 2=Delta			2=Delta	Voltage transducer measurement con-nection
Amplitude Corr A	0.9000...1.1000		0.0001	1.0000	Phase A Voltage phasor magnitude

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					correction of an external voltage transformer
Amplitude Corr B	0.9000...1.1000		0.0001	1.0000	Phase B Voltage phasor magnitude correction of an external voltage transformer
Amplitude Corr C	0.9000...1.1000		0.0001	1.0000	Phase C Voltage phasor magnitude correction of an external voltage transformer
Angle Corr A	-8.0000...8.0000	deg	0.0001	0.0000	Phase A Voltage phasor angle correction of an external voltage transformer
Angle Corr B	-8.0000...8.0000	deg	0.0001	0.0000	Phase B Voltage phasor angle correction of an external voltage transformer
Angle Corr C	-8.0000...8.0000	deg	0.0001	0.0000	Phase C Voltage phasor angle correction of an external voltage transformer

Table 132: UTVTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Frequency adaptivity	0=Disable 1=Enable 2=Main frequency source 3=Backup frequency source			0=Disable	Frequency adaptivity selection

Table 133: UTVTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...800.000	kV	0.001	11.547	Primary voltage
Secondary voltage	57...240	V	1	100	Secondary voltage
Amplitude Corr	0.9000...1.1000		0.0001	1.0000	Amplitude correction
Angle correction	-8.0000...8.0000	deg	0.0001	0.0000	Angle correction factor

Table 134: UTVTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Frequency adaptivity	0=Disable 1=Enable			0=Disable	Frequency adaptivity selection

3.17.4 Residual current preprocessing, current measured as voltage RESUTCTR

3.17.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
Residual current preprocessing, current measured as voltage	RESUTCTR	Io(U)	Io(U)

3.17.4.2 Function block

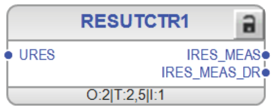


Figure 93: Function block

3.17.4.3 Functionality

The preprocessing block RESUTCTR is used for setting up the residual current measurement when the current is measured as voltage and the measured signal is wired via VT channel.

Input channel for RESUTCTR can be physical hardware voltage channel only.

The output *IRES_MEAS* channel of the RESUTCTR can be connected to only GSLPTOC which optionally can use this special way of current measurement.

The residual primary rated current can be set using *Primary current* setting. The setting *Secondary voltage* defines the nominal voltage of the measuring arrangement. This is used as a reference to scale the measurements accordingly.

Residual current magnitude correction of an external measuring arrangement can be made using *Amplitude Corr* setting.

Residual current angle correction of an external measuring arrangement can be made using *Angle Correction* setting.

Reverse polarity setting is used to reverse the polarity of residual CT.

Purpose of the outputs `IRES_MEAS` and `IRES_MEAS_DR` are described in the Outputs table.

Frequency adaptivity functionality is enabled by first enabling the main *Frequency adaptivity* setting under System parameter settings (**Configuration** > **System** > **Frequency adaptivity**), then by setting RESUTCTR *Frequency adaptivity* mode to “Enable”.

3.17.4.4 Signals

RESUTCTR Input signals

Table 135: RESUTCTR Input signals

Name	Type	Default	Description
URES	SIGNAL	-	Residual voltage

RESUTCTR Output signals

Table 136: RESUTCTR Output signals

Name	Type	Description
IRES_MEAS	SIGNAL	Residual current, measured
IRES_MEAS_DR	SIGNAL	Residual current, measured, for disturbance recorder

3.17.4.5 RESUTCTR Settings

Table 137: RESUTCTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Primary current	1.0...15000.0	A	0.1	100.0	Primary current
Secondary voltage	4...240		1	10	Secondary voltage
Amplitude Corr	0.9000...1.1000		0.0001	1.0000	Amplitude correction
Angle correction	-8.0000...8.0000	deg	0.0001	0.0000	Angle correction factor

Table 138: RESUTCTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the residual measurement
Frequency adaptivity	0=Disable 1=Enable			0=Disable	Frequency adaptivity selection

3.18 GOOSE function blocks

GOOSE function blocks are used for connecting incoming GOOSE data to application. They support BOOLEAN, Dbpos, Enum, FLOAT32, INT8 and INT32 data types.

Common signals

The VALID output indicates the validity of received GOOSE data, which means in case of valid, that the GOOSE communication is working and received data quality bits (if configured) indicate good process data. Invalid status is caused either by bad data quality bits or GOOSE communication failure. See IEC 61850 engineering guide for details.

The OUT output passes the received GOOSE value for the application. Default value (0) is used if VALID output indicates invalid status. The IN input is defined in the GOOSE configuration and can always be seen in SMT sheet.

Settings

The GOOSE function blocks do not have any parameters available in LHMI or PCM600.

3.18.1 Received GOOSE binary information GOOSERCV_BIN

3.18.1.1 Function block

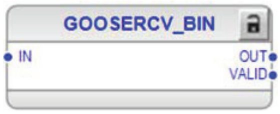


Figure 94: Function block

3.18.1.2 Functionality

The received GOOSE binary information function GOOSERCV_BIN is used to connect the GOOSE binary inputs to the application.

3.18.1.3 Signals

Table 139: GOOSERCV_BIN Input signals

Name	Type	Default	Description
IN	BOOLEAN	0	Input signal

Table 140: GOOSERCV_BIN Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
VALID	BOOLEAN	Output signal

3.18.2 Received GOOSE double binary information GOOSERCV_DP

3.18.2.1 Function block

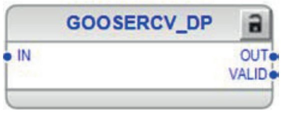


Figure 95: Function block

3.18.2.2 Functionality

The received GOOSE double binary information function GOOSERCV_DP is used to connect the GOOSE double binary inputs to the application.

3.18.2.3 Signals

Table 141: GOOSERCV_DP Input signals

Name	Type	Default	Description
IN	Dbpos	00	Input signal

Table 142: GOOSERCV_DP Output signals

Name	Type	Description
OUT	Dbpos	Output signal
VALID	BOOLEAN	Output signal

3.18.3 Received GOOSE measured value information GOOSERCV_MV

3.18.3.1 Function block

Figure 96: Function block

3.18.3.2 Functionality

The received GOOSE measured value information function GOOSERCV_MV is used to connect the GOOSE measured value inputs to the application.

3.18.3.3 Signals

Table 143: GOOSERCV_MV Input signals

Name	Type	Default	Description
IN	FLOAT32	0	Input signal

Table 144: GOOSERCV_MV Output signals

Name	Type	Description
OUT	FLOAT32	Output signal
VALID	BOOLEAN	Output signal

3.18.4 Received GOOSE 8-bit integer value information GOOSERCV_INT8

3.18.4.1 Function block

Figure 97: Function block

3.18.4.2 Functionality

The received GOOSE 8-bit integer value information function GOOSERCV_INT8 is used to connect the GOOSE 8-bit integer inputs to the application.

3.18.4.3 Signals

Table 145: GOOSERCV_INT8 Input signals

Name	Type	Default	Description
IN	INT8	0	Input signal

Table 146: GOOSERCV_INT8 Output signals

Name	Type	Description
OUT	INT8	Output signal
VALID	BOOLEAN	Output signal

3.18.5 Received GOOSE 32-bit integer value information GOOSERCV_INT32

3.18.5.1 Function block

Figure 98: Function block

3.18.5.2 Functionality

The received GOOSE 32-bit integer value information function GOOSERCV_INT32 is used to connect GOOSE 32-bit integer inputs to the application.

3.18.5.3 Signals

Table 147: GOOSERCV_INT32 Input signals

Name	Type	Default	Description
IN	INT32	0	Input signal

Table 148: GOOSERCV_INT32 Output signals

Name	Type	Description
OUT	INT32	Output signal
VALID	BOOLEAN	Output signal

3.18.6 Received GOOSE interlocking information GOOSERCV_INTL

3.18.6.1 Function block

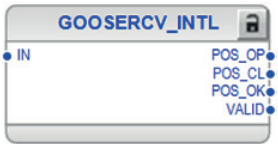


Figure 99: Function block

3.18.6.2 Functionality

The received GOOSE interlocking information function GOOSERCV_INTL is used to connect the GOOSE double binary input to the application and extracting single binary position signals from the double binary position signal.

The `OP` output signal indicates that the position is open. Default value (0) is used if `VALID` output indicates invalid status.

The `CL` output signal indicates that the position is closed. Default value (0) is used if `VALID` output indicates invalid status.

The `OK` output signal indicates that the position is neither in faulty or intermediate state. The default value (0) is used if `VALID` output indicates invalid status.

3.18.6.3 Signals

Table 149: GOOSERCV_INTL Input signals

Name	Type	Default	Description
IN	Dbpos	0	Input signal

Table 150: GOOSERCV_INTL Output signals

Name	Type	Description
OP	BOOLEAN	Position open output signal
CL	BOOLEAN	Position closed output signal
OK	BOOLEAN	Position OK output signal
VALID	BOOLEAN	Output signal

3.18.7 Received GOOSE measured value (phasor) information GOOSERCV_CMV

3.18.7.1 Function block

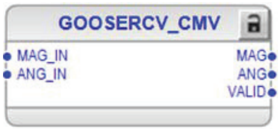


Figure 100: Function block

3.18.7.2 Functionality

The received GOOSE measured value (phasor) information function GOOSERCV_CMV is used to connect GOOSE measured value inputs to the application. The MAG_IN(amplitude) and ANG_IN (angle) inputs are defined in the GOOSE configuration (PCM600).

The MAG output passes the received GOOSE amplitude and ANG the received angle value for the application.

3.18.7.3 Signals

Table 151: GOOSERCV_CMV Input signals

Name	Type	Default	Description
MAG_IN	FLOAT32	0	Input signal (ampli-tude)
ANG_IN	FLOAT32	0	Input signal (angle)

Table 152: GOOSERCV_CMV Output signals

Name	Type	Description
MAG	FLOAT32	Output signal (amplitude)
ANG	FLOAT32	Output signal (angle)
VALID	BOOLEAN	Output signal

3.18.8 Received GOOSE enumerator value information GOOSERCV_ENUM

3.18.8.1 Function block

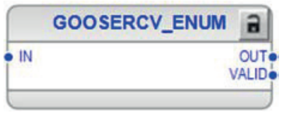


Figure 101: Function block

3.18.8.2 Functionality

The received GOOSE enumerator value information function GOOSERCV_ENUM is used to connect GOOSE enumerator inputs to the application.

3.18.8.3 Signals

Table 153: GOOSERCV_ENUM Input signals

Name	Type	Default	Description
IN	Enum	0	Input signal

Table 154: GOOSERCV_ENUM Output signals

Name	Type	Description
OUT	Enum	Output signal
VALID	BOOLEAN	Output signal

3.19 Type conversion function blocks

3.19.1 Good signal quality QTY_GOOD

3.19.1.1 Function block

Figure 102: Function block

3.19.1.2 Functionality

The good signal quality function QTY_GOOD evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The IN input can be connected to any logic application signal (except preprocessing block). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The OUT output indicates quality good of the input signal. Input signals that have no quality bits set or only test bit is set, will indicate quality good status.

3.19.1.3 Signals

Table 155: QTY_GOOD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 156: QTY_GOOD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.19.2 Bad signal quality QTY_BAD

3.19.2.1 Function block

Figure 103: Function block

3.19.2.2 Functionality

The bad signal quality function QTY_BAD evaluates the quality bits of the input signal and passes it as a Boolean signal for the application.

The IN input can be connected to any logic application signal (except preprocessing block). Due to application logic quality bit propagation, each (simple and even combined) signal has quality which can be evaluated.

The OUT output indicates quality bad of the input signal. Input signals that have any other than test bit set, will indicate quality bad status.

3.19.2.3 Signals

Table 157: QTY_BAD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 158: QTY_BAD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.19.3 Received GOOSE test mode QTY_GOOSE_TEST

3.19.3.1 Function block

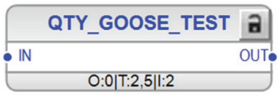


Figure 104: Function block

3.19.3.2 Functionality

The GOOSE test mode function QTY_GOOSE_TEST determines whether test mode is used between two relays communicating over GOOSE. The conditions needed for enabling the test mode differ in both editions 1 and 2 of the IEC 61850 standard. For more information, see the IEC 61850 engineering guide.

The `IN` input can be connected to any GOOSE application logic output signal, for example, GOOSERCV_BIN.

The `OUT` output indicates the test mode status of the GOOSE function block. When the output is in the true (1) state, the GOOSE test mode is active. The value false (0) indicates that the test mode is not in use.

3.19.3.3 Signals

Table 159: QTY_GOOSE_TEST Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 160: QTY_GOOSE_TEST Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.19.4 GOOSE communication quality QTY_GOOSE_COMM

3.19.4.1 Function block

Figure 105: Function block

3.19.4.2 Functionality

The GOOSE communication quality function QTY_GOOSE_COMM evaluates the peer device communication status from the quality bits of the input signal and passes it as a Boolean signal to the application.

The `IN` input can be connected to any GOOSE application logic output signal, for example, GOOSERCV_BIN.

The `COMMVALID` output indicates the communication status of the GOOSE function block. When the output is in the true (1) state, the GOOSE communication is active. The value false (0) indicates communication timeout.

3.19.4.3 Signals

Table 161: QTY_GOOSE_COMM Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 162: QTY_GOOSE_COMM Output signals

Name	Type	Description
COMMVALID	BOOLEAN	Output signal

3.19.5 GOOSE data health T_HEALTH

3.19.5.1 Function block

Figure 106: Function block

3.19.5.2 Functionality

The GOOSE data health function T_HEALTH evaluates enumerated data of “Health” data attribute. This function block can only be used with GOOSE.

The IN input can be connected to GOOSERCV_ENUM function block, which is receiving the LD0.LLN0.Health.stVal data attribute sent by another device.

The outputs OK, WARNING and ALARM are extracted from the enumerated input value. Only one of the outputs can be active at a time. In case the GOOSERCV_ENUM function block does not receive the value from the sending device or it is invalid, the default value (0) is used and the ALARM is activated in the T_HEALTH function block.

3.19.5.3 Signals

Table 163: T_HEALTH Input signals

Name	Type	Default	Description
IN1	Any	0	Input signal

Table 164: T_HEALTH Output signals

Name	Type	Description
OK	BOOLEAN	Output signal
WARNING	BOOLEAN	Output signal
ALARM	BOOLEAN	Output signal

3.19.6 Fault direction evaluation T_DIR

3.19.6.1 Function block

Figure 107: Function block

3.19.6.2 Functionality

The fault direction evaluation function T_DIR evaluates enumerated data of the FAULT_DIR and DIRECTION data attributes of the directional functions.

The outputs FWD and REV are extracted from the enumerated input value.

3.19.6.3 Signals

Table 165: T_DIR Input signals

Name	Type	Default	Description
DIR	Enum	0	Input signal

Table 166: T_DIR Output signals

Name	Type	Description
FWD	BOOLEAN	Direction forward
REV	BOOLEAN	Direction backward

3.19.7 Fault direction evaluation T_DIR_FWD

3.19.7.1 Function block

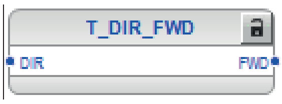


Figure 108: Function block

3.19.7.2 Functionality

The fault direction evaluation function T_DIR_FWD evaluates enumerated data of the FAULT_DIR and DIRECTION data attributes of the directional functions.

The output `FWD` is extracted from the enumerated input value.

3.19.7.3 Signals

Table 167: T_DIR_FWD Input signals

Name	Type	Default	Description
DIR	Enum	0	Input signal

Table 168: T_DIR_FWD Output signals

Name	Type	Description
FWD	BOOLEAN	Direction forward

3.19.8 Fault direction evaluation T_DIR_REV

3.19.8.1 Function block

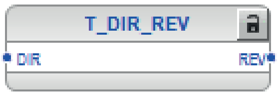


Figure 109: Function block

3.19.8.2 Functionality

The fault direction evaluation function T_DIR_REV evaluates enumerated data of the FAULT_DIR and DIRECTION data attributes of the directional functions.

The output REV is extracted from the enumerated input value.

3.19.8.3 Signals

Table 169: T_DIR_REV Input signals

Name	Type	Default	Description
DIR	Enum	0	Input signal

Table 170: T_DIR_REV Output signals

Name	Type	Description
REV	BOOLEAN	Direction backward

3.19.9 Enumerator to boolean conversion T_TCMD

3.19.9.1 Function block

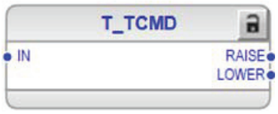


Figure 110: Function block

3.19.9.2 Functionality

The enumerator to boolean conversion function T_TCMD is used to convert enumerated input signals to boolean output signals.

Table 171: Conversion from enumerated to Boolean

IN	RAISE	LOWER
0	FALSE	FALSE
1	FALSE	TRUE
2	TRUE	FALSE
x	FALSE	FALSE

3.19.9.3 Signals

Table 172: T_TCMD input signals

Name	Type	Default	Description
IN	Enum	0	Input signal

Table 173: T_TCMD output signals

Name	Type	Description
RAISE	BOOLEAN	Raise command
LOWER	BOOLEAN	Lower command

3.19.10 32-bit integer to binary command conversion T_TCMD_BIN

3.19.10.1 Function block

Figure 111: Function block

3.19.10.2 Functionality

The 32-bit integer to binary command conversion function T_TCMD_BIN is used to convert 32 bit integer input signal to boolean output signals.

Table 174: Conversion from integer to Boolean

IN	RAISE	LOWER
0	FALSE	FALSE
1	FALSE	TRUE
2	TRUE	FALSE
x	FALSE	FALSE

3.19.10.3 Signals

Table 175: T_TCMD_BIN input signals

Name	Type	Default	Description
IN	INT32	0	Input signal

Table 176: T_TCMD_BIN output signals

Name	Type	Description
RAISE	BOOLEAN	Raise command
LOWER	BOOLEAN	Lower command

3.19.11 Binary command to 32-bit integer conversion T_BIN_TCMD

3.19.11.1 Function block

Figure 112: Function block

3.19.11.2 Functionality

The binary command to 32-bit integer conversion function T_BIN_TCMD is used to convert boolean input signals to 32 bit integer output signals.

Table 177: Conversion from Boolean to integer

RAISE	LOWER	OUT
FALSE	FALSE	0
FALSE	TRUE	1
TRUE	FALSE	2

3.19.11.3 Signals

Table 178: T_BIN_TCMD input signals

Name	Type	Default	Description
RAISE	BOOLEAN	0	Raise command
LOWER	BOOLEAN	0	Lower command

Table 179: T_BIN_TCMD output signals

Name	Type	Description
OUT	INT32	Output signal

3.19.12 Integer 32-bit to real conversion T_I32_TO_R

3.19.12.1 Function block

Figure 113: Function block

3.19.12.2 Functionality

The integer 32-bit to real conversion function T_I32_TO_R converts a 32-bit integer to a real value. The output quality follows the input quality information.

If the integer value is greater than 2097151, then the real value is set to 2097151 and the output quality is set as bad. If the integer value is less than –2097152, then the real value is set to -2097152 and the output quality is set as bad.

3.19.12.3 Signals

Table 180: T_I32_TO_R Input signals

Name	Type	Default	Description
INT32_IN	INT32	0	Integer input value

Table 181: T_I32_TO_R Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real output value

3.19.13 Real to integer 8-bit conversion T_R_TO_I8

3.19.13.1 Function block

Figure 114: Function block

3.19.13.2 Functionality

The real to integer 8-bit conversion function T_R_TO_I8 converts a real to an integer 8-bit value. The real value is floored to integer value. The output quality follows the input quality information.

If the real value is 10.6, 10.5, 10.4, –10.6, –10.5, –10.4, the integer value is converted to 10, 10, 10, –11, –11, –11, respectively.

3.19.13.3 Signals

Table 182: T_R_TO_I8 Input signals

Name	Type	Default	Description
REAL_IN	FLOAT32	0	Real input value

Table 183: T_R_TO_I8 Output signals

Name	Type	Description
INT8_OUT	INT8	Integer output value

3.19.14 Real to integer 32-bit conversion T_R_TO_I32

3.19.14.1 Function block

Figure 115: Function block

3.19.14.2 Functionality

The real to integer 32-bit conversion function T_R_TO_I32 converts a real to an integer 32-bit value. The real value is floored to integer value. The output quality follows the input quality information.

If the real value is 10.6, 10.5, 10.4, –10.6, –10.5, –10.4, the integer value is converted to 10, 10, 10, –11, –11, –11, respectively.

3.19.14.3 Signals

Table 184: T_R_TO_I32 Input signals

Name	Type	Default	Description
REAL_IN	FLOAT32	0	Real input value

Table 185: T_R_TO_I32 Output signals

Name	Type	Description
INT32_OUT	INT32	Integer output value

3.19.15 Integer 32-bit switch selector SWITCHI32

3.19.15.1 Function block

Figure 116: Function block

3.19.15.2 Functionality

The integer 32-bit switch selector function SWITCHI32 is operated by the `CTL_SW` input, which selects the output value `INT32_OUT` between the `INT32_IN1` and `INT32_IN2` inputs.

Table 186: SWITCHI32

CTL_SW value	INT_OUT value
FALSE (0)	INT32_IN1
TRUE (1)	INT32_IN2

3.19.15.3 Signals

Table 187: SWITCHI32 Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	0	Control Switch
INT_IN1	INT32	0	Integer input value 1
INT_IN2	INT32	0	Integer input value 2

Table 188: SWITCHI32 Output signals

Name	Type	Description
INT_OUT	INT32	Integer switch output

3.19.16 Integer 32-bit to boolean conversion T_I32_TO_B16

3.19.16.1 Function block

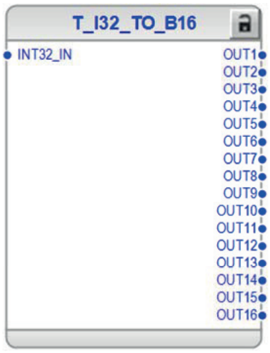


Figure 117: Function block

3.19.16.2 Functionality

The integer 32-bit to boolean conversion function T_I32_TO_B16 is used to transform an integer input `INT32_IN` into a set of 16 binary (logical) signals `OUT1…OUT16`. T_I32_TO_B16 is designed for receiving the integer input locally.

Conversion is done for the lowest 16 bits only. If `INT32_IN` is higher than 65535 (2^{16}–1), the higher bits are ignored in conversion.

3.19.16.3 Signals

Table 189: T_I32_TO_B16 Input signals

Name	Type	Default	Description
INT32_IN	INT32	0	Integer input value

Table 190: T_I32_TO_B16 Output signals

Name	Type	Description
OUT1	BOOLEAN	Boolean output value 1
OUT2	BOOLEAN	Boolean output value 2
OUT3	BOOLEAN	Boolean output value 3
OUT4	BOOLEAN	Boolean output value 4
OUT5	BOOLEAN	Boolean output value 5
OUT6	BOOLEAN	Boolean output value 6
OUT7	BOOLEAN	Boolean output value 7
OUT8	BOOLEAN	Boolean output value 8
OUT9	BOOLEAN	Boolean output value 9

Table continues on the next page

Name	Type	Description
OUT10	BOOLEAN	Boolean output value 10
OUT11	BOOLEAN	Boolean output value 11
OUT12	BOOLEAN	Boolean output value 12
OUT13	BOOLEAN	Boolean output value 13
OUT14	BOOLEAN	Boolean output value 14
OUT15	BOOLEAN	Boolean output value 15
OUT16	BOOLEAN	Boolean output value 16

3.19.17 Boolean to integer 32-bit conversion T_B16_TO_I32

3.19.17.1 Function block

Figure 118: Function block

3.19.17.2 Functionality

The boolean to integer 32-bit conversion function T_B16_TO_I32 is used to transform a set of 16 binary (logical) signals `IN1...IN16` into an integer 32-bit output `INT32_OUT` value.

3.19.17.3 Signals

Table 191: T_B16_TO_I32 Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0 (FALSE)	Boolean input value 1
IN2	BOOLEAN	0 (FALSE)	Boolean input value 2
IN3	BOOLEAN	0 (FALSE)	Boolean input value 3
IN4	BOOLEAN	0 (FALSE)	Boolean input value 4
IN5	BOOLEAN	0 (FALSE)	Boolean input value 5
IN6	BOOLEAN	0 (FALSE)	Boolean input value 6
IN7	BOOLEAN	0 (FALSE)	Boolean input value 7

Table continues on the next page

Name	Type	Default	Description
IN8	BOOLEAN	0 (FALSE)	Boolean input value 8
IN9	BOOLEAN	0 (FALSE)	Boolean input value 9
IN10	BOOLEAN	0 (FALSE)	Boolean input value 10
IN11	BOOLEAN	0 (FALSE)	Boolean input value 11
IN12	BOOLEAN	0 (FALSE)	Boolean input value 12
IN13	BOOLEAN	0 (FALSE)	Boolean input value 13
IN14	BOOLEAN	0 (FALSE)	Boolean input value 14
IN15	BOOLEAN	0 (FALSE)	Boolean input value 15
IN16	BOOLEAN	0 (FALSE)	Boolean input value 16

Table 192: T_B16_TO_I32 Output signals

Name	Type	Description
INT32_OUT	INT32	Integer output value

3.19.18 Integer 8-bit to integer 32-bit conversion T_I8_TO_I32

3.19.18.1 Function block

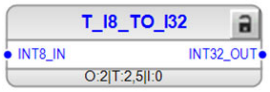


Figure 119: Function block

3.19.18.2 Functionality

The integer 8-bit to integer 32-bit conversion function T_I8_TO_I32 converts a 8-bit integer value to a 32-bit integer value. The output quality follows the input quality information.

3.19.18.3 Signals

Table 193: T_I8_TO_I32 Input signals

Name	Type	Default	Description
INT8_IN	INT8	0	Integer input value

Table 194: T_I8_TO_I32 Output signals

Name	Type	Description
INT32_OUT	INT32	Integer output value

3.20 Configurable logic blocks

3.20.1 Minimum pulse timer

3.20.1.1 Minimum pulse timer, two channels TPGAPC (ANSI 62TP)

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Minimum pulse timer, two channels	TPGAPC	TP	62TP

Function block

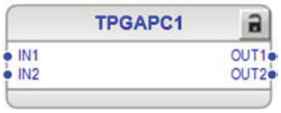


Figure 120: Function block

Functionality

The minimum pulse timer, two channels, function TPGAPC contains two independent timers. The function has a settable pulse length (in milliseconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the *Pulse time* setting. Both timers use the same setting parameter.

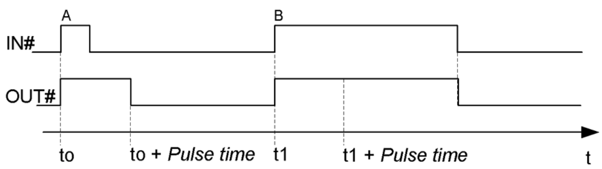


Figure 121: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 195: TPGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2

Table 196: TPGAPC Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

Settings

Table 197: TPGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...60000	ms	1	0	Minimum pulse time

3.20.1.2 Minimum pulse timer second resolution, two channels TPSGAPC (ANSI 62TPS)

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Minimum pulse timer second resolution, two channels	TPSGAPC	TPS	62TPS

Function block

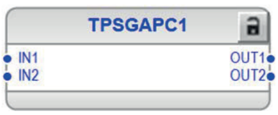


Figure 122: Function block

Functionality

The minimum pulse timer second resolution, two channels, function TPSGAPC contains two independent timers. The function has a settable pulse length (in seconds). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the *Pulse time* setting. Both timers use the same setting parameter.

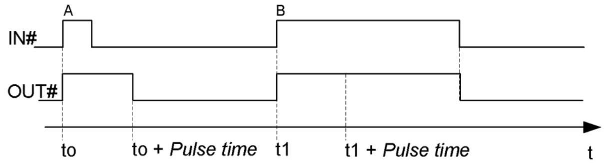


Figure 123: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 198: TPSGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2

Table 199: TPSGAPC Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

Settings

Table 200: TPSGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...300	s	1	0	Minimum pulse time

3.20.1.3 Minimum pulse timer minutes resolution, two channels TPMGAPC (ANSI 62TPM)

Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Minimum pulse timer minutes resolution, two channels	TPMGAPC	TPM	62TPM

Function block

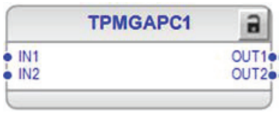


Figure 124: Function block

Functionality

The minimum pulse timer minutes resolution, two channels, function TPMGAPC contains two independent timers. The function has a settable pulse length (in minutes). The timers are used for setting the minimum pulse length for example, the signal outputs. Once the input is activated, the output is set for a specific duration using the *Pulse time* setting. Both timers use the same setting parameter.

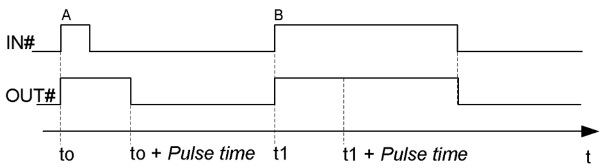


Figure 125: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 201: TPMGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2

Table 202: TPMGAPC Output signals

Name	Type	Description
OUT1	BOOLEAN	Output 1 status
OUT2	BOOLEAN	Output 2 status

Settings

Table 203: TPMGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...2880	min	1	0	Minimum pulse time

Technical revision history

Table 204: TPMGAPC Technical revision history

Product connectivity level	Technical revision	Change
PCL2	E	Changed the maximum pulse time from 5 h to 48 h

3.20.2 Pulse timer, eight channels PTGAPC (ANSI 62PT)

3.20.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Pulse timer, eight channels	PTGAPC	PT	62PT

3.20.2.2 Function block

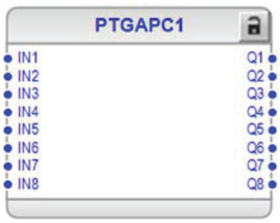


Figure 126: Function block

3.20.2.3 Functionality

The pulse timer function PTGAPC contains eight independent timers. The function has a settable pulse length. Once the input is activated, the output is set for a specific duration using the *Pulse delay time* setting.

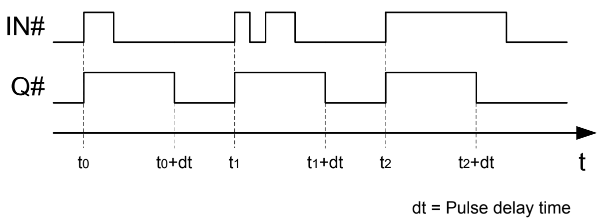


Figure 127: Timer operation

3.20.2.4 Signals

Table 205: PTGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 206: PTGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1 status
Q2	BOOLEAN	Output 2 status
Q3	BOOLEAN	Output 3 status
Q4	BOOLEAN	Output 4 status
Q5	BOOLEAN	Output 5 status
Q6	BOOLEAN	Output 6 status
Q7	BOOLEAN	Output 7 status
Q8	BOOLEAN	Output 8 status

3.20.2.5 Settings

Table 207: PTGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time 1	0...3600000	ms	1	0	Pulse time
Pulse time 2	0...3600000	ms	1	0	Pulse time
Pulse time 3	0...3600000	ms	1	0	Pulse time
Pulse time 4	0...3600000	ms	1	0	Pulse time
Pulse time 5	0...3600000	ms	1	0	Pulse time
Pulse time 6	0...3600000	ms	1	0	Pulse time

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time 7	0...3600000	ms	1	0	Pulse time
Pulse time 8	0...3600000	ms	1	0	Pulse time

3.20.2.6 Monitored data

Table 208: PTGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
T_LEFT1	FLOAT32	0...3600	s	Time left 1
T_LEFT2	FLOAT32	0...3600	s	Time left 2
T_LEFT3	FLOAT32	0...3600	s	Time left 3
T_LEFT4	FLOAT32	0...3600	s	Time left 4
T_LEFT5	FLOAT32	0...3600	s	Time left 5
T_LEFT6	FLOAT32	0...3600	s	Time left 6
T_LEFT7	FLOAT32	0...3600	s	Time left 7
T_LEFT8	FLOAT32	0...3600	s	Time left 8

3.20.2.7 Technical data

Table 209: PTGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.20.2.8 Technical revision history

Table 210: PTGAPC Technical revision history

Product connectivity level	Technical revision	Change
PCL2	E	Changed the *Pulse time* step to 1 ms

3.20.3 Daily timer DTMGAPC (ANSI DTM)

3.20.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Daily timer	DTMGAPC	DTM	DTM

3.20.3.2 Function block

Figure 128: Function block

3.20.3.3 Functionality

The daily timer function DTMGAPC is used to activate or deactivate its output at the set time of the day. It is possible to set a different activation or deactivation time separately for each day of the week.

3.20.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of DTMGAPC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

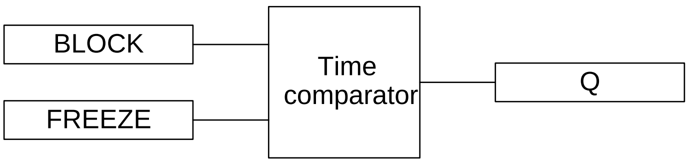


Figure 129: Functional module diagram

Time comparator

This module compares the current day and time with the activation hour and minute defined with the settings *xxx Act hour* and *xxx Act Mn*, respectively. When the time of the day reaches the set activation time, output Q is activated and remains active for the duration defined by the setting *xxx off delay*.

The output remains active until the next day if the value for *xxx off delay* is set so that it results into rollover of the day.

Different activation and deactivation times can be set for all days of the week. The activation and deactivation can also be disabled for a specific day. For example, if the activation or deactivation is not needed on Sundays, the setting *Sunday Act enable* can be set as "False".

Activation of the BLOCK input deactivates the function output whereas the activation of the FREEZE input freezes the output. The BLOCK input always has a higher priority than the FREEZE input.

3.20.3.5 Application

DTMGAPC is useful in applications that require signal activation and deactivation at a specific time of the day. Different activation times and duration can be set for different days of the week. For example, if the signal should be active on Mondays between 7:15 and 16:00, the *Monday Act enable* setting should be "True", *Monday Act hour* should be "7", *Monday Act Mn* should be "15", and *Monday off delay* should be "525" minutes. The behavior of output Q is illustrated in *Figure 130*.

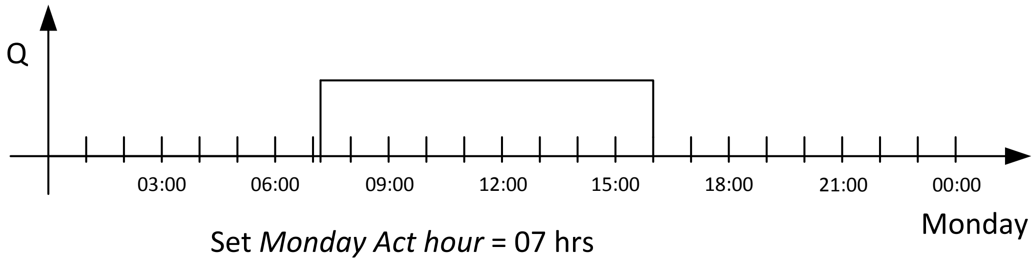


Figure 130: Example setting values for output Q activation

3.20.3.6 Signals

DTMGAPC Input signals

Table 211: DTMGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for binary output
FREEZE	BOOLEAN	0=False	Freeze signal for binary output

DTMGAPC Output signals

Table 212: DTMGAPC Output signals

Name	Type	Description
Q	BOOLEAN	Output status

3.20.3.7 DTMGAPC Settings

Table 213: DTMGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Monday Act enable	0=False 1=True			false	Activation / deactivation need on Monday
Monday Act hour	0...23	h		8	Activation hour time for Monday

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Monday Act Mn	0...59	min		0	Activation minute time for Monday
Monday off delay	1...1440	min	1	60	Activation duration for Monday
Tuesday Act enable	0=False 1=True			false	Activation / deactivation need on Tuesday
Tuesday Act hour	0...23	h		8	Activation hour time for Tuesday
Tuesday Act Mn	0...59	min		0	Activation minute time for Tuesday
Tuesday off delay	1...1440	min	1	60	Activation duration for Tuesday
Wednesday Act enable	0=False 1=True			false	Activation / deactivation need on Wednesday
Wednesday Act hour	0...23	h		8	Activation hour time for Wednesday
Wednesday Act Mn	0...59	min		0	Activation minute time for Wednesday
Wednesday off delay	1...1440	min	1	60	Activation duration for Wednesday
Thursday Act enable	0=False 1=True			false	Activation / deactivation need on Thursday
Thursday Act hour	0...23	h		8	Activation hour time for Thursday
Thursday Act Mn	0...59	min		0	Activation minute time for Thursday
Thursday off delay	1...1440	min	1	60	Activation duration for Thursday
Friday Act enable	0=False 1=True			false	Activation / deactivation need on Friday
Friday Act hour	0...23	h		8	Activation hour time for Friday
Friday Act Mn	0...59	min		0	Activation minute time for Friday
Friday off delay	1...1440	min	1	60	Activation duration for Friday
Saturday Act enable	0=False 1=True			false	Activation / deactivation need on Saturday
Saturday Act hour	0...23	h		8	Activation hour time for Saturday
Saturday Act Mn	0...59	min		0	Activation minute time for Saturday
Saturday off delay	1...1440	min	1	60	Activation duration for Saturday
Sunday Act enable	0=False 1=True			false	Activation / deactivation need on Sunday
Sunday Act hour	0...23	h		8	Activation hour time for Sunday
Sunday Act Mn	0...59	min		0	Activation minute time for Sunday
Sunday off delay	1...1440	min	1	60	Activation duration for Sunday

3.20.3.8 DTMGAPC Monitored data

Table 214: DTMGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
DTMGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

3.20.4 Calendar function CALGAPC (ANSI CAL)

3.20.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Calendar function	CALGAPC	CAL	CAL

3.20.4.2 Function block

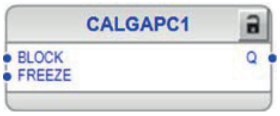


Figure 131: Function block

3.20.4.3 Functionality

The calendar function CALGAPC is used to activate a function output at a set activation date of the calendar year. The output remains activated till the set deactivation date of the calendar year.

3.20.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of CALGAPC can be described with a module diagram.

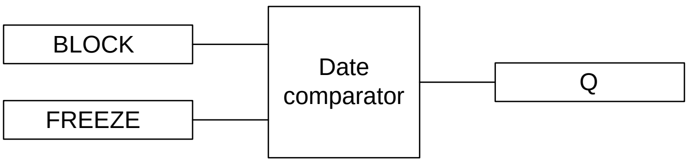


Figure 132: Functional module diagram

Date comparator

This module compares the current date (excluding the calendar year) with the set activation and deactivation date and month settings. If the system date and month are the same or greater than *Activation day* and *Activation month* settings, output Q is activated and remains active till the date reaches the set *Deactivation day* and *Deactivation month* settings.

Activation of the BLOCK input deactivates the function output whereas the activation of the FREEZE input freezes the output. The BLOCK input always has a higher priority than the FREEZE input.

The module automatically handles the leap day and different month lengths.

- The function output remains active during the leap day if the leap day falls within the set activation period.
- If the set *Activation day* is not a valid date (for example, 31st April), then the output does not activate.
- If the set *Deactivation day* is not a valid date (for example, 31st April), then the last date of the month is considered.

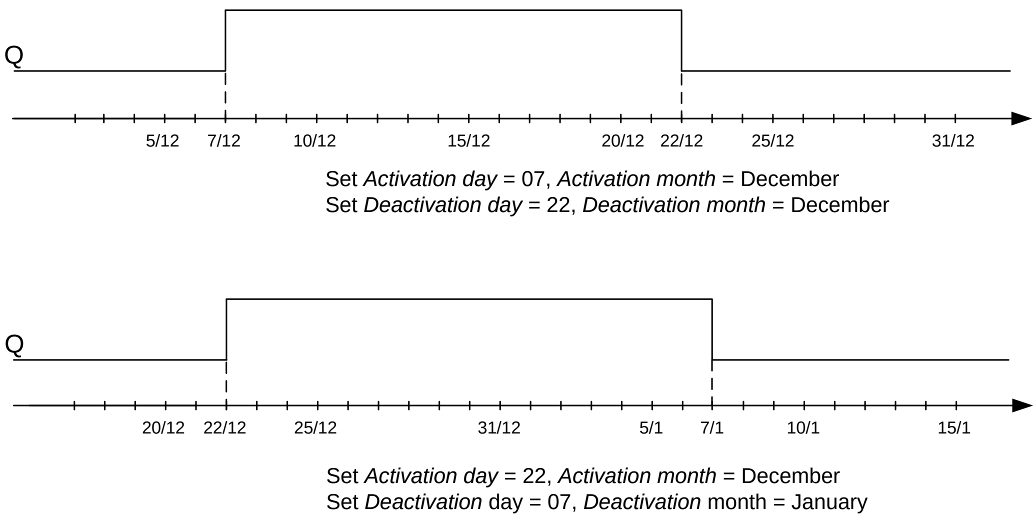


Figure 133: Examples of how output Q is activated for different settings

3.20.4.5 Application

The function activates an output for a specific set duration of the calendar year.

Consider an application where the output of the daily timer function DTMGAPC needs to be activated only for specific days of the calendar year. The output of CALGAPC can be connected to the BLOCK input of DTMGAPC (using NOT gate) so that DTMGAPC activates only for the duration defined by CALGAPC.

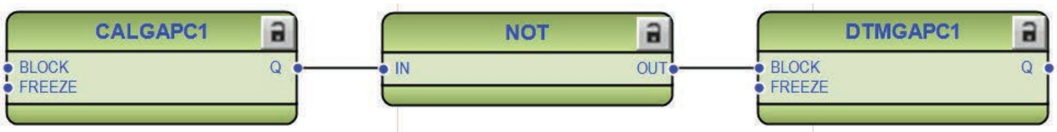


Figure 134: Example of Calendar function usage

3.20.4.6 Signals

CALGAPC Input signals

Table 215: CALGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for binary output
FREEZE	BOOLEAN	0=False	Freeze signal for binary output

CALGAPC Output signals

Table 216: CALGAPC Output signals

Name	Type	Description
Q	BOOLEAN	Output status

3.20.4.7 CALGAPC Settings

Table 217: CALGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Activation day	1...31			1	Activation day
Activation month	1=January 2=February 3=March 4=April 5=May 6=June 7=July 8=August 9=September 10=October 11=November 12=December			1=January	Activation month
Deactivation day	1...31			31	Deactivation day
Deactivation month	1=January 2=February 3=March 4=April 5=May 6=June 7=July 8=August 9=September 10=October 11=November			1=January	Deactivation month

Parameter	Values (Range)	Unit	Step	Default	Description
	12=December				

3.20.4.8 CALGAPC Monitored data

Table 218: CALGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
CALGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

3.20.5 Time delay off, eight channels TOFGAPC (ANSI 62TOF)

3.20.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Time delay off, eight channels	TOFGAPC	TOF	62TOF

3.20.5.2 Function block

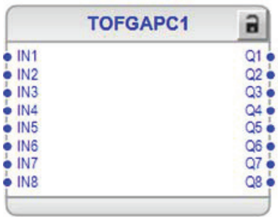


Figure 135: Function block

3.20.5.3 Functionality

The time delay off, eight channels, function TOFGAPC can be used, for example, for a drop-off-delayed output related to the input signal. The function contains eight independent timers. There is a settable delay in the timer. Once the input is activated, the output is set immediately. When the input is cleared, the output stays on until the time set with the *Off delay time* setting has elapsed.

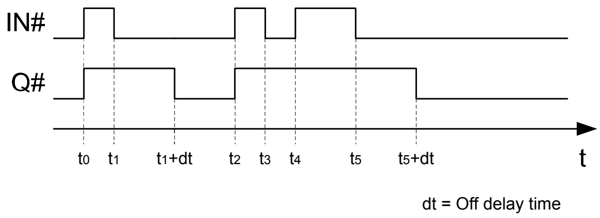


Figure 136: Timer operation

3.20.5.4 Signals

Table 219: TOFGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1 status
IN2	BOOLEAN	0=False	Input 2 status
IN3	BOOLEAN	0=False	Input 3 status
IN4	BOOLEAN	0=False	Input 4 status
IN5	BOOLEAN	0=False	Input 5 status
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 220: TOFGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1 status
Q2	BOOLEAN	Output 2 status
Q3	BOOLEAN	Output 3 status
Q4	BOOLEAN	Output 4 status
Q5	BOOLEAN	Output 5 status
Q6	BOOLEAN	Output 6 status
Q7	BOOLEAN	Output 7 status
Q8	BOOLEAN	Output 8 status

3.20.5.5 Settings

Table 221: TOFGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Off delay time 1	0...3600000	ms	1	0	Off delay time
Off delay time 2	0...3600000	ms	1	0	Off delay time
Off delay time 3	0...3600000	ms	1	0	Off delay time
Off delay time 4	0...3600000	ms	1	0	Off delay time
Off delay time 5	0...3600000	ms	1	0	Off delay time

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Off delay time 6	0...3600000	ms	1	0	Off delay time
Off delay time 7	0...3600000	ms	1	0	Off delay time
Off delay time 8	0...3600000	ms	1	0	Off delay time

3.20.5.6 Monitored data

Table 222: TOFGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
T_LEFT1	FLOAT32	0...3600	s	Time left 1
T_LEFT2	FLOAT32	0...3600	s	Time left 2
T_LEFT3	FLOAT32	0...3600	s	Time left 3
T_LEFT4	FLOAT32	0...3600	s	Time left 4
T_LEFT5	FLOAT32	0...3600	s	Time left 5
T_LEFT6	FLOAT32	0...3600	s	Time left 6
T_LEFT7	FLOAT32	0...3600	s	Time left 7
T_LEFT8	FLOAT32	0...3600	s	Time left 8

3.20.5.7 Technical data

Table 223: TOFGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.20.5.8 Technical revision history

Table 224: TOFGAPC Technical revision history

Product connectivity level	Technical revision	Change
PCL2	D	Changed the *Off delay time* step to 1 ms

3.20.6 Time delay on, eight channels TONGAPC (ANSI 62TON)

3.20.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Time delay on, eight channels	TONGAPC	TON	62TON

3.20.6.2 Function block

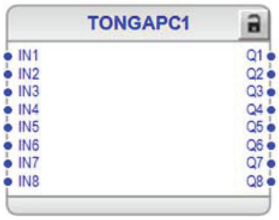


Figure 137: Function block

3.20.6.3 Functionality

The time delay on, eight channels, function TONGAPC can be used, for example, for time-delaying the output related to the input signal. TONGAPC contains eight independent timers. The timer has a settable time delay. Once the input is activated, the output is set after the time set by the *On delay time* setting has elapsed.

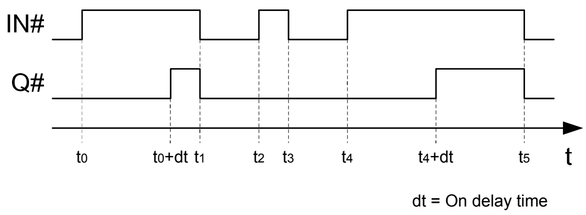


Figure 138: Timer operation

3.20.6.4 Signals

Table 225: TONGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	Input 1
IN2	BOOLEAN	0=False	Input 2
IN3	BOOLEAN	0=False	Input 3
IN4	BOOLEAN	0=False	Input 4
IN5	BOOLEAN	0=False	Input 5
IN6	BOOLEAN	0=False	Input 6
IN7	BOOLEAN	0=False	Input 7
IN8	BOOLEAN	0=False	Input 8

Table 226: TONGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1
Q2	BOOLEAN	Output 2

Table continues on the next page

Name	Type	Description
Q3	BOOLEAN	Output 3
Q4	BOOLEAN	Output 4
Q5	BOOLEAN	Output 5
Q6	BOOLEAN	Output 6
Q7	BOOLEAN	Output 7
Q8	BOOLEAN	Output 8

3.20.6.5 Settings

Table 227: TONGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
On delay time 1	0...3600000	ms	1	0	On delay time
On delay time 2	0...3600000	ms	1	0	On delay time
On delay time 3	0...3600000	ms	1	0	On delay time
On delay time 4	0...3600000	ms	1	0	On delay time
On delay time 5	0...3600000	ms	1	0	On delay time
On delay time 6	0...3600000	ms	1	0	On delay time
On delay time 7	0...3600000	ms	1	0	On delay time
On delay time 8	0...3600000	ms	1	0	On delay time

3.20.6.6 Monitored data

Table 228: TONGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
T_LEFT1	FLOAT32	0...3600	s	Time left 1
T_LEFT2	FLOAT32	0...3600	s	Time left 2
T_LEFT3	FLOAT32	0...3600	s	Time left 3
T_LEFT4	FLOAT32	0...3600	s	Time left 4
T_LEFT5	FLOAT32	0...3600	s	Time left 5
T_LEFT6	FLOAT32	0...3600	s	Time left 6
T_LEFT7	FLOAT32	0...3600	s	Time left 7
T_LEFT8	FLOAT32	0...3600	s	Time left 8

3.20.6.7 Technical data

Table 229: TONGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.20.6.8 Technical revision history

Table 230: TONGAPC Technical revision history

Product connectivity level	Technical revision	Change
PCL2	D	Changed the *On delay time* step to 1 ms

3.20.7 SR flip-flop, eight channels, nonvolatile SRGAPC (ANSI SR)

3.20.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
SR flip-flop, eight channels, nonvolatile	SRGAPC	SR	SR

3.20.7.2 Function block

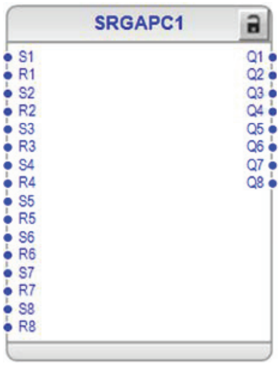


Figure 139: Function block

3.20.7.3 Functionality

The SR flip-flop, eight channels, nonvolatile function SRGAPC is a simple SR flip-flop with a memory that can be set or that can reset an output from the `S#` or `R#` inputs, respectively. The function contains eight independent set-reset flip-flop latches where the SET input has the higher priority over the RESET input. The status of each `Q#` output is retained in the nonvolatile memory. The individual reset for each `Q#` output is available on the LHMI or through tool via communication.

Table 231: Truth table for SRGAPC

S#	R#	Q#
0	0	0[1]
0	1	0
1	0	1
1	1	1

3.20.7.4 Signals

Table 232: SRGAPC Input signals

Name	Type	Default	Description
S1	BOOLEAN	0=False	Set Q1 output when set
R1	BOOLEAN	0=False	Resets Q1 output when set
S2	BOOLEAN	0=False	Set Q2 output when set
R2	BOOLEAN	0=False	Resets Q2 output when set
S3	BOOLEAN	0=False	Set Q3 output when set
R3	BOOLEAN	0=False	Resets Q3 output when set
S4	BOOLEAN	0=False	Set Q4 output when set
R4	BOOLEAN	0=False	Resets Q4 output when set
S5	BOOLEAN	0=False	Set Q5 output when set
R5	BOOLEAN	0=False	Resets Q5 output when set
S6	BOOLEAN	0=False	Set Q6 output when set
R6	BOOLEAN	0=False	Resets Q6 output when set
S7	BOOLEAN	0=False	Set Q7 output when set
R7	BOOLEAN	0=False	Resets Q7 output when set
S8	BOOLEAN	0=False	Set Q8 output when set
R8	BOOLEAN	0=False	Resets Q8 output when set

[1] Keep state/no change

Table 233: SRGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

3.20.7.5 Settings

Table 234: SRGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset Q1	0=Cancel 1=Reset			0=Cancel	Resets Q1 output when set
Reset Q2	0=Cancel 1=Reset			0=Cancel	Resets Q2 output when set
Reset Q3	0=Cancel 1=Reset			0=Cancel	Resets Q3 output when set
Reset Q4	0=Cancel 1=Reset			0=Cancel	Resets Q4 output when set
Reset Q5	0=Cancel 1=Reset			0=Cancel	Resets Q5 output when set
Reset Q6	0=Cancel 1=Reset			0=Cancel	Resets Q6 output when set
Reset Q7	0=Cancel 1=Reset			0=Cancel	Resets Q7 output when set
Reset Q8	0=Cancel 1=Reset			0=Cancel	Resets Q8 output when set

3.20.8 Boolean value event creation MVGAPC (ANSI MV)

3.20.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Boolean value event creation	MVGAPC	MV	MV

3.20.8.2 Function block

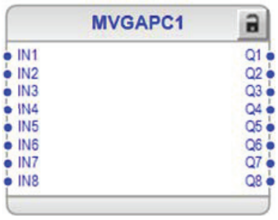


Figure 140: Function block

3.20.8.3 Functionality

The boolean value event creation function MVGAPC is used for user logic bits. Each input state is directly copied to the output state. This allows the creating of events from advanced logic combinations.

3.20.8.4 Signals

Table 235: MVGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0=False	IN1 status
IN2	BOOLEAN	0=False	IN2 status
IN3	BOOLEAN	0=False	IN3 status
IN4	BOOLEAN	0=False	IN4 status
IN5	BOOLEAN	0=False	IN5 status
IN6	BOOLEAN	0=False	IN6 status
IN7	BOOLEAN	0=False	IN7 status
IN8	BOOLEAN	0=False	IN8 status

Table 236: MVGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

3.20.8.5 Settings

Table 237: MVGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Description				MVGAPC1 Q1	Output description
Description				MVGAPC1 Q2	Output description
Description				MVGAPC1 Q3	Output description
Description				MVGAPC1 Q4	Output description
Description				MVGAPC1 Q5	Output description
Description				MVGAPC1 Q6	Output description
Description				MVGAPC1 Q7	Output description
Description				MVGAPC1 Q8	Output description

3.20.9 Integer value event creation MVI4GAPC (ANSI MVI4)

3.20.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Integer value event creation	MVI4GAPC	MVI4	MVI4

3.20.9.2 Function block

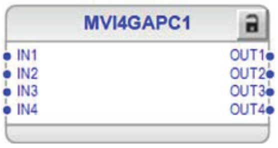


Figure 141: Function block

3.20.9.3 Functionality

The integer value event creation function MVI4GAPC is used for creation of the events from the integer values. The integer input value is received via `IN1...4` input. The integer output value is available on `OUT1...4` output.

The integer input range is from –2147483648 to 2147483647.

3.20.9.4 Signals

Table 238: MVI4GAPC Input signals

Name	Type	Default	Description
IN1	INT32	0	Integer input value 1
IN2	INT32	0	Integer input value 2
IN3	INT32	0	Integer input value 3
IN4	INT32	0	Integer input value 4

Table 239: MVI4GAPC Output signals

Name	Type	Description
OUT1	INT32	Integer output value 1
OUT2	INT32	Integer output value 2
OUT3	INT32	Integer output value 3
OUT4	INT32	Integer output value 4

3.20.10 Analog value event creation with scaling SCA4GAPC (ANSI SCA4)

3.20.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Analog value event creation with scaling	SCA4GAPC	SCA4	SCA4

3.20.10.2 Function block

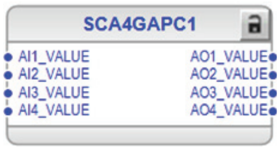


Figure 142: Function block

3.20.10.3 Functionality

The analog value event creation with scaling function SCA4GAPC is used for scaling the analog value. It allows creating events from analog values.

The analog value received via the `AIn_VALUE` input is scaled with the *Scale ratio n* setting. The scaled value is available on the `AOn_VALUE` output.

Analog input range is from –10000.0 to 10000.0.

Analog output range is from –2000000.0 to 2000000.0.

If the value of the `AIn_VALUE` input exceeds the analog input range, `AOn_VALUE` is set to 0.0.

If the result of `AIn_VALUE` multiplied by the Scale ratio n setting exceeds the analog output range, `AOn_VALUE` shows the minimum or maximum value, according to analog value range.

3.20.10.4 Signals

Table 240: SCA4GAPC Input signals

Name	Type	Default	Description
AI1_VALUE	FLOAT32	0.0	Analog input value of channel 1
AI2_VALUE	FLOAT32	0.0	Analog input value of channel 2
AI3_VALUE	FLOAT32	0.0	Analog input value of channel 3
AI4_VALUE	FLOAT32	0.0	Analog input value of channel 4

Table 241: SCA4GAPC Output signals

Name	Type	Description
AO1_VALUE	FLOAT32	Analog value 1 after scaling
AO2_VALUE	FLOAT32	Analog value 2 after scaling
AO3_VALUE	FLOAT32	Analog value 3 after scaling
AO4_VALUE	FLOAT32	Analog value 4 after scaling

3.20.10.5 Settings

Table 242: SCA4GAPC settings

Parameter	Values (Range)	Unit	Step	Default	Description
Scale ratio 1	0.001...1000.000		0.001	1.000	Scale ratio for analog value 1
Scale ratio 2	0.001...1000.000		0.001	1.000	Scale ratio for analog value 2
Scale ratio 3	0.001...1000.000		0.001	1.000	Scale ratio for analog value 3
Scale ratio 4	0.001...1000.000		0.001	1.000	Scale ratio for analog value 4

3.20.11 16 settable real values SETRGAPC

3.20.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
16 settable real values	SETRGAPC	SETRGAPC	SETRGAPC

3.20.11.2 Function block

Figure 143: Function block

3.20.11.3 Functionality

The value of function outputs `AO1_VALUE`...`AO16_VALUE` can be set with settings *Set value 1*...*Set value 16*.

3.20.11.4 Signals

Table 243: SETRGAPC Output signals

Name	Type	Description
AO1_VALUE	FLOAT32	Analog value 1
AO2_VALUE	FLOAT32	Analog value 2
AO3_VALUE	FLOAT32	Analog value 3
AO4_VALUE	FLOAT32	Analog value 4
AO5_VALUE	FLOAT32	Analog value 5
AO6_VALUE	FLOAT32	Analog value 6
AO7_VALUE	FLOAT32	Analog value 7
AO8_VALUE	FLOAT32	Analog value 8
AO9_VALUE	FLOAT32	Analog value 9
AO10_VALUE	FLOAT32	Analog value 10
AO11_VALUE	FLOAT32	Analog value 11
AO12_VALUE	FLOAT32	Analog value 12
AO13_VALUE	FLOAT32	Analog value 13
AO14_VALUE	FLOAT32	Analog value 14
AO15_VALUE	FLOAT32	Analog value 15
AO16_VALUE	FLOAT32	Analog value 16

3.20.11.5 Settings

Table 244: SETRGAPC Non-group settings (Basic)

IEC name	Values (Range)	Unit	Step	Default	Description
Set value 1	–2000000.000...2000000.000		0.001	0	Set value for analog value 1
Set value 2	–2000000.000...2000000.000		0.001	0	Set value for analog value 2
Set value 3	–2000000.000...2000000.000		0.001	0	Set value for analog value 3
Set value 4	–2000000.000...2000000.000		0.001	0	Set value for analog value 4
Set value 5	–2000000.000...2000000.000		0.001	0	Set value for analog value 5
Set value 6	–2000000.000...2000000.000		0.001	0	Set value for analog value 6
Set value 7	–2000000.000...2000000.000		0.001	0	Set value for analog value 7
Set value 8	–2000000.000...2000000.000		0.001	0	Set value for analog value 8
Set value 9	–2000000.000...2000000.000		0.001	0	Set value for analog value 9
Set value 10	–2000000.000...2000000.000		0.001	0	Set value for analog value 10
Set value 11	–2000000.000...2000000.000		0.001	0	Set value for analog value 11
Set value 12	–2000000.000...2000000.000		0.001	0	Set value for analog value 12
Set value 13	–2000000.000...2000000.000		0.001	0	Set value for analog value 13
Set value 14	–2000000.000...2000000.000		0.001	0	Set value for analog value 14
Set value 15	–2000000.000...2000000.000		0.001	0	Set value for analog value 15
Set value 16	–2000000.000...2000000.000		0.001	0	Set value for analog value 16

3.20.12 16 settable 32-bit integer values SETI32GAPC

3.20.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
16 settable 32-bit integer values	SETI32GAPC	SETI32GAPC	SETI32GAPC

3.20.12.2 Function block

Figure 144: Function block

3.20.12.3 Functionality

The value of function outputs `IO1_VALUE`...`IO16_VALUE` can be set with settings *Set value 1*...*Set value 16*.

3.20.12.4 Signals

Table 245: SETI32GAPC Output signals

Name	Type	Description
IO1_VALUE	INT32	Integer value 1
IO2_VALUE	INT32	Integer value 2
IO3_VALUE	INT32	Integer value 3
IO4_VALUE	INT32	Integer value 4
IO5_VALUE	INT32	Integer value 5
IO6_VALUE	INT32	Integer value 6
IO7_VALUE	INT32	Integer value 7
IO8_VALUE	INT32	Integer value 8
IO9_VALUE	INT32	Integer value 9
IO10_VALUE	INT32	Integer value 10
IO11_VALUE	INT32	Integer value 11
IO12_VALUE	INT32	Integer value 12
IO13_VALUE	INT32	Integer value 13
IO14_VALUE	INT32	Integer value 14
IO15_VALU	INT32	Integer value 15
IO16_VALUE	INT32	Integer value 16

3.20.12.5 Settings

Table 246: SETI32GAPC Non-group settings (Basic)

IEC name	Values (Range)	Unit	Step	Default	Description
Set value 1	–2147483648...2147483647		1	0	Set value for integer value 1
Set value 2	–2147483648...2147483647		1	0	Set value for integer value 2
Set value 3	–2147483648...2147483647		1	0	Set value for integer value 3
Set value 4	–2147483648...2147483647		1	0	Set value for integer value 4
Set value 5	–2147483648...2147483647		1	0	Set value for integer value 5
Set value 6	–2147483648...2147483647		1	0	Set value for integer value 6
Set value 7	–2147483648...2147483647		1	0	Set value for integer value 7
Set value 8	–2147483648...2147483647		1	0	Set value for integer value 8
Set value 9	–2147483648...2147483647		1	0	Set value for integer value 9
Set value 10	–2147483648...2147483647		1	0	Set value for integer value 10
Set value 11	–2147483648...2147483647		1	0	Set value for integer value 11
Set value 12	–2147483648...2147483647		1	0	Set value for integer value 12
Set value 13	–2147483648...2147483647		1	0	Set value for integer value 13
Set value 14	–2147483648...2147483647		1	0	Set value for integer value 14
Set value 15	–2147483648...2147483647		1	0	Set value for integer value 15
Set value 16	–2147483648...2147483647		1	0	Set value for integer value 16

3.20.13 Generic control points SPCGAPC (ANSI SPCG)

3.20.13.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Generic control points	SPCGAPC	SPC	SPCG

3.20.13.2 Function block

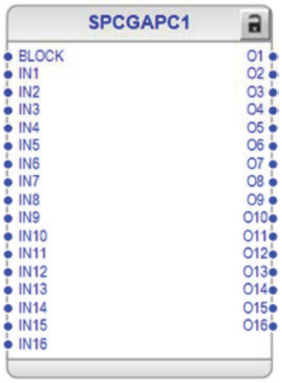


Figure 145: Function block

3.20.13.3 Functionality

The generic control points function SPCGAPC contains 16 independent control points. SPCGAPC offers the capability to activate its outputs through a local or remote control. The local control request can be issued through the buttons in the single-line diagram or via inputs and the remote control request through communication. The rising edge of the input signal is interpreted as a control request, and the output operation is triggered. When remote control requests are used the control points behaves as persistent.

The *Loc Rem restriction* setting is used for enabling or disabling the restriction for SPCGAPC to follow the R/L button state. If *Loc Rem restriction* is "True", as it is by default, the local or remote control operations are accepted according to the R/L button state.

Each of the 16 generic control point outputs has the *Operation mode*, *Pulse length* and *Description* setting. If *Operation mode* is "Toggle", the output state is toggled for every control request received. If Operation mode is "Pulsed", the output pulse of a preset duration (the *Pulse length* setting) is generated for every control request received. The *Description* setting can be used for storing information on the actual use of the control point in application, for instance.

For example, if the *Operation mode* is "Toggle", the output O# is initially “False”. The rising edge in IN# sets O# to “True”. The falling edge of IN# has no effect. Next rising edge of IN# sets O# to “False”.

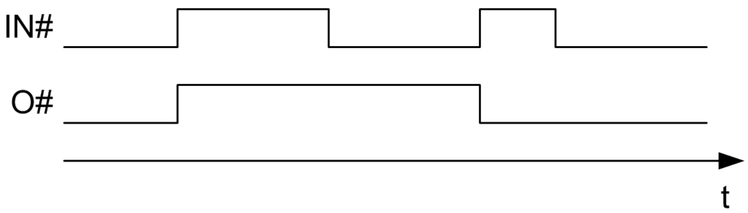


Figure 146: Operation in "Toggle" mode

The BLOCK input can be used for blocking the functionality of the outputs. The operation of the BLOCK input depends on the Operation mode setting. If Operation mode is "Toggle", the output state freezes and cannot be changed while the BLOCK input is active. If *Operation mode* is "Pulsed", the activation of the BLOCK input resets the outputs to the "False" state and further control requests are ignored while the BLOCK input is active.

From the remote communication point of view SPCGAPC toggled operation mode is always working as persistent mode. The output O# follows the value written to the input IN#.

3.20.13.4 Signals

Table 247: SPCGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode
IN1	BOOLEAN	0=False	Input of control point 1
IN2	BOOLEAN	0=False	Input of control point 2
IN3	BOOLEAN	0=False	Input of control point 3
IN4	BOOLEAN	0=False	Input of control point 4
IN5	BOOLEAN	0=False	Input of control point 5
IN6	BOOLEAN	0=False	Input of control point 6
IN7	BOOLEAN	0=False	Input of control point 7
IN8	BOOLEAN	0=False	Input of control point 8
IN9	BOOLEAN	0=False	Input of control point 9
IN10	BOOLEAN	0=False	Input of control point 10
IN11	BOOLEAN	0=False	Input of control point 11
IN12	BOOLEAN	0=False	Input of control point 12
IN13	BOOLEAN	0=False	Input of control point 13
IN14	BOOLEAN	0=False	Input of control point 14
IN15	BOOLEAN	0=False	Input of control point 15
IN16	BOOLEAN	0=False	Input of control point 16

Table 248: SPCGAPC Output signals

Name	Type	Description
O1	BOOLEAN	Output 1 status
O2	BOOLEAN	Output 2 status
O3	BOOLEAN	Output 3 status
O4	BOOLEAN	Output 4 status
O5	BOOLEAN	Output 5 status
O6	BOOLEAN	Output 6 status
O7	BOOLEAN	Output 7 status
O8	BOOLEAN	Output 8 status
O9	BOOLEAN	Output 9 status
O10	BOOLEAN	Output 10 status
O11	BOOLEAN	Output 11 status
O12	BOOLEAN	Output 12 status
O13	BOOLEAN	Output 13 status
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

3.20.13.5 Settings

Table 249: SPCGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Loc Rem restriction	0=False 1=True			1=True	Local remote switch restriction
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 7	Generic control point description
Operation mode	0=Pulsed			-1=Off	Operation mode for generic control point

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Toggle/Persistent -1=Off				
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle/Persistent -1=Off			-1=Off	Operation mode for generic control point

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGAPC1 Output 16	Generic control point description

3.20.14 Pulse counter for energy measurement PCGAPC

3.20.14.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Pulse counter for energy measurement	PCGAPC	PCGAPC	PCGAPC

3.20.14.2 Function block

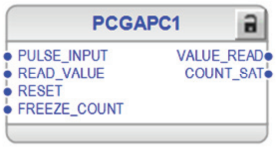


Figure 147: Function block

3.20.14.3 Functionality

The pulse counter for energy measurement function PCGAPC counts externally generated binary pulses, for example, pulses coming from an external energy meter, for the calculation of energy consumption values. The pulses are captured by the binary input module and read by PCGAPC. The number of pulses in the counter is then reported via the station bus to the automation system or read via the station monitoring system as a service value. The scaled value is also available over IEC 61850 communication.

The pulses are captured by the binary input module and read by PCGAPC with a frequency of up to 40 Hz. PCGAPC can also be used as a general-purpose counter.

3.20.14.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of PCGAPC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

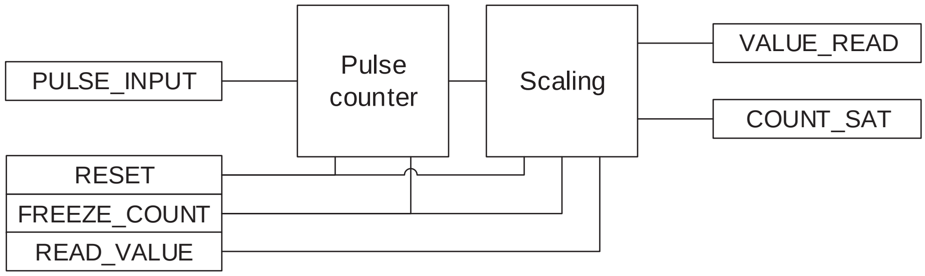


Figure 148: Functional module diagram

Pulse counter

This module counts the number of pulses available at PULSE_INPUT. The count value is incremented depending upon *Count criteria* setting.

Table 250: Relation between setting Count criteria and count value behavior

***Count criteria* values**	**PULSE_INPUT count value**
Rising edge	Count value is incremented on the rising edge of PULSE_IN-PUT.
Falling edge	Count value is incremented on the falling edge of PULSE_IN-PUT.
On change	Count value is incremented each time a rising edge or falling edge is available at PULSE_INPUT.
Freeze	Counting is frozen.

The count value is available at COUNT_VALUE in the Monitored data view and is stored in a nonvolatile memory. This output is updated cyclically and sent to the station HMI over various communication protocols, depending on the Reporting interval setting. The start of *Reporting interval* corresponds to the start of the function operation in the protection relay.

Binary output `VALUE_READ` activates for a fixed 200 ms each time the reporting timer completes its cycle. It is also possible to update COUNT_VALUE before completion of *Reporting interval* and make it available for communication by providing a minimum 1-second-long pulse at `READ_VALUE` input. Besides COUNT_VALUE activation, `READ_VALUE` also activates output `VALUE_READ` for 200 ms.

The activation of RESET resets COUNT_VALUE to zero. Activation of FREEZE_COUNT freezes further counting.

Changing *Count criteria* does not reset COUNT_VALUE.

Scaling

This module scales the count value available at COUNT_VALUE. The scaling depends on the *Unit selection* setting. When the function is used for general-purpose counting, *Unit selection* is set as "Count" and the count value is multiplied by the *Pulse quantity* setting to calculate the scaled value.

When using this function for energy measurement, *Unit selection* is set accordingly, that is, real, active or apparent energy and the count value is divided by *Impulse ratio* to calculate the scaled value. The prefix for unit of *Impulse ratio* is defined by setting *Impulse ratio prefix*.

The energy meter defines the impulse ratio (also known as meter constant), that is, it indicates the number of pulses the meter generated per kWh (or MWh). *Impulse ratio* must be set based on the energy meter used.

For example, if the impulse ratio is 100 impulses / MWh, set *Impulse ratio* as 100 and *Impulse ratio prefix* as Mega.

If the impulse ratio is 800 impulses / KWh, set *Impulse ratio* as 800 and *Impulse ratio prefix* as Kilo.

The scaled value is available at SCALED_VALUE in the Monitored data view. This output is updated cyclically and sent to the station HMI over various communication protocols depending on *Reporting interval* setting. The start of *Reporting interval* corresponds to the start of the function operation in the protection relay.

The activation of RESET resets SCALED_VALUE to zero.

If *Pulse quantity*, *Impulse ratio* or *Impulse ratio prefix* is changed in between, SCALED_VALUE is updated immediately based on the new setting.

Binary output VALUE_READ activates for a fixed 200 ms each time the reporting timer completes its cycle.

It is also possible to update SCALED_VALUE before completion of *Reporting interval* and make it available for communication by providing a pulse at READ_VALUE input. The pulse width should be greater than 1 s. Besides updating SCALED_VALUE, the READ_VALUE activation also activates output VALUE_READ for 200 ms.

Activation of FREEZE_COUNT input immediately updates SCALED_VALUE output with a pulse at VALUE_READ output.

Output COUNT_SAT activates when either SCALED_VALUE or COUNT_VALUE exceeds the count range and it is not possible to count further.

Figure 149 and *Figure 150* explain PCGAPC operation.

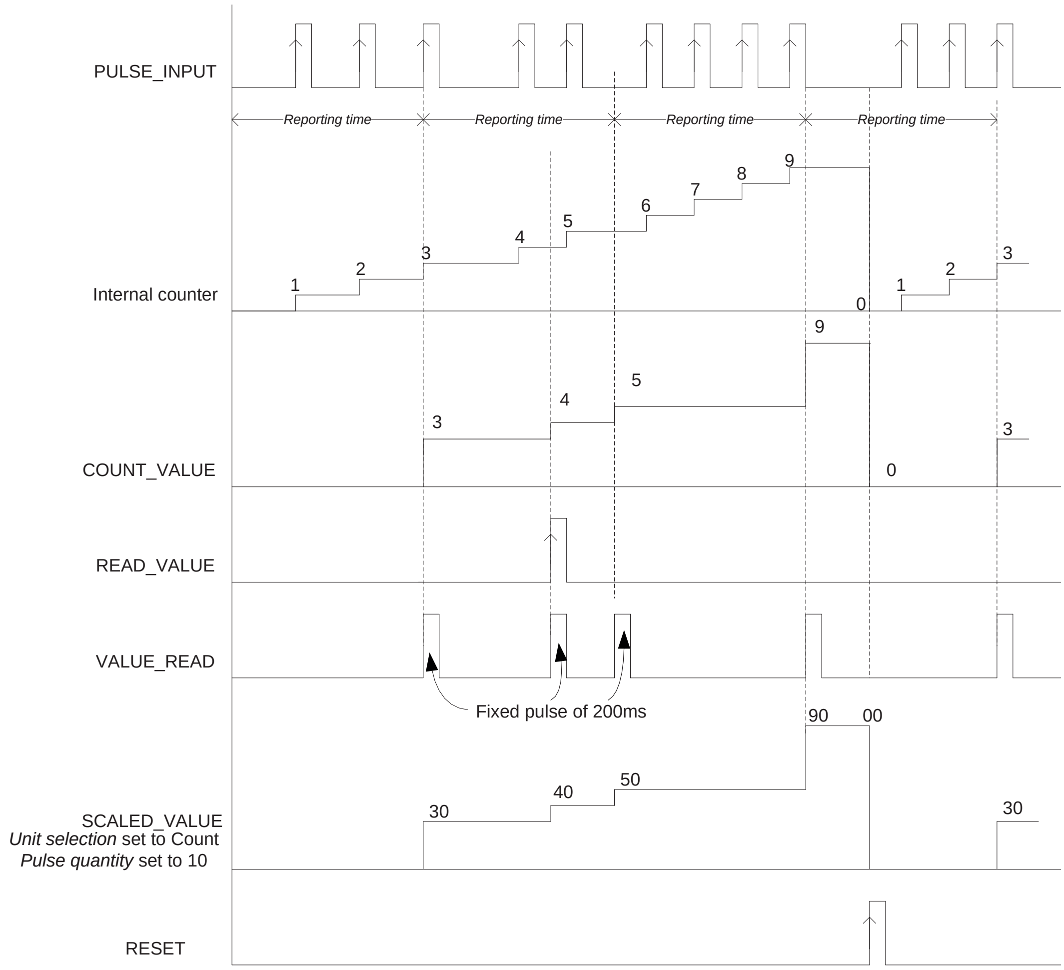


Figure 149: PCGAPC operation

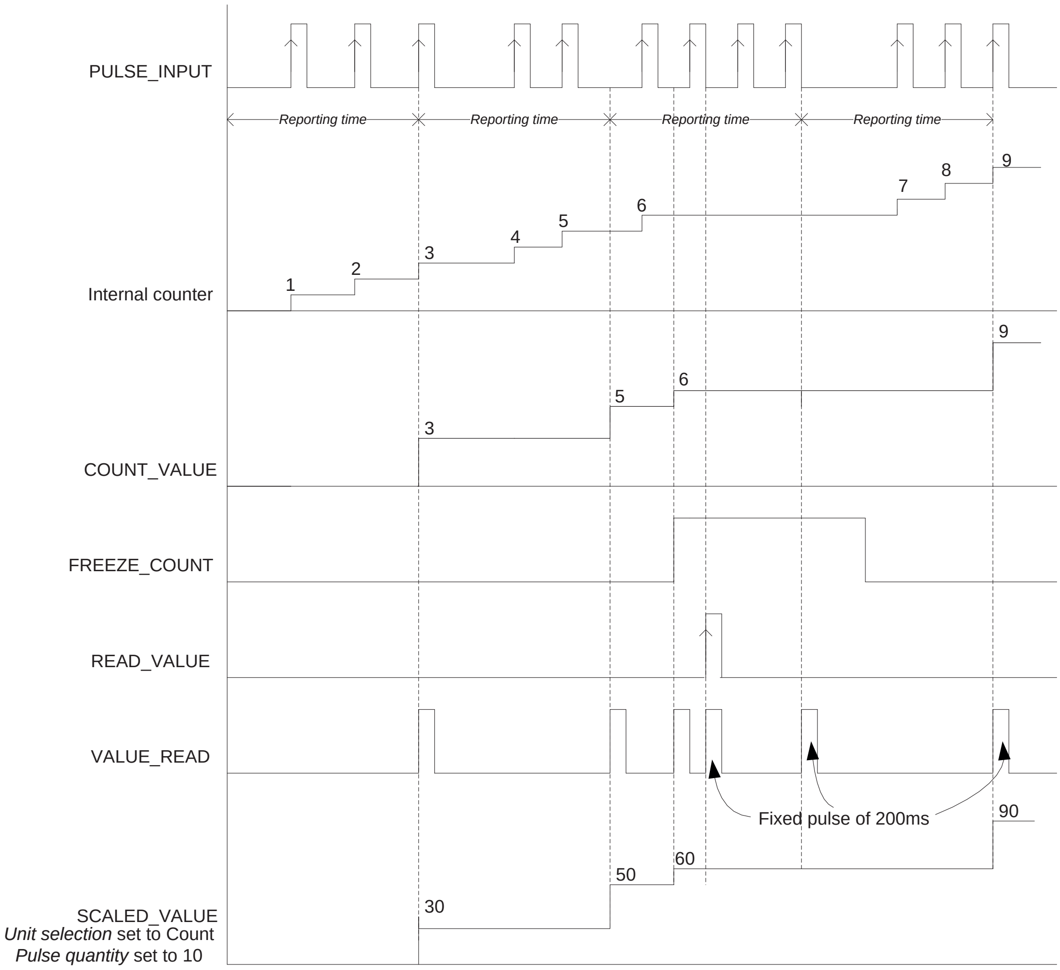


Figure 150: Behavior of FREEZE_COUNT input

3.20.14.5 Application

PCGAPC counts externally generated binary pulses, for example, pulses coming from an external energy meter, for the calculation of energy consumption values. The pulses are captured by the binary input module and read by PCGAPC with a frequency of up to 40 Hz. The number of pulses in the counter is then reported via the station bus to the substation automation system or read via the station monitoring system as a service value. When using IEC 61850, a scaled service value is available over the station bus.

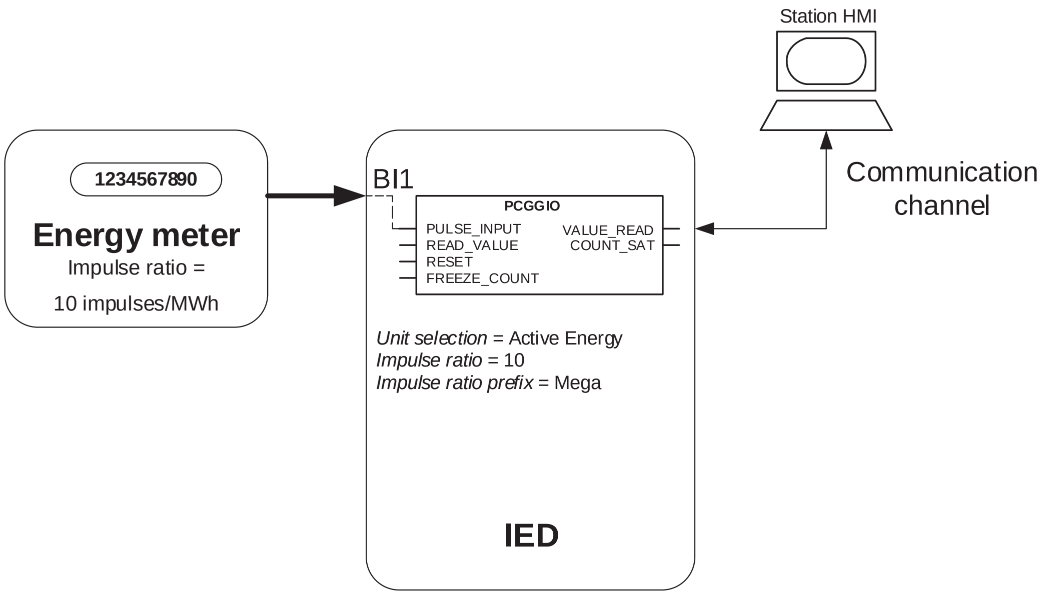


Figure 151: Typical application of PCGAPC

PCGAPC can also be used as a general-purpose counter.

3.20.14.6 Signals

PCGAPC Input signals

Table 251: PCGAPC Input signals

Name	Type	Default	Description
PULSE_INPUT	BOOLEAN	0=False	Connect binary input channel for counting
READ_VALUE	BOOLEAN	0=False	Initiates an additional pulse counter reading
RESET	BOOLEAN	0=False	Resets pulse counter value
FREEZE_COUNT	BOOLEAN	0=False	Freeze counting of pulse available at in-put

PCGAPC Output signals

Table 252: PCGAPC Output signals

Name	Type	Description
VALUE_READ	BOOLEAN	Scaled value is updated
COUNT_SAT	BOOLEAN	Counter reaches saturation limit and cannot count fur-ther

3.20.14.7 PCGAPC Settings

Table 253: PCGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Count criteria	1=Freeze 2=Rising edge 3=Falling edge 4=On change			2=Rising edge	Pulse counter criteria
Unit selection	1=Count 71=Apparent energy 72=Active energy 73=Reactive energy			1=Count	Measured quantity for SCALED_VALUE output
Impulse ratio	1...9999		1	1	Energy meter constant
Impulse ratio prefix	0=No prefix 3=k 6=M			0=No prefix	Prefix for unit of impulse ratio
Pulse quantity	0.0001...90000.0000		0.0001	1.0000	Factor to be multiplied with COUNT_VALUE
Reporting interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes 6=180 minutes			0=1 minute	Reporting interval for counter value

3.20.14.8 PCGAPC Monitored data

Table 254: PCGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
COUNT_VALUE	INT64	0...2147483647	da	Actual pulse counter value
SCALED_VALUE	FLOAT32	0.0000...1000.0000		Scaled value derived from COUNT_VALUE

3.20.15 Hotline tag HLTGAPC

3.20.15.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Hotline tag	HLTGAPC	HLTGAPC	HLTGAPC

3.20.15.2 Function block

Figure 152: Function block

3.20.15.3 Functionality

The hotline tag function HLTGAPC is used to block all reclosing of the breaker, from both local and remote sources, when activated. When the function is activated locally, it can only be reset locally. If activated remotely, it can be reset depending on the *Remote tag mode* setting.

3.20.15.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off". When the *Operation* setting is changed from "off" to "on", the monitored variable TAG_SOURCE is set to “None” and saved to a nonvolatile memory.

When the *Operation* setting is "on" and a reboot occurs, the TAG_SOURCE variable is read from the nonvolatile memory.

The operation of HLTGAPC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

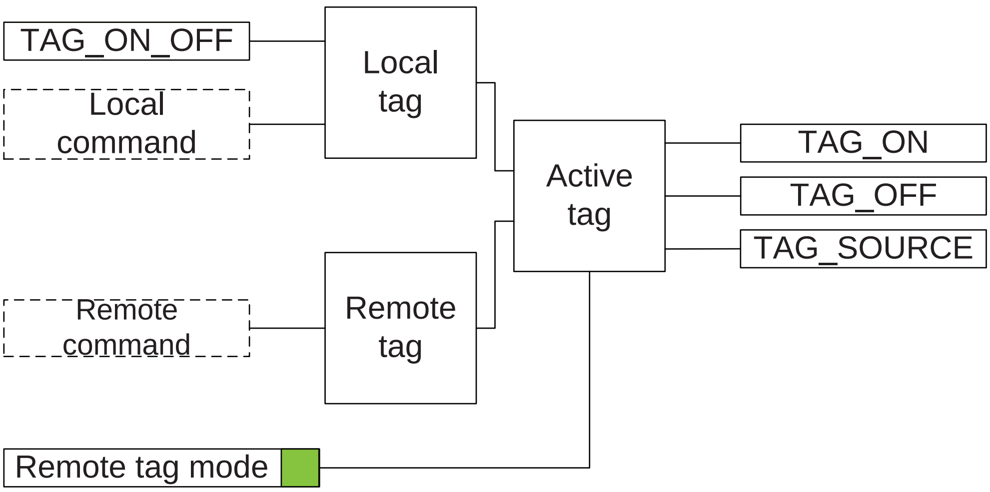


Figure 153: Functional module diagram

Local tag

Local tag is activated or deactivated on rising edge detection of `TAG_ON_OFF` input or with a local command from the LHMI when the protection relay is in local mode.

If a rising edge tag is detected locally, and the status of the nonvolatile variable TAG_SOURCE is “None”, the tag is locally activated. TAG_SOURCE changes to “Local” while `TAG_ON` is set to TRUE and `TAG_OFF` to FALSE.

If a rising edge tag is detected locally, and the status of TAG_SOURCE is “Local”, the tag is locally deactivated. TAG_SOURCE changes to “None” while `TAG_ON` is set to FALSE and `TAG_OFF` to TRUE.

When TAG_SOURCE is “Remote” and the *Remote tag mode* setting is "Untag Rem only", all local commands are prohibited. However, when the *Remote tag mode* setting is "Untag Loc or Rem", deactivation can be done locally.

Remote tag

Remote tag is activated or deactivated on rising edge detection through a communication channel in remote mode.

If a rising edge tag is detected remotely, and the status of the nonvolatile variable TAG_SOURCE is “None”, the tag is remotely activated. TAG_SOURCE changes to “Remote” while `TAG_ON` is set to TRUE and `TAG_OFF` to FALSE.

If a rising edge tag is detected remotely, and the status of TAG_SOURCE is “Remote”, the tag is remotely deactivated. TAG_SOURCE changes to “None” while `TAG_ON` is set to FALSE and `TAG_OFF` to TRUE.

If TAG_SOURCE is “Local”, remote commands are always prohibited.

3.20.15.5 Application

HLTGAPC is used to prevent the protection relay from reclosing and re-energizing a feeder where maintenance is performed. While HLTGAPC is active, no reclosing is allowed regardless of whether it is initiated through a protection trip, requested locally through the LHMI, or remotely through a communications command.

In order to operate correctly, HLTGAPC must be properly configured with Application Configuration. The `TAG_ON` and `TAG_OFF` outputs are connected where they can block or enable any reclosing that is configured. Typically, `TAG_ON` can be used on a recloser function block to inhibit reclosing and `TAG_OFF` can be used on a circuit breaker function block to enable closing.

A LED or a button on the LHMI can be used to indicate that the HLTGAPC condition is active. HLTGAPC can be activated, and the panel tagged, from the LHMI or from a remote communications command. The protection relay retains the original source (local or remote) of HLTGAPC and allows HLTGAPC to be deactivated only from the same source. That is, a locally initiated HLTGAPC can only be deactivated locally and a remotely initiated HLTGAPC can only be deactivated remotely. An exception to this rule allowing remotely initiated HLTGAPC commands to be deactivated locally can be made by changing the *Remote tag mode* setting from the default "Untag Rem only" to "Untag Loc or Rem". It is not possible to allow locally initiated HLTGAPC to be deactivated remotely.

As an alternative to using a button to activate HLTGAPC locally, the function can be activated from the Control menu of the LHMI.

The HLTGAPC status and the original source of the function are retained if power is removed and restored or through any other re-initialization of the protection relay. The HLTGAPC condition prior to the protection relay's reboot is automatically restored after the protection relay re-initializes.

The tag activation, deactivation and status information can be configured through the Graphical Display Editor (GDE).

3.20.15.6 Signals

HLTGAPC Input signals

Table 255: HLTGAPC Input signals

Name	Type	Default	Description
TAG_ON_OFF	BOOLEAN	0=False	Toggles the local tag on/off with each rising edge

HLTGAPC Output signals

Table 256: HLTGAPC Output signals

Name	Type	Description
TAG_ON	BOOLEAN	Hotline tag active
TAG_OFF	BOOLEAN	Hotline tag is not active

3.20.15.7 HLTGAPC Settings

Table 257: HLTGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Remote tag mode	1=Untag Rem only 2=Untag Loc or Rem			1=Untag Rem only	Deactivation mode for remotely set hotline tag

3.20.15.8 HLTGAPC Monitored data

Table 258: HLTGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
TAG_SOURCE	Enum	0=None 1=Local 2=Remote		Source of active hotline tag
HLTGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

3.20.16 Voltage switch VMSWI (ANSI VSWI)

3.20.16.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage switch	VMSWI	VSWI	VSWI

3.20.16.2 Function block

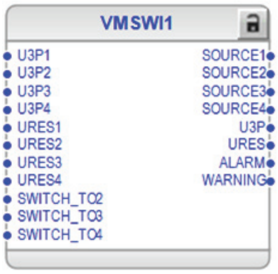


Figure 154: Function block

3.20.16.3 Functionality

The voltage switch function VMSWI performs the switching function between up to four voltage groups (Bus1, Bus 2, Bus 3 and Bus 4).

Residual voltage input can be optional and depends of the application configuration. The switching operation can also be associated with the residual voltage if available.

The calculated components U+, U- and U_0 and the calculated P2P / P2E (depending of the wye/delta mode) are switch-controlled as well.

3.20.16.4 Analog channel configuration

VMSWI has eight analog group inputs which must be properly configured. All inputs can be connected to GRPOFF.

Table 259: Analog inputs

Input	Description
U3P1 [1]	Three-phase voltages
U3P2 [1]	Three-phase voltages
U3P3 [1]	Three-phase voltages
U3P4 [1]	Three-phase voltages
URES1 [1]	Residual voltage (measured or calculated)
URES2 [1]	Residual voltage (measured or calculated)

Table continues on the next page

[1] Can be connected to GRPOFF

Input	Description
URES3 [1]	Residual voltage (measured or calculated)
URES4 [1]	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 260: Special conditions

Condition	Description
U3P1/U3P2/U3P3/U3P4 connected to real measurements	The function requires that at least one voltage channel is connected. The function requires that all the U3Px that are connected to real source must be capable of providing (at least) the same data that the default source U3P1 is capable of. E.g. if the source UTVTR conneted to U3P1 has two inputs (e.g. UL1, UL2) connected then others need to also have at least two inputs connected (e.g. UL1, UL2 or UL2, UL3 or UL3, UL1).
URES1/URES2/URES3/URES4 calculated	The function requires that all three voltage channels are connected to calculate the residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

3.20.16.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

For this function, the setting is hidden and fixed to "on".

The switch logic depends on inputs SWITCH_TO2, SWITCH_TO3 and SWITCH_TO4. Source 1 is selected as default and switching is done on increased priority.

GRPOFF signal must be connected to unused voltage inputs. GRPOFF signal is available as output from the Protection function block.

Table 261: Switching operation

Control input signals			Outputs					
SWITCH_TO 2	SWITCH_TO 3	SWITCH_TO 4	SOURCE1	SOURCE2	SOURCE3	SOURCE4	Source for U3P	Source for URES
FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	U3P1	URES1
TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	U3P2	URES2
x [1]	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	U3P3	URES3
x [1]	x [1]	TRUE	FALSE	FALSE	FALSE	TRUE	U3P4	URES4

[1] No difference

If the numbers of channels connected to U3P1...U3P4 and URES1...URES4 does not match with the number of connected SWITCH_TOx inputs, the configuration of the function fails.

Outputs ALARM and URES_ALARM indicate bad quality data of system measurements for selected U3P and URES, respectively.

Outputs WARNING and URES_WARNING indicate questionable quality data of system measurements for selected U3P and URES, respectively.

Depending on the connected U3P channels to the voltage switch, the *Primary voltage* settings between the source U3P must match. Respectively, depending on the connected URES channels, the *Primary voltage* settings between the source URES must match. Setting validation for the primary voltages fails unless they are all stored simultaneously to the protection relay.

3.20.16.6 Signals

Table 262: VMSWI Input signals

Name	Type	Default	Description
U3P1	SIGNAL	-	Three-phase voltages 1
U3P2	SIGNAL	-	Three-phase voltages 2
U3P3	SIGNAL	-	Three-phase voltages 3
U3P4	SIGNAL	-	Three-phase voltages 4
URES1	SIGNAL	-	Residual voltage 1
URES2	SIGNAL	-	Residual voltage 2
URES3	SIGNAL	-	Residual voltage 3
URES4	SIGNAL	-	Residual voltage 4
SWITCH_TO2	BOOLEAN	0=False	Switch to source 2
SWITCH_TO3	BOOLEAN	0=False	Switch to source 3
SWITCH_TO4	BOOLEAN	0=False	Switch to source 4

Table 263: VMSWI Output signals

Name	Type	Description
SOURCE1	BOOLEAN	Selected voltage source is source 1
SOURCE2	BOOLEAN	Selected voltage source is source 2
SOURCE3	BOOLEAN	Selected voltage source is source 3
SOURCE4	BOOLEAN	Selected voltage source is source 4
U3P	SIGNAL	Three-phase voltages
URES	SIGNAL	Residual voltage
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning

3.20.16.7 VMSWI Monitored data

Table 264: VMSWI Monitored data

Name	Type	Values (Range)	Unit	Description
SWITCH_POS	Enum	1=Source 1 2=Source 2 3=Source 3 4=Source 4		Switch position

3.20.17 Current switch CMSWI

3.20.17.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current switch	CMSWI	CMSWI	CMSWI

3.20.17.2 Function block

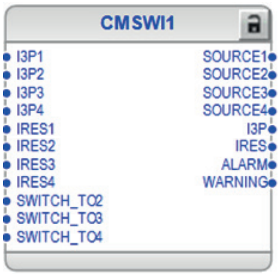


Figure 155: Function block

3.20.17.3 Functionality

The current switch function CMSWI performs the switching function between up to four current groups (Bus1, Bus 2, Bus 3 and Bus 4). The residual current input is optional and depends of the application configuration. Switching operation can also be associated with the residual current if this is available.

3.20.17.4 Analog channel configuration

CMSWI has eight analog group inputs which must be properly configured. All inputs can be connected to `GRPOFF`.

Table 265: Analog inputs

Input	Description
I3P1 [1]	Three-phase currents
I3P2 [1]	Three-phase currents
I3P3 [1]	Three-phase currents
I3P4 [1]	Three-phase currents
IRES1 [1]	Residual current (measured or calculated)
IRES2 [1]	Residual current (measured or calculated)
IRES3 [1]	Residual current (measured or calculated)
IRES4 [1]	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

3.20.17.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

For this function, the setting is hidden and fixed to "on".

The switch logic depends on inputs SWITCH_TO2, SWITCH_TO3 and SWITCH_TO4. Source 1 is selected as default and switching is done on increased priority.

GRPOFF signal must be connected to unused current inputs. GRPOFF signal is available as output from the Protection function block.

Table 266: Switching operation

Control input signals			Outputs					
SWITCH_TO 2	SWITCH_TO 3	SWITCH_TO 4	SOURCE1	SOURCE2	SOURCE3	SOURCE4	Source for I3P	Source for IRES
FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE	I3P1	IRES1
TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE	I3P2	IRES2
x [1]	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE	I3P3	IRES3
x [1]	x [1]	TRUE	FALSE	FALSE	FALSE	TRUE	I3P4	IRES4

If the numbers of channels connected to I3P1...I3P4 and IRES1...IRES4 does not match with the number of connected SWITCH_TOx inputs, the configuration of the function fails.

Outputs ALARM and IRES_ALARM indicate bad quality data of system measurements for selected I3P and IRES, respectively.

Outputs WARNING and IRES_WARNING indicate questionable quality data of system measurements for selected I3P and IRES, respectively.

[1] Can be connected to GRPOFF
[1] No difference

Depending on the connected I3P channels to the current switch, the *Primary current* settings between the source I3P must match. Depending on the connected IRES channels, the *Primary current* settings between the source IRES must match. Setting validation for the primary current fails unless they are all stored simultaneously to the protection relay.

3.20.17.6 Signals

Table 267: CMSWI Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
I3P3	SIGNAL	-	Three-phase currents 3
I3P4	SIGNAL	-	Three-phase currents 4
IRES1	SIGNAL	-	Residual current 1
IRES2	SIGNAL	-	Residual current 2
IRES3	SIGNAL	-	Residual current 3
IRES4	SIGNAL	-	Residual current 4
SWITCH_TO2	BOOLEAN	0=False	Switch to source 2
SWITCH_TO3	BOOLEAN	0=False	Switch to source 3
SWITCH_TO4	BOOLEAN	0=False	Switch to source 4

Table 268: CMSWI Output signals

Name	Type	Description
SOURCE1	BOOLEAN	Selected current source is source 1
SOURCE2	BOOLEAN	Selected current source is source 2
SOURCE3	BOOLEAN	Selected current source is source 3
SOURCE4	BOOLEAN	Selected current source is source 4
I3P	SIGNAL	Three-phase currents
IRES	SIGNAL	Residual current
ALARM	BOOLEAN	Alarm
WARNING	BOOLEAN	Warning

3.20.17.7 CMSWI Monitored data

Table 269: CMSWI Monitored data

Name	Type	Values (Range)	Unit	Description
SWITCH_POS	Enum	1=Source 1 2=Source 2		Switch position

Name	Type	Values (Range)	Unit	Description
		3=Source 3 4=Source 4		

3.20.18 Generic up-down counter UDFCNT

3.20.18.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Generic up-down counter	UDFCNT	UDCNT	UDCNT

3.20.18.2 Function block

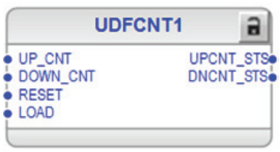


Figure 156: Function block

3.20.18.3 Functionality

The Generic up-down counter function UDFCNT counts up or down for each positive edge of the corresponding inputs. The counter value output can be reset to zero or preset to some other value if required.

The function provides up-count and down-count status outputs, which specify the relation of the counter value to a loaded preset value and to zero respectively.

3.20.18.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of UDFCNT can be described with a module diagram. All the modules in the diagram are explained in the next sections.

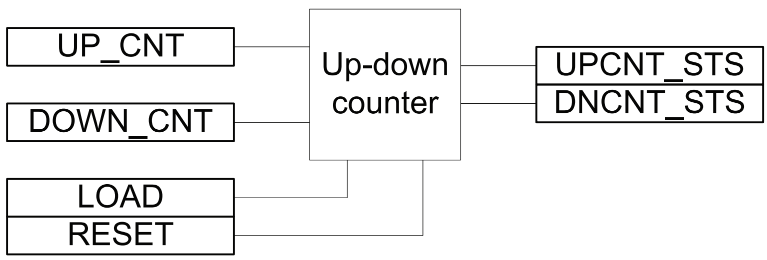


Figure 157: Functional module diagram

Up-down counter

Each rising edge of the UP_CNT input increments the counter value CNT_VAL by one and each rising edge of the DOWN_CNT input decrements the CNT_VAL by one. If there is a rising edge at both the inputs UP_CNT and DOWN_CNT, the counter value CNT_VAL is unchanged. The CNT_VAL is available in the monitored data view.

The counter value CNT_VAL is stored in a nonvolatile memory. The range of the counter is 0...+2147483647. The count of CNT_VAL saturates at the final value of 2147483647, that is, no further increment is possible.

The value of the setting *Counter load value* is loaded into counter value CNT_VAL either when the LOAD input is set to "True" or when the *Load Counter* is set to "Load" in the LHMI. Until the LOAD input is "True", it prevents all further counting.

The function also provides status outputs UPCNT_STS and DNCNT_STS. The UPCNT_STS is set to "True" when the CNT_VAL is greater than or equal to the setting Counter load value. DNCNT_STS is set to "True" when the CNT_VAL is zero.

The RESET input is used for resetting the function. When this input is set to "True" or when *Reset counter* is set to "reset", the CNT_VAL is forced to zero.

3.20.18.5 Signals

Table 270: UDFCNT Input signals

Name	Type	Default	Description
UP_CNT	BOOLEAN	0=False	Input for up counting
DOWN_CNT	BOOLEAN	0=False	Input for down counting
RESET	BOOLEAN	0=False	Reset input for counter
LOAD	BOOLEAN	0=False	Load input for counter

Table 271: UDFCNT Output signals

Name	Type	Description
UPCNT_STS	BOOLEAN	Status of the up counting
DNCNT_STS	BOOLEAN	Status of the down counting

3.20.18.6 Settings

Table 272: UDFCNT Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Counter load value	0...2147483647		1	10000	Preset counter value
Reset counter	0=Cancel			0=Cancel	Resets counter value

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Reset				
Load counter	0=Cancel 1=Load			0=Cancel	Loads the counter to preset value

3.20.18.7 Monitored data

Table 273: UDFCNT Monitored data

Name	Type	Values (Range)	Unit	Description
CNT_VAL	INT64	0...2147483647		Output counter value

3.20.19 Current sum CMSUM (ANSI CSUM)

3.20.19.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current sum	CMSUM	CSUM	CSUM

3.20.19.2 Function block

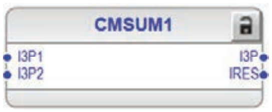


Figure 158: Function block

3.20.19.3 Functionality

The current sum function CMSUM is a phase-by-phase specific summing function for two current triplets. Output `I3P` can be used as normal current input for the application functions using current. Different measurement modes (DFT, RMS, Peak-to-peak) are supported. Also, positive, negative and zero-sequence components are calculated for the summed currents. Output `IRES` provides the calculated residual current based on the summed currents.

Example configuration:

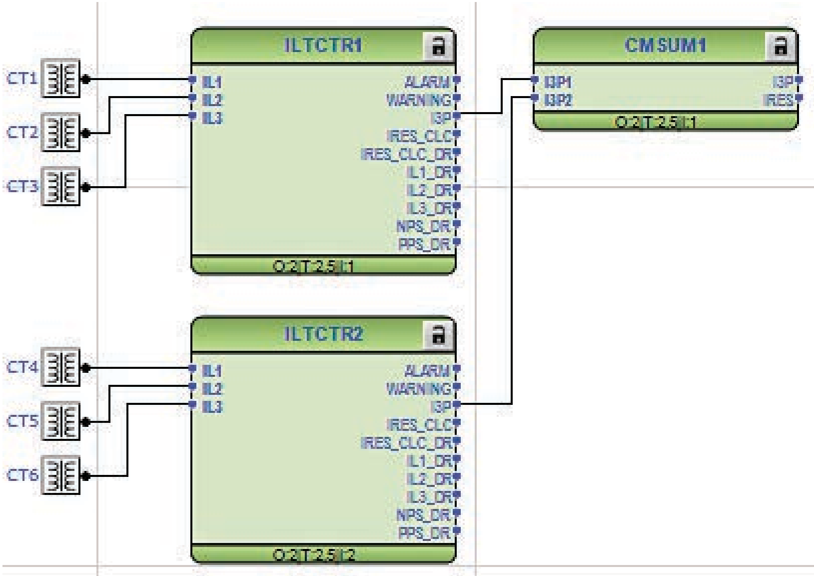


Figure 159: Current summing configuration

3.20.19.4 Analog channel configuration

CMSUM has two analog group inputs which must be properly configured, that is, both of the ILTCTR function blocks connected to these inputs must have the same primary current setting value.

Table 274: Analog inputs

Input	Description
I3P1	Three-phase currents
I3P2	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

3.20.19.5 Signals

Table 275: CMSUM Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2

Table 276: CMSUM Output signals

Name	Type	Description
I3P	SIGNAL	Summed three-phase currents
IRES	SIGNAL	Calculated residual current of summed three-phase currents

3.20.20 Transformer data combiner OLGAPC

3.20.20.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Transformer data combiner	OLGAPC	OLGAPC	OLGAPC

3.20.20.2 Function block

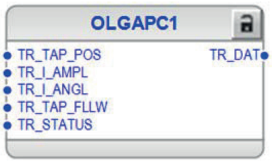


Figure 160: Function block

3.20.20.3 Functionality

The transformer data combiner function OLGAPC is intended for the voltage regulator function OL5ATCC.

3.20.20.4 Operation principle

The function of OLGAPC is to collect data from a parallel transformer via GOOSE communication. The `TR_DAT` output, which contains the combined input data, is connected to the OL5ATCC function block.

3.20.20.5 Application

See the application example in *Figure 161*.

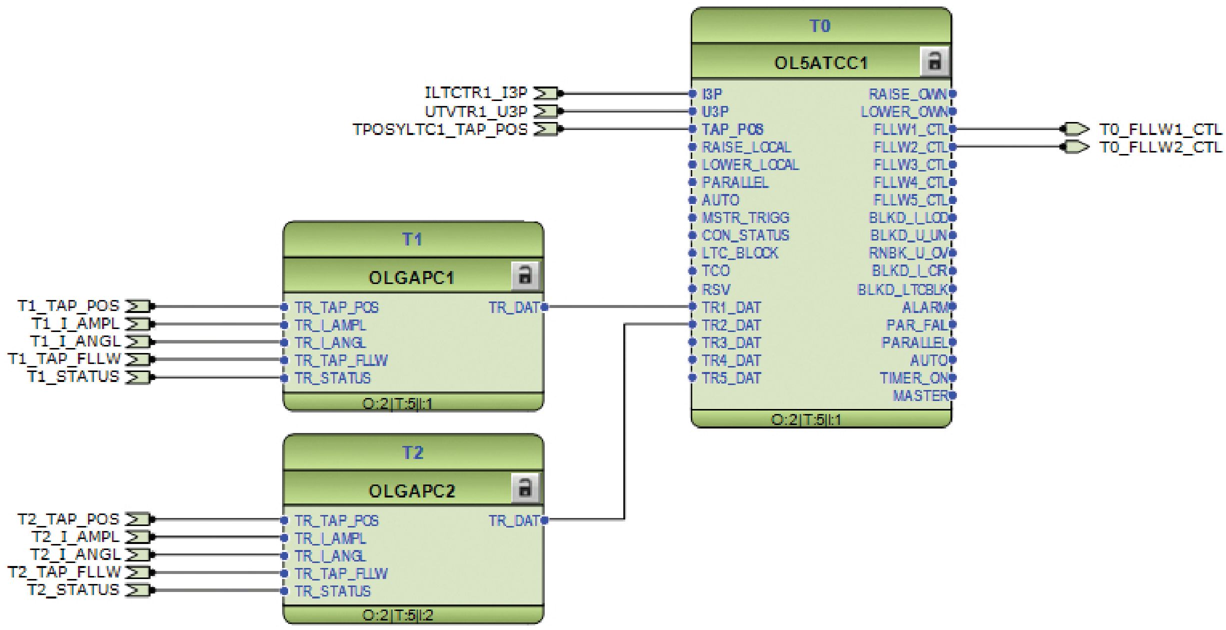


Figure 161: Application example

3.20.20.6 Signals

OLGAPC Input signals

Table 277: OLGAPC Input signals

Name	Type	Default	Description
TR_TAP_POS	INT32	0	Integer value representing tap changer position of transformer
TR_I_AMPL	FLOAT32	0.00	Received current magnitude from transformer
TR_I_ANGL	FLOAT32	0.00	Received current angle from transformer
TR_STATUS	Enum	0=Independent	Transformer status information

OLGAPC Output signals

Table 278: OLGAPC Output signals

Name	Type	Description
TR_DAT	INT8_TRDAT	Analog output

3.20.21 Controllable gate, 8 channels GATEGAPC

3.20.21.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Controllable gate, 8 channels	GATEGAPC	GATEGAPC	GATEGAPC

3.20.21.2 Function block

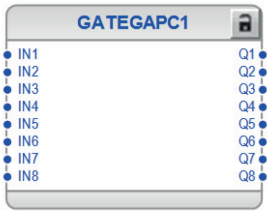


Figure 162: Function block

3.20.21.3 Functionality

Controllable gate function GATEGAPC can pass each input IN1...IN8 to output Q1...Q8 depending on the related setting *Connect INx to Qx*. Additionally, each output Qx can be named with *Description* setting.

3.20.21.4 Signals

Table 279: GATEGAPC Input signals

Name	Type	Default	Description
IN1	BOOLEAN	0	IN1 status
IN2	BOOLEAN	0	IN2 status
IN3	BOOLEAN	0	IN3 status
IN4	BOOLEAN	0	IN4 status
IN5	BOOLEAN	0	IN5 status
IN6	BOOLEAN	0	IN6 status
IN7	BOOLEAN	0	IN7 status
IN8	BOOLEAN	0	IN8 status

Table 280: GATEGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Q1 status
Q2	BOOLEAN	Q2 status
Q3	BOOLEAN	Q3 status

Table continues on the next page

Name	Type	Description
Q4	BOOLEAN	Q4 status
Q5	BOOLEAN	Q5 status
Q6	BOOLEAN	Q6 status
Q7	BOOLEAN	Q7 status
Q8	BOOLEAN	Q8 status

3.20.21.5 Settings

Table 281: GATEGAPC settings

Parameter	Values (Range)	Unit	Step	Default	Description
Connect IN1 to Q1	1=On 0=Off			0=Off	IN1 to Q1 connection
Description	GATEGAPC1 Q1				Output description
Connect IN2 to Q2	1=On 0=Off			0=Off	IN2 to Q2 connection
Description	GATEGAPC1 Q2				Output description
Connect IN3 to Q3	1=On 0=Off			0=Off	IN3 to Q3 connection
Description	GATEGAPC1 Q3				Output description
Connect IN4 to Q4	1=On 0=Off			0=Off	IN4 to Q4 connection
Description	GATEGAPC1 Q4				Output description
Connect IN5 to Q5	1=On 0=Off			0=Off	IN5 to Q5 connection
Description	GATEGAPC1 Q5				Output description
Connect IN6 to Q6	1=On 0=Off			0=Off	IN6 to Q6 connection
Description	GATEGAPC1 Q6				Output description
Connect IN7 to Q7	1=On 0=Off			0=Off	IN7 to Q7 connection
Description	GATEGAPC1 Q7				Output description
Connect IN8 to Q8	1=On 0=Off			0=Off	IN8 to Q8 connection
Description	GATEGAPC1 Q8				Output description

3.21 Standard logic operators

3.21.1 OR gate with two inputs OR, six inputs OR6 and twenty inputs OR20

3.21.1.1 Function block

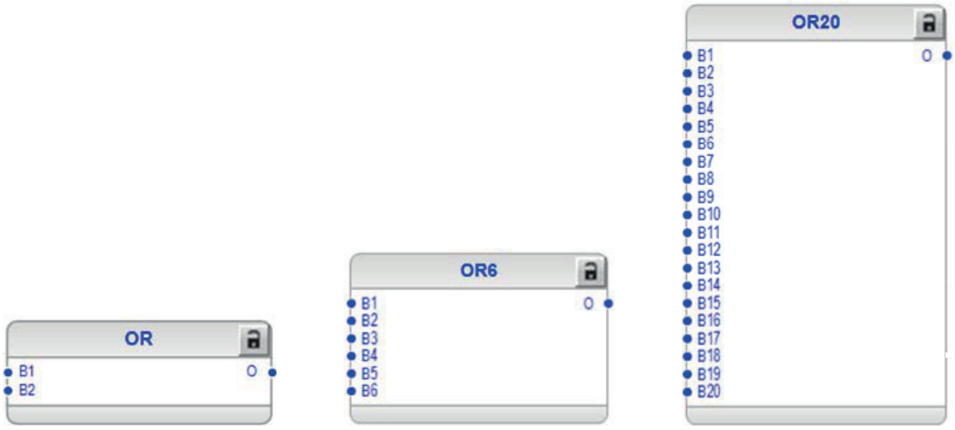


Figure 163: Function block

3.21.1.2 Functionality

OR, OR6 and OR20 are used to form general combinatory expressions with boolean variables.

The O output is activated when at least one input has the value TRUE. The default value of all inputs is FALSE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

OR has two inputs, OR6 six and OR20 twenty inputs.

3.21.1.3 Signals

Table 282: OR Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2

Table 283: OR6 Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2
B3	BOOLEAN	0	Input signal 3
B4	BOOLEAN	0	Input signal 4
B5	BOOLEAN	0	Input signal 5
B6	BOOLEAN	0	Input signal 6

Table 284: OR20 Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2
B3	BOOLEAN	0	Input signal 3
B4	BOOLEAN	0	Input signal 4
B5	BOOLEAN	0	Input signal 5
B6	BOOLEAN	0	Input signal 6
B7	BOOLEAN	0	Input signal 7
B8	BOOLEAN	0	Input signal 8
B9	BOOLEAN	0	Input signal 9
B10	BOOLEAN	0	Input signal 10
B11	BOOLEAN	0	Input signal 11
B12	BOOLEAN	0	Input signal 12
B13	BOOLEAN	0	Input signal 13
B14	BOOLEAN	0	Input signal 14
B15	BOOLEAN	0	Input signal 15
B16	BOOLEAN	0	Input signal 16
B17	BOOLEAN	0	Input signal 17
B18	BOOLEAN	0	Input signal 18
B19	BOOLEAN	0	Input signal 19
B20	BOOLEAN	0	Input signal 20

Table 285: OR Output signals

Name	Type	Description
O	BOOLEAN	Output signal

Table 286: OR6 Output signals

Name	Type	Description
O	BOOLEAN	Output signal

Table 287: OR20 Output signals

Name	Type	Description
O	BOOLEAN	Output signal

3.21.1.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.2 AND gate with two inputs AND, six inputs AND6 and twenty inputs AND20

3.21.2.1 Function block

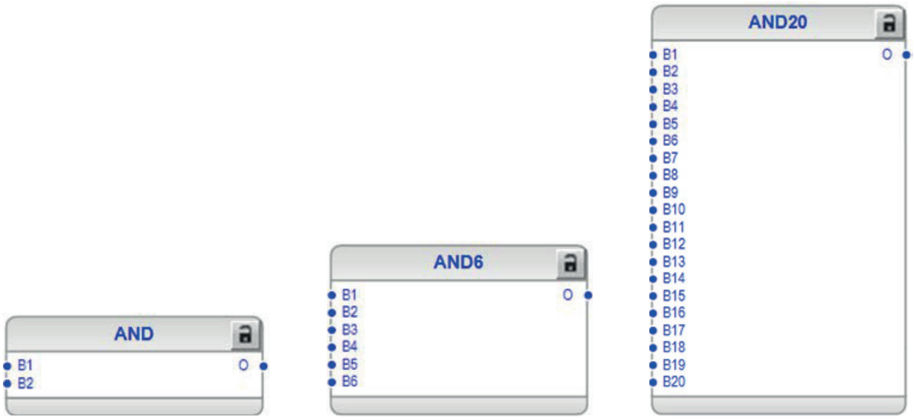


Figure 164: Function blocks

3.21.2.2 Functionality

AND, AND6 and AND20 are used to form general combinatory expressions with boolean variables.

The default value in all inputs is logical TRUE, which makes it possible to use only the required number of inputs and leave the rest disconnected.

AND has two inputs, AND6 six inputs and AND20 twenty inputs.

3.21.2.3 Signals

Table 288: AND Input signals

Name	Type	Default	Description
B1	BOOLEAN	1	Input signal 1
B2	BOOLEAN	1	Input signal 2

Table 289: AND6 Input signals

Name	Type	Default	Description
B1	BOOLEAN	1	Input signal 1
B2	BOOLEAN	1	Input signal 2
B3	BOOLEAN	1	Input signal 3
B4	BOOLEAN	1	Input signal 4
B5	BOOLEAN	1	Input signal 5
B6	BOOLEAN	1	Input signal 6

Table 290: AND20 Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2
B3	BOOLEAN	0	Input signal 3
B4	BOOLEAN	0	Input signal 4
B5	BOOLEAN	0	Input signal 5
B6	BOOLEAN	0	Input signal 6
B7	BOOLEAN	0	Input signal 7
B8	BOOLEAN	0	Input signal 8
B9	BOOLEAN	0	Input signal 9
B10	BOOLEAN	0	Input signal 10
B11	BOOLEAN	0	Input signal 11
B12	BOOLEAN	0	Input signal 12
B13	BOOLEAN	0	Input signal 13
B14	BOOLEAN	0	Input signal 14
B15	BOOLEAN	0	Input signal 15
B16	BOOLEAN	0	Input signal 16
B17	BOOLEAN	0	Input signal 17
B18	BOOLEAN	0	Input signal 18
B19	BOOLEAN	0	Input signal 19
B20	BOOLEAN	0	Input signal 20

Table 291: AND Output signals

Name	Type	Description
O	BOOLEAN	Output signal

Table 292: AND6 Output signals

Name	Type	Description
O	BOOLEAN	Output signal

Table 293: AND20 Output signals

Name	Type	Description
O	BOOLEAN	Output signal

3.21.2.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.3 XOR gate with two inputs XOR

3.21.3.1 Function block

Figure 165: Function block

3.21.3.2 Functionality

The exclusive OR function XOR is used to generate combinatory expressions with boolean variables.

The output signal is TRUE if the input signals are different and FALSE if they are equal.

3.21.3.3 Signals

Table 294: XOR Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2

Table 295: XOR Output signals

Name	Type	Description
O	BOOLEAN	Output signal

3.21.3.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.4 NOT gate NOT

3.21.4.1 Function block

Figure 166: Function block

3.21.4.2 Functionality

NOT is used to generate combinatory expressions with boolean variables.

NOT inverts the input signal.

3.21.4.3 Signals

Table 296: NOT Input signal

Name	Type	Default	Description
1	BOOLEAN	0	Input signal

Table 297: NOT Output signal

Name	Type	Description
O	BOOLEAN	Output signal

3.21.4.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.5 Rising edge detector R_TRIG

3.21.5.1 Function block

Figure 167: Function block

3.21.5.2 Functionality

R_TRIG is used as a rising edge detector.

R_TRIG detects the transition from FALSE to TRUE at the `CLK` input. When the rising edge is detected, the element assigns the output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

3.21.5.3 Signals

Table 298: R_TRIG Input signals

Name	Type	Default	Description
CLK	BOOLEAN	0	Input signal

Table 299: R_TRIG Output signals

Name	Type	Description
Q	BOOLEAN	Output signal

3.21.5.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.6 Falling edge detector F_TRIG

3.21.6.1 Function block

Figure 168: Function block

3.21.6.2 Functionality

F_TRIG is used as a falling edge detector.

The function detects the transition from TRUE to FALSE at the CLK input. When the falling edge is detected, the element assigns the Q output to TRUE. At the next execution round, the output is returned to FALSE despite the state of the input.

3.21.6.3 Signals

Table 300: F_TRIG Input signals

Name	Type	Default	Description
CLK	BOOLEAN	0	Input signal

Table 301: F_TRIG Output signals

Name	Type	Description
Q	BOOLEAN	Output signal

3.21.6.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.7 Switching device status decoder CLOSE position T_POS_CL, OPEN position T_POS_OP and OK status T_POS_OK

3.21.7.1 Function block

Figure 169: Function blocks

3.21.7.2 Functionality

The circuit breaker position information can be communicated with the IEC 61850 GOOSE messages. The position information is a double binary data type which is fed to the POS input.

T_POS_CL and T_POS_OP are used for extracting the circuit breaker status information. Respectively, T_POS_OK is used to validate the intermediate or faulty breaker position.

Table 302: Cross reference between circuit breaker position and function block output

Circuit breaker position	Output of the function block		
	T_POS_CL	T_POS_OP	T_POS_OK
Intermediate '00'	FALSE	FALSE	FALSE
Close '01'	TRUE	FALSE	TRUE
Open '10'	FALSE	TRUE	TRUE
Faulty '11'	TRUE	TRUE	FALSE

3.21.7.3 Signals

Table 303: T_POS_CL Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 304: T_POS_OP Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 305: T_POS_OK Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 306: T_POS_CL Output signals

Name	Type	Description
CLOSE	BOOLEAN	Output signal

Table 307: T_POS_OP Output signals

Name	Type	Description
CLOSE	BOOLEAN	Output signal

Table 308: T_POS_OK Output signals

Name	Type	Description
CLOSE	BOOLEAN	Output signal

3.21.7.4 Settings

The function does not have any parameters available in LHMI or PCM600.

3.21.8 SR flip-flop, volatile SR

3.21.8.1 Function block

Figure 170: Function block

3.21.8.2 Functionality

The SR flip-flop output Q can be set or reset from the S or R inputs. S input has a higher priority over the R input. Output NOTQ is the negation of output Q.

The statuses of outputs Q and NOTQ are not retained in the nonvolatile memory.

Table 309: Truth table for SR flip-flop

S	R	Q
0	0	0 [1]
0	1	0
1	0	1
1	1	1

3.21.8.3 Signals

Table 310: SR Input signals

Name	Type	Default	Description
S	BOOLEAN	0=False	Set Q output when set
R	BOOLEAN	0=False	Resets Q output when set

Table 311: SR Output signals

Name	Type	Description
Q	BOOLEAN	Q status
NOTQ	BOOLEAN	NOTQ status

3.21.9 RS flip-flop, volatile RS

3.21.9.1 Function block

Figure 171: Function block

3.21.9.2 Functionality

The RS flip-flop output Q can be set or reset from the S or R inputs. R input has a higher priority over the S input. Output NOTQ is the negation of output Q.

The statuses of outputs Q and NOTQ are not retained in the nonvolatile memory.

[1] Keep state/no change

Table 312: Truth table for RS flip-flop

S	R	Q
0	0	0 [1]
0	1	0
1	0	1
1	1	0

3.21.9.3 Signals

Table 313: RS Input signals

Name	Type	Default	Description
S	BOOLEAN	0=False	Set Q output when set
R	BOOLEAN	0=False	Resets Q output when set

Table 314: RS Output signals

Name	Type	Description
Q	BOOLEAN	Q status
NOTQ	BOOLEAN	NOTQ status

3.22 Mathematical operators

3.22.1 Real addition ADDR

3.22.1.1 Function block

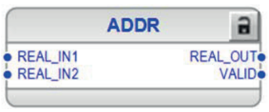


Figure 172: Function block

3.22.1.2 Functionality

The real addition function ADDR adds the inputs `REAL_IN1` and `REAL_IN2` together. ADDR executes the equation

`REAL_OUT` = `REAL_IN1` + `REAL_IN2`

[1] Keep state/no change

If the value of the sum is outside the range, then the output quality is set as bad and VALID is set to FALSE. The minimum negative sum value is restricted to –2097152.000 and the maximum positive sum value is restricted to 2097152.000.

3.22.1.3 Signals

Table 315: ADDR Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2

Table 316: ADDR Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real output 1
VALID	BOOLEAN	Output validity

3.22.2 Real division DIVR

3.22.2.1 Function block

Figure 173: Function block

3.22.2.2 Functionality

The real division function DIVR divides the REAL_IN1 input by REAL_IN2. DIVR executes the equation

$$REAL\_OUT = \frac{REAL\_IN1}{REAL\_IN2}$$

(Equation 8)

If the denominator value is less than ≈ 0.001, the resultant quotient is considered out of range.

If the value of the quotient is outside the range, then the output quality is set as bad and VALID is set to FALSE. The minimum negative quotient value is restricted to –2097152.000 and the maximum positive quotient value is restricted to 2097152.000.

3.22.2.3 Signals

Table 317: DIVR Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2

Table 318: DIVR Output signals

Name	Type	Description
REAL_OUT	IN1	Real output
VALID	BOOLEAN	Output validity

3.22.3 Real multiplication MULR

3.22.3.1 Function block

Figure 174: Function block

3.22.3.2 Functionality

The real multiplication function MULR multiplies the real input `REAL_IN1` by the real input `REAL_IN2` together. MULR executes the equation

`REAL_OUT` = `REAL_IN1` x `REAL_IN2`

If the value of the product is outside the range, then the output quality is set as bad and `VALID` is set to FALSE. The minimum negative product value is restricted to -2097152.000 and the maximum positive product value is restricted to 2097152.000.

3.22.3.3 Signals

Table 319: MULR Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2

Table 320: MULR Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real output
VALID	BOOLEAN	Output validity

3.22.4 Real subtraction SUBR

3.22.4.1 Function block

Figure 175: Function block

3.22.4.2 Functionality

The real subtraction function SUBR subtracts input `REAL_IN2` from `REAL_IN1`. SUBR executes the equation

`REAL_OUT` = `REAL_IN1` – `REAL_IN2`

If the value of the difference is outside the range, then the output quality is set as bad and `VALID` is set to FALSE. The minimum negative difference value is restricted to –2097152.000 and the maximum positive difference value is restricted to 2097152.000.

3.22.4.3 Signals

Table 321: SUBR Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2

Table 322: SUBR Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real output
VALID	BOOLEAN	Output validity

3.22.5 Real equal comparator EQR

3.22.5.1 Function block

Figure 176: Function block

3.22.5.2 Functionality

The real equal comparator function EQR compares the real input REAL_IN1 with the real input REAL_IN2 and activates the binary output OUT if REAL_IN1 is within the region of REAL_IN2 + TOLR and REAL_IN2 –TOLR, that is, if REAL_IN1 ≥ (REAL_IN2 – TOLR) and REAL_IN1 ≤ (REAL_IN2 + TOLR), OUT = 1, else OUT = 0.

If inputs REAL_IN1 or REAL_IN2 are outside the range, then OUT is set to 0.

Figure 177: Region of EQR comparison

EQR requires a positive value for TOLR, otherwise it may not function properly. The TOLR value can be set using SETRGAPC.

EQR function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have closely varying values.

3.22.5.3 Signals

Table 323: EQR Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2
TOLR	FLOAT32	0	Tolerance for comparison

Table 324: EQR Output signals

Name	Type	Description
OUT	BOOLEAN	Output value

3.22.6 Real not equal comparator NER

3.22.6.1 Function block

Figure 178: Function block

3.22.6.2 Functionality

The real not equal comparator function NER compares the real input REAL_IN1 with the real input REAL_IN2 and activates the binary output OUT if REAL_IN1 is outside the region of REAL_INT2 + TOLR and REAL_IN2 - TOLR. That is, if REAL_IN1 < (REAL_IN2 - TOLR) or REAL_IN1 > (REAL_IN2 + TOLR), OUT= 1, else OUT = 0.

If inputs REAL_IN1 or REAL_IN2 are outside the range, then OUT is set to 0.

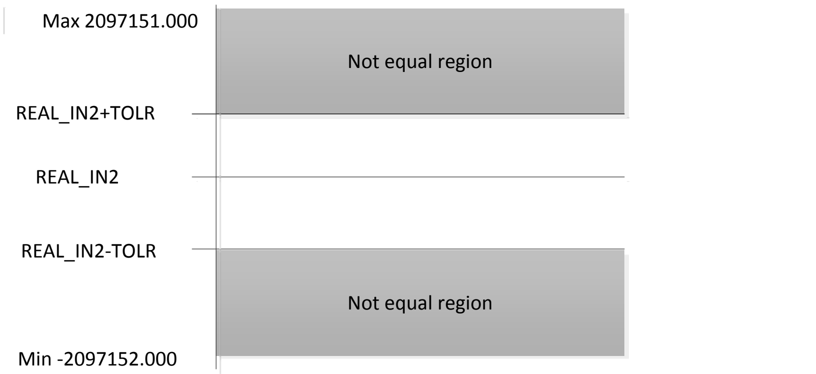


Figure 179: Region of NER comparison

NER requires a positive value for TOLR, otherwise it may not function properly. The TOLR value can be set using SETRGAPC.

NER function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have closely varying values.

3.22.6.3 Signals

Table 325: NER Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2
TOLR	FLOAT32	0	Tolerance for comparison

Table 326: NER Output signals

Name	Type	Description
OUT	BOOLEAN	Output value

3.22.7 Real greater than or equal comparator GER

3.22.7.1 Function block

Figure 180: Function block

3.22.7.2 Functionality

The real greater than or equal comparator function GER compares the real input REAL_IN1 with the real input REAL_IN2 and activates the binary output OUT if REAL_IN1 is equal to or greater than REAL_IN2 - TOLR or greater than input REAL_IN2. That is, if REAL_IN1≥ (REAL_IN2 - TOLR) or REAL_IN1 > (REAL_IN2), OUT = 1, else OUT = 0.

If inputs REAL_IN1 or REAL_IN2 are outside the range, then OUT is set to 0.

Figure 181: Region of GER comparison

GER function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have closely varying values.

3.22.7.3 Signals

Table 327: GER Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2
TOLR	FLOAT32	0	Tolerance for comparison

Table 328: GER Output signals

Name	Type	Description
OUT	BOOLEAN	Output value

3.22.8 Real less than or equal comparator LER

3.22.8.1 Function block

Figure 182: Function block

3.22.8.2 Functionality

The real less than or equal comparator function LER compares real input REAL_IN1 with the real input REAL_IN2 and activates the binary output OUT if REAL_IN1 is equal to or less than REAL_IN2 + TOLR or less than REAL_IN2 input. That is, if REAL_IN1 ≤ (REAL_IN2 + TOLR) or REAL_IN1 < (REAL_IN2), OUT = 1, else OUT = 0.

LER function blocks do not have the hysteresis feature. Oscillating outputs should be avoided when comparing analog signals that have closely varying values.

Figure 183: Region of LER comparison

3.22.8.3 Signals

Table 329: LER Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input 1
REAL_IN2	FLOAT32	0	Real input 2
TOLR	FLOAT32	0	Tolerance for comparison

Table 330: LER Output signals

Name	Type	Description
OUT	BOOLEAN	Output value

3.22.9 Real maximum value selector MAX3R

3.22.9.1 Function block

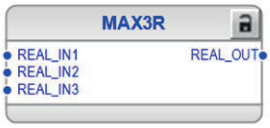


Figure 184: Function block

3.22.9.2 Functionality

The real maximum value selector function MAX3R selects the maximum value from three analog values. Disconnected inputs and inputs whose quality is bad are ignored. If all inputs are disconnected or the quality is bad, MAX3R output value is set to -2^{21}.

3.22.9.3 Signals

Table 331: MAX3R Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input value 1
REAL_IN2	FLOAT32	0	Real input value 2
REAL_IN3	FLOAT32	0	Real input value 3

Table 332: MAX3R Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real output value

3.22.10 Real minimum value selector MIN3R

3.22.10.1 Function block

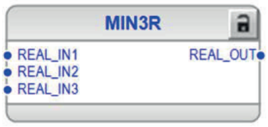


Figure 185: Function block

3.22.10.2 Functionality

The real minimum value selector function MIN3R selects the minimum value from three analog values. Disconnected inputs and inputs whose quality is bad are ignored. If all inputs are disconnected or the quality is bad, MIN3R output value is set to 2^{21}.

3.22.10.3 Signals

Table 333: MIN3R Input signals

Name	Type	Default	Description
REAL_IN1	FLOAT32	0	Real input value 1
REAL_IN2	FLOAT32	0	Real input value 2
REAL_IN3	FLOAT32	0	Real input value 3

Table 334: MIN3R Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real output value

3.22.11 Real switch selector SWITCHR

3.22.11.1 Function block

Figure 186: Function block

3.22.11.2 Functionality

The real switch selector function SWITCHR is operated by the `CTL_SW` input and selects the output value `REAL_OUT` between the `REAL_IN1` and `REAL_IN2` inputs.

Table 335: SWITCHR

CTL_SW value	REAL_OUT value
TRUE (1)	REAL_IN1
FALSE (0)	REAL_IN2

3.22.11.3 Signals

Table 336: SWITCHR Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	0	Control Switch
REAL_IN1	FLOAT32	0	Real input value 1
REAL_IN2	FLOAT32	0	Real input value 2

Table 337: SWITCHR Output signals

Name	Type	Description
REAL_OUT	FLOAT32	Real switch output

3.22.12 Integer 32-bit switch selector SWITCHI32

3.22.12.1 Function block

Figure 187: Function block

3.22.12.2 Functionality

The integer 32-bit switch selector function SWITCHI32 is operated by the `CTL_SW` input, which selects the output value `INT32_OUT` between the `INT32_IN1` and `INT32_IN2` inputs.

Table 338: SWITCHI32

CTL_SW value	INT_OUT value
FALSE (0)	INT32_IN1
TRUE (1)	INT32_IN2

3.22.12.3 Signals

Table 339: SWITCHI32 Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	0	Control Switch
INT_IN1	INT32	0	Integer input value 1
INT_IN2	INT32	0	Integer input value 2

Table 340: SWITCHI32 Output signals

Name	Type	Description
INT_OUT	INT32	Integer switch output

3.23 Factory settings restoration

In case of configuration data loss or any other file system error that prevents the protection relay from working properly, the whole file system can be restored to the original factory state. All default settings and configuration files stored in the factory are restored. For further information on restoring factory settings, see the operation manual.

3.24 Load profile LDPRLRC (ANSI LOADPROF)

3.24.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Load profile recorder	LDPRLRC	LOADPROF	LOADPROF

3.24.2 Function block

Figure 188: Function block

3.24.3 Functionality

The protection relay is provided with a load profile recorder. The load profile feature stores the historical load data captured at a periodical time interval (demand interval). Up to 12 load quantities can be selected for recording and storing in a nonvolatile memory. The value range for the recorded load quantities is about eight times the nominal value, and values higher than that saturate. The recording time depends on a settable demand interval parameter and the amount of quantities selected. The record output is in the COMTRADE format.

3.24.3.1 Quantities

Table 341: Signals supported by the load profile recorder

Function	Signal	Description
CMMXU	I_DMD_A	Demand value of IL1 current
	I_DMD_B	Demand value of IL2 current
	I_DMD_C	Demand value of IL3 current

Table continues on the next page

Function	Signal	Description
PEMMXU	S_DMD	Demand value of apparent power
	P_DMD	Demand value of active power
	Q_DMD	Demand value of reactive power
	PF_DMD	Demand value of power factor
RESCMMXU	I_DMD_RES	Demand value of residual current
VMMXU	U_DMD_AB	Demand value of U12 voltage
	U_DMD_BC	Demand value of U23 voltage
	U_DMD_CA	Demand value of U31 voltage
	U_DMD_A	Demand value of UL1 voltage
	U_DMD_B	Demand value of UL2 voltage
	U_DMD_C	Demand value of UL3 voltage
RESVMMXU	U_DMD_RES	Demand value of residual voltage
VAMMXU	U_DMD	Demand value of phase voltage

If the data source for the selected quantity is removed, for example, with Application Configuration in PCM600, the load profile recorder stops recording it and the previously collected data are cleared.

3.24.3.2 Length of record

The recording capability is about 7.4 years when one quantity is recorded and the demand interval is set to 180 minutes. The recording time scales down proportionally when a shorter demand time is selected or more quantities are recorded. The recording lengths in days with different settings used are presented in *Table 342*. When the recording buffer is fully occupied, the oldest data are overwritten by the newest data.

Table 342: Recording capability in days with different settings

	Demand interval						
	1 minute	5 minutes	10 minutes	15 minutes	30 minutes	60 minutes	180 minutes
Amount of quantities	**Recording capability in days**						
1	15.2	75.8	151.6	227.4	454.9	909.7	2729.2
2	11.4	56.9	113.7	170.6	341.1	682.3	2046.9

Table continues on the next page

	Demand interval						
3	9.1	45.5	91.0	136.5	272.9	545.8	1637.5
4	7.6	37.9	75.8	113.7	227.4	454.9	1364.6
5	6.5	32.5	65.0	97.5	194.9	389.9	1169.6
6	5.7	28.4	56.9	85.3	170.6	341.1	1023.4
7	5.1	25.3	50.5	75.8	151.6	303.2	909.7
8	4.5	22.7	45.5	68.2	136.5	272.9	818.8
9	4.1	20.7	41.4	62.0	124.1	248.1	744.3
10	3.8	19.0	37.9	56.9	113.7	227.4	682.3
11	3.5	17.5	35.0	52.5	105.0	209.9	629.8
12	3.2	16.2	32.5	48.7	97.5	194.9	584.8

3.24.3.3 Uploading of record

The protection relay stores the load profile COMTRADE files to the C:\LDP\COMTRADE folder. The files can be uploaded with the PCM600 tool or any appropriate computer software that can access the C:\LDP\COMTRADE folder.

The load profile record consists of two COMTRADE file types: the configuration file (.CFG) and the data file (.DAT). The file name is same for both file types.

To ensure that both the uploaded file types are generated from the same data content, the files need to be uploaded successively. Once either of the files is uploaded, the recording buffer is halted to give time to upload the other file.

Data content of the load profile record is sequentially updated. Therefore, the size attribute for both COMTRADE files is "0".

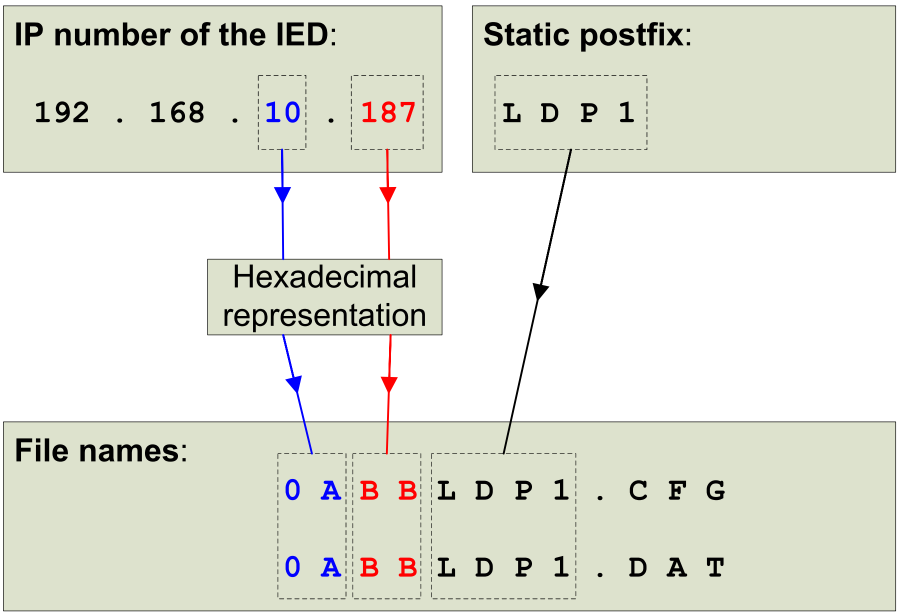


Figure 189: Load profile record file naming

3.24.3.4 Clearing of record

The load profile record can be cleared with *Reset load profile rec* via HMI, communication or the ACT input in PCM600. Clearing of the record is allowed only on the engineer and administrator authorization levels.

The load profile record is automatically cleared if the quantity selection parameters are changed or any other parameter which affects the content of the COMTRADE configuration file is changed. Also, if data source for selected quantity is removed, for example, with ACT, the load profile recorder stops recording and previously collected data are cleared.

3.24.4 Configuration

The load profile record can be configured with the PCM600 or any tool supporting the IEC 61850 standard.

The load profile record can be enabled or disabled with the *Operation* setting under the **Configuration/Load Profile Record** menu.

Any demand output can be connected to any of the quantity channels of the load profile record. The mapping is done in Application Configuration in PCM600.

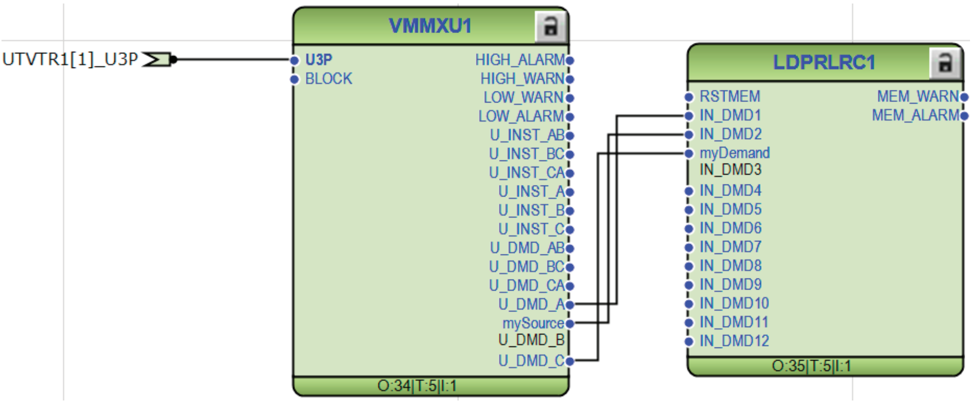


Figure 190: Example of a load profile record ACT configuration

The memory consumption of load profile record is supervised, and indicated with two signals `MEM_WARN` and `MEM_ALARM`, which could be used to notify the customer that recording should be backlogged by reading the recorded data from the protection relay. The levels for MEM_WARN and MEM_ALARM are set by two parameters *Mem.warn level* and *Mem. Alarm level*.

The IP number of the protection relay and the content of the Bay name setting are both included in the COMTRADE configuration file for identification purposes.

3.24.5 Signals

3.24.5.1 LDPRLRC Output signals

Table 343: LDPRLRC Output signals

Name	Type	Description
MEM_WARN	BOOLEAN	Recording memory warning status
MEM_ALARM	BOOLEAN	Recording memory alarm status

3.24.6 LDPRLRC Settings

Table 344: LDPRLRC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Mem. warning level	0...100	%	1	0	Set memory warning level
Mem. alarm level	0...100	%	1	0	Set memory alarm level

3.24.7 LDPRLRC Monitored data

Table 345: LDPRLRC Monitored data

Name	Type	Values (Range)	Unit	Description
Rec. memory used	INT32	0...100	%	How much recording memory is currently used

3.25 Ethernet channel supervision functions

The protection relay offers a bandwidth rate limiting functionality to limit the Ethernet/TCP network traffic. The main purpose of this feature is the possibility to divide network segments for different multicast frame types and also to limit the network congestion and traffic towards the protection relay processing during network attacks (such as a Denial of Service attack) or in case of network configuration issues.

See the cyber security deployment guideline for the Ethernet filter and rate limiter functionality.

3.25.1 Redundant Ethernet channel supervision RCHLCCH

3.25.1.1 Function block

Figure 191: Function block

3.25.1.2 Functionality

Redundant Ethernet channel supervision RCHLCCH represents LAN A and LAN B redundant Ethernet channels.

3.25.1.3 Signals

Table 346: RCHLCCH Output signals

Name	Values (Range)	Description
CHLIV	BOOLEAN	Status of redundant Ethernet channel LAN A When *Redundant mode* is set to "HSR" or "PRP", value is TRUE if the protection relay is receiving redundancy supervision frames. Otherwise the value is FALSE.
REDCHLIV	BOOLEAN	Status of redundant Ethernet channel LAN B When *Redundant mode* is set to "HSR" or "PRP", value is TRUE if the protection relay is receiving redundancy supervision frames. Otherwise the value is FALSE.
LNKLIV	BOOLEAN	Link status of redundant port LAN A Valid only when *Redundant mode* is set to "HSR" or "PRP". Value is "Up" or "Down".
REDLNKLIV	BOOLEAN	Link status of redundant port LAN B Valid only when *Redundant mode* is set to "HSR" or "PRP". Value is "Up" or "Down".

3.25.1.4 Settings

Table 347: RCHLCCH Settings

Parameter	Values (Range)	Unit	Step	Default	Description
Redundant mode	Off PRP HSR				Mode selection for Ethernet switch on redundant communication modules. The "None" mode is used with normal and Self-healing Ethernet topologies.
Filter Mode A_B	Off SMV GOOSE GOOSE & SMV			Off	Filtering selection for message types
Goose rate limiter A_B	0.512...90.000			10.000	Goose rate limit (Mbps)
SMV rate limit A_B	0.512...90.000			70.000	Sampled measured values rate limit (Mbps)
Def. rate limit A_B	0.512...90.000			8.000	Default rate limit (Mbps)

3.25.1.5 Monitored data

Monitored data is available in four locations.

- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CHLIV_A**
- **Monitoring** > **Communication/** > **Ethernet** > **Activity** > **REDCHLIV_B**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNKLIV_A**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **REDLNKLIV_B**

3.25.1.6 Diagnostics

Diagnostics data is available in **Monitoring** > **Communication** > **Ethernet** > **Diagnostics** > **A_B**.

Table 348: Diagnostic parameters for the redundant Ethernet channels LAN A and LAN B

Parameter	Values (Range)	Unit	Step	Default	Description
Reset counters	FALSE / TRUE			FALSE	Reset counters command
GOOSE limit count	0...1000000			0	Goose rate limit exceed count
SMV limit count	0...1000000			0	Sampled measured values limit exceed count
Ucast limit count	0...1000000			0	Unicast rate limit exceed count
Def. limit count	0...1000000			0	Default rate limit exceed count
GOOSE limit alarm	FALSE / TRUE			FALSE	Goose rate limit exceed alarm
SMV limit alarm	FALSE / TRUE			FALSE	Sampled measured values limit alarm
Ucast limit alarm	FALSE / TRUE			FALSE	Unicast rate limit exceed alarm
Def. limit alarm	FALSE / TRUE			FALSE	Default rate limit exceed alarm

3.25.2 Ethernet channel supervision SCHLCCH

3.25.2.1 Function block

Figure 192: Function block

3.25.2.2 Functionality

Ethernet channel supervision SCHLCCH represents X1/LAN, X2/LAN and X3/LAN Ethernet channels.

An unused Ethernet port can be set "Off" with the setting **Configuration** > **Communication** > **Ethernet** > **Rear port(s)** > **Port x Mode**. This setting closes the port from software, disabling the Ethernet communication in that port. Closing an unused Ethernet port enhances the cyber security of the relay.

3.25.2.3 Signals

Table 349: SCHLCCH1 Output signals

Name	Type	Description
CH1LIV	BOOLEAN	Status of Ethernet channel X1/LAN When *Redundant mode* is set to "None" or port is not one of the redundant ports (LAN A or LAN B), value is TRUE if the port is receiving Ethernet frames. Otherwise the value is FALSE.
LNK1LIV	BOOLEAN	Link status of Ethernet port X1/LAN Value is "Up" or "Down".

Table 350: SCHLCCH2 Output signals

Name	Type	Description
CH2LIV	BOOLEAN	Status of Ethernet channel X2/LAN When *Redundant mode* is set to "None" or port is not one of the redundant ports (LAN A or LAN B), value is TRUE if the port is receiving Ethernet frames. Otherwise the value is FALSE.
LNK2LIV	BOOLEAN	Link status of Ethernet port X2/LAN Value is "Up" or "Down".

Table 351: SCHLCCH3 Output signals

Name	Type	Description
CH3LIV	BOOLEAN	Status of Ethernet channel X3/LAN When *Redundant mode* is set to "None" or port is not one of the redundant ports (LAN A or LAN B), value is TRUE if the port is receiving Ethernet frames. Otherwise the value is FALSE.
LNK3LIV	BOOLEAN	Link status of Ethernet port X3/LAN Value is "Up" or "Down".

3.25.2.4 Settings

Table 352: SCHLCCH Settings

Parameter [1]	Values (Range)	Unit	Step	Default	Description
Port n Mode	Off On Dedicated channel [2]			On	Mode selection for rear port(s). If port is not used, it can be set to “Off”. Port cannot be set to “Off” when *Redundant mode* is “HSR” or “PRP” and port is one of the redundant ports (LAN A or LAN B).
Filter Mode Xn	Off SMV GOOSE GOOSE & SMV			Off	Selection for message filtering
Goose rate limiter Xn	0.512...90.000			10.000	Goose rate limit (Mbps)
SMV rate limit Xn	0.512...90.000			70.000	Sampled measured values rate limit (Mbps)
Def. rate limit Xn	0.512...90.000			8.000	Default rate limit (Mbps)

3.25.2.5 Monitored data

Monitored data is available in six locations.

- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CH1LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CH2LIV**
- **Monitoring/** > **Communication** > **Ethernet** > **Activity** > **CH3LIV**
- **Monitoring/** > **Communication** > **Ethernet** > **Link statuses** > **LNK1LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNK2LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNK3LIV**

3.25.2.6 Diagnostics

Diagnostics data is available in **Monitoring** > **Communication** > **Ethernet** > **Diagnostics** > **Xn** (n = 1...3).

Table 353: Diagnostic parameters for X1/LAN, X2/LAN and X3/LAN

Parameter	Values (Range)	Unit	Step	Default	Description
Reset counters	FALSE / TRUE			FALSE	Reset counters command
GOOSE limit count	0...1000000			0	Goose rate limit exceed count
SMV limit count	0...1000000			0	Sampled measured values limit exceed count
Ucast limit count	0...1000000			0	Unicast rate limit exceed count
Def. limit count	0...1000000			0	Default rate limit exceed count
GOOSE limit alarm	FALSE / TRUE			FALSE	Goose rate limit exceed alarm
SMV limit alarm	FALSE / TRUE			FALSE	Sampled measured values limit alarm
Ucast limit alarm	FALSE / TRUE			FALSE	Unicast rate limit exceed alarm
Def. limit alarm	FALSE / TRUE			FALSE	Default rate limit exceed alarm

[1] n = 1...3
[2] Only available for port X3

3.26 External HMI wake-up EIHMI

3.26.1 Function block

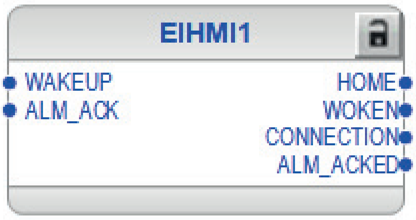


Figure 193: Function block

3.26.2 Functionality

The external HMI wake-up function EIHMI is a control block that is used to control certain parts of the HMI with Application Configuration in PCM600.

Some data can be bound to control options to enable the required features: remote HMI wake-up, remote acknowledgment of alarms, information when the device has been woken up, indication when the Home button on the HMI is activated and indication when alarms are being acknowledged either remotely or from the HMI.

All functionalities described here are applicable only to paired HMI devices.

3.26.3 Operation principle

The input signal WAKEUP is used to wake the HMI from a low-power state and restore the display's backlight if it has been dimmed or turned off. The display's backlight can be controlled with parameter *Backlight timeout* under **Configuration** > **HMI**. The HMI remains in normal operation mode as long as there is user input from the HMI or a wake-up signal before the time set with *Backlight timeout* elapses.

The signal used to wake up the HMI is boolean rising edge. The wake-up can be triggered only after the connected signal has been in FALSE state for longer than a single function cycle.

The input signal ALM_ACK is used to acknowledge all active and fleeting alarms. These alarms are displayed on the HMI's alarms page and mini-alarms widget.

The signal used to acknowledge the alarms is boolean rising edge. Acknowledge alarms can be triggered only after the connected signal has been in the FALSE state for longer than a single function cycle. The actual acknowledgement takes effect only after the ALM_ACKED output has been in the FALSE state for longer than 100 ms.

The output signal HOME is activated when the capacitive Home button is activated on the HMI unit. This generates a boolean TRUE value pulse that persists for a second until the output is reset to FALSE. The output remains in this state until the Home button is pressed again.

The output signal WOKEN is activated whenever the HMI device is woken from a low-power state. This generates a one-second boolean TRUE value pulse. After one second, the output is reset to FALSE. A new output can be triggered once the HMI has entered the low-power state.

The output CONNECTION is activated whenever the paired HMI is connected to the protection relay. If the communication between the protection relay and the HMI is severed, this output resets itself to FALSE until communication has been restored.

When an SHMI is connected and paired with the protection relay, the CONNECTION output is activated when the user navigates from the SHMI navigation page to the HMI view. The CONNECTION output is deactivated when the user returns to the navigation view or the connection between the relay and the SHMI is lost. The output can be used to visually indicate that the SHMI is connected to the relay in the panel, and it works as an LHMI for the relay.

The output ALM_ACKED is activated when any alarms are acknowledged either by the boolean rising edge on the ALM_ACK input or by acknowledging alarms from the HMI. This generates a one-second boolean TRUE value pulse. After one second, the output is reset to FALSE until some alarms are acknowledged. There is at least a 100 ms FALSE state between each pulse. If alarms are acknowledged from the HMI during the TRUE state or within 100 ms after resetting to FALSE, additional pulses are not be produced.

PCM600 parameters

EIHMI contains three paths to populate parameters visible in Parameter Setting in PCM600.

- **Configuration** > **HMI**
- **Monitoring** > **Detached LHMI**
- **Information** > **HW modules** > **EIHMI1**

3.26.4 Application

Substation HMI wake-up (door sensor)

In this example, substation HMI devices need to be woken up when a person enters the substation to see that everything works as expected.

A switch signal is directly connected to the binary input, which activates the paired HMI.

Depending on the hardware solution, this hardware signal can be distributed to all affected protection relays on the substation. Optionally, the processed signal can be routed in horizontal communication through process bus communications, that is, GOOSE, to other protection relays.

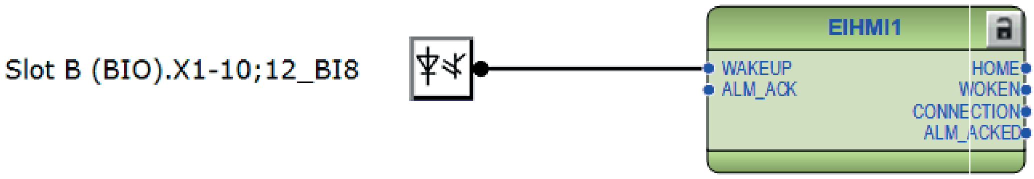


Figure 194: Binary input connection

Do not keep the HMI backlight always on as it may cause premature and unnecessary wear of the display panel.

3.26.5 Signals

Table 354: EIHMI Input signals

Name	Type	Default	Description
WAKEUP	BOOLEAN	0=False	HMI wake-up command
ALM_ACK	BOOLEAN	0=False	Acknowledge alarms command

Table 355: EIHMI Output signals

Name	Type	Description
HOME	BOOLEAN	HMI home button indicator
WOKEN	BOOLEAN	HMI woken indicator
CONNECTION	BOOLEAN	HMI connection status indicator
ALM_ACKED	BOOLEAN	Alarms acknowledged indicator

3.26.6 Settings

Table 356: HMI configuration parameters

Parameter	Description
Backlight brightness	Controls the HMI maximum backlight brightness. Actual brightness can be lower due to thermal compensation.
Enable USB access	Enables or disables HMI connector X2.
Enable HMI service port	Enables or disables HMI service port X1.2.

3.26.7 Monitored data

Table 357: HMI monitoring parameters

Parameter	Description
CONNECTION	Status of connection between the protection relay and HMI. The parameter is set TRUE when the paired HMI is connected to the protection relay.
Service port IP address	IP address of service port connector X1.2. Changes to this setting are available only on the HMI.
Main unit port IP address	IP address assigned to the main unit port connector X1.1. Changes to this setting are available only on the HMI.

3.27 HMI Ethernet channel supervision HMILCCH

3.27.1 Function block

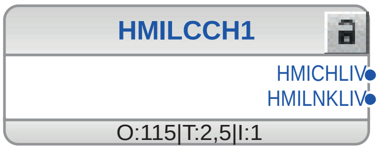


Figure 195: Function block

3.27.2 Functionality

Ethernet channel supervision HMILCCH represents the X0/HMI Ethernet channel.

3.27.3 Signals

Table 358: HMILCCH Output signals

Name	Type	Description
HMICHLIV	BOOLEAN	Status of the Ethernet channel X0/LAN Val-ue is TRUE if the port is receiving Ethernet frames. Otherwise the value is FALSE.
HMILNKLIV	BOOLEAN	Link status of Ethernet port X0/LAN Value is "Up" or "Down".

3.27.4 Settings

Table 359: HMILCCH Settings

Parameter	Values (Range)	Unit	Step	Default	Description
IP Address				192.168.2.254	IP address for the HMI.
MAC Address				XX-XX-XX-XX-XXXX	MAC address for the HMI. This parameter is read-only.

3.27.5 Monitored data

Monitored data is available in two locations.

- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **HMICHLIV**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **HMICHLIV**

3.28 Line differential communication port supervision SCHLCCH6

3.28.1 Function block

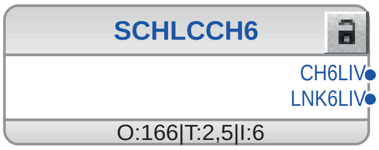


Figure 196: Function block

3.28.2 Functionality

Line differential channel supervision function SCHLCCH6 represents the X6/LD line differential channel.

3.28.3 Signals

Table 360: SCHLCCH6 Output signals

Name	Type	Description
CH6LIV	BOOLEAN	Status of the line differential port X5/LD Value is TRUE if the port is receiving Ethernet frames. Otherwise the value is FALSE.
LNK6LIV	BOOLEAN	Link status of the line differential port X6/LD Value is "Up" or "Down".

3.28.4 Monitored data

Monitored data is available in two locations.

- **Monitoring** > **Communication** > **Ethernet** > **Activity** > **CH6LIV**
- **Monitoring** > **Communication** > **Ethernet** > **Link statuses** > **LNK6LIV**

3.28.5 Diagnostics

Diagnostics data is available in **Monitoring** > **Communication** > **Ethernet** > **Diagnostics** > **X&**.

Table 361: Parameters read from the SFP module connected in the X6/LD line differential channel

Parameter	Values (Range)	Unit	Step	Default	Description
Temperature	–128.0...128.0	C		0	Measured SFP transceiver temperature
Voltage	0.000...6.550	V		0	Measured SFP transceiver voltage
Bias current	0.0...131.0	mA		0	Measured SFP transceiver bias current
Tx power	0.000...6.550	MW		0	Measured SFP transceiver's transmitter power
Rx power	0.000...6.550	mW		0	Measured SFP transceiver's receiver power
XCVR detected	FALSE / TRUE			FALSE	SFP Transceiver detection state
Rx Power alarm	FALSE / TRUE			FALSE	SFP Receiver power alarm
Tx Power alarm	FALSE / TRUE			FALSE	SFP Transmitter power alarm
Voltage alarm	FALSE / TRUE			FALSE	SFP transceiver voltage alarm
Temperature alarm	FALSE / TRUE			FALSE	SFP temperature alarm
Part name	SFP not inserted SFP not supported 2RCA045621 (MM 2 km) 2RCA045622 (SM 20 km) 2RCA045623 (SM 50 km)			SFP not inserted	Name, type and operational distance for the SFP module

4 Protection functions

4.1 Three-phase current protection

4.1.1 Three-phase non-directional overcurrent protection PHxPTOC (ANSI 51P-1, 51P-2, 50P)

4.1.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase non-directional over-current protection, low stage	PHLPTOC	3I>	51P-1
Three-phase non-directional over-current protection, high stage	PHHPTOC	3I>>	51P-2
Three-phase non-directional over-current protection, instantaneous stage	PHIPTOC	3I>>>	50P

4.1.1.2 Function block

Figure 197: Function block

4.1.1.3 Functionality

The three-phase non-directional overcurrent protection function PHxPTOC is used as one-phase, two-phase or three-phase non-directional overcurrent and short-circuit protection.

The function starts when the current exceeds the set limit. The operate time characteristics for low stage PHLPTOC and high stage PHHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage PHIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.1.1.4 Analog input configuration

PHxPTOC has one analog group input which must be properly configured.

Table 362: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHxPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

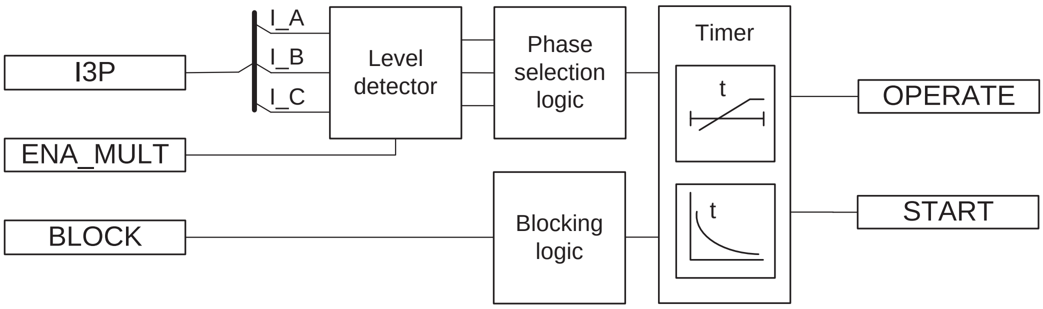


Figure 198: Functional module diagram

Level detector

The measured phase currents are compared phasewise to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector reports the exceeding of the value to the phase selection logic. If the `ENA_MULT` input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

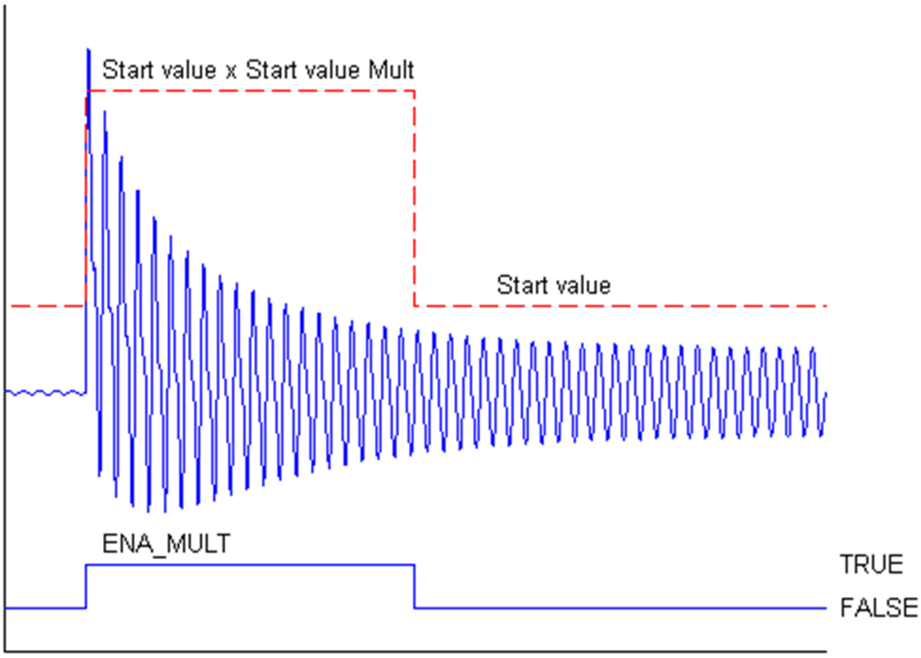


Figure 199: Start value behavior with ENA_MULT input activated

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the timer module.

Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.2.1 IDMT curves for overcurrent protection* in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.1.6 Measurement modes

The function operates on four alternative measurement modes: "RMS", "DFT", "Peak-to-Peak" and "P-to-P + backup". Additionally, there is “Wide P-to-P” measurement mode in some products variants. The measurement mode is selected with the setting *Measurement mode*.

Table 363: Measurement modes supported by PHxPTOC stages

Measurement mode	PHLPTOC	PHHPTOC	PHIPTOC
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	
P-to-P + backup			x
Wide P-to-P	x [2]		

For a detailed description of the measurement modes, see *Chapter 11.6 Measurement modes* in this manual.

4.1.1.7 Timer characteristics

PHxPTOC supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings. When the DT characteristic is selected, it is only affected by the *Operate delay time* and *Reset delay time* settings.

The protection relay provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. One curve is for rectifier bridge protection. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The DT characteristics can be chosen by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The timer characteristics supported by different stages comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages:

Table 364: Timer characteristics supported by different stages

Operating curve type	PHLPTOC	PHHPTOC
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	x
(10) IEC Very Inverse	x	x
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	x
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable	x	x
(18) RI type	x	
(19) RD type	x	
(20) UK rectifier	x	

[2] Available only in REG615 standard configurations C and D

PHIPTOC supports only definite time characteristic.

For a detailed description of timers, see *Chapter 11 General function block features* in this manual.

Table 365: Reset time characteristics supported by different stages

Reset curve type	PHLPTOC	PHHPTOC	Note
(1) Immediate	x	x	Available for all operate time curves
(2) Def time reset	x	x	Available for all operate time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

The *Type of reset curve* setting does not apply to PHIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.1.1.8 Application

PHxPTOC is used in several applications in the power system. The applications include but are not limited to:

- Selective overcurrent and short-circuit protection of feeders in distribution and subtransmission systems
- Backup overcurrent and short-circuit protection of power transformers and generators
- Overcurrent and short-circuit protection of various devices connected to the power system, for example shunt capacitor banks, shunt reactors and motors
- General backup protection

PHxPTOC is used for single-phase, two-phase and three-phase non-directional overcurrent and short-circuit protection. Typically, overcurrent protection is used for clearing two and three-phase short circuits. Therefore, the user can choose how many phases, at minimum, must have currents above the start level for the function to operate. When the number of start-phase settings is set to "1 out of 3", the operation of PHxPTOC is enabled with the presence of high current in one-phase.

When the setting is "2 out of 3" or "3 out of 3", single-phase faults are not detected. The setting "3 out of 3" requires the fault to be present in all three phases.

Many applications require several steps using different current start levels and time delays. PHxPTOC consists of three protection stages.

- Low PHLPTOC
- High PHHPTOC
- Instantaneous PHIPTOC

PHLPTOC is used for overcurrent protection. The function contains several types of time-delay characteristics. PHHPTOC and PHIPTOC are used for fast clearance of very high overcurrent situations.

Transformer overcurrent protection

The purpose of transformer overcurrent protection is to operate as main protection, when differential protection is not used. It can also be used as coarse back-up protection for differential protection in faults inside the zone of protection, that is, faults occurring in incoming or outgoing feeders, in the region of transformer terminals and tank cover. This means that the magnitude range of the fault current can be very wide. The range varies from 6xI_n to several hundred times I_n, depending on the impedance of the transformer and the source impedance of the feeding network. From this point of view, it is clear that the operation must be both very fast and selective, which is usually achieved by using coarse current settings.

The purpose is also to protect the transformer from short circuits occurring outside the protection zone, that is through-faults. Transformer overcurrent protection also provides protection for the LV-side busbars. In this case the magnitude of the fault current is typically lower than 12xI_n depending on the fault location and transformer impedance. Consequently, the protection must operate as fast as possible taking into account the selectivity requirements, switching-in currents, and the thermal and mechanical withstand of the transformer and outgoing feeders.

Traditionally, overcurrent protection of the transformer has been arranged as shown in *Figure 200*. The low-set stage PHLPTOC operates time-selectively both in transformer and LV-side busbar faults. The high-set stage PHHPTOC operates instantaneously making use of current selectivity only in transformer HV-side faults. If there is a possibility, that the fault current can also be fed from the LV-side up to the HV-side, the transformer must also be equipped with LV-side overcurrent protection. Inrush current detectors are used in start-up situations to multiply the current start value setting in each particular protection relay where the inrush current can occur. The overcurrent and contact based circuit breaker failure protection CCBRBRF is used to confirm the protection scheme in case of circuit breaker malfunction.

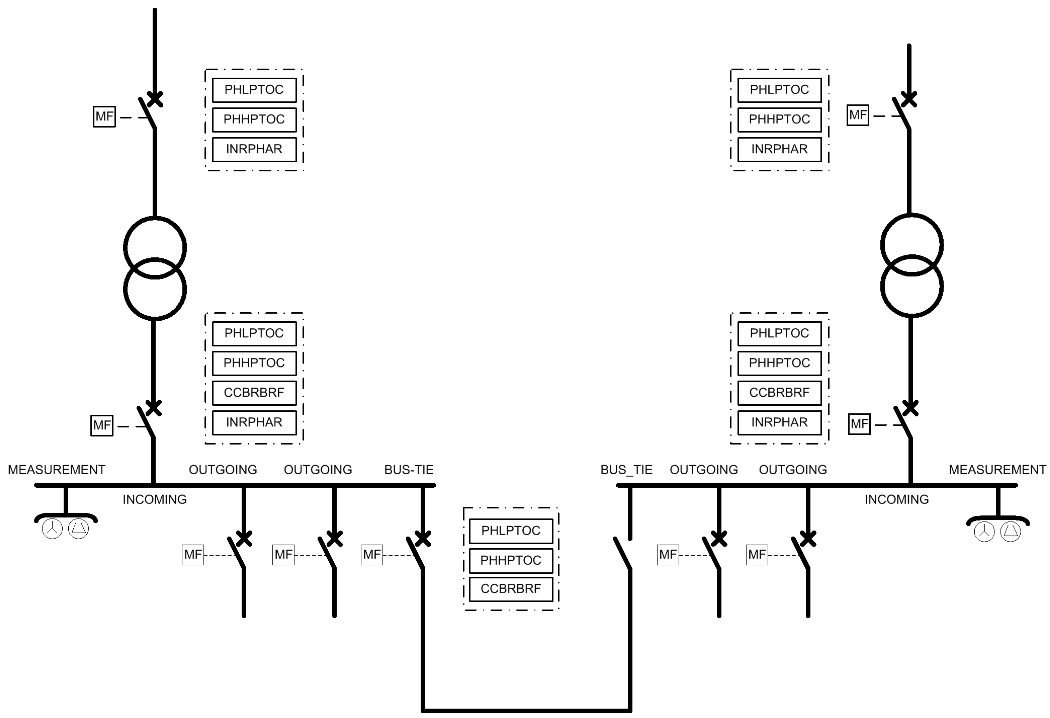


Figure 200: Example of traditional time selective transformer overcurrent protection

The operating times of the main and backup overcurrent protection of the above scheme become quite long, this applies especially in the busbar faults and also in the transformer LV-terminal faults. In order to improve the performance of the above scheme, a multiple-stage overcurrent protection with reverse blocking is proposed. *Figure 202* shows this arrangement.

Overcurrent protection with line differential protection

The line differential protection relay has also four separate overcurrent functions which can be used as the backup protection of line differential function for lines and cables. There are three stages available with definite or inverse time characteristics and an instantaneous stage.

The differential protection is available only if the communication between the units is working properly and no CT failure situation is detected. If a communication failure exists, the protect area or unit is left out from the primary protection scheme. Therefore it is practical to use overcurrent protection as a local backup functionality.

In the standard configuration of the protection relay, the backup overcurrent protection is implemented with four overcurrent stages so that under normal conditions, that is, when the line differential communication is healthy, only two lowest stages are available for the remote backup protection. In case a line differential communication failure exists, two more stages are released for rapid local backup overcurrent and short circuit protection. These stages are blocked in normal situation and automatically unblocked when the communication failure is detected. The setting of the overcurrent stages for local backup protection has to be considered carefully in order to achieve the best possible protection performance under abnormal conditions.

Two situations, case A and B, are shown in *Figure 201*. In case A, the communication media is valid and therefore the line differential protection is in operation. In this case, the two lowest stages of overcurrent protection are in operation simultaneously. In case B, a communication failure causes a situation where the line differential function is not able to work properly. Unblocking of the two highest overcurrent protection stages releases these functions to protect the line against overcurrents and short-circuits.

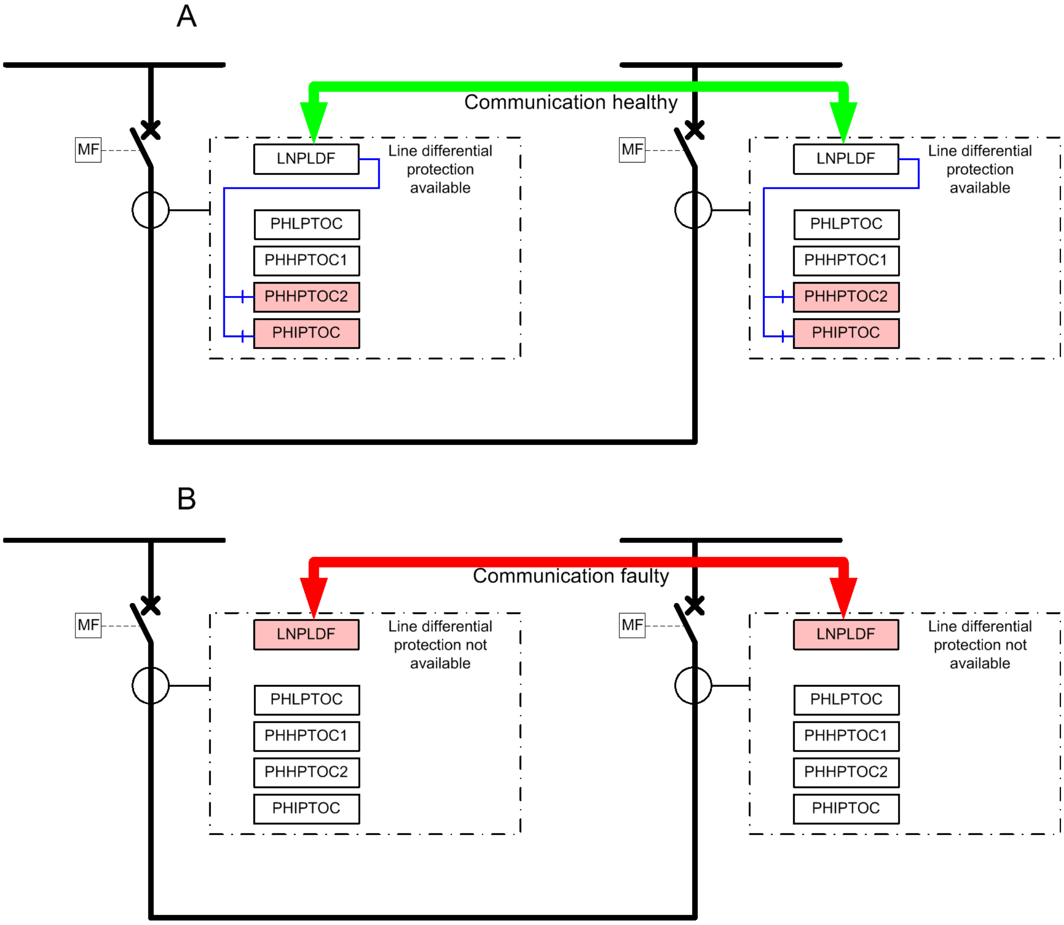


Figure 201: Backup overcurrent protection for line differential applications

Transformer and busbar overcurrent protection with reverse blocking principle

By implementing a full set of overcurrent protection stages and blocking channels between the protection stages of the incoming feeders, bus-tie and outgoing feeders, it is possible to speed up the operation of overcurrent protection in the busbar and transformer LV-side faults without impairing the selectivity. Also, the security degree of busbar protection is increased, because there is now a dedicated, selective and fast busbar protection functionality which is based on the blockable overcurrent protection principle. The additional time selective stages on the transformer HV and LV-sides provide increased security degree of backup protection for the transformer, busbar and also for the outgoing feeders.

Depending on the overcurrent stage in question, the selectivity of the scheme in *Figure 202* is based on the operating current, operating time or blockings between successive overcurrent stages. With blocking channels, the operating time of the protection can be drastically shortened if compared to the simple time selective protection. In addition to the busbar protection, this blocking principle is applicable for the protection of transformer LV terminals and short lines. The functionality and performance of the proposed overcurrent protections can be summarized as seen in the table.

Table 366: Proposed functionality of numerical transformer and busbar overcurrent protection. DT = definite time, IDMT = inverse definite minimum time

O/C-stage	Operating char.	Selectivity mode	Operation speed	Sensitivity
HV/3I>	DT/IDMT	time selective	low	very high
HV/3I>>	DT	blockable/time selective	high/low	high
HV/3I>>>	DT	current selective	very high	low
LV/3I>	DT/IDMT	time selective	low	very high
LV/3I>>	DT	time selective	low	high
LV/3I>>>	DT	blockable	high	high

In case the bus-tie breaker is open, the operating time of the blockable overcurrent protection is approximately 100 ms (relaying time). When the bus-tie breaker is closed, that is, the fault current flows to the faulted section of the busbar from two directions, the operation time becomes as follows: first the bus-tie relay unit trips the tie breaker in the above 100 ms, which reduces the fault current to a half. After this the incoming feeder relay unit of the faulted bus section trips the breaker in approximately 250 ms (relaying time), which becomes the total fault clearing time in this case.

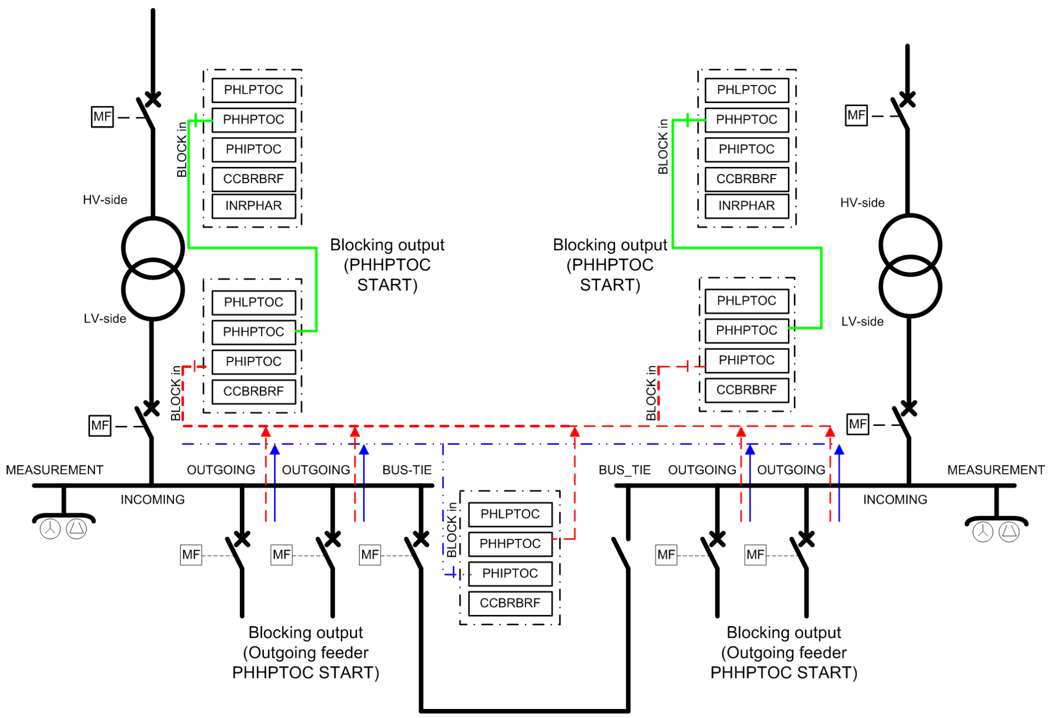


Figure 202: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown). Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

The operating times of the time selective stages are very short, because the grading margins between successive protection stages can be kept short. This is mainly due to the advanced measuring principle allowing a certain degree of CT saturation, good operating accuracy and short retardation times of the numerical units. So, for example, a grading margin of 150 ms in the DT mode of operation can be used, provided that the circuit breaker interrupting time is shorter than 60 ms.

The sensitivity and speed of the current-selective stages become as good as possible due to the fact that the transient overreach is very low. Also, the effects of switching inrush currents on the setting values can be reduced by using the protection relay's logic, which recognizes the transformer energizing inrush current and blocks the operation or multiplies the current start value setting of the selected overcurrent stage with a predefined multiplier setting.

Finally, a dependable trip of the overcurrent protection is secured by both a proper selection of the settings and an adequate ability of the measuring transformers to reproduce the fault current. This is important in order to maintain selectivity and also for the protection to operate without additional time delays. For additional information about available measuring modes and current transformer requirements, see *Chapter 11.6 Measurement modes* in this manual.

Radial outgoing feeder overcurrent protection

The basic requirements for feeder overcurrent protection are adequate sensitivity and operation speed taking into account the minimum and maximum fault current levels along the protected line, selectivity requirements, inrush currents and the thermal and mechanical withstand of the lines to be protected.

In many cases the above requirements can be best fulfilled by using multiple-stage overcurrent units. *Figure 203* shows an example of this. A brief coordination study has been carried out between the incoming and outgoing feeders.

The protection scheme is implemented with three-stage numerical overcurrent protection, where the low-set stage PHLPTOC operates in IDMT-mode and the two higher stages PHHPTOC and PHIPTOC in DT-mode. Also the thermal withstand of the line types along the feeder and maximum expected inrush currents of the feeders are shown. Faults occurring near the station where the fault current levels are the highest are cleared rapidly by the instantaneous stage in order to minimize the effects of severe short circuit faults. The influence of the inrush current is taken into consideration by connecting the inrush current detector to the start value multiplying input of the instantaneous stage. By this way the start value is multiplied with a predefined setting during the inrush situation and nuisance tripping can be avoided.

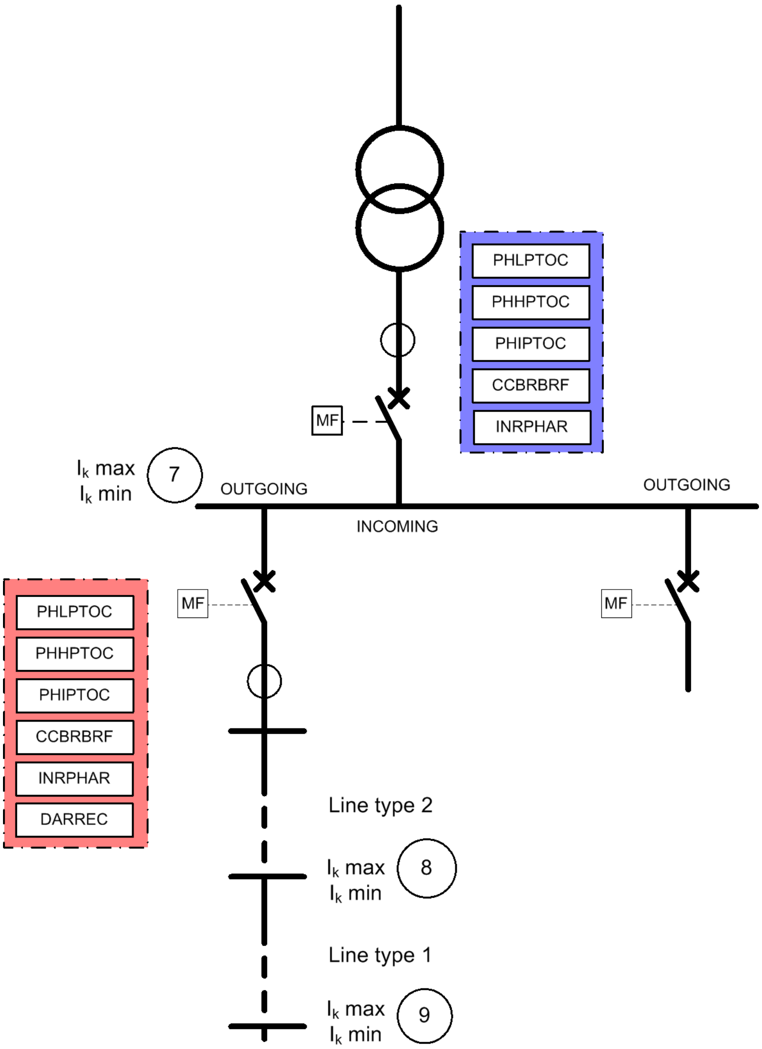


Figure 203: Functionality of numerical multiple-stage overcurrent protection

The coordination plan is an effective tool to study the operation of time selective operation characteristics. All the points mentioned earlier, required to define the overcurrent protection parameters, can be expressed simultaneously in a coordination plan. In *Figure 204*, the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

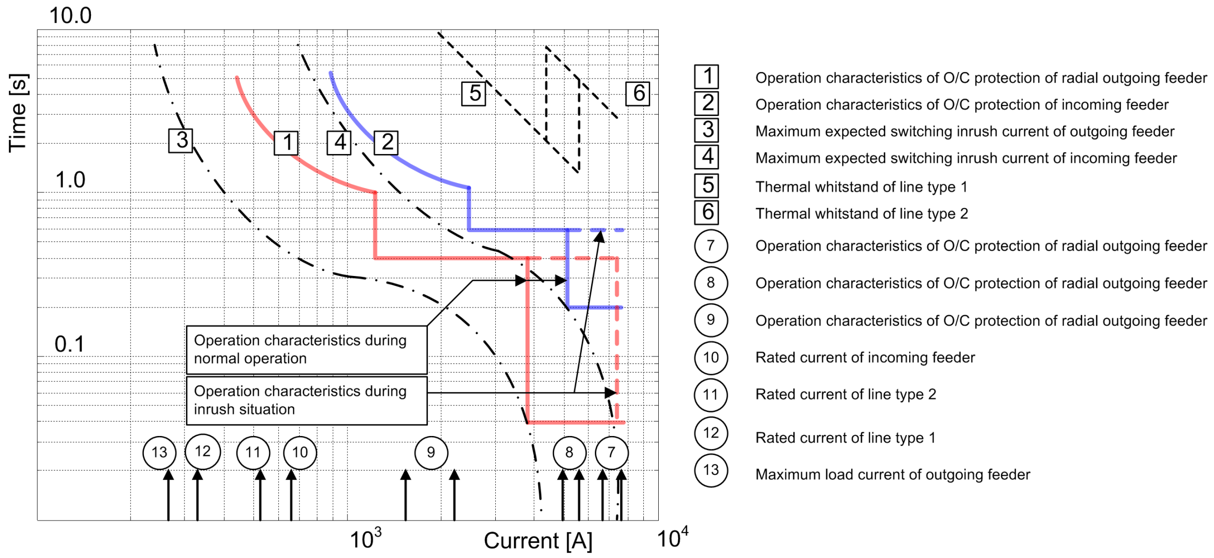


Figure 204: Example coordination of numerical multiple-stage overcurrent protection

4.1.1.9 Signals

PHLPTOC Input signals

Table 367: PHLPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

PHHPTOC Input signals

Table 368: PHHPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

PHIPTOC Input signals

Table 369: PHIPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

PHLPTOC Output signals

Table 370: PHLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

PHHPTOC Output signals

Table 371: PHHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

PHIPTOC Output signals

Table 372: PHIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.1.10 Settings

PHLPTOC Settings

Table 373: PHLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...10.00	xIn	0.01	0.05	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type 20=UK rectifier			15=IEC Def. Time	Selection of time delay curve type

Table 374: PHLPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 375: PHLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start pha-ses	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for oper-ate activation
Curve parameter A	0.0086...50000.0000		0.0001	28.2000	Parameter A for customer program-mable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer program-mable curve
Curve parameter C	0.02...6.00		0.01	2.00	Parameter C for customer program-mable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer program-mable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer program-mable curve

Table 376: PHLPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak 5=Wide P-to-P			2=DFT	Selects used measurement mode

PHHPTOC Settings

Table 377: PHHPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 378: PHHPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 379: PHHPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 380: PHHPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

PHIPTOC Settings

Table 381: PHIPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	1.00	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Operate delay time	20...300000	ms	10	20	Operate delay time

Table 382: PHIPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table 383: PHIPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.1.11 Monitored data

PHLPTOC Monitored data

Table 384: PHLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHLPTOC	Enum	1=on		Status

Name	Type	Values (Range)	Unit	Description
		2=blocked 3=test 4=test/blocked 5=off		

PHHPTOC Monitored data

Table 385: PHHPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHHPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

PHIPTOC Monitored data

Table 386: PHIPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHIPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.1.12 Technical data

Table 387: PHxPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
	PHLPTOC	±1.5% of the set value or ±0.002 × I_n		
	PHHPTOC and PHIPTOC	±1.5% of set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n)		
Start time [1]		Minimum	Typical	Maximum
	PHIPTOC: [2]	8 ms	12 ms	15 ms

Table continues on the next page

Characteristic		Value		
	I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	7 ms	9 ms	12 ms
	PHHPTOC and PHLPTOC: [3] I_{Fault} = 2 × set *Start value*	23 ms	26 ms	29 ms
Reset time		Typically <40 ms		
Reset ratio		Typically 0.96		
Retardation time		<30 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [4]		
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression P-to-P+backup: No suppression		

4.1.1.13 Technical revision history

Table 388: PHLPTOC Technical revision history

Product connectivity level	Technical revision	Change
PCL4	G	Setting *Start value* maximum value extended to 10.00xIn.

4.1.2 Three-phase directional overcurrent protection DPHxPDOC (ANSI 67P/51P-1, 67P/51P-2)

1 *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.
2 Measured with static signal output (SSO).
3 Includes the delay of the signal output contact (SO).
4 *Maximum Start value* = 2.5 × I_n, *Start value* multiples in the range of 1.5...20.

4.1.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase directional overcurrent protection, low stage	DPHLPDOC	3I> ->	67P/51P-1
Three-phase directional overcurrent protection, high stage	DPHHPDOC	3I>> ->	67P/51P-2

4.1.2.2 Function block

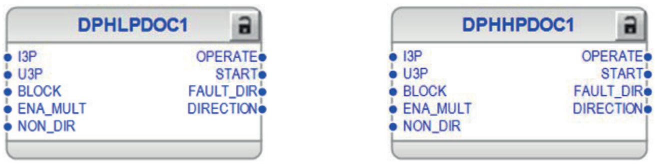


Figure 205: Function block

4.1.2.3 Functionality

The three-phase directional overcurrent protection function DPHxPDOC is used as one-phase, two-phase or three-phase directional overcurrent and short-circuit protection for feeders.

DPHxPDOC starts up when the value of the current exceeds the set limit and directional criterion is fulfilled. The operate time characteristics for low stage DPHLPDOC and high stage DPHHPDOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.1.2.4 Analog channel configuration

DPHxPDOC has two analog group inputs which must be properly configured.

Table 389: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 390: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DPHxPDOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

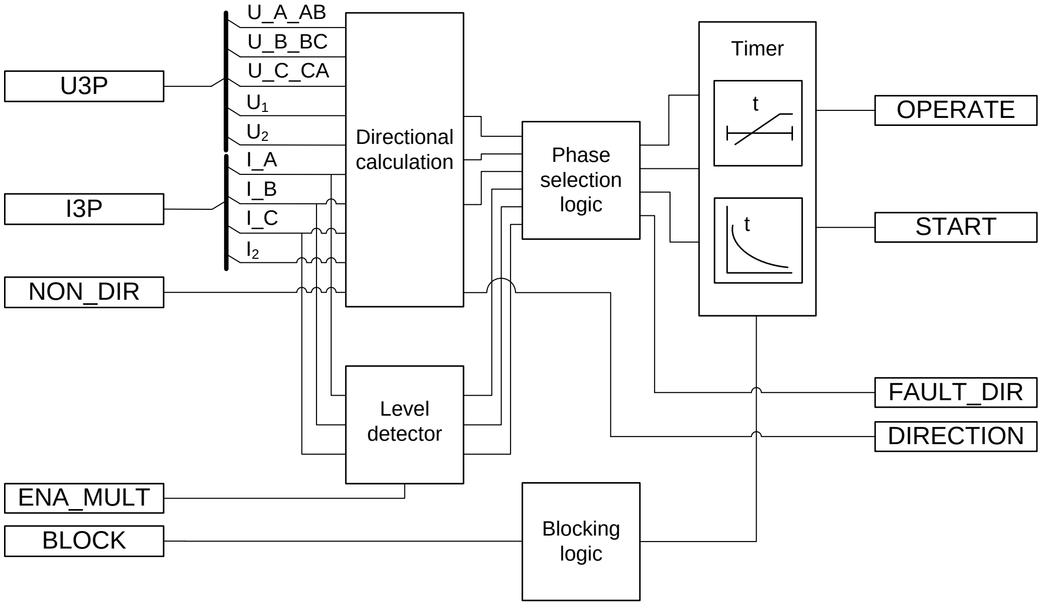


Figure 206: Functional module diagram

Directional calculation

The directional calculation compares the current phasors to the polarizing phasor. A suitable polarization quantity can be selected from the different polarization quantities, which are the positive sequence voltage, negative sequence voltage, self-polarizing (faulted) voltage and cross-polarizing voltages (healthy voltages). The polarizing method is defined with the *Pol quantity* setting.

Table 391: Polarizing quantities

Polarizing quantity	Description
Pos. seq. volt	Positive sequence voltage
Neg. seq. volt	Negative sequence voltage
Self pol	Self polarization
Cross pol	Cross polarization

The directional operation can be selected with the *Directional mode* setting. The user can select either "Non-directional", "Forward" or "Reverse" operation. By setting the value of *Allow Non Dir* to "True", the non-directional operation is allowed when the directional information is invalid.

The *Characteristic angle* setting is used to turn the directional characteristic. The value of *Characteristic angle* should be chosen in such a way that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the non-operating zone. The value of *Characteristic angle* depends on the network configuration.

Reliable operation requires both the operating and polarizing quantities to exceed certain minimum amplitude levels. The minimum amplitude level for the operating quantity (current) is set with the *Min operate current* setting. The minimum amplitude level for the polarizing quantity (voltage) is set with the *Min operate voltage* setting. If the amplitude level of the operating quantity or polarizing quantity is below the set level, the direction information of the corresponding phase is set to "Unknown".

The polarizing quantity validity can remain valid even if the amplitude of the polarizing quantity falls below the value of the *Min operate voltage* setting. In this case, the directional information is provided by a special memory function for a time defined with the *Voltage Mem time* setting.

DPHxPDOC is provided with a memory function to secure a reliable and correct directional protection relay operation in case of a close short circuit or an earth fault characterized by an extremely low voltage. At sudden loss of the polarization quantity, the angle difference is calculated on the basis of a fictive voltage. The fictive voltage is calculated using the positive phase sequence voltage measured before the fault occurred, assuming that the voltage is not affected by the fault. The memory function enables the function to operate up to a maximum of three seconds after a total loss of voltage. This time can be set with the *Voltage Mem time* setting. The voltage memory cannot be used for the "Negative sequence voltage" polarization because it is not possible to substitute the positive sequence voltage for negative sequence voltage without knowing the network unsymmetry level. This is the reason why the fictive voltage angle and corresponding direction information are frozen immediately for this polarization mode when the need for a voltage memory arises and these are kept frozen until the time set with *Voltage Mem time* elapses.

The value for the *Min operate voltage* setting should be carefully selected since the accuracy in low signal levels is strongly affected by the measuring device accuracy.

When the voltage falls below *Min operate voltage* at a close fault, the fictive voltage is used to determine the phase angle. The measured voltage is applied again as soon as the voltage rises above *Min operate voltage* and hysteresis. The fictive voltage is also discarded if the measured voltage stays below *Min operate voltage* and hysteresis for longer than *Voltage Mem time* or if the fault current disappears while the fictive voltage is in use. When the voltage is below *Min operate voltage* and hysteresis and the fictive voltage is unusable, the fault direction cannot be determined. The fictive voltage can be unusable for two reasons:

- The fictive voltage is discarded after *Voltage Mem time*
- The phase angle cannot be reliably measured before the fault situation.

DPHxPDOC can be forced to the non-directional operation with the NON_DIR input. When the NON_DIR input is active, DPHxPDOC operates as a non-directional overcurrent protection, regardless of the *Directional mode* setting.

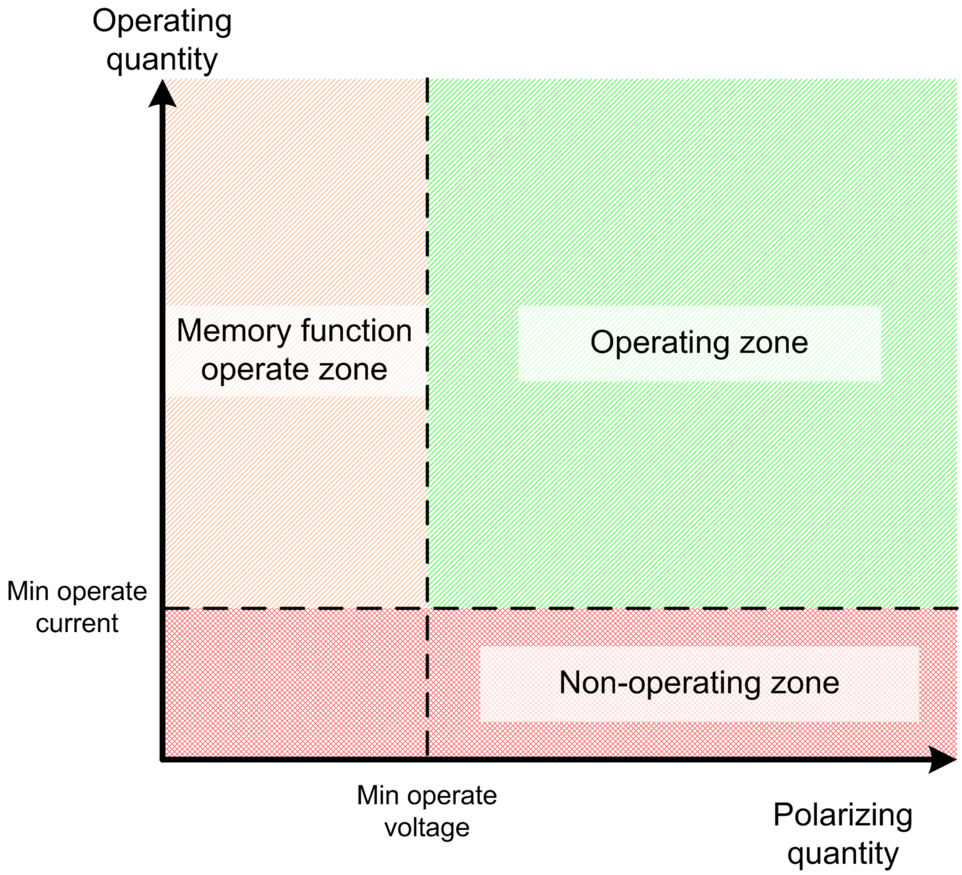


Figure 207: Operating zones at minimum magnitude levels

The DIRECTION output indicates on which operating sector the current is measured. The value combines phase-specific directions which are available in monitored data as DIR_A, DIR_B and DIR_C.

Level detector

The measured phase currents are compared phasewise to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector reports the exceeding of the value to the phase selection logic. If the ENA_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

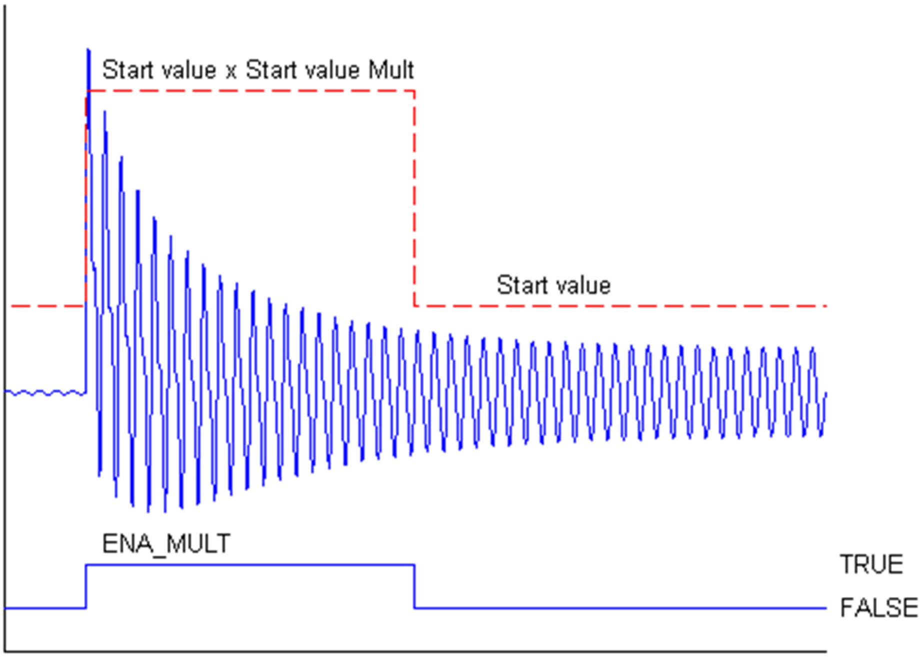


Figure 208: Start value behavior with ENA_MULT input activated

Phase selection logic

If the fault criteria are fulfilled in the level detector and the directional calculation, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the timer module.

FAULT_DIR gives the detected direction of the fault during fault situations, that is, when the START output is active.

Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and Curve parameter E.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.2.1 IDMT curves for overcurrent protection* in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.2.6 Measurement modes

The function operates on three alternative measurement modes: “RMS”, “DFT” and “Peak-to-Peak” . The measurement mode is selected with the *Measurement mode* setting.

Table 392: Measurement modes supported by DPHxPDOC stages

Measurement mode	DPHLPDOC	DPHHPDOC
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

4.1.2.7 Directional overcurrent characteristics

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the counterclockwise sector and the *Min forward angle* setting gives the corresponding clockwise sector, measured from the *Characteristic angle* setting.

In the backward operation area, the *Max reverse angle* setting gives the counterclockwise sector and the *Min reverse angle* setting gives the corresponding clockwise sector, a measurement from the *Characteristic angle* setting that has been rotated 180 degrees.

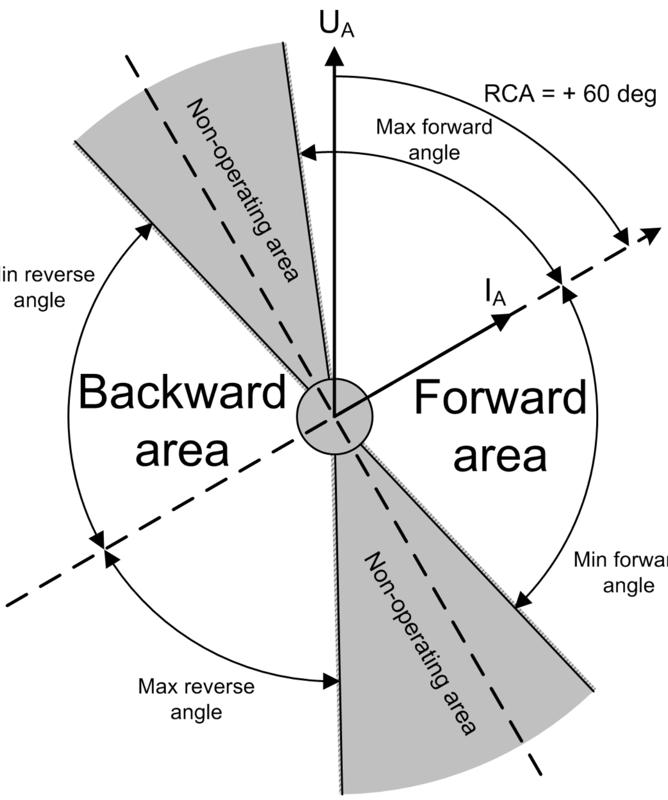


Figure 209: Configurable operating sectors

Table 393: Momentary per phase direction value for monitored data view

Criterion for per phase direction information	The value for DIR_A/_B/_C
The ANGLE_X is not in any of the defined sectors, or the direction cannot be defined due too low amplitude	0 = unknown
The ANGLE_X is in the forward sector	1 = forward

Table continues on the next page

Criterion for per phase direction information	The value for DIR_A/_B/_C
The ANGLE_X is in the reverse sector	2 = backward
(The ANGLE_X is in both forward and reverse sectors, that is, when the sectors are overlapping)	3 = both

Table 394: Momentary phase combined direction value for monitored data view

Criterion for phase combined direction information	The value for DIRECTION
The direction information (DIR_X) for all phases is unknown	0 = unknown
The direction information (DIR_X) for at least one phase is forward, none being in reverse	1 = forward
The direction information (DIR_X) for at least one phase is reverse, none being in forward	2 = backward
The direction information (DIR_X) for some phase is forward and for some phase is reverse	3 = both

FAULT_DIR gives the detected direction of the fault during fault situations, that is, when the START output is active.

Self-polarizing as polarizing method

Table 395: Equations for calculating angle difference for self-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_A$	$ANGLE\_A = \varphi(\underline{U}_A) - \varphi(\underline{I}_A) - \varphi_{RCA}$ (Equation 9)
B	$\underline{I}_B$	$\underline{U}_B$	$ANGLE\_B = \varphi(\underline{U}_B) - \varphi(\underline{I}_B) - \varphi_{RCA}$ (Equation 10)
C	$\underline{I}_C$	$\underline{U}_C$	$ANGLE\_C = \varphi(\underline{U}_C) - \varphi(\underline{I}_C) - \varphi_{RCA}$ (Equation 11)
A - B	$\underline{I}_A-\underline{I}_B$	$\underline{U}_{AB}$	$ANGLE\_A = \varphi(\underline{U}_{AB}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA}$ (Equation 12)
B - C	$\underline{I}_B-\underline{I}_C$	$\underline{U}_{BC}$	$ANGLE\_B = \varphi(\underline{U}_{BC}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA}$ (Equation 13)
C - A	$\underline{I}_C-\underline{I}_A$	$\underline{U}_{CA}$	$ANGLE\_C = \varphi(\underline{U}_{CA}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA}$ (Equation 14)

In an example case of the phasors in a single-phase earth fault where the faulted phase is phase A, the angle difference between the polarizing quantity U_A and operating quantity I_A is marked as φ. In the self-polarization method, there is no need to rotate the polarizing quantity.

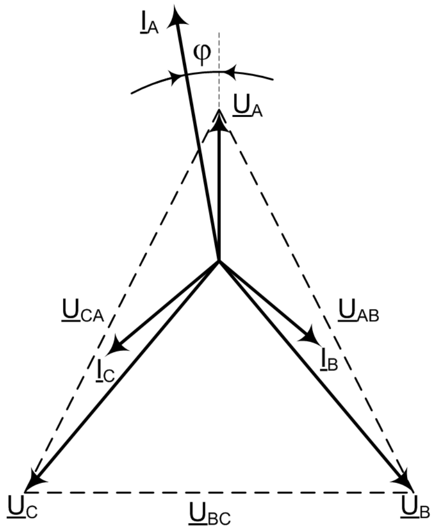


Figure 210: Single-phase earth fault, phase A

In an example case of a two-phase short-circuit failure where the fault is between phases B and C, the angle difference is measured between the polarizing quantity U_{BC} and operating quantity $\underline{I}_B$ - $\underline{I}_C$ in the self-polarizing method.

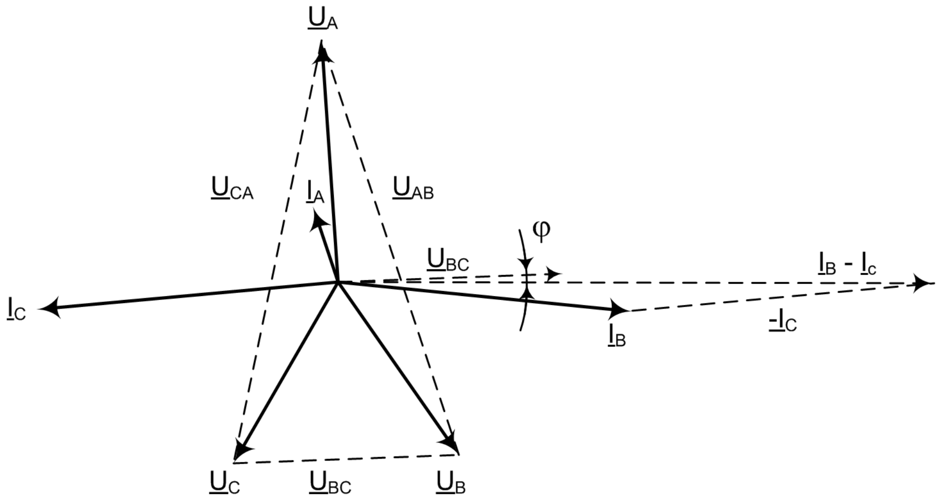


Figure 211: Two-phase short circuit, short circuit is between phases B and C

Cross-polarizing as polarizing quantity

Table 396: Equations for calculating angle difference for cross-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_{BC}$	$ANGLE\_A = \varphi(\underline{U}_{BC}) - \varphi(\underline{I}_A) - \varphi_{RCA} + 90^o$ (Equation 15)
B	$\underline{I}_B$	$\underline{U}_{CA}$	$ANGLE\_B = \varphi(\underline{U}_{CA}) - \varphi(\underline{I}_B) - \varphi_{RCA} + 90^o$ (Equation 16)
C	$\underline{I}_C$	$\underline{U}_{AB}$	$ANGLE\_C = \varphi(\underline{U}_{AB}) - \varphi(\underline{I}_C) - \varphi_{RCA} + 90^o$ (Equation 17)
A - B	$\underline{I}_A$-$\underline{I}_B$	$\underline{U}_{BC}$-$\underline{U}_{CA}$	$ANGLE\_A = \varphi(\underline{U}_{BC} - \underline{U}_{CA}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 90^o$ (Equation 18)
B - C	$\underline{I}_B$-$\underline{I}_C$	$\underline{U}_{CA}$-$\underline{U}_{AB}$	$ANGLE\_B = \varphi(\underline{U}_{CA} - \underline{U}_{AB}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} + 90^o$ (Equation 19)
C - A	$\underline{I}_C$-$\underline{I}_A$	$\underline{U}_{AB}$-$\underline{U}_{BC}$	$ANGLE\_C = \varphi(\underline{U}_{AB} - \underline{U}_{BC}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 90^o$ (Equation 20)

The angle difference between the polarizing quantity U_{BC} and operating quantity I_A is marked as ϕ in an example of the phasors in a single-phase earth fault where the faulted phase is phase A. The polarizing quantity is rotated with 90 degrees. The characteristic angle is assumed to be ~ 0 degrees.

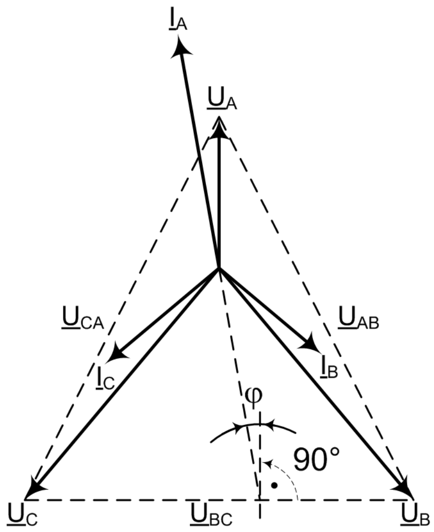


Figure 212: Single-phase earth fault, phase A

In an example of the phasors in a two-phase short-circuit failure where the fault is between the phases B and C, the angle difference is measured between the polarizing quantity $\underline{U}_{AB}$ and operating quantity $\underline{I}_B$ - $\underline{I}_C$ marked as ϕ.

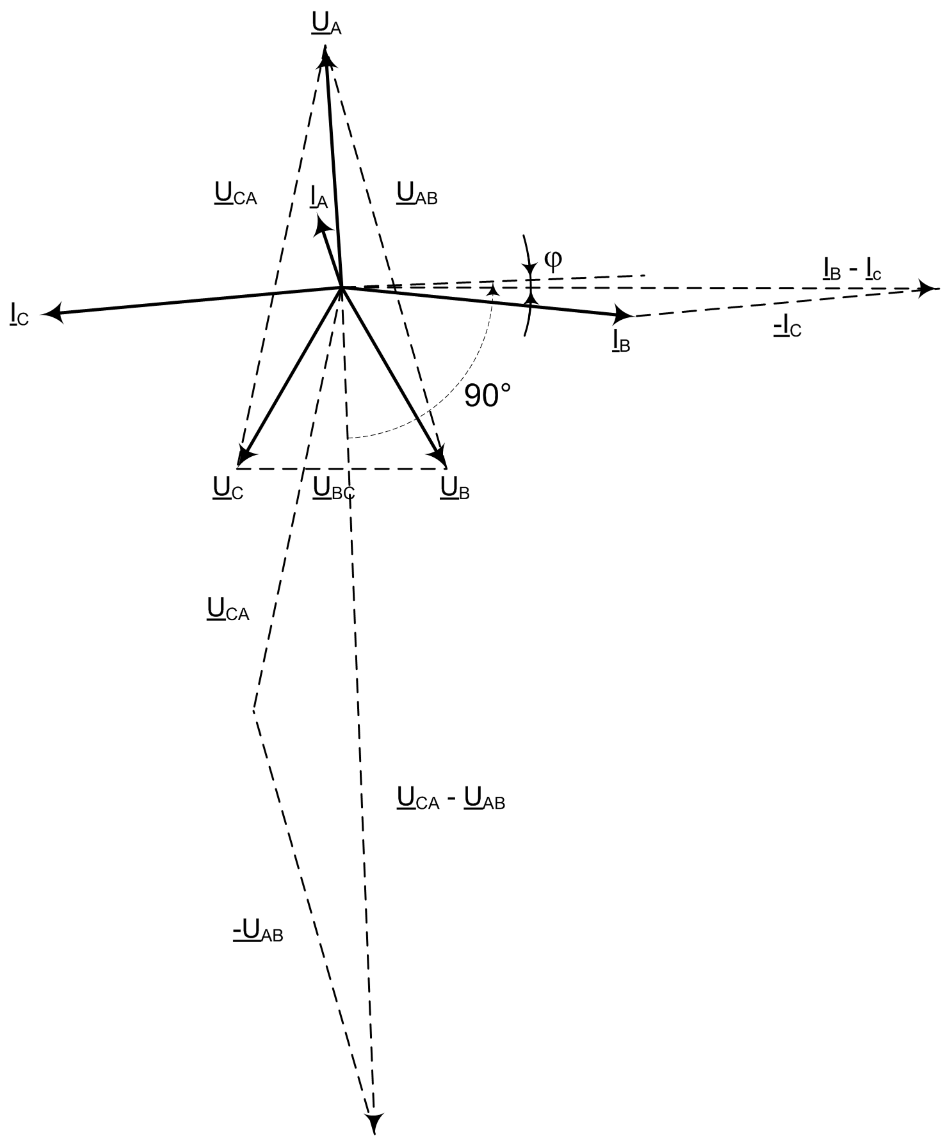


Figure 213: Two-phase short circuit, short circuit is between phases B and C

The equations are valid when network rotating direction is counter-clockwise, that is, ABC. If the network rotating direction is reversed, 180 degrees is added to the calculated angle difference. This is done automatically with a system parameter *Phase rotation*.

Negative sequence voltage as polarizing quantity

When the negative voltage is used as the polarizing quantity, the angle difference between the operating and polarizing quantity is calculated with the same formula for all fault types:

$$ANGLE\_X = \varphi(-\underline{U}_2) - \varphi(\underline{I}_2) - \varphi_{RCA}$$

(Equation 21)

This means that the actuating polarizing quantity is - $\underline{U}_2$.

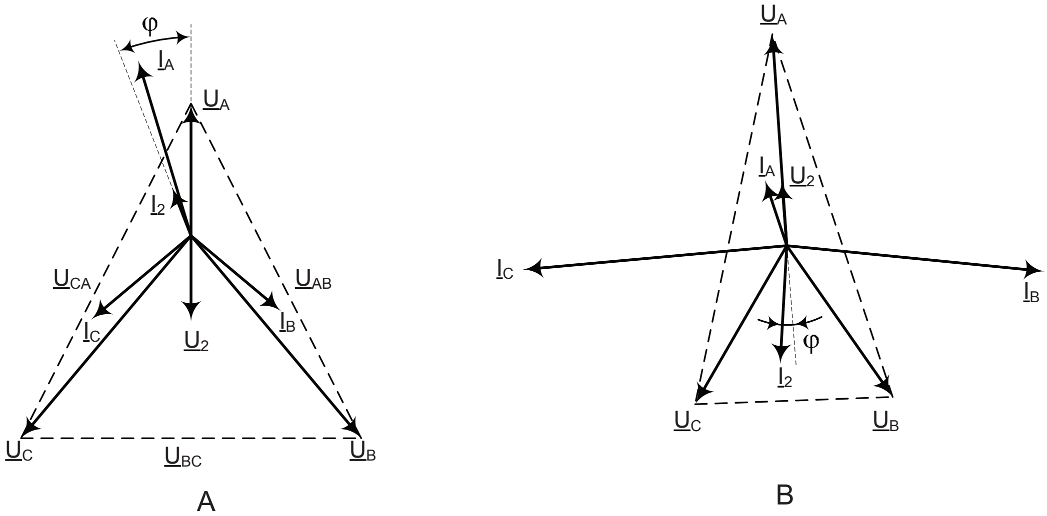


Figure 214: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage -U2

Positive sequence voltage as polarizing quantity

Table 397: Equations for calculating angle difference for positive-sequence quantity polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_1$	$$ANGLE\_A = \varphi(\underline{U}_1) - \varphi(\underline{I}_A) - \varphi_{RCA}$$ (Equation 22)
B	$\underline{I}_B$	$\underline{U}_1$	$$ANGLE\_B = \varphi(\underline{U}_1) - \varphi(\underline{I}_B) - \varphi_{RCA} - 120^\circ$$ (Equation 23)
C	$\underline{I}_C$	$\underline{U}_1$	$$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C) - \varphi_{RCA} + 120^\circ$$ (Equation 24)
A - B	$\underline{I}_A - \underline{I}_B$	$\underline{U}_1$	$$ANGLE\_A = \varphi(\underline{U}_1) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 30^\circ$$ (Equation 25)

Table continues on the next page

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
B - C	$\underline{I}_B - \underline{I}_C$	$\underline{U}_1$	$$ANGLE\_B = \varphi(\underline{U}_1) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} - 90^\circ$$ (Equation 26)
C - A	$\underline{I}_C - \underline{I}_A$	$\underline{U}_1$	$$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 150^\circ$$ (Equation 27)

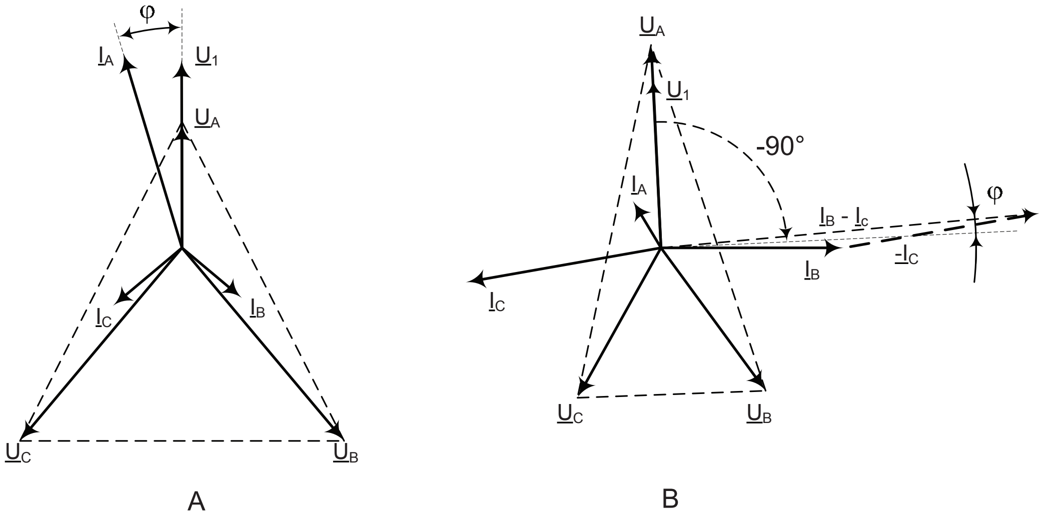


Figure 215: Phasors in a single-phase earth fault, phase A to ground, and a two-phase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage U 1

Network rotation direction

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equations for calculating the angle difference needs to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The change in the network rotating direction affects the phase-to-phase voltages polarization method where the calculated angle difference needs to be rotated 180 degrees. Also, when the sequence components are used, which are, the positive sequence voltage or negative sequence voltage components, the calculation of the components are affected but the angle difference calculation remains the same. When the phase-to-ground voltages are used as the polarizing method, the network rotating direction change has no effect on the direction calculation.

The network rotating direction is set in the protection relay using the parameter in the HMI menu **Configuration** > **System** > **Phase rotation**. The default parameter value is "ABC".

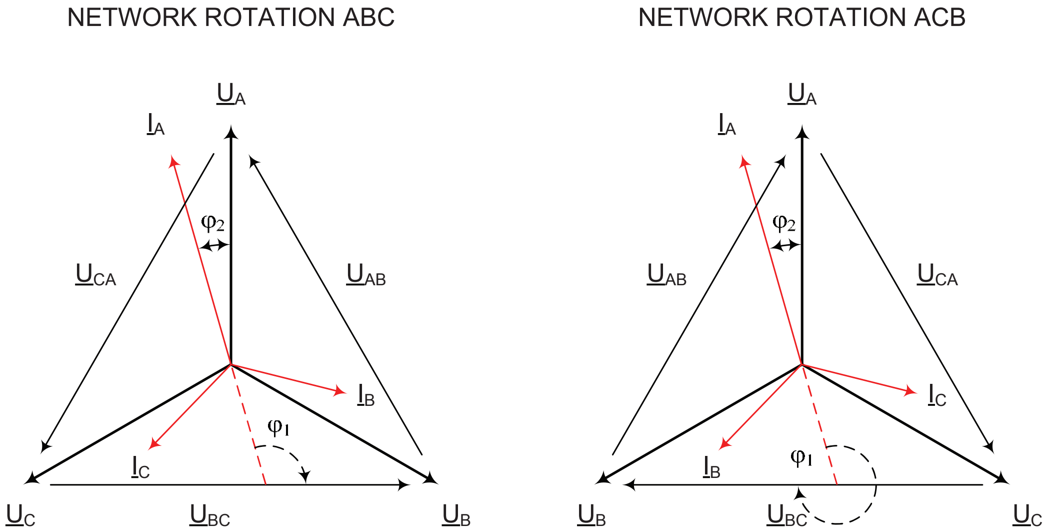


Figure 216: Examples of network rotating direction

4.1.2.8 Application

DPHxPDOC is used as short-circuit protection in three-phase distribution or sub transmission networks operating at 50 or 60 Hz.

In radial networks, phase overcurrent protection relays are often sufficient for the short circuit protection of lines, transformers and other equipment. The current-time characteristic should be chosen according to the common practice in the network. It is recommended to use the same current-time characteristic for all overcurrent protection relays in the network. This includes the overcurrent protection of transformers and other equipment.

The phase overcurrent protection can also be used in closed ring systems as short circuit protection. Because the setting of a phase overcurrent protection system in closed ring networks can be complicated, a large number of fault current calculations are needed. There are situations with no possibility to have the selectivity with a protection system based on overcurrent protection relays in a closed ring system.

In some applications, the possibility of obtaining the selectivity can be improved significantly if DPHxPDOC is used. This can also be done in the closed ring networks and radial networks with the generation connected to the remote in the system thus giving fault current infeed in reverse direction. Directional overcurrent protection relays are also used to have a selective protection scheme, for example in case of parallel distribution lines or power transformers fed by the same single source. In ring connected supply feeders between substations or feeders with two feeding sources, DPHxPDOC is also used.

Parallel lines or transformers

When the lines are connected in parallel and if a fault occurs in one of the lines, it is practical to have DPHxPDOC to detect the direction of the fault. Otherwise, there is a risk that the fault situation in one part of the feeding system can de-energize the whole system connected to the LV side.

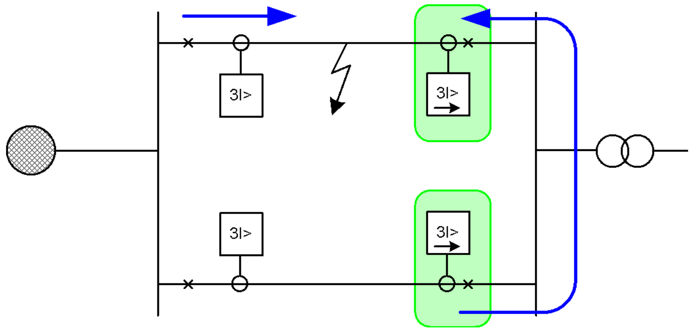


Figure 217: Overcurrent protection of parallel lines using directional protection relays

DPHxPDOC can be used for parallel operating transformer applications. In these applications, there is a possibility that the fault current can also be fed from the LV-side up to the HV-side. Therefore, the transformer is also equipped with directional overcurrent protection.

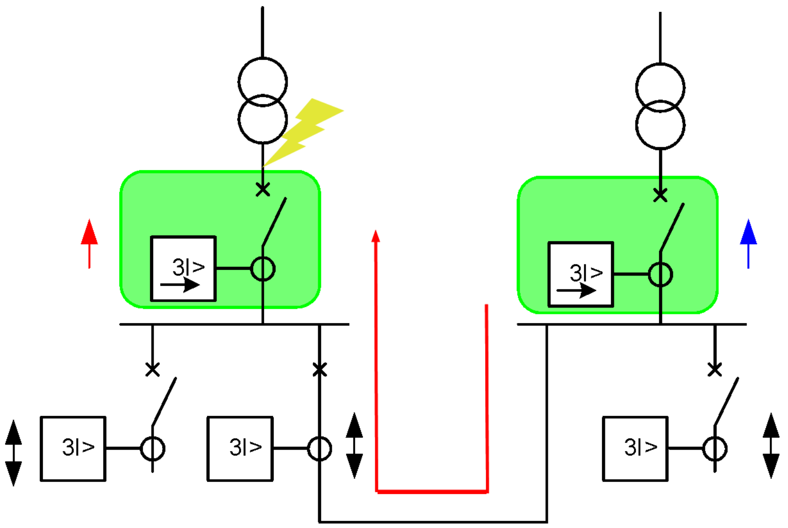


Figure 218: Overcurrent protection of parallel operating transformers

Closed ring network topology

The closed ring network topology is used in applications where electricity distribution for the consumers is secured during network fault situations. The power is fed at least from two directions which means that the current direction can be varied. The time grading between the network level stages is challenging without unnecessary delays in the time settings. In this case, it is practical to use the directional overcurrent protection relays to achieve a selective protection scheme. Directional overcurrent functions can be used in closed ring applications. The arrows define the operating direction of the directional functionality. The double arrows define the non-directional functionality where faults can be detected in both directions.

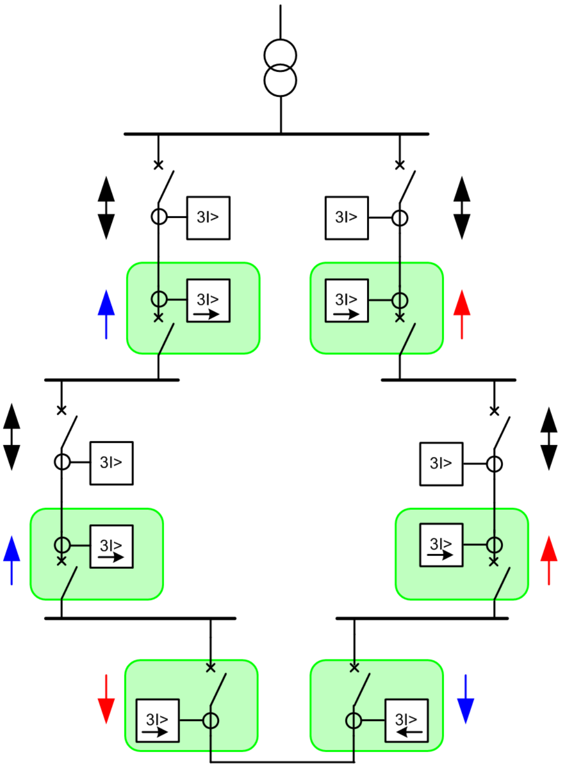


Figure 219: Closed ring network topology where feeding lines are protected with directional overcurrent protection relays

4.1.2.9 Signals

DPHLPDOC Input signals

Table 398: DPHLPDOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

DPHHPDOC Input signals

Table 399: DPHHPDOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
NON_DIR	BOOLEAN	0=False	Forces protection to non-directional

DPHLPDOC Output signals

Table 400: DPHLPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
FAULT_DIR	Enum	Detected fault direction
DIRECTION	Enum	Direction information

DPHHPDOC Output signals

Table 401: DPHHPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
FAULT_DIR	Enum	Detected fault direction
DIRECTION	Enum	Direction information

4.1.2.10 Settings

DPHLPDOC Settings

Table 402: DPHLPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...10.00	xIn	0.01	0.05	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 403: DPHLPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Pol quantity	1=Self pol 4=Neg. seq. volt. 5=Cross pol 7=Pos. seq. volt.			5=Cross pol	Reference quantity used to determine fault direction

Table 404: DPHLPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 405: DPHLPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

DPHHPDOC Settings

Table 406: DPHHPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv.			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable				
Operate delay time	40...300000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 407: DPHHPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Pol quantity	1=Self pol 4=Neg. seq. volt. 5=Cross pol 7=Pos. seq. volt.			5=Cross pol	Reference quantity used to determine fault direction

Table 408: DPHHPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve
Num of start phases	1=1 out of 3 2=2 out of 3			1=1 out of 3	Number of phases required for operate activation

Parameter	Values (Range)	Unit	Step	Default	Description
	3=3 out of 3				

Table 409: DPHHPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

4.1.2.11 Monitored data

DPHLPDOC Monitored data

Table 410: DPHLPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
DIR_A	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
VMEM_USED	BOOLEAN	0=False 1=True		Voltage memory in use status
DPHLPDOC	Enum	1=on 2=blocked 3=test		Status

Name	Type	Values (Range)	Unit	Description
		4=test/blocked 5=off		

DPHHPDOC Monitored data

Table 411: DPHHPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
DIR_A	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward -1=both		Direction phase C
ANGLE_A	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase A
ANGLE_B	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase B
ANGLE_C	FLOAT32	-180.00...180.00	deg	Calculated angle difference, Phase C
VMEM_USED	BOOLEAN	0=False 1=True		Voltage memory in use status
DPHHPDOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.2.12 Technical data

Table 412: DPHxPDOC Technical data

Characteristic		Value
Operation accuracy	DPHLPDOC	Depending on the frequency of the current/voltage measured: f_n ±2 Hz
		Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n

Table continues on the next page

Characteristic		Value		
		Phase angle: ±2°		
	DPHHPDOC	Current: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n) Voltage: ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°		
Start time [1, 2]	I_{Fault}= 2.0 x set *Start value*	Minimum	Typical	Maximum
		39 ms	43 ms	47 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [3]		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.1.2.13 Technical revision history

Table 413: DPHLPDOC Technical revision history

Product connectivity level	Technical revision	Change
PCL4	G	Setting *Start value* maximum value extended to 10.00xIn.

1 *Measurement mode* and *Pol quantity* = default, current before fault = 0.0 × I_n, voltage before fault = 1.0 × U_n, f_n = 50 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact
3 Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20

4.1.3 Three-phase voltage-dependent overcurrent protection PHPVOC (ANSI 51V)

4.1.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase voltage-dependent overcurrent protection	PHPVOC	3I(U)>	51V

4.1.3.2 Function block

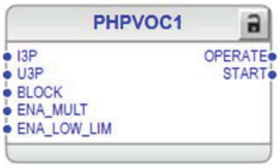


Figure 220: Function block

4.1.3.3 Functionality

The three-phase voltage-dependent overcurrent protection function PHPVOC is used for single-phase, two-phase or three-phase voltage-dependent time overcurrent protection of generators against overcurrent and short circuit conditions.

PHPVOC starts when the input phase current exceeds a limit which is dynamically calculated based on the measured terminal voltages. The operating characteristics can be selected to be either inverse definite minimum time IDMT or definite time DT.

PHPVOC contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.1.3.4 Analog channel configuration

PHPVOC has two analog group inputs which all must be properly configured.

Table 414: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 415: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPVOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

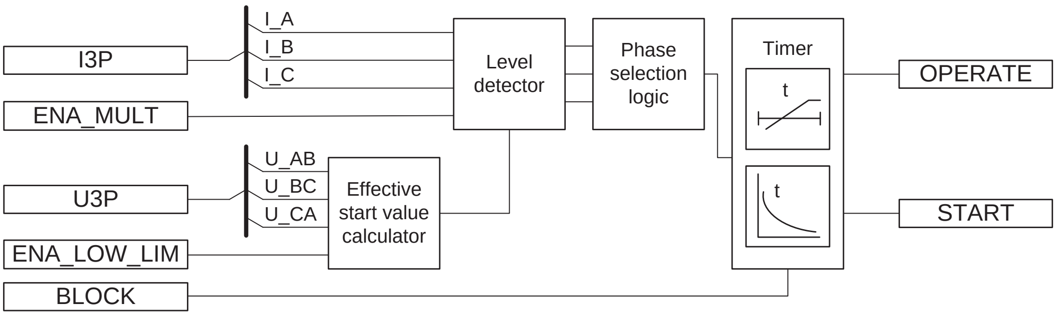


Figure 221: Functional module diagram

Effective start value calculator

The normal starting current above which the overcurrent protection starts is set through the *Start value* setting. The Effective start value of the current may need to be changed during certain conditions like magnetizing inrush or when the terminal voltages drop due to a fault. Hence, the effective start value calculator module dynamically calculates the effective start value above which the overcurrent protection starts.

Four methods of calculating the effective start value are provided in PHPVOC. These can be chosen with the *Control mode* setting to be either "Voltage control", "Input control", "Volt & Input Ctrl" or "No Volt dependency".

The calculated effective start value per phase, `EFF_ST_VAL_A`, `EFF_ST_VAL_B`, `EFF_ST_VAL_C`, is available in the Monitored data view and is used by the Level detector module.

All three phase-to-phase voltages should be available for the function to operate properly.

Voltage control mode

In the Voltage control mode, the Effective start value is calculated based on the magnitude of input voltages `U_AB`, `U_BC` and `U_CA`. The voltage dependency is phase sensitive, which means that the magnitude of one input voltage controls the start value of only the corresponding phase, that is, the magnitude of voltage inputs `U_AB`, `U_BC` and `U_CA` independently control the current start values of phases A, B and C.

Two voltage control characteristics, voltage step and voltage slope, can be achieved with the *Voltage high limit* and *Voltage low limit* settings.

The voltage step characteristic is achieved when the *Voltage high limit* setting is equal to the *Voltage low limit* setting. The effective start value is calculated based on the equations.

Voltage level	Effective start value (I> effective)
U < *Voltage high limit*	*Start value low*
U ≥ *Voltage high limit*	*Start value*

In this example, U represents the measured input voltage. This voltage step characteristic is graphically represented in *Figure 222*.

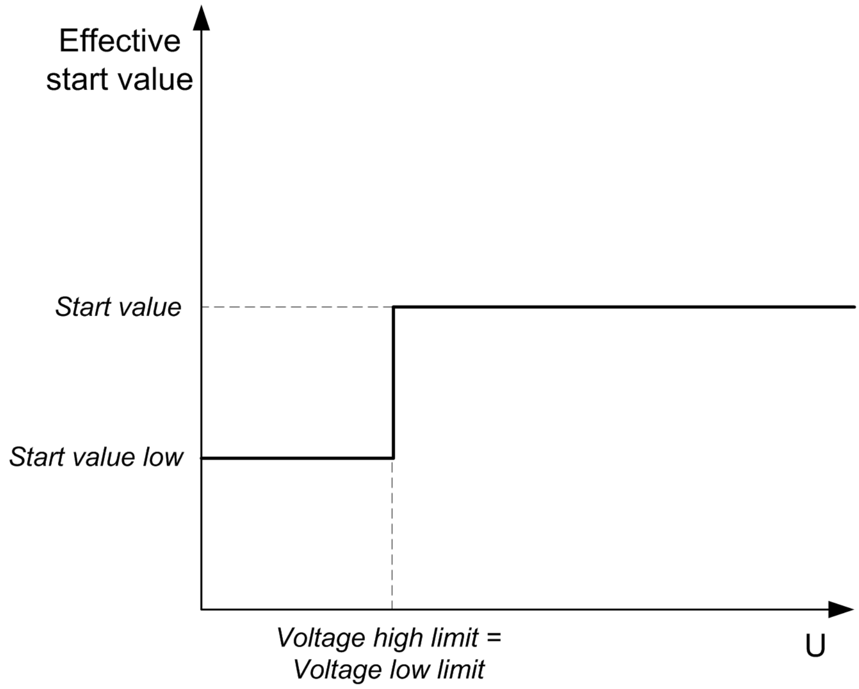


Figure 222: Effective start value for voltage step characteristic

The voltage slope characteristic is achieved by assigning different values to *Voltage high limit* and *Voltage low limit*. The effective start value calculation is based on the equations.

Voltage level	Effective start value (I> effective)
U < *Voltage low limit*	*Start value low*
U ≥ *Voltage high limit*	*Start value*

If *Voltage low limit* ≤ U < *Voltage high limit*,

$$I{>}(effective) = I{>} - [\ ((I{>} - A) / (C - D)) * (C - U)\ ]$$

(Equation 28)

A	set *Start value low*
I>	set *Start value*
C	set *Voltage high limit*
D	set *Voltage low limit*

Here U represents the measured input voltage. The voltage slope characteristic is graphically represented.

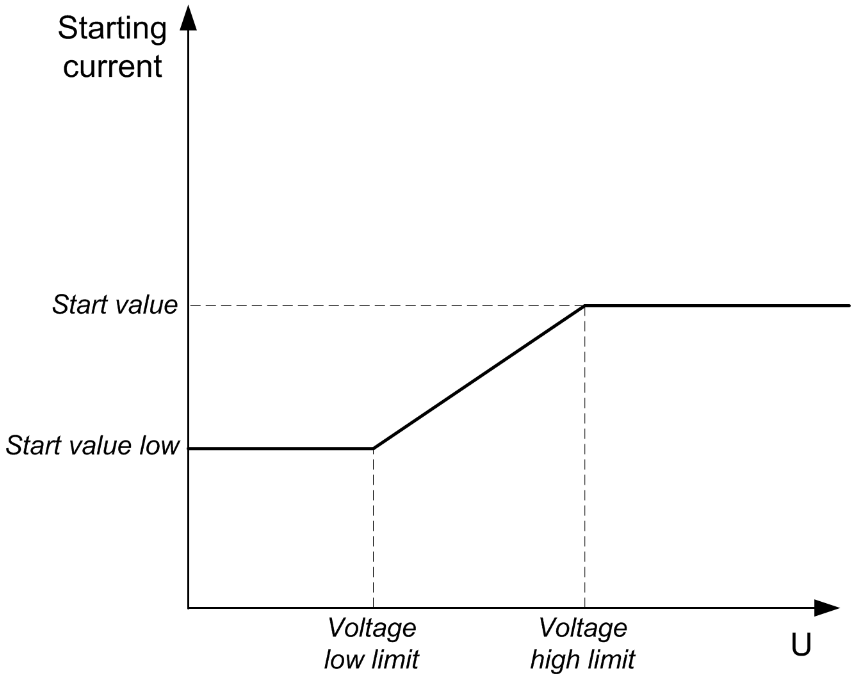


Figure 223: Effective start value or voltage slope characteristic

To achieve the voltage slope characteristics, *Voltage high limit* must always be set to a value greater than *Voltage low limit*.

If *Voltage high limit* is lower than *Voltage low limit*, the voltage step characteristic is active with *Voltage low limit* being the cutoff value.

The value of the setting *Start value* should always be greater than the setting *Start value low*. Otherwise, *Start value low* is used as the effective start value.

External input control mode

The External input control mode is used to enable voltage control from an external application. If *Control mode* is set to the "Input Control" mode, the effective start value for all phases is influenced by the status of the binary input `ENA_U_MULT`.

$$\begin{aligned}&\textit{If ENA\_U\_MULT is TRUE:}\\&\textit{Effective start value} = \textit{Start value low}\end{aligned}$$

(Equation 29)

$$\begin{aligned}&\textit{If ENA\_U\_MULT is FALSE:}\\&\textit{Effective start value} = \textit{Start value}\end{aligned}$$

(Equation 30)

Voltage and input control mode

If *Control mode* is set to "Voltage and input Ctrl", both the "Voltage control" and "Input control" modes are used. However, the “Input control” functionality is dominant over the “Voltage control” mode when `ENA_LOW_LIM` is active.

No voltage dependency mode

When *Control mode* is set to "No Volt dependency", the effective start value has no voltage dependency and the function acts as a normal time overcurrent function with effective start value being equal to the *Start value* setting.

Level detector

The measured phase currents are compared phasewise to the calculated effective start value. If the measured value exceeds the calculated effective start value, the Level detector reports the exceeding value to the phase selection logic. If the `ENA_MULT` input is active, the effective start value is multiplied by the *Start value Mult* setting.

Do not set the multiplier *Start value Mult* setting higher than necessary. If the value is too high, the function may not operate at all during an inrush followed by a fault, no matter how severe the fault is.

The start value multiplication is normally done when the inrush detection function INRPHAR is connected to the `ENA_MULT` input.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the measured current exceeds the setting. If the phase information matches the *Num of start phases* setting, the phase selection logic activates the Timer module.

Timer

Once activated, the Timer module activates the `START` output.

Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

When the user programmable IDMT curve is selected, the operation time characteristics are defined by the settings *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

In a drop-off situation, that is, when a fault suddenly disappears before the operating delay is exceeded, the timer reset state is activated. The functionality of the Timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The *Time multiplier* is used for scaling the IDMT operate and reset times.

The *Minimum operate time* setting defines the minimum desired operating time for IDMT operation. The setting is applicable only when the IDMT curves are used.

Though the *Time multiplier* and *Minimum operate time* settings are common for different IDMT curves, the operating time essentially depends upon the type of IDMT curve chosen.

The Timer calculates the start duration value START_DUR which indicates the percentage ratio of the start situation and the set operating time. This output is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.3.6 Application

The three-phase voltage-dependent overcurrent protection is used as a backup protection for the generators and system from damage due to the phase faults which are not cleared by primary protection and associated breakers.

In case of a short circuit, the sustained fault current of the generator, determined by the machine synchronous reactance, could be below the full-load current. If the generator excitation power is fed from the generator terminals, a voltage drop caused by a short circuit also leads to low fault current. The primary protection, like normal overcurrent protection, might not detect this kind of fault situation. In some cases, the automatic voltage regulator AVR can help to maintain high fault currents by controlling the generator excitation system. If the AVR is out of service or if there is an internal fault in the operation of AVR, the low fault currents can go unnoticed and therefore a voltage-depended overcurrent protection should be used for backup.

Two voltage control characteristics, voltage step and voltage slope, are available in PHPVOC. The choice is made based on the system conditions and the level of protection to be provided.

Voltage step characteristic is applied to generators used in industrial systems. Under close-up fault conditions when the generator terminal voltages drop below the settable threshold value, a new start value of the current, well below the normal load current, is selected. The control voltage setting should ensure that PHPVOC does not trip under the highest loading conditions to which the system can be subjected. Choosing too high a value for the control voltage may allow an undesired operation of the function during wide-area disturbances. When the terminal voltage of the generator is above the control voltage value, the normal start value is used. This ensures that PHPVOC does not operate during normal overloads when the generator terminal voltages are maintained near the normal levels.

Voltage slope characteristic is often used as an alternative to impedance protection on small to medium (5...150 MVA) size generators to provide backup to the differential protection. Other applications of the voltage slope characteristic protection exist in networks to provide better coordination and fault detection than plain overcurrent protection. The voltage slope method provides an improved sensitivity of overcurrent operation by making the overcurrent start value proportional to the terminal voltage. The current start value varies correspondingly with the generator terminal voltages between the set voltage high limit and voltage low limit, ensuring the operation of PHPVOC despite the drop in fault current value.

The operation of PHPVOC should be time-graded with respect to the main protection scheme to ensure that PHPVOC does not operate before the main protection.

4.1.3.7 Signals

PHPVOC Input signals

Table 416: PHPVOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
ENA_LOW_LIM	BOOLEAN	0=False	Enable signal for voltage dependent lower start value

PHPVOC Output signals

Table 417: PHPVOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.3.8 PHPVOC Settings

Table 418: PHPVOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.05	Start value
Start value low	0.05...1.00	xIn	0.01	0.05	Lower start value based on voltage control
Voltage high limit	0.01...1.00	xUn	0.01	1.00	Voltage high limit for voltage control
Voltage low limit	0.01...1.00	xUn	0.01	1.00	Voltage low limit for voltage control
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scal-ing the start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	40...200000	ms	10	40	Operate delay time

Table 419: PHPVOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 420: PHPVOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 421: PHPVOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Control mode	1=Voltage control 2=Input control 3=Voltage and input Ctl 4=No Volt dependency			1=Voltage control	Type of control
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.3.9 PHPVOC Monitored data

Table 422: PHPVOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFF_ST_VAL_A	FLOAT32	0.00...50.00	xIn	Effective start value for phase A
EFF_ST_VAL_B	FLOAT32	0.00...50.00	xIn	Effective start value for phase B
EFF_ST_VAL_C	FLOAT32	0.00...50.00	xIn	Effective start value for phase C
PHPVOC	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

4.1.3.10 Technical data

Table 423: PHPVOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: f_n ±2 Hz
	Current: ±1.5% of the set value or ± 0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n
Start time ,[2]	Typically 26 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.1.4 Accidental energization protection GAEPVOC (ANSI 27/50)

4.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Accidental energization protection	GAEPVOC	U<,I>	27/50

4.1.4.2 Function block

Figure 224: Function block

[1] *Measurement mode* = default, current before fault = 0.0 × I_n, f_n = 50 Hz, fault current in one phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

4.1.4.3 Functionality

The accidental energization protection function GAEPVOC for the synchronous generator is an overcurrent protection function which is enabled only when the generator is at a standstill or in turning gear. The function is used to protect the generator rotor from damage due to rapid heating.

A number of field conditions, such as generator operating errors, breaker head flashovers, control circuit malfunctions, false actuation of breaker, or a combination of these can cause accidental energization of the generators. The generator under this condition suddenly causes a relatively heavy load to the surrounding network, which might lead to power balance instability.

Since the generator starts behaving as an asynchronous motor, this three-phase current develops higher current in the rotor, which may thermally damage the generator in a few seconds. A very high thermal stress in both the stator winding and the rotor has been produced by this situation.

The prime mover can also suffer from mechanical damage in moving parts like turbine blades or gearing teeth. Lack of oil may damage the bearings as lube pumps are not in operation when the generator is at a standstill. The turning gear oil pumps are not in operation either and the accidental energization may significantly damage the turning gear.

4.1.4.4 Analog channel configuration

GAEPVOC has two analog group inputs which must be properly configured.

Table 424: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 425: Special conditions

Condition	Description
U3P connected real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.4.5 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "on" and "off".

The operation of GAEPVOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

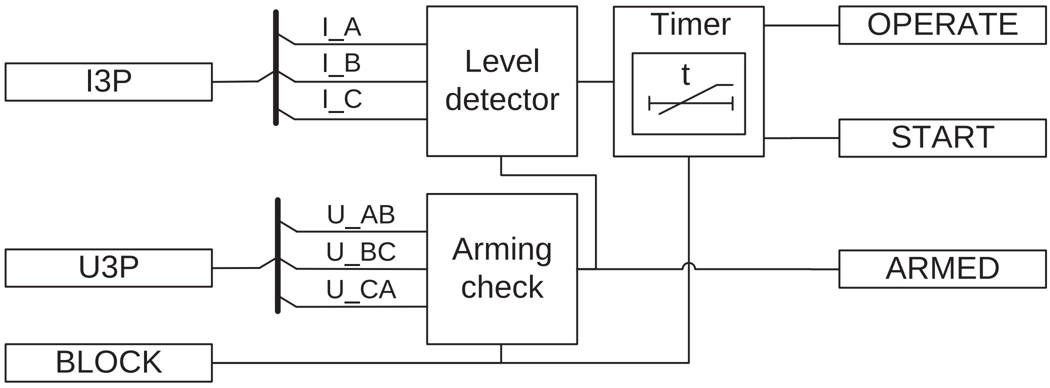


Figure 225: Functional module diagram

Arming check

The fundamental frequency component of the three measured phase-to-phase generator side voltages are compared with setting *Arm set voltage*. If all measured voltages are below the set *Arm set voltage* for longer than *Arm delay time*, the ARMED signal is set to TRUE and simultaneously Level detector is enabled.

The value of *Arm set voltage* must be set lower than any emergency low voltage condition that can occur when the system is under extreme stress conditions. When the generator returns to service and the voltage exceeds the *Disarm set voltage* setting, the scheme is automatically removed from service (Level detector disabled) after a time delay (*Disarm delay time setting*) and the ARMED output is set to FALSE. GAEPVOC must only be activated when the generator is out-of-service and disabled when the generator is online.

The setting value of *Arm set voltage* should be less than the setting value of *Disarm set voltage*.

Activation of BLOCK input resets the ARMED output to FALSE state.

Level detector

The measured peak-to-peak values of three phase currents are compared with the set *Start value*. If the measured values exceed *Start value*, an enable signal is sent to Timer.

Timer

Once activated, Timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If a drop-off situation occurs, the Timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, Timer resets.

The activation of the BLOCK input resets Timer and blocks the START and OPERATE outputs.

Timer calculates the start duration value START_DUR which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

4.1.4.6 Application

Accidental energization protection or dead machine protection is necessary as part of the generator protection application. In case of operating error, breaker head flashovers, control circuit malfunctions or a combination of these, the generator may be accidentally energized while offline. High currents might cause mechanical and thermal stress to the generator and cables, and other related power station equipment.

4.1.4.7 Signals

GAEPVOC Input signals

Table 426: GAEPVOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

GAEPVOC Output signals

Table 427: GAEPVOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ARMED	BOOLEAN	Current limit active (Armed)

4.1.4.8 GAEPVOC Settings

Table 428: GAEPVOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...9.00	xIn	0.01	1.20	Start value
Arm set voltage	0.05...1.00	xUn	0.01	0.30	Voltage level to arm the protection (Phase-to-phase value of voltage)
Disarm set voltage	0.50...1.50	xUn	0.01	0.80	Voltage level to disarm the pro-

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					tection (Phase-to-phase value of voltage)
Operate delay time	20...300000	ms	10	40	Operate delay time
Arm delay time	40...300000	ms	10	5000	Time delay to arm the function
Disarm delay time	40...300000	ms	10	500	Time delay to disarm the function

Table 429: GAEPVOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 430: GAEPVOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.4.9 GAEPVOC Monitored data

Table 431: GAEPVOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
GAEPVOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.4.10 Technical data

Table 432: GAEPVOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltages: f_n ±2 Hz
	Current: ±1.5% of the set value or ± 0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n
Start time [1,2]	Typically 20 ms
Reset time	Typically 35 ms
Reset ratio	Typically 0.96

Table continues on the next page

1 Results based on statistical distribution of 1000 measurements.
2 Measured with static signal output (SSO).

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	Voltage: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5, … Current: No suppression

4.1.5 Three-phase thermal protection for feeders, cables and distribution transformers T1PTTR (ANSI 49F)

4.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal protection for feeders, cables and distribution transformers	T1PTTR	3Ith>F	49F

4.1.5.2 Function block

Figure 226: Function block

4.1.5.3 Functionality

The increased utilization of power systems closer to the thermal limits has generated a need for a thermal overload function also for power lines.

A thermal overload is in some cases not detected by other protection functions, and the introduction of the three-phase thermal protection for feeders, cables and distribution transformers function T1PTTR allows the protected circuit to operate closer to the thermal limits.

An alarm level gives an early warning to allow operators to take action before the line trips. The early warning is based on the three-phase current measuring function using a thermal model with first order thermal loss with the settable time constant. If the temperature rise continues the function will operate based on the thermal model of the line.

Re-energizing of the line after the thermal overload operation can be inhibited during the time the cooling of the line is in progress. The cooling of the line is estimated by the thermal model.

4.1.5.4 Analog channel configuration

T1PTTR has one analog group input which must be properly configured.

Table 433: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of T1PTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog GOOSE to connect AMB_TEMP input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

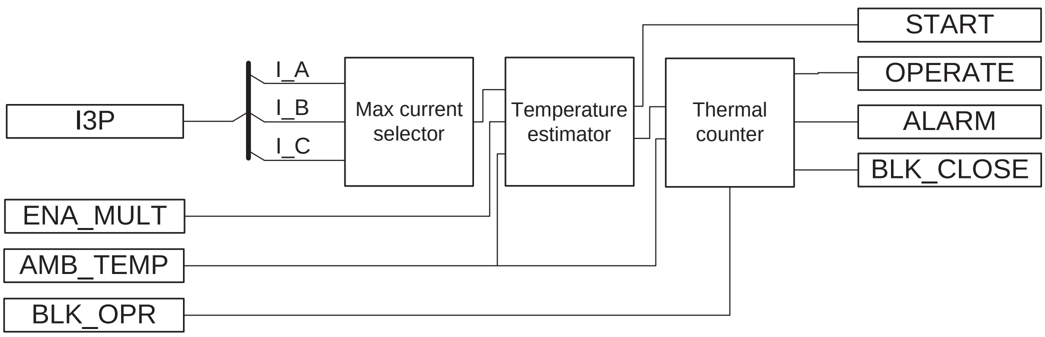


Figure 227: Functional module diagram

Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the temperature estimator.

Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left(\frac{I}{I_{ref}}\right)^2 \cdot T_{ref}$$

(Equation 31)

I	the highest phase current
I_{ref}	set *Current reference*
T_{ref}	set *Temperature rise*

The ambient temperature is added to the calculated final temperature rise estimation, and the ambient temperature value used in the calculation is also available in the monitored data as TEMP_AMB in degrees. If the final temperature estimation is higher than the set *Maximum temperature*, the START output is activated.

Current reference and *Temperature rise* setting values are used in the final temperature estimation together with the ambient temperature. It is suggested to set these values to the maximum steady state current allowed for the line or cable under emergency operation for a few hours per years. Current values with the corresponding conductor temperatures are given in cable manuals. These values are given for conditions such as ground temperatures, ambient air temperature, the way of cable laying and ground thermal resistivity.

Thermal counter

The actual temperature at the actual execution cycle is calculated as:

$$\Theta_n = \Theta_{n-1} + \left(\Theta_{final} - \Theta_{n-1}\right) \cdot \left(1 - e^{-\frac{\Delta t}{\tau}}\right)$$

(Equation 32)

Θ_n	calculated present temperature
Θ_{n-1}	calculated temperature at previous time step
Θ_{final}	calculated final temperature with actual current
Δt	time step between calculation of actual temperature
t	thermal time constant for the protected device (line or cable), set *Time constant*

The actual temperature of the protected component (line or cable) is calculated by adding the ambient temperature to the calculated temperature, as shown above. The ambient temperature can be given a constant value or it can be measured. The calculated component temperature can be monitored as it is exported from the function as a real figure.

When the component temperature reaches the set alarm level *Alarm value*, the output signal ALARM is set. When the component temperature reaches the set trip level *Maximum temperature*, the OPERATE output is activated. The OPERATE signal pulse length is fixed to 100 ms.

There is also a calculation of the present time to operation with the present current. This calculation is only performed if the final temperature is calculated to be above the operation temperature:

$$t_{operate} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{operate}}{\Theta_{final} - \Theta_{n}}\right)$$

(Equation 33)

Caused by the thermal overload protection function, there can be a lockout to reconnect the tripped circuit after operating. The lockout output BLK_CLOSE is activated at the same time when the OPERATE output is activated and is not reset until the device temperature has cooled down below the set value of the *Reclose temperature* setting. The *Maximum temperature* value must be set at least two degrees above the set value of *Reclose temperature*.

The time to lockout release is calculated, that is, the calculation of the cooling time to a set value. The calculated temperature can be reset to its initial value (the *Initial temperature* setting) via a control parameter that is located under the clear menu. This is useful during testing when secondary injected current has given a calculated false temperature level.

$$t_{lockout\_release} = -\tau \cdot \ln\left(\frac{\Theta_{final} - \Theta_{lockout\_release}}{\Theta_{final} - \Theta_{n}}\right)$$

(Equation 34)

Here the final temperature is equal to the set or measured ambient temperature.

In some applications, the measured current can involve a number of parallel lines. This is often used for cable lines where one bay connects several parallel cables. By setting the *Current multiplier* parameter to the number of parallel lines (cables), the actual current on one line is used in the protection algorithm. To activate this option, the ENA_MULT input must be activated.

The ambient temperature can be measured with the RTD measurement. The measured temperature value is then connected, for example, from the AI_VAL3 output of the X130 RTD function to the AMB_TEMP input of T1PTTR.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the AMB_TEMP input. The *Env temperature Set* setting is also used when the ambient temperature measurement connected to T1PTTR is set to “Not in use” in the X130 RTD function.

The temperature calculation is initiated from the value defined with the *Initial temperature* setting parameter. This is done in case the protection relay is powered up, the function is turned "Off" and back "On" or reset through the Clear menu. The temperature is also stored in the nonvolatile memory and restored in case the protection relay is restarted.

The thermal time constant of the protected circuit is given in seconds with the *Time constant* setting. Please see cable manufacturers manuals for further details.

T1PTTR thermal model complies with the IEC 60255-149 standard.

4.1.5.6 Application

The lines and cables in the power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses will be higher than expected. As a consequence, the temperature of the conductors will increase. If the temperature of the lines and cables reaches too high values, it can cause a risk of damages by, for example, the following ways:

- The sag of overhead lines can reach an unacceptable value.
- If the temperature of conductors, for example aluminium conductors, becomes too high, the material will be destroyed.
- In cables the insulation can be damaged as a consequence of overtemperature, and therefore phase-to-phase or phase-to-earth faults can occur.

In stressed situations in the power system, the lines and cables may be required to be overloaded for a limited time. This should be done without any risk for the above-mentioned risks.

The thermal overload protection provides information that makes temporary overloading of cables and lines possible. The thermal overload protection estimates the conductor temperature continuously. This estimation is made by using a thermal model of the line/cable that is based on the current measurement.

If the temperature of the protected object reaches a set warning level, a signal is given to the operator. This enables actions in the power system to be done before dangerous temperatures are reached. If the temperature continues to increase to the maximum allowed temperature value, the protection initiates a trip of the protected line.

4.1.5.7 Signals

T1PTTR Input signals

Table 434: T1PTTR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLK_OPR	BOOLEAN	0=False	Block signal for operate outputs
ENA_MULT	BOOLEAN	0=False	Enable Current multiplier
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

T1PTTR Output signals

Table 435: T1PTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Thermal Alarm
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibite reclose.

4.1.5.8 T1PTTR Settings

Table 436: T1PTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature Set	-50...100	°C	1	40	Ambient temperature used when no external temperature measurement available
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature
Temperature rise	0.0...200.0	°C	0.1	75.0	End temperature rise above ambient
Time constant	60...60000	s	1	2700	Time constant of the line in seconds.
Maximum temperature	22.0...200.0	°C	0.1	90.0	Temperature level for operate
Alarm value	20.0...150.0	°C	0.1	80.0	Temperature level for start (alarm)
Reclose temperature	20.0...150.0	°C	0.1	70.0	Temperature for reset of block reclose after operate

Table 437: T1PTTR Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current multiplier	1...5		1	1	Current multiplier when function is used for parallel lines

Table 438: T1PTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 439: T1PTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial temperature	-50.0...100.0	°C	0.1	0.0	Temperature raise above ambient temperature at startup

4.1.5.9 T1PTTR Monitored data

Table 440: T1PTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP	FLOAT32	-100.0...9999.9	°C	The calculated temperature of the protected object
TEMP_RL	FLOAT32	0.00...99.99		The calculated temperature of the protected object relative to the operate level
T_OPERATE	INT32	0...60000	s	Estimated time to operate
T_ENA_CLOSE	INT32	0...60000	s	Estimated time to deactivate BLK_CLOSE
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calculation
T1PTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.5.10 Technical data

Table 441: T1PTTR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Operate time accuracy [1]	±2.0% of the theoretical value or ±0.50 s

4.1.6 Three-phase thermal overload protection, two time constants T2PTTR (ANSI 49T/G/C)

4.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase thermal overload protection, two time constants	T2PTTR	3Ith>T/G/C	49T/G/C

[1] Overload current > 1.2 × Operate level temperature

4.1.6.2 Function block

Figure 228: Function block

4.1.6.3 Functionality

The three-phase thermal overload protection, two time constants, protection function T2PTTR protects the transformer mainly from short-time overloads. The transformer is protected from long-time overloads with the oil temperature detector included in its equipment.

The alarm signal gives an early warning to allow the operators to take action before the transformer trips. The early warning is based on the three-phase current measuring function using a thermal model with two settable time constants. If the temperature rise continues, T2PTTR operates based on the thermal model of the transformer.

After a thermal overload operation, the re-energizing of the transformer is inhibited during the transformer cooling time. The transformer cooling is estimated with a thermal model.

4.1.6.4 Analog channel configuration

T2PTTR has one analog group input which must be properly configured.

Table 442: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.6.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of T2PTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog GOOSE to connect AMB_TEMP input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

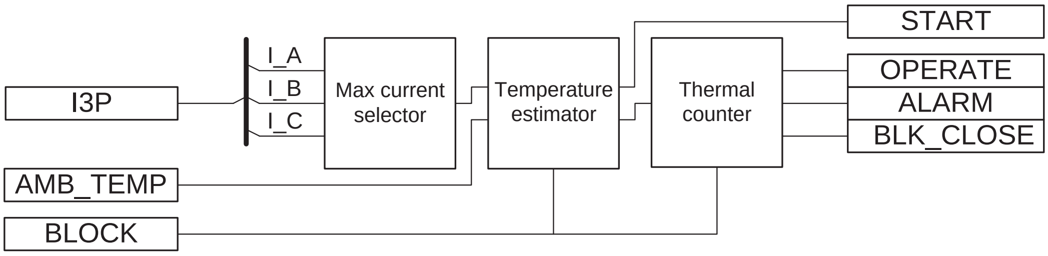


Figure 229: Functional module diagram

Max current selector

The max current selector of the function continuously checks the highest measured TRMS phase current value. The selector reports the highest value to the thermal counter.

Temperature estimator

The final temperature rise is calculated from the highest of the three-phase currents according to the expression:

$$\Theta_{final} = \left(\frac{I}{I_{ref}}\right)^2 \cdot T_{ref}$$

(Equation 35)

I	highest measured phase current
I_{ref}	the set value of the *Current reference* setting
T_{ref}	the set value of the *Temperature rise* setting (temperature rise (°C) with the steady-state current I_{ref}

The ambient temperature value is added to the calculated final temperature rise estimation. If the total value of temperature is higher than the set operate temperature level, the START output is activated.

The *Current reference* setting is a steady-state current that gives the steady-state end temperature value *Temperature rise*. It gives a setting value corresponding to the rated power of the transformer.

The *Temperature rise* setting is used when the value of the reference temperature rise corresponds to the *Current reference* value. The temperature values with the corresponding transformer load currents are usually given by transformer manufacturers.

Thermal counter

T2PTTR applies the thermal model of two time constants for temperature measurement. The temperature rise in degrees Celsius (°C) is calculated from the highest of the three-phase currents according to the expression:

$$\Delta\Theta = \left[p * \left(\frac{I}{I_{ref}} \right)^2 * T_{ref} \right] \cdot \left(1 - e^{-\frac{\Delta t}{\tau 1}} \right) + \left[(1-p) \cdot \left(\frac{I}{I_{ref}} \right)^2 \cdot T_{ref} \right] \cdot \left(1 - e^{-\frac{\Delta t}{\tau 2}} \right)$$

(Equation 36)

ΔΘ	calculated temperature rise (°C) in transformer
I	measured phase current with the highest TRMS value
I_{ref}	the set value of the *Current reference* setting (rated current of the protected object)
T_{ref}	the set value of the *Temperature rise* setting (temperature rise setting (°C) with the steady-state current I_{ref})
p	the set value of the *Weighting factor p* setting (weighting factor for the short time constant)
Δt	time step between the calculation of the actual temperature
t_1	the set value of the *Short time constant* setting (the short heating / cooling time constant)
t_2	the set value of the *Long time constant* setting (the long heating / cooling time constant)

The warming and cooling following the two time-constant thermal curve is a characteristic of transformers. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. The *Short time constant* setting describes the warming of the transformer with respect to windings. The *Long time constant* setting describes the warming of the transformer with respect to the oil. Using the two time-constant model, the protection relay is able to follow both fast and slow changes in the temperature of the protected object.

The *Weighting factor p* setting is the weighting factor between *Short time constant* τ_1 and *Long time constant* τ_2. The higher the value of the *Weighting factor p* setting, the larger is the share of the steep part of the heating curve. When *Weighting factor p* =1, only *Short-time constant* is used. When *Weighting factor p* = 0, only *Long time constant* is used.

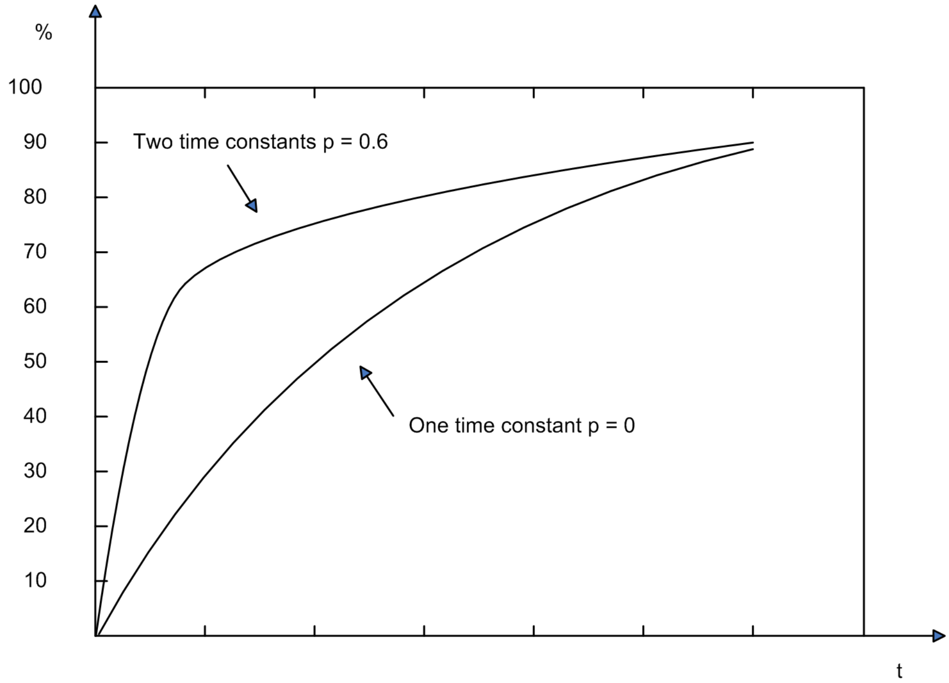


Figure 230: Effect of the Weighting factor p factor and the difference between the two time constants and one time constant models

The actual temperature of the transformer is calculated by adding the ambient temperature to the calculated temperature.

$$\Theta = \Delta\Theta + \Theta_{amb}$$

(Equation 37)

Θ	temperature in transformer (°C)
$\Delta\Theta$	calculated temperature rise (°C) in transformer
Θ_{amb}	set value of the *Env temperature Set* setting or measured ambient temperature

The ambient temperature can be measured with RTD measurement. The measured temperature value is connected, for example, from the `AI_VAL3` output of the X130 RTD function to the `AMB_TEMP` input of T2PTTR.

The *Env temperature Set* setting is used to define the ambient temperature if the ambient temperature measurement value is not connected to the `AMB_TEMP` input. The *Env temperature Set* setting is also used when the ambient temperature measurement connected to T2PTTR is set to “Not in use” in the X130 RTD function.

The temperature calculation is initiated from the value defined with the *Initial temperature* and *Max temperature* setting parameters. The initial value is a percentage of *Max temperature* defined by *Initial temperature*. This is done when the protection relay is powered up or the function is turned off and back on or reset through the Clear menu. The temperature is stored in a nonvolatile memory and restored if the protection relay is restarted.

The *Max temperature* setting defines the maximum temperature of the transformer in degrees Celsius (°C). The value of the *Max temperature* setting is usually given by transformer manufacturers. The actual alarm, operating and lockout temperatures for T2PTTR are given as a percentage value of the *Max temperature* setting.

When the transformer temperature reaches the alarm level defined with the *Alarm temperature* setting, the ALARM output signal is set. When the transformer temperature reaches the trip level value defined with the *Operate temperature* setting, the OPERATE output is activated. The OPERATE output is deactivated when the value of the measured current falls below 10 percent of the *Current Reference* value or the calculated temperature value falls below *Operate temperature*.

There is also a calculation of the present time to operation with the present current. T_OPERATE is only calculated if the final temperature is calculated to be above the operation temperature. The value is available in the monitored data view.

After operating, there can be a lockout to reconnect the tripped circuit due to the thermal overload protection function. The BLK_CLOSE lockout output is activated when the device temperature is above the *Reclose temperature* lockout release temperature setting value. The time to lockout release T_ENA_CLOSE is also calculated. The value is available in the monitored data view.

4.1.6.6 Application

The transformers in a power system are constructed for a certain maximum load current level. If the current exceeds this level, the losses are higher than expected. This results in a rise in transformer temperature. If the temperature rise is too high, the equipment is damaged:

- Insulation within the transformer ages faster, which in turn increases the risk of internal phase-to-phase or phase-to-earth faults.
- Possible hotspots forming within the transformer degrade the quality of the transformer oil.

During stressed situations in power systems, it is required to overload the transformers for a limited time without any risks. The thermal overload protection provides information and makes temporary overloading of transformers possible.

The permissible load level of a power transformer is highly dependent on the transformer cooling system. The two main principles are:

- ONAN: The air is naturally circulated to the coolers without fans, and the oil is naturally circulated without pumps.
- OFAF: The coolers have fans to force air for cooling, and pumps to force the circulation of the transformer oil.

The protection has several parameter sets located in the setting groups, for example one for a non-forced cooling and one for a forced cooling situation. Both the permissive steady-state loading level as well as the thermal time constant are influenced by the transformer cooling system. The active setting group can be changed by a parameter, or through a binary input if the binary input is enabled for it. This feature can be used for transformers where forced cooling is taken out of operation or extra cooling is switched on. The parameters can also be changed when a fan or pump fails to operate.

The thermal overload protection continuously estimates the internal heat content, that is, the temperature of the transformer. This estimation is made by using a thermal model of the transformer which is based on the current measurement.

If the heat content of the protected transformer reaches the set alarm level, a signal is given to the operator. This enables the action that needs to be taken in the power systems before the temperature reaches a high value. If the temperature continues to rise to the trip value, the protection initiates the trip of the protected transformer.

After the trip, the transformer needs to cool down to a temperature level where the transformer can be taken into service again. T2PTTR continues to estimate the heat content of the transformer during this cooling period using a set cooling time constant. The energizing of the transformer is blocked until the heat content is reduced to the set level.

The thermal curve of two time constants is typical for a transformer. The thermal time constants of the protected transformer are given in seconds with the *Short time constant* and *Long time constant* settings. If the manufacturer does not state any other value, the *Long time constant* can be set to 4920 s (82 minutes) for a distribution transformer and 7260 s (121 minutes) for a supply transformer. The corresponding *Short time constants* are 306 s (5.1 minutes) and 456 s (7.6 minutes).

If the manufacturer of the power transformer has stated only one, that is, a single time constant, it can be converted to two time constants. The single time constant is also used by itself if the p-factor *Weighting factor p* setting is set to zero and the time constant value is set to the value of the *Long time constant* setting. The thermal image corresponds to the one time constant model in that case.

Table 443: Conversion table between one and two time constants

Single time constant (min)	*Short time constant* (min)	*Long time constant* (min)	*Weighting factor p*
10	1.1	17	0.4
15	1.6	25	0.4
20	2.1	33	0.4
25	2.6	41	0.4
30	3.1	49	0.4
35	3.6	58	0.4
40	4.1	60	0.4
45	4.8	75	0.4
50	5.1	82	0.4
55	5.6	90	0.4
60	6.1	98	0.4
65	6.7	107	0.4
70	7.2	115	0.4
75	7.8	124	0.4

The default *Max temperature* setting is 105°C. This value is chosen since even though the IEC 60076-7 standard recommends 98°C as the maximum allowable temperature in long-time loading, the standard also states that a transformer can withstand the emergency loading for weeks or even months, which may produce the winding temperature of 140°C. Therefore, 105°C is a safe maximum temperature value for a transformer if the *Max temperature* setting value is not given by the transformer manufacturer.

4.1.6.7 Signals

T2PTTR Input signals

Table 444: T2PTTR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

T2PTTR Output signals

Table 445: T2PTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Thermal Alarm
BLK_CLOSE	BOOLEAN	Thermal overload indicator. To inhibite reclose.

4.1.6.8 T2PTTR Settings

Table 446: T2PTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature Set	-50...100	°C	1	40	Ambient temperature used when no external temperature measurement available
Temperature rise	0.0...200.0	°C	0.1	78.0	End temperature rise above ambient
Max temperature	22.0...200.0	°C	0.1	105.0	Maximum temperature allowed for the transformer
Operate temperature	80.0...120.0	%	0.1	100.0	Operate temperature, percent value
Alarm temperature	40.0...100.0	%	0.1	90.0	Alarm temperature, percent value
Reclose temperature	40.0...100.0	%	0.1	60.0	Temperature for reset of block reclose after operate
Short time constant	6...60000	s	1	450	Short time constant in seconds
Long time constant	60...60000	s	1	7200	Long time constant in seconds
Weighting factor p	0.00...1.00		0.01	0.40	Weighting factor of the short time constant

Table 447: T2PTTR Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature

Table 448: T2PTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 449: T2PTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial temperature	0.0...100.0	%	0.1	80.0	Initial temperature, percent value

4.1.6.9 T2PTTR Monitored data

Table 450: T2PTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP	FLOAT32	-100.0...9999.9	°C	The calculated temperature of the protected object
TEMP_RL	FLOAT32	0.00...99.99		The calculated temperature of the protected object relative to the operate level
T_OPERATE	INT32	0...60000	s	Estimated time to operate
T_ENA_CLOSE	INT32	0...60000	s	Estimated time to deactivate BLK_CLOSE in seconds
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calculation
T2PTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.6.10 Technical data

Table 451: T2PTTR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 x I_n (at currents in the range of 0.01...4.00 x I_n)
Operate time accuracy[1]	±2.0% of the theoretical value or ±0.50 s

4.1.7 Motor load jam protection JAMPTOC (ANSI 50TDJAM)

4.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor load jam protection	JAMPTOC	Ist>	50TDJAM

4.1.7.2 Function block

Figure 231: Function block

4.1.7.3 Functionality

The motor load jam protection function JAMPTOC is used for protecting the motor in stall or mechanical jam situations during the running state.

When the motor is started, a separate function is used for the startup protection, and JAMPTOC is normally blocked during the startup period. When the motor has passed the starting phase, JAMPTOC monitors the magnitude of phase currents. The function starts when the measured current exceeds the breakdown torque level, that is, above the set limit. The operation characteristic is definite time.

The function contains a blocking functionality. It is possible to block the function outputs.

4.1.7.4 Analog channel configuration

JAMPTOC has one analog group input which must be properly configured.

[1] Overload current > 1.2 x Operate level temperature

Table 452: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.7.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of JAMPTOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

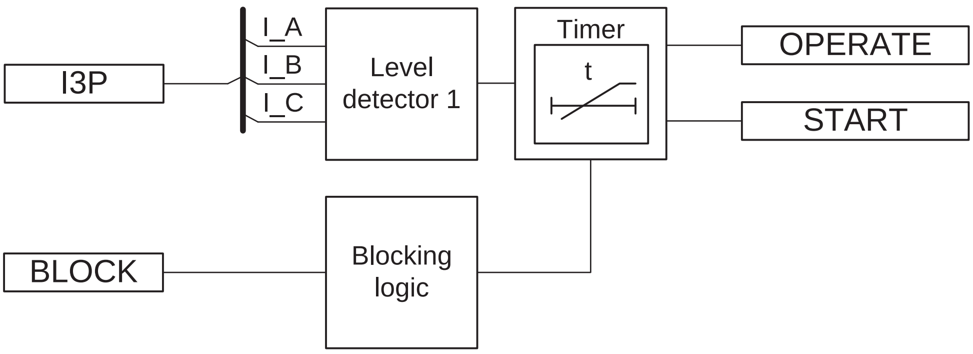


Figure 232: Functional module diagram

Level detector

The measured phase currents are compared to the set *Start value*. The TRMS values of the phase currents are considered for the level detection. The timer module is enabled if at least two of the measured phase currents exceed the set *Start value*.

Timer

Once activated, the internal START signal is activated. The value is available only through the Monitored data view. The time characteristic is according to DT. When the operation timer has reached the *Operate delay time* value, the OPERATE output is activated.

When the timer has elapsed but the motor stall condition still exists, the OPERATE output remains active until the phase currents values drop below the *Start value*, that is, until the stall condition persists. If the drop-off situation occurs while the operating time is still counting, the reset timer is activated. If the drop-off time exceeds the set *Reset delay time*, the operating timer is reset.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.1.7.6 Application

The motor protection during stall is primarily needed to protect the motor from excessive temperature rise, as the motor draws high currents during the stall phase. This condition causes a temperature rise in the stator windings. Due to reduced speed, the temperature also rises in the rotor. The rotor temperature rise is more critical when the motor stops.

The physical and dielectric insulations of the system deteriorate with age and the deterioration is accelerated by the temperature increase. Insulation life is related to the time interval during which the insulation is maintained at a given temperature.

An induction motor stalls when the load torque value exceeds the breakdown torque value, causing the speed to decrease to zero or to some stable operating point well below the rated speed. This occurs, for example, when the applied shaft load is suddenly increased and is greater than the producing motor torque due to the bearing failures. This condition develops a motor current almost equal to the value of the locked-rotor current.

JAMPTOC is designed to protect the motor in stall or mechanical jam situations during the running state. To provide a good and reliable protection for motors in a stall situation, the temperature effects on the motor have to be kept within the allowed limits.

4.1.7.7 Signals

JAMPTOC Input signals

Table 453: JAMPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

JAMPTOC Output signals

Table 454: JAMPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

4.1.7.8 JAMPTOC Settings

Table 455: JAMPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	0.10...10.00	xIn	0.01	2.50	Start value
Operate delay time	100...120000	ms	10	2000	Operate delay time

Table 456: JAMPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	100	Reset delay time

4.1.7.9 JAMPTOC Monitored data

Table 457: JAMPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START	BOOLEAN	0=False 1=True		Start
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
JAMPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.7.10 Technical data

Table 458: JAMPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Reset time	Typically 40 ms
Reset ratio	Typically 0.96

Table continues on the next page

Characteristic	Value
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms

4.1.8 Loss of load supervision LOFLPTUC (ANSI 37)

4.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Loss of load supervision	LOFLPTUC	3I<	37

4.1.8.2 Function block

Figure 233: Function block

4.1.8.3 Functionality

The loss of load supervision function LOFLPTUC is used to detect a sudden load loss which is considered as a fault condition.

LOFLPTUC starts when the current is less than the set limit. It operates with the definite time (DT) characteristics, which means that the function operates after a predefined operate time and resets when the fault current disappears.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.1.8.4 Analog channel configuration

LOFLPTUC has one analog group input which must be properly configured.

Table 459: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing

blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.8.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LOFLPTUC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

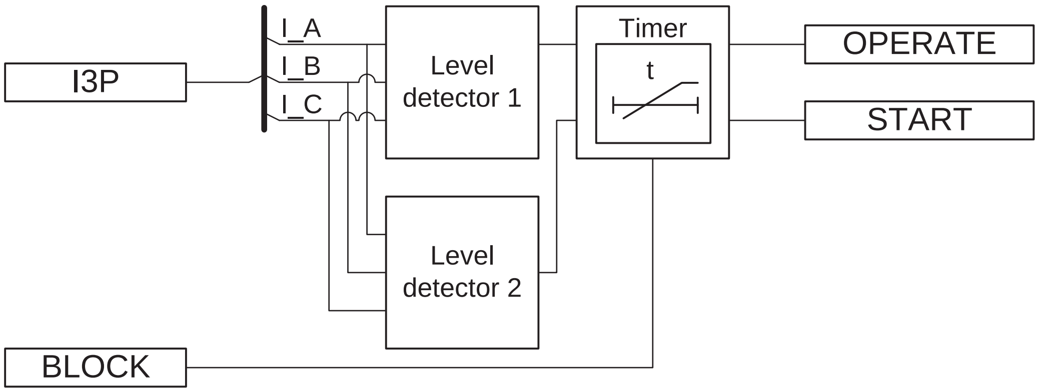


Figure 234: Functional module diagram

Level detector 1

This module compares the phase currents (RMS value) to the set *Start value high* setting. If all the phase current values are less than the set *Start value high* value, the loss of load condition is detected and an enable signal is sent to the timer. This signal is disabled after one or several phase currents have exceeded the set *Start value high* value of the element.

Level detector 2

This is a low-current detection module, which monitors the de-energized condition of the motor. It compares the phase currents (RMS value) to the set *Start value low* setting. If any of the phase current values is less than the set *Start value low*, a signal is sent to block the operation of the timer.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

The `BLOCK` signal blocks the operation of the function and resets the timer.

4.1.8.6 Application

When a motor runs with a load connected, it draws a current equal to a value between the no-load value and the rated current of the motor. The minimum load current can be determined by studying the characteristics of the connected load. When the current drawn by the motor is less than the minimum load current drawn, it can be inferred that the motor is either disconnected from the load or the coupling mechanism is faulty. If the motor is allowed to run in this condition, it may aggravate the fault in the coupling mechanism or harm the personnel handling the machine. Therefore, the motor has to be disconnected from the power supply as soon as the above condition is detected.

LOFLPTUC detects the condition by monitoring the current values and helps disconnect the motor from the power supply instantaneously or after a delay according to the requirement.

When the motor is at standstill, the current will be zero and it is not recommended to activate the trip during this time. The minimum current drawn by the motor when it is connected to the power supply is the no load current, that is, the higher start value current. If the current drawn is below the lower start value current, the motor is disconnected from the power supply. LOFLPTUC detects this condition and interprets that the motor is de-energized and disables the function to prevent unnecessary trip events.

4.1.8.7 Signals

LOFLPTUC Input signals

Table 460: LOFLPTUC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block all binary out-puts by resetting timers

LOFLPTUC Output signals

Table 461: LOFLPTUC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.8.8 LOFLPTUC Settings

Table 462: LOFLPTUC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value low	0.01...0.50	xIn	0.01	0.10	Current setting/Start value low
Start value high	0.01...1.00	xIn	0.01	0.50	Current setting/Start value high
Operate delay time	400...600000	ms	10	2000	Operate delay time

Table 463: LOFLPTUC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 464: LOFLPTUC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.8.9 LOFLPTUC Monitored data

Table 465: LOFLPTUC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
LOFLPTUC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.8.10 Technical data

Table 466: LOFLPTUC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × I_n
Start time	Typically 300 ms
Reset time	Typically 40 ms
Reset ratio	Typically 1.04
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms

4.1.9 Loss of phase, undercurrent PHPTUC (ANSI 37)

4.1.9.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
Loss of phase, undercurrent	PHPTUC1	3I<	37

4.1.9.2 Function block

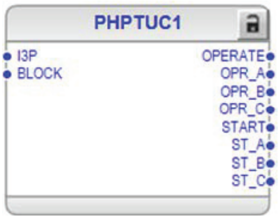


Figure 235: Function block

4.1.9.3 Functionality

The phase undercurrent protection function PHPTUC is used to detect an undercurrent that is considered as a fault condition.

PHPTUC starts when the current is less than the set limit. Operation time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs and reset the definite timer.

4.1.9.4 Analog input configuration

PHPTUC has one analog group input which must be properly configured.

Table 467: Analog inputs

Input	**Description**
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.9.5 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "On" and "Off".

The operation of PHPTUC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

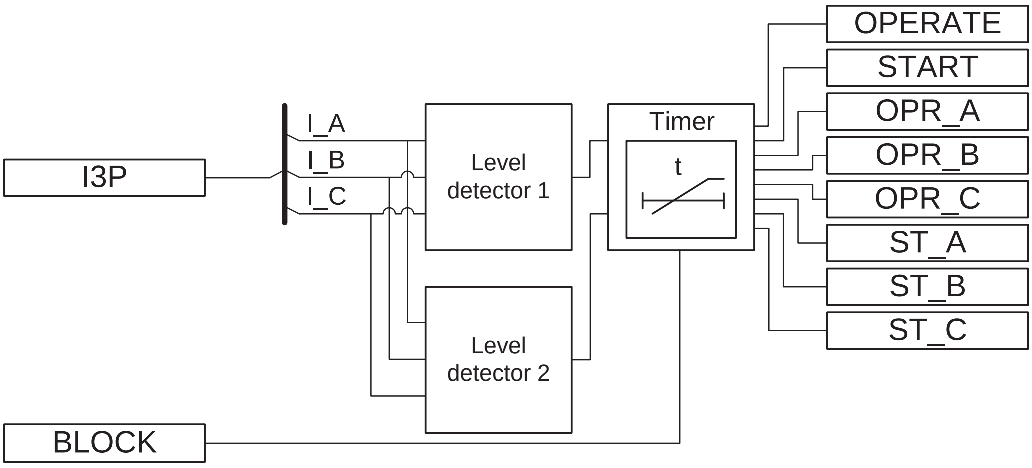


Figure 236: Functional module diagram

Level detector 1

This module compares the phase currents (RMS value) to the *Start value* setting. The *Operation mode* setting can be used to select the "3-phase" or "1-phase" mode.

If in the "3-phase" mode all the phase current values are less than the value of the *Start value* setting, the condition is detected and an enable signal is sent to the timer. This signal is disabled after one or several phase currents have exceeded the set *Start value* value of the element.

If in the "1-phase" mode any of the phase current values are less than the value of the *Start value* setting, the condition is detected and an enable signal is sent to the timer. This signal is disabled after all the phase currents have exceeded the set *Start value* value of the element.

The protection relay does not accept the *Start value* to be smaller than *Current block value*.

Level detector 2

This is a low-current detection module that monitors the de-energized condition of the protected object. The module compares the phase currents (RMS value) to the *Current block value* setting. If all the phase current values are less than the *Current block value* setting, a signal is sent to block the operation of the timer.

Timer

Once activated, the timer activates the `START` output and the phase-specific `ST_X output`. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output and the phase specific `OPR_X` output are activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available through the monitored data view.

The BLOCK signal blocks the operation of the function and resets the timer.

4.1.9.6 Application

In some cases, smaller distribution power transformers are used where the high-side protection involves only power fuses. When one of the high-side fuses blows in a single-phase condition, knowledge of it on the secondary side is lacking. The resulting negative-sequence current leads to a premature failure due to excessive heating and breakdown of the transformer insulation. Knowledge of this condition when it occurs allows for a quick fuse replacement and saves the asset.

The *Current block value* setting can be set to zero to not block PHPTUC with a low three-phase current. However, this results in an unnecessary event sending when the transformer or protected object is disconnected.

Phase-specific start and operate can give a better picture about the evolving faults when one phase has started first and another follows.

PHPTUC is meant to be a general protection function, so that it could be used in other cases too.

In case of undercurrent-based motor protection, see the Loss of load protection.

4.1.9.7 Signals

Table 468: PHPTUC Input signals

Name	Type	Default	Description
I3P	SIGNAL	–	Three-phase currents
BLOCK	BOOLEAN	0=False	Block all binary outputs by resetting timers

Table 469: PHPTUC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_A	BOOLEAN	Operate phase A
OPR_B	BOOLEAN	Operate phase B
OPR_C	BOOLEAN	Operate phase C
START	BOOLEAN	Start
ST_A	BOOLEAN	Start phase A
ST_B	BOOLEAN	Start phase B
ST_C	BOOLEAN	Start phase C

4.1.9.8 Settings

Table 470: PHPTUC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Current block value	0.00...0.50	xIn	0.01	0.10	Low current setting to block internally
Start value	0.01...1.00	xIn	0.01	0.50	Current setting to start
Operate delay time	50...200000	ms	10	2000	Operate delay time

Table 471: PHPTUC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Three Phase 2=Single Phase			1=Three Phase	Number of phases needed to start

Table 472: PHPTUC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.9.9 Monitored data

Table 473: PHPTUC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHPTUC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.9.10 Technical data

Table 474: PHPTUC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the current measured: f_n ±2 Hz
	±1.5% of the set value or ± 0.002 × I_n

Table continues on the next page

Characteristic	Value
Start time	Typically <55 ms
Reset time	<40 ms
Reset ratio	Typically 1.04
Retardation time	<35 ms
Operate time accuracy in definite time mode	mode ±1.0% of the set value or ±20 ms

4.1.10 Thermal overload protection for motors MPTTR (ANSI 49M)

4.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Thermal overload protection for motors	MPTTR	3Ith>M	49M

4.1.10.2 Function block

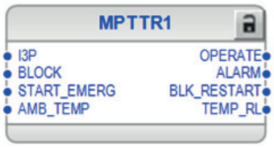


Figure 237: Function block

4.1.10.3 Functionality

The thermal overload protection for motors function MPTTR protects the electric motors from overheating. MPTTR models the thermal behavior of motor on the basis of the measured load current and disconnects the motor when the thermal content reaches 100 percent. The thermal overload conditions are the most often encountered abnormal conditions in industrial motor applications. The thermal overload conditions are typically the result of an abnormal rise in the motor running current, which produces an increase in the thermal dissipation of the motor and temperature or reduces cooling. MPTTR prevents an electric motor from drawing excessive current and overheating, which causes the premature insulation failures of the windings and, in worst cases, burning out of the motors.

4.1.10.4 Analog channel configuration

MPTTR has one analog group input which must be properly configured.

Table 475: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.1.10.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MPTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog GOOSE to connect AMB_TEMP input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

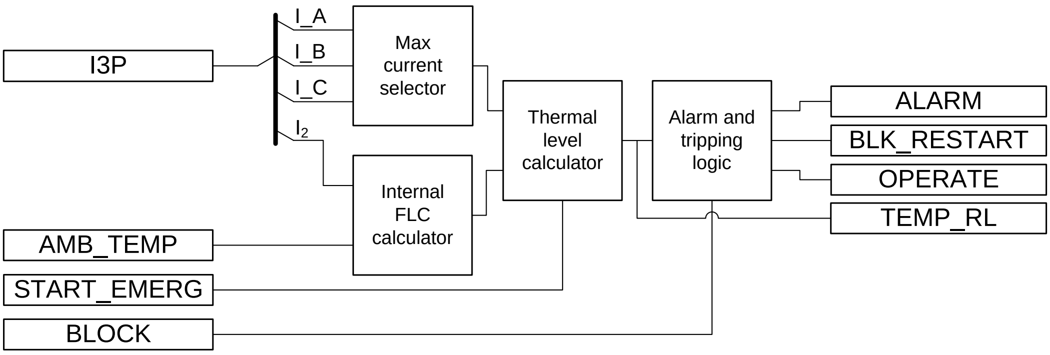


Figure 238: Functional module diagram

Max current selector

Max current selector selects the highest measured TRMS phase current and reports it to Thermal level calculator.

Internal FLC calculator

Full load current (FLC) of the motor is defined by the manufacturer at an ambient temperature of 40°C. Special considerations are required with an application where the ambient temperature of a motor exceeds or remains below 40°C. A motor operating at a higher temperature, even if at or below rated load, can subject the motor windings to excessive temperature similar to that resulting from overload operation at normal ambient temperature. The motor rating has to be appropriately reduced for operation in such high ambient temperatures. Similarly, when the ambient temperature is considerably lower than the nominal 40°C, the motor can be slightly overloaded. For calculating thermal level it is better that the FLC values are scaled for different temperatures. The scaled currents are known as internal FLC. An internal FLC is calculated based on the ambient temperature shown in the table. The *Env temperature mode* setting defines whether the thermal level calculations are based on FLC or internal FLC.

When the value of the *Env temperature mode* setting is set to the "FLC Only" mode, no internal FLC is calculated. Instead, the FLC given in the data sheet of the manufacturer is used. When the value of the *Env temperature mode* setting is set to "Set Amb Temp" mode, the internal FLC is calculated based on the ambient temperature taken as an input through the *Env temperature Set* setting. When the *Env temperature mode* setting is on "Use input" mode, the internal FLC is calculated from temperature data available through resistance temperature detectors (RTDs) using the `AMB_TEMP` input.

Table 476: Modification of internal FLC

Ambient Temperature T_{amb}	Internal FLC
<20°C	FLC x 1.09
20 to <40°C	FLC x (1.18 - T_{amb} x 0.09/20)
40°C	FLC
>40 to 65°C	FLC x (1 –[(T_{amb} -40)/100])
>65°C	FLC x 0.75

The ambient temperature is used for calculating thermal level and it is available in the monitored data view from the `TEMP_AMB` output. The activation of the `BLOCK` input does not affect the `TEMP_AMB` output.

The *Env temperature Set* setting is used:

- If the ambient temperature measurement value is not connected to the AMB_TEMP input in ACT.
- When the ambient temperature measurement connected to 49M is set to "Not in use" in the RTD function.
- In case of any errors or malfunctioning in the RTD output.

Thermal level calculator

The module calculates the thermal load considering the TRMS and negative-sequence currents. The heating up of the motor is determined by the square value of the load current.

However, in case of unbalanced phase currents, the negative-sequence current also causes additional heating. By deploying a protection based on both current components, abnormal heating of the motor is avoided.

The thermal load is calculated based on different situations or operations and it also depends on the phase current level. The equations used for the heating calculations are:

$$\theta_B = \left[\left(\frac{I}{k \times I_r}\right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r}\right)^2\right] \times \left(1 - e^{-t/\tau}\right) \times p\%$$

(Equation 38)

$$\theta_A = \left[\left(\frac{I}{k \times I_r} \right)^2 + K_2 \times \left(\frac{I_2}{k \times I_r} \right)^2 \right] \times \left(1 - e^{-t/\tau}\right) \times 100\%$$

(Equation 39)

I	TRMS value of the measured max of phase currents
I_r	set *Current reference*, FLC or internal FLC
I_2	measured negative sequence current
k	set value of *Overload factor*
K_2	set value of *Negative Seq factor*
p	set value of *Weighting factor*
t	time constant

The equation θ_B is used when the values of all the phase currents are below the overload limit, that is, k x I_r. The equation θ_A is used when the value of any one of the phase currents exceeds the overload limit.

During overload condition, the thermal level calculator calculates the value of θ_B in background, and when the overload ends the thermal level is brought linearly from θ_A to θ_B with a speed of 1.66 percent per second. For the motor at standstill, that is, when the current is below the value of 0.12 x I_r, the cooling is expressed as:

$$\theta = \theta_{02} \times e^{\frac{-t}{\tau}}$$

(Equation 40)

θ_{02}	initial thermal level when cooling begins

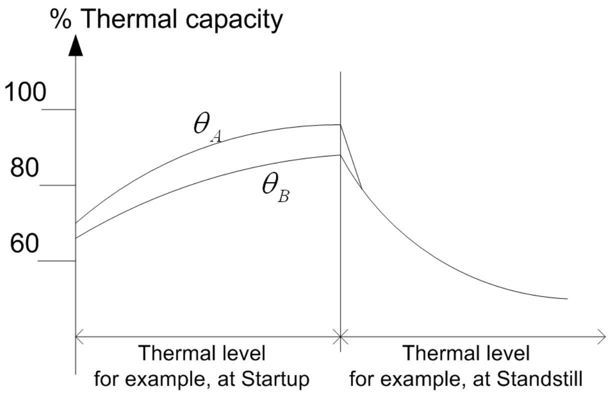


Figure 239: Thermal behavior

The required overload factor and negative sequence current heating effect factor are set by the values of the *Overload factor* and *Negative Seq factor* settings.

In order to accurately calculate the motor thermal condition, different time constants are used in the above equations. These time constants are employed based on different motor running conditions, for example starting, normal or stop, and are set through the *Time constant start*, *Time constant normal* and *Time constant stop* settings. Only one time constant is valid at a time.

Table 477: Time constant and the respective phase current values

Time constant (tau) in use	Phase current
Time constant start	Any current whose value is over 2.5 x I_r
Time constant normal	Any current whose value is over 0.12 x I_r and all currents are below 2.5 x I_r
Time constant stop	All the currents whose values are below 0.12 x I_r

The *Weighting factor p* setting determines the ratio of the thermal increase of the two curves $θ_A$ and $θ_B$.

The thermal level at the power-up of the protection relay is defined by the *Initial thermal Val* setting.

The temperature calculation is initiated from the value defined in the *Initial thermal Val* setting. This is done if the protection relay is powered up or the function is turned off and back on or reset through the Clear menu.

The calculated temperature of the protected object relative to the operate level, the TEMP_RL output, is available through the monitored data view. The activation of the BLOCK input does not affect the calculated temperature.

The calculated temperature of the protected object relative to the operate level, the TEMP_RL output, is available through the monitored data view or through the output signal TEMP_RL. The activation of the BLOCK input does not affect the calculated temperature.

The thermal level at the beginning of the start-up condition of a motor and at the end of the start-up condition is available in the monitored data view at the THERMLEV_ST and THERMLEV_END outputs respectively. The activation of the BLOCK input does not have any effect on these outputs.

Alarm and tripping logic

The module generates alarm, restart inhibit and tripping signals.

When the thermal level exceeds the set value of the *Alarm thermal value* setting, the ALARM output is activated. Sometimes a condition arises when it becomes necessary to inhibit the restarting of a motor, for example in case of some extreme starting condition like long starting time. If the thermal content exceeds the set value of the *Restart thermal val* setting, the BLK_RESTART output is activated. The time for the next possible motor start-up is available through the monitored data view from the T_ENARESTART output. The T_ENARESTART output estimates the time for the BLK_RESTART deactivation considering as if the motor is stopped.

When the emergency start signal START_EMERG is set high, the thermal level is set to a value below the thermal restart inhibit level. This allows at least one motor start-up, even though the thermal level has exceeded the restart inhibit level.

When the thermal content reaches 100 percent, the OPERATE output is activated. The OPERATE output is deactivated when the value of the measured current falls below 12 percent of *Current reference* or the thermal content drops below 100 percent.

The activation of the BLOCK input blocks the ALARM, BLK_RESTART and OPERATE outputs.

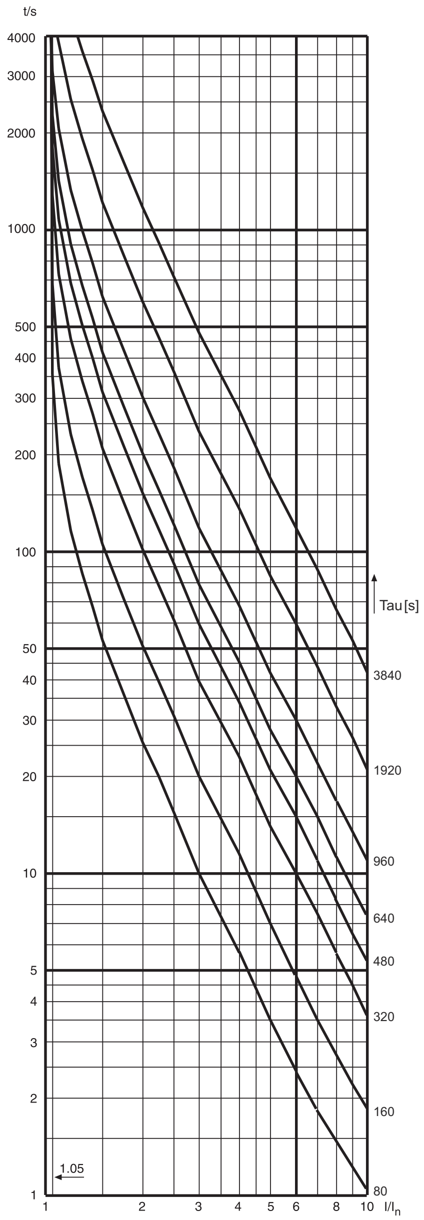


Figure 240: Trip curves when no prior load and p=20...100 %. Overload factor = 1.05.

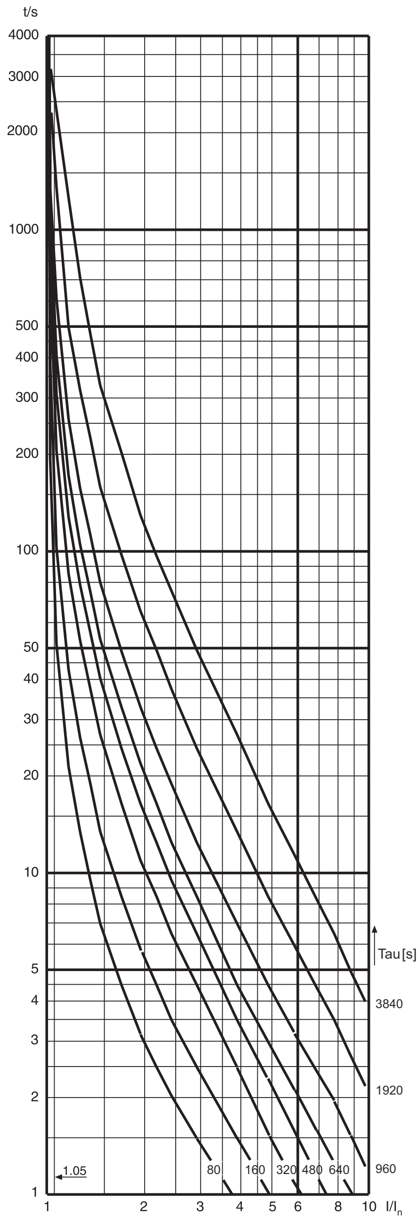


Figure 241: Trip curves at prior load 1 x FLC and p=100 %, Overload factor = 1.05.

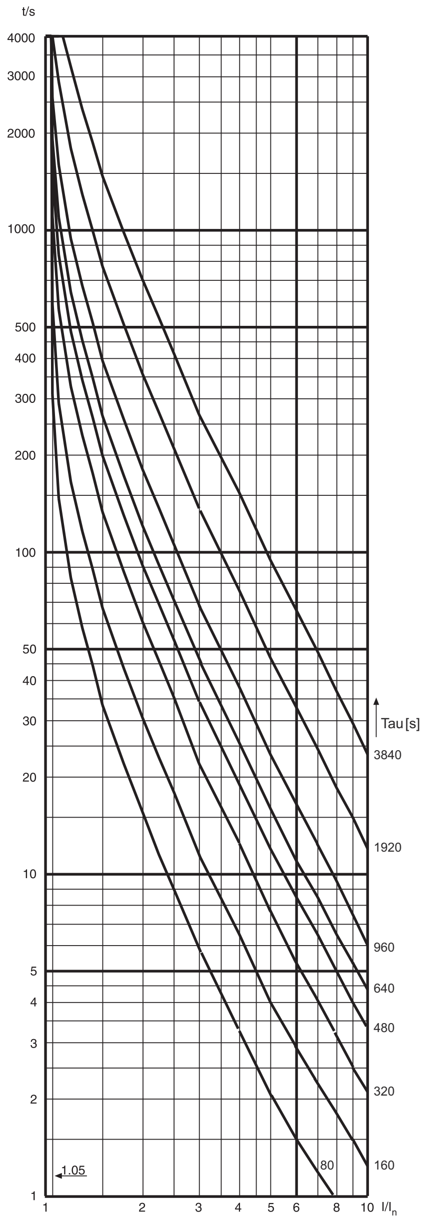


Figure 242: Trip curves at prior load 1 x FLC and p=50 %. Overload factor = 1.05.

4.1.10.6 Application

MPTTR is intended to limit the motor thermal level to predetermined values during the abnormal motor operating conditions. This prevents a premature motor insulation failure.

The abnormal conditions result in overheating and include overload, stalling, failure to start, high ambient temperature, restricted motor ventilation, reduced speed operation, frequent starting or jogging, high or low line voltage or frequency, mechanical failure of the driven load, improper installation and unbalanced line voltage or single phasing. The protection of insulation failure by the implementation of current sensing cannot detect some of these conditions, such as restricted ventilation. Similarly, the protection by sensing temperature alone can be inadequate in cases like frequent starting or jogging. The thermal overload protection addresses these deficiencies to a larger extent by deploying a motor thermal model based on load current.

The thermal load is calculated using the true RMS phase value and negative sequence value of the current. The heating up of the motor is determined by the square value of the load current. However, while calculating the thermal level, the rated current should be re-rated or de-rated depending on the value of the ambient temperature. Apart from current, the rate at which motor heats up or cools is governed by the time constant of the motor.

Setting the weighting factor

There are two thermal curves: one which characterizes the short-time loads and long-time overloads and which is also used for tripping and another which is used for monitoring the thermal condition of the motor. The value of the *Weighting factor p* setting determines the ratio of the thermal increase of the two curves.

When the *Weighting factor p* setting is 100 percent, a pure single time constant thermal unit is produced which is used for application with the cables. As presented in *Figure 243*, the hot curve with the value of *Weighting factor p* being 100 percent only allows an operate time which is about 10 percent of that with no prior load. For example, when the set time constant is 640 seconds, the operate time with the prior load 1 x FLC (full Load Current) and overload factor 1.05 is only 2 seconds, even if the motor could withstand at least 5 to 6 seconds. To allow the use of the full capacity of the motor, a lower value of *Weighting factor p* should be used.

Normally, an approximate value of half of the thermal capacity is used when the motor is running at full load. Thus by setting *Weighting factor p* to 50 percent, the protection relay notifies a 45 to 50 percent thermal capacity use at full load.

For direct-on-line started motors with hot spot tendencies, the value of *Weighting factor p* is typically set to 50 percent, which will properly distinguish between short-time thermal stress and long-time thermal history. After a short period of thermal stress, for example a motor start-up, the thermal level starts to decrease quite sharply, simulating the leveling out of the hot spots. Consequently, the probability of successive allowed start-ups increases.

When protecting the objects without hot spot tendencies, for example motors started with soft starters, and cables, the value of *Weighting factor p* is set to 100 percent. With the value of *Weighting factor p* set to 100 percent, the thermal level decreases slowly after a heavy load condition. This makes the protection suitable for applications where no hot spots are expected. Only in special cases where the thermal overload protection is required to follow the characteristics of the object to be protected more closely and the thermal capacity of the object is very well known, a value between 50 and 100 percent is required.

For motor applications where, for example, two hot starts are allowed instead of three cold starts, the value of the setting *Weighting factor p* being 40 percent has proven to be useful. Setting the value of *Weighting factor p* significantly below 50 percent should be handled carefully as there is a possibility to overload the protected object as a thermal unit might allow too many hot starts or the thermal history of the motor has not been taken into account sufficiently.

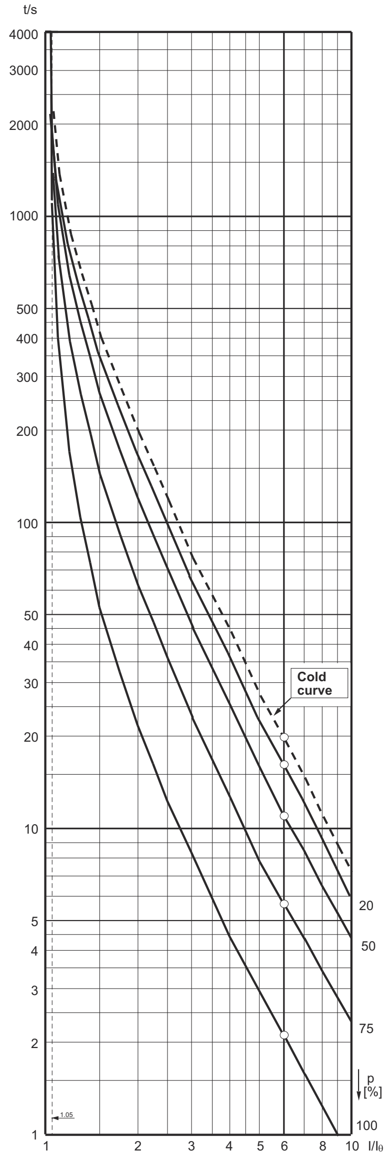


Figure 243: The influence of Weighting factor p at prior load 1xFLC, timeconstant = 640 s, and Overload factor = 1.05

Setting the overload factor

The value of *Overload factor* defines the highest permissible continuous load. The recommended value is 1.05.

Setting the negative sequence factor

During the unbalance condition, the symmetry of the stator currents is disturbed and a counter-rotating negative sequence component current is set up. An increased stator current causes additional heating in the stator and the negative sequence component current excessive heating in the rotor. Also mechanical problems like rotor vibration can occur.

The most common cause of unbalance for three-phase motors is the loss of phase resulting in an open fuse, connector or conductor. Often mechanical problems can be more severe than the heating effects and therefore a separate unbalance protection is used.

Unbalances in other connected loads in the same busbar can also affect the motor. A voltage unbalance typically produces 5 to 7 times higher current unbalance. Because the thermal overload protection is based on the highest TRMS value of the phase current, the additional heating in stator winding is automatically taken into account. For more accurate thermal modeling, the *Negative Seq factor* setting is used for taking account of the rotor heating effect.

$$Negative\,Seq\ factor = \frac{R_{R2}}{R_{R1}}$$

(Equation 41)

R_{R2}	Rotor negative sequence resistance
R_{R1}	Rotor positive sequence resistance

A conservative estimate for the setting can be calculated:

$$Negative\,Seq\ factor = \frac{175}{I_{LR}^2}$$

(Equation 42)

I_{LR}	Locked rotor current (multiple of set *Rated current*). The same as the start-up current at the beginning of the motor start-up.

For example, if the rated current of a motor is 230 A, start-up current is 5.7 x I_r,

$$Negative\,Seq\ factor = \frac{175}{5.7^2} = 5.4$$

(Equation 43)

Setting the thermal restart level

The restart disable level can be calculated as follows:

$$\theta_i = 100\% - \left(\frac{\textit{startup time of the motor}}{\textit{operate time when no prior load}} \times 100\% + margin \right)$$

(Equation 44)

For example, the motor start-up time is 11 seconds, start-up current 6 x rated and *Time constant start* is set for 800 seconds. Using the trip curve with no prior load, the operation time at 6 x rated current is 25 seconds, one motor start-up uses 11/25 ≈ 45 percent of the thermal capacity of the motor. Therefore, the restart disable level must be set to below 100 percent - 45 percent = 55 percent, for example to 50 percent (100 percent - (45 percent + margin), where margin is 5 percent).

Setting the thermal alarm level

Tripping due to high overload is avoided by reducing the load of the motor on a prior alarm.

The value of *Alarm thermal value* is set to a level which allows the use of the full thermal capacity of the motor without causing a trip due to a long overload time. Generally, the prior alarm level is set to a value of 80 to 90 percent of the trip level.

4.1.10.7 Signals

MPTTR Input signals

Table 478: MPTTR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
START_EMERG	BOOLEAN	0=False	Signal for indicating the need for emergency start
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

MPTTR Output signals

Table 479: MPTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
ALARM	BOOLEAN	Thermal Alarm
BLK_RESTART	BOOLEAN	Thermal overload indicator, to inhibit restart
TEMP_RL	FLOAT32	The calculated temperature of the protected object relative to the operate level

4.1.10.8 MPTTR Settings

Table 480: MPTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Overload factor	1.00...1.20		0.01	1.05	Overload factor (k)
Alarm thermal value	50.0...100.0	%	0.1	95.0	Thermal level above which function gives an alarm
Restart thermal Val	20.0...80.0	%	0.1	40.0	Thermal level above which function inhibits motor restarting

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Negative Seq factor	0.0...10.0		0.1	0.0	Heating effect factor for negative sequence current
Weighting factor p	20.0...100.0	%	0.1	50.0	Weighting factor (p)
Time constant normal	80...4000	s	1	320	Motor time constant during the normal operation of motor
Time constant start	80...4000	s	1	320	Motor time constant during the start of motor
Time constant stop	80...60000	s	1	500	Motor time constant during the standstill condition of motor
Env temperature mode	1=FLC Only 2=Use input 3=Set Amb Temp			1=FLC Only	Mode of measuring ambient temperature
Env temperature Set	-20.0...70.0	°C	0.1	40.0	Ambient temperature used when no external temperature measurement available

Table 481: MPTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 482: MPTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.30...2.00	xIn	0.01	1.00	Rated current (FLC) of the motor
Initial thermal Val	0.0...100.0	%	0.1	74.0	Initial thermal level of the motor

4.1.10.9 MPTTR Monitored data

Table 483: MPTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calculation
THERMLEV_ST	FLOAT32	0.00...9.99		Thermal level at beginning of motor startup
THERMLEV_END	FLOAT32	0.00...9.99		Thermal level at the end of motor startup situation
T_ENARESTART	INT32	0...99999	s	Estimated time to reset of block restart
MPTTR	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		5=off		
Therm-Lev:1	FLOAT32	0.00...9.99		Thermal level of protected object (1.00 is the operate level)

4.1.10.10 Technical data

Table 484: MPTTR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current measurement: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Operate time accuracy [1]	±2.0% of the theoretical value or ±0.50 s

4.1.11 Thermal overload protection for rotors RPTTR (ANSI 49R)

4.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Thermal overload protection for rotors	RPTTR	3Ith>R	49R

4.1.11.2 Function block

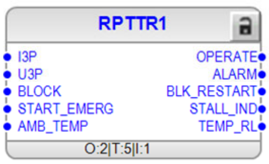


Figure 244: Function block

4.1.11.3 Functionality

The thermal overload protection for rotors RPTTR protects the rotor of the induction motor from overheating. RPTTR models the rotor thermal behavior on the basis of the measured load current and voltage and disconnects the motor when the thermal content reaches 100 percent. The rotor thermal overload conditions are

[1] Overload current > 1.2 × Operate level temperature

often encountered during the motor start-up and with abnormal conditions such as locked rotor or unbalance, which both produce excess heat due to the skin effect. The skin effect causes the current to distribute in a smaller surface in the rotor bars, increasing the resistance, and therefore also the heating effect.

The function also provides locked rotor protection. The locked rotor condition can be identified from the slip estimate that the function calculates.

4.1.11.4 Analog channel configuration

RPTTR has two analog group inputs which must be properly configured.

Table 485: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

4.1.11.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of RPTTR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

The function uses ambient temperature which can be measured locally or remotely. Local measurement is done by the protection relay. Remote measurement uses analog IEC 61850-8-1 GOOSE to connect AMB_TEMP input.

If the quality of remotely measured temperature is invalid or communication channel fails the function uses ambient temperature set in *Env temperature Set*.

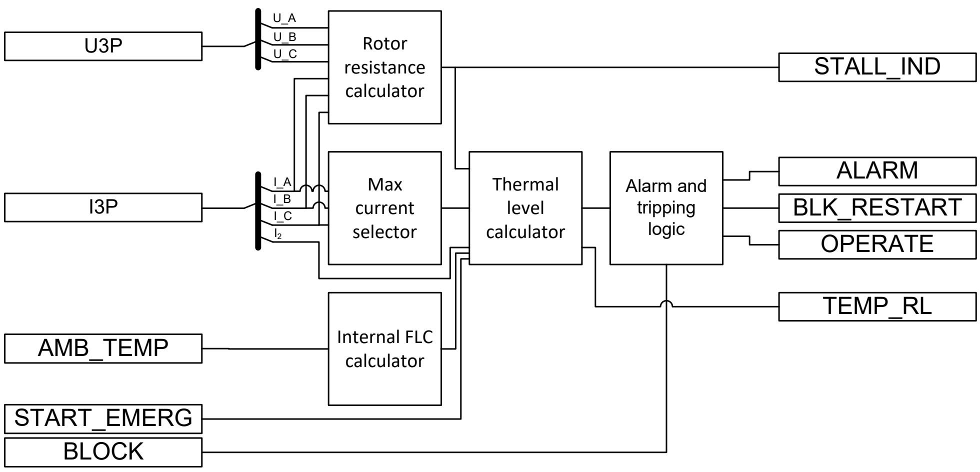


Figure 245: RPTTR module diagram

Alarm and tripping logic

The modules generate alarm, restart inhibit and tripping signal.

When the thermal level exceeds the set value of the *Alarm thermal value* setting, the ALARM output is activated. Sometimes a condition arises when it becomes necessary to inhibit the restarting of a motor, for example in case of some extreme starting condition like long starting time. If the thermal content exceeds the set value of the *Restart thermal Val* setting, the BLK_RESTART output is activated. The time for the next possible motor start-up is available through the monitored data view from T_ENARESTART. The T_ENARESTART estimates the time for the BLK_RESTART deactivation considering as if the motor is stopped.

When the emergency start signal START_EMERG is set high, the thermal level is set to a value below the *Restart thermal Val*. This allows at least one motor start-up, even though the thermal level has exceeded the *Restart thermal Val*.

When the thermal content reaches 100 percent, the OPERATE output is activated. The OPERATE output is deactivated when the value of the measured current falls below 12 percent of *Current reference* or the thermal content drops below 100 percent.

The activation of the BLOCK input blocks the ALARM, BLK_RESTART and OPERATE outputs.

Thermal level calculator

The module calculates the thermal load based on the rotor resistances factors, true RMS and negative sequence current. The rotor heating is determined by the squared value of the load current.

However, in case of unbalanced phase currents, the negative-sequence current also causes additional heating. By deploying a protection based on both current components, abnormal heating of rotor is avoided.

The equations used for the thermal level calculations are:

$$\theta_A = \left(R_{r+} \cdot \left(\frac{I}{k \cdot I_{IFLC}}\right)^2 + R_{r-} \cdot \left(\frac{I_2}{k \cdot I_{IFLC}}\right)^2 \right) \cdot \left(1 - e^{-\frac{t}{\tau}}\right) \cdot 100\%$$

(Equation 45)

$$\theta_B = \left(R_{r+} \cdot \left(\frac{I}{k \cdot I_{IFLC}}\right)^2 + R_{r-} \cdot \left(\frac{I_2}{k \cdot I_{IFLC}}\right)^2 \right) \cdot \left(1 - e^{-\frac{t}{\tau}}\right) \cdot p\%$$

(Equation 46)

θA	is the thermal level during overload,
θB	is the thermal level during nominal conditions,
R_{r+}	is the rotor positive sequence resistance factor,
R_{r-}	is the rotor negative sequence resistance factor,
I	is the True RMS value of the measured max of phase currents,
I_{IFLC}	is the calculated internal FLC,
I_2	is the measured negative sequence current,

Table continues on the next page

k	is the set value of *Overload factor*,
ρ	is the set value of *Weighting factor* and
t	is the time constant.

The equation θB is used whenever all phase current is below overload limit i.e. 2.5 · I_{IFLC}, whereas equation θA is used when any of the phase current exceeds overload limit.

During overload condition, the function calculated the θB in background, when overload ends the thermal level is brought linearly from θA to θB, with speed of 1.66% per second. For the motor at standstill i.e. when the current is below the value 0.12 · I_{IFLC}, the cooling can be expressed as:

$$\theta = \theta_{02} \cdot e^{-\frac{t}{\tau}}$$

(Equation 47)

θ_{02}	= initial thermal level when cooling begins

The thermal behavior can be understood from *Figure 246*.

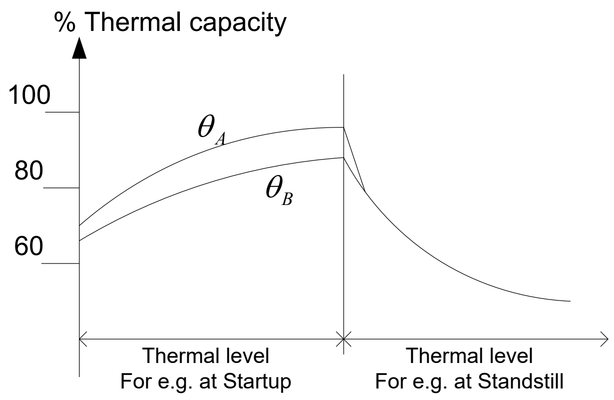


Figure 246: Thermal behavior

The required *Overload factor* is used to define the highest permissible continuous load. The recommended value is at minimum 1.05.

In order to accurately calculate the rotor thermal condition, different time constants are used in the above equations. These time constants are employed based on different motor running conditions, for example starting, normal or stop, and are set through the *Time constant start*, *Time constant normal*, and *Time constant stop* settings. Only one time constant is valid at a time. Different running conditions are defined by the comparison of the I_{IFLC} and the phase currents, which can be seen in *Table 486*.

Table 486: Time constant and the respective phase current values

Time constant in use	Phase current
tStart	Any current is over 2.5 · I_{IFLC}
tNormal	Any current is over 0.12 · I_{IFLC} and all currents are below 2.5 · I_{IFLC}
tStop	All currents are below 0.12 · I_{IFLC}

Setting *Weighting factor p* determines the ratio of the thermal increase of the two curves θA and θB.

The thermal level of the rotor at power up of the protection relay is defined by the setting *Initial thermal Val*.

The temperature calculation is initiated from the value defined in the *Initial thermal Val* setting. This is done if the protection relay is powered up or the function is turned off and back on or reset through the Clear menu.

Calculated thermal level TEMP_RL is available in monitored data view.

Thermal levels at the beginning and the end of the latest startup are available through the monitored data view at THERMLEV_ST and THERMLEV_END respectively.

Internal FLC calculator

Full load current (FLC) of the motor is defined by the manufacturer at an ambient temperature of 40°C. The FLC of the motor is set by *Current reference* setting. Special considerations are required with an application where the ambient temperature of a motor exceeds or remains below 40°C. A motor operating in a higher ambient temperature, even at or below rated load, can subject the motor windings to excessive temperature. The motor rating has to be appropriately reduced for operation in such high ambient temperatures. Similarly, when the ambient temperature is considerably lower than the nominal 40°C, the motor can be slightly overloaded. For calculating thermal level, it is better that the FLC values are scaled for different temperatures. The scaled currents are known as internal FLC (I_{IFLC}). An I_{IFLC} is calculated based on the ambient temperature shown in the table. The *Env temperature mode* setting defines whether the thermal level calculations are based on FLC or I_{IFLC}.

When the value of the *Env temperature mode* setting is set to the "FLC Only" mode, no I_{IFLC} is calculated. Instead, the FLC given in the data sheet of the manufacturer is used. When the value of the *Env temperature mode* setting is set to "Set Amb Temp" mode, the I_{IFLC} is calculated based on the ambient temperature taken as an input through the Env temperature Set setting. When the *Env temperature mode* setting is on "Use input" mode, the I_{IFLC} is calculated from temperature data available through resistance temperature detectors (RTDs) using the `AMB_TEMP` input.

Table 487: Temperature dependency of I_{IFLC}

Ambient Temperature (T_{amb})	I_{IFLC}
<20°C	FLC x 1.09
20 to <40°C	FLC x (1.18 - T_{amb} x 0.09/20)
40°C	FLC
>40 to 65°C	FLC x (1 –[(T_{amb} -40)/100])
>65°C	FLC x 0.75

The ambient temperature TEMP_AMB is available in the monitored data view.

The *Env temperature Set* setting is used:

- If the ambient temperature measurement value is not connected to the AMB_TEMP input in ACT.
- When the ambient temperature measurement connected to RPTTR is set to "Not in use" in the RTD function.
- In case of any errors or malfunctioning in the RTD input.

Max current selector

Max current selector selects the highest measured True RMS phase current and reports it to Thermal level calculator.

Rotor resistance calculator

The module calculates rotor resistances as a function of estimated slip. Slip estimate is based on the measured phase currents and line voltages.

Necessary initial values for slip estimation are rotor resistance at locked rotor and rotor resistance at nominal speed, calculated with following equations. Settings mentioned in equations can be found from the motor datasheet information.

$$R_N = 1 - \frac{RPM_N}{RPM_S}$$

(Equation 48)

R_N	is the rotor resistance at nominal speed,
RPM_N	is the setting *Nominal speed* and
RPM_S	is the setting *Synchronous* speed.

$$R_L = \frac{T_L}{I_L^2}$$

(Equation 49)

R_L	is the rotor resistance at locked rotor,
T_L	is the setting *Relative starting torque* and
I_L	is the setting *Relative starting current* .

In addition to R_N and R_L, the slip estimate calculation uses line voltages and phase currents to calculate the apparent total resistance and the initial stator resistance.

$$S = \frac{R_N}{1.2 \cdot (R - R_{SI}) - (R_L - R_N)}$$

(Equation 50)

S	is the motor slip,
R	is the apparent total resistance calculated from line voltages and phase currents,

Table continues on the next page

R_{SI}	is the initial stator resistance calculated from line voltages and phase currents,
R_N	is the rotor resistance at nominal speed and
R_L	is the rotor resistance at locked rotor.

The rotor positive and negative sequence resistance vary depending on the motor slip. The slip estimate values are used to calculate the rotor positive and negative sequence resistance factors:

$$R_{r+} = \frac{(R_L - R_N) \cdot S + R_N}{R_N}$$

(Equation 51)

$$R_{r-} = \frac{(R_L - R_N) \cdot (2 - S) + R_N}{R_N}$$

(Equation 52)

R_{r+}	is the rotor positive sequence resistance factor,
R_{r-}	is the rotor negative sequence resistance factor,
R_L	is the rotor resistance at locked rotor,
R_N	is the rotor resistance at nominal speed and
S	is the motor slip.

These resistance factors are then used in the thermal calculations to depict the thermal behavior that the skin effect causes.

The skin effect describes the situation where the rotor bars are induced with high amplitude and high frequency current which make the current flow in the rotor bars to be distributed close to the rotor bar surface, increasing the resistance of the rotor bar.

The rotor resistances depend on the relation of the rotating magnetic fluxes and the rotor speed, i.e. slip. The faster the fluxes cut the rotor bars the higher amplitude and higher frequency currents are induced to the rotor bars.

The rotor positive sequence resistance factor R_{r+} is at its highest at motor standstill (S=1), and smallest when the slip is at nominal value (S≈0). The rotor negative sequence resistance factor R_{r-}, however, grows larger as the rotor starts to revolve in the intended direction since the magnetic flux that the unbalance creates rotates in the opposite direction compared to the rotor, making the skin effect stronger.

STALL_IND output is provided for monitoring purposes or external logic. A TRUE value indicates that the rotor is stalling. The output is functional only when the motor is energized.

The rotational speed of the rotor is provided in monitored data at SPEED_RPM. The monitored data is also only functional when the motor is energized.

4.1.11.6 Application

Rotor thermal overload protection function is intended to prevent the rotor from overheating especially during motor starting and abnormal operating conditions which cause the heating to be rapid. This prevents premature degeneration of the rotor unit. Additionally, the function provides an estimate of the motor slip, which allows identify locked rotor. This function is applicable for direct-on-line started induction motors with the motor line voltages available.

The rotor thermal overload protection function should be used in parallel with the motor thermal overload protection function MPTTR. This way both, the more rapid heating of the rotor, and the stable heating of the entire motor are taken into account.

Abnormal conditions that can result in overheating the rotor include overload, stalling, failure to start, high ambient temperature, restricted motor ventilation, reduced speed operation, frequent starting or jogging, high or low line voltage or frequency, mechanical failure of the driven load, improper installation, and unbalanced line voltage or single phasing. Protecting from insulation failure by implementation of current sensing alone cannot detect all of these conditions, such as restricted ventilation. Similarly, protection by sensing temperature alone may be inadequate, in cases like frequent starting or jogging. Thermal overload protection addresses these deficiencies to a large extent by deploying a rotor thermal model based on load current and the load voltage.

Rotor thermal level is calculated based on the rotor resistance factors, True RMS phase currents and negative sequence current. The rotor resistance factor is based on the estimated slip, that is calculated based on the measured line voltage and measured load current.

In addition, motor ambient temperature is taken into account in the thermal level calculation. Apart from current and the rotor resistance factor, the rate at which rotor heats up or cools is governed by time constant of the rotor.

Selecting of weighing factor

Motor manufacturers usually define two thermal limit curves one for warm and one for cold starts. The demands that these curves set are answered with the corresponding relay curves *Figure 247*.

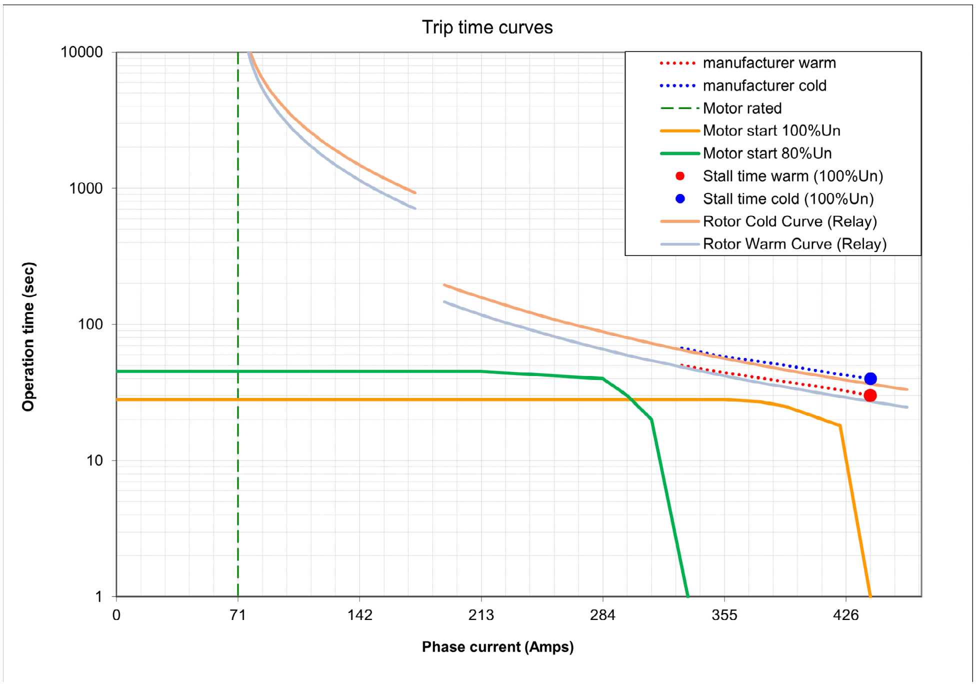


Figure 247: Trip time curves

In order to account for the difference between the warm and cold curves the *Weighting factor p* is used. This defines the difference, which is based on the warm and cold locked rotor times defined by the motor manufacturer. *Weighting factor p* can be calculated by the following equation:

$$Weighting\ factor\ p = k^2 \cdot \left(1 - \frac{LRT_{warm}}{LRT_{cold}}\right) \cdot 100\%$$

(Equation 53)

k	is the *Overload factor*,
LRT_{warm}	is the locked rotor time for warm start and
LRT_{cold}	is the locked rotor time for warm start.

The *Weighting factor p* for the rotor is usually lower than for the stator, since the temperature limit for the rotor is often higher. Therefore, the used thermal capacity, when running at full load, can be quite low. For example, with warm and cold locked rotor times being 5 and 6 seconds and *Overload factor* being 1.05, the *Weighting factor p* could be set to 18.4%.

$$Weighting\ factor\ p = 1.05^2 \cdot \left(1 - \frac{5}{6}\right) \cdot 100\% = 18.4\%$$

(Equation 54)

In addition, the *Weighting factor p* is used in the cumulative thermal level calculation. It is used to properly distinguish between short-time thermal stress and long-time thermal history, allowing more critical situations like motor start-ups to be taken into consideration more carefully.

Setting of thermal restart level

The *Restart thermal Val* can be calculated as follows:

$$\theta_i = 100\% - \left(\frac{start\!-\!up\ time\ of\ the\ motor}{operate\ time\ when\ no\ prior\ load}\right) \cdot 100\% + margin$$

(Equation 55)

For instance, if the start-up time of the motor is 4 seconds, and the calculated operate time of the thermal protection stage for cold motor is 6 seconds, one motor start-up will use 4/6 = 66.6% of the thermal capacity of the motor. Therefore, the *Restart thermal Val* must be set to below 100% - 66.6% = 33.3% say to 28.3% (100% - (66.6% + margin), where margin is 5%).

Setting of thermal alarm level

Tripping due to high overload can be avoided by reducing the load of the motor when the thermal level reaches a set alarm level.

The *Alarm thermal value* can be set to a level, which will allow the use of the motor's full thermal capacity without causing a trip due to long time overload. Generally, the *Alarm thermal value* is set to 80….90% of the trip level.

4.1.11.7 Signals

RPTTR Input signals

Table 488: RPTTR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
START_EMERG	BOOLEAN	0=False	Signal for indicating the need for emergency start
AMB_TEMP	FLOAT32	0	The ambient temperature used in the calculation

RPTTR Output signals

Table 489: RPTTR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
ALARM	BOOLEAN	Thermal Alarm
BLK_RESTART	BOOLEAN	Thermal overload indicator, to inhibit restart
STALL_IND	BOOLEAN	Indicates that the rotor is stalling
TEMP_RL	FLOAT32	The calculated temperature of the protected object relative to the operate level

4.1.11.8 RPTTR Settings

Table 490: RPTTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Env temperature mode	1=FLC Only 2=Use input 3=Set Amb Temp			1=FLC Only	Mode of measuring ambient temperature
Env temperature Set	-20.0...70.0	°C	0.1	40.0	Ambient temperature used when no external temperature measurement available
Overload factor	1.00...1.20		0.01	1.05	Overload factor (k)
Alarm value	50.0...100.0	%	0.1	95.0	Temperature level for start (alarm)
Restart thermal Val	20.0...80.0	%	0.1	40.0	Thermal level above which function inhibits motor restarting
Weighting factor p	20.0...100.0	%	0.1	50.0	Weighting factor (p)
Time constant normal	80...10000	s	1	320	Rotor time constant during the normal operation of motor
Time constant start	80...10000	s	1	320	Rotor time constant during the start of motor
Time constant stop	80...60000	s	1	500	Rotor time constant during the standstill condition of motor

Table 491: RPTTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Relative starting torque	0.10...3.00		0.01	0.70	Relative starting torque i.e. locked rotor torque

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Relative starting current	100.0...2000.0	%Ir	0.1	600.0	Relative starting current i.e. locked rotor current
Motor synchronous speed	125...3600		1	1500	Motor synchronous speed in rpm
Motor nominal speed	100...3599		1	1485	Motor speed at nominal load in rpm

Table 492: RPTTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.30...2.00	xIn	0.01	1.00	Rated current (FLC) of the motor
Initial thermal Val	0.0...100.0	%	0.1	74.0	Initial thermal level of the rotor
Slip Clc delay	10...2000	ms	1	200	Delay before slip estimate calculation starts

4.1.11.9 RPTTR Monitored data

Table 493: RPTTR Monitored data

Name	Type	Values (Range)	Unit	Description
TEMP_AMB	FLOAT32	-99...999	°C	The ambient temperature used in the calculation
THERMLEV_ST	FLOAT32	0.00...9.99		Thermal level at beginning of motor startup
THERMLEV_END	FLOAT32	0.00...9.99		Thermal level at the end of motor startup situation
T_ENARESTART	INT32	0...99999	s	Estimated time to reset of block restart
I_REF_CLC	FLOAT32	0.1...3.0		Adjusted Rated current (FLC) of the motor
RPTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Therm-Lev:1	FLOAT32	0.00...9.99		Thermal level of protected object (1.00 is the operate level)

4.1.11.10 Technical data

Table 494: RPTTR Technical data

Characteristics	Value
Operation accuracy	Depending on the frequency of the measured current fn ±2 Hz
	Current measurement ±1.5% of the set value or ±0.002 x I_n (at currents in the range of ≤4.00 x I_n)
Operate time accuracy	±2.0% of the theoretical value or ±0.50 s

4.1.12 Generator shaft current leakage protection GSLPTOC (ANSI 38,51)

4.1.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Generator shaft current leakage protection	GSLPTOC	I>,GS	38, 51

4.1.12.2 Function block

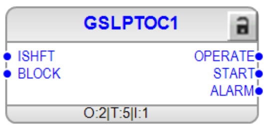


Figure 248: Function block

4.1.12.3 Functionality

Generator shaft current leakage protection function GSLPTOC protects the generator rotor bearings from damage caused by the shaft leakage current.

The function compares measured shaft current to the set alarm and operate levels. Operate time characteristics are according to definite time (DT).

4.1.12.4 Analog channel configuration

GSLPTOC has one analog input which must be properly configured.

Table 495: Analog inputs

Input	Description
ISHFT	Measured shaft current

4.1.12.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of *Generator shaft current leakage protection* can be described by using a module diagram (see figure below). All the modules in the diagram are explained in the next sections.

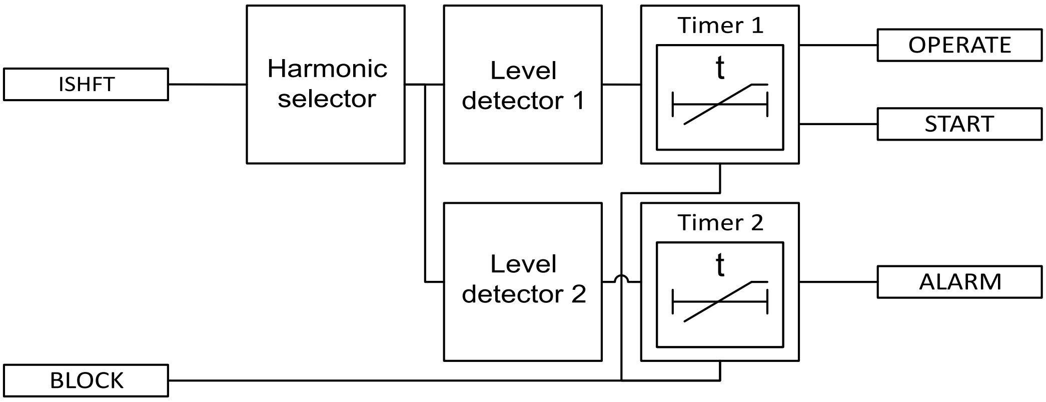


Figure 249: Functional module diagram

Harmonic selector

This module receives the shaft current measurement signal ISHAFT from the measurement arrangement. The recommended measurement arrangements (axial shaft CT with resistor or Rogowski coil with integrator) provide a voltage signal which is amplified for the relay input. The voltage signal is converted to current inside the function. Alternatively shaft current can be directly measured by relay current input when CT is used alone.

The operating harmonic component is selected according to the *Select harmonic* setting which is obtained from the commissioning test.

The selected harmonic component from the shaft current measurement is available in monitored data under `I_SHAFT`. Additionally, each of the available harmonics are available in monitored data under `I_SHAFT_H1, I_SHAFT_H3` and `I_SHAFT_H5`.

Level detector 1

The module compares the measured shaft current to the setting *Operate start value*, which is set in primary amps. If the level exceeds the set value, a enable signal is sent to Timer 1 module.

Level detector 2

The module compares the measured shaft current to the setting *Alarm start value*, which is set in primary amps. If the level exceeds the set value, a enable signal is sent to Timer 2 module.

Timer 1

Once activated, the Timer 1 activates the `START` output. The time characteristics are according to DT. When the operate timer reaches the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module generates an `OPERATE` signal, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets.

The activation of the `BLOCK` signal resets the Timer 1 and deactivates the `OPERATE` and `START` outputs.

The module calculates the start duration value *START_DUR*, which indicates the percentage ratio of the start time and the set operating time. The value is available in the monitored data view.

Timer 2

Once activated, the alarm timer is activated. The time characteristics are according to DT. When the alarm timer reaches the value set by *Alarm delay time*, the ALARM output is activated. If the fault disappears before the module generates an ALARM signal, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the alarm timer resets. The activation of the BLOCK signal resets the Timer 2 and deactivates the ALARM output.

4.1.12.6 Application

In order to prevent the generator shaft from getting electrically charged the shaft is grounded. Different types of generators have different ways for shaft grounding. With hydro-generators, the water acts as a grounding point, and with turbogenerators the shaft can be grounded with a slip ring. However, the leakage current can still occur if the bearing pedestal, which is isolated from the ground, becomes grounded. This imposes shaft voltage on the oil-film of the bearing. The current can break the insulation that the oil-film provides and thus it can cause pitting and abrasion on the bearing face.

The measured shaft current is fed to the protection relay. The function compares the current signal to the set alarm and operate levels. Operate time characteristics are according to definite time.

Measurement device options

There are two different applicable shaft current measurement devices, the Rogowski coil and the current transformer (CT). Both devices are installed around the generator shaft. For both devices it is necessary to amplify the voltage signal. The recommended measurement principles are depicted in *Figure 250* and *Figure 251*.

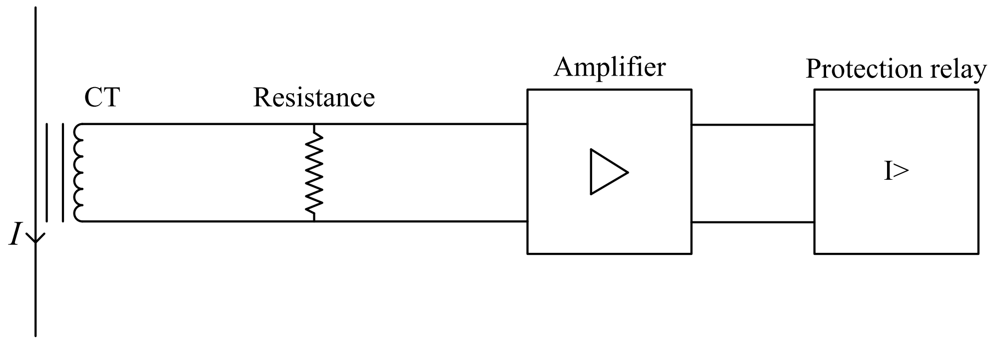


Figure 250: Current transformer measurement arrangement

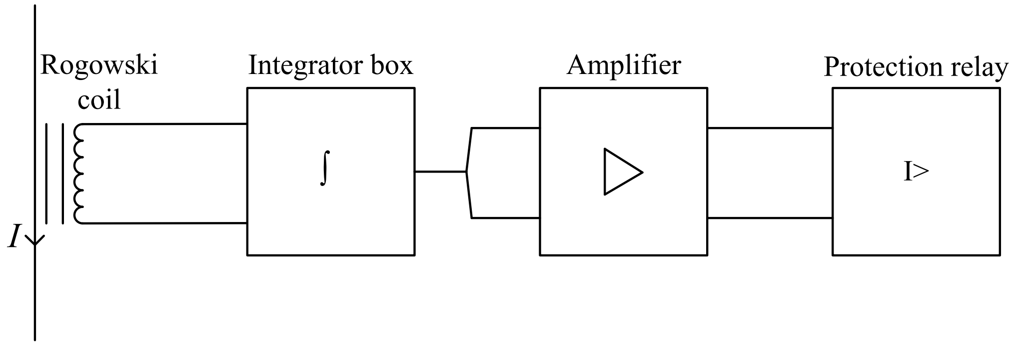


Figure 251: Rogowski coil measurement arrangement

It is also possible to feed shaft current, measured with CT, directly to the relay current input. Proper signal levels need to be ensured for reaching acceptable operation accuracy.

Setting *Alarm start value* and *Operate start value*

The current level that causes damage to bearings depends on the contact surface of the bearings. Current densities over 0.1 A/mm^2 start to damage the bearings. This can be generalized so, that currents over 1 A can be considered harmful. Therefore, the recommended setting for *Operate start value* is 0.5 A and for *Alarm start value* 0.25 A. Both values are set in primary amperes.

4.1.12.7 Signals

GSLPTOC Input signals

Table 496: GSLPTOC Input signals

Name	Type	Default	Description
ISHFT	SIGNAL	-	Analog input
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

GSLPTOC Output signals

Table 497: GSLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.1.12.8 GSLPTOC Settings

Table 498: GSLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Sel operate harmonic	1=Fundamental 3=Third harmonic 5=Fifth harmonic			1=Fundamental	Select operating harmonic
Alarm start value	0.10...10.00	A	0.01	0.25	Alarm start value
Operate start value	0.10...10.00	A	0.01	0.50	Operate start value
Alarm delay time	40...30000	ms	10	3000	Alarm delay time
Operate delay time	40...30000	ms	10	3000	Operate delay time

Table 499: GSLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...10000	ms	1	1000	Reset delay time

4.1.12.9 GSLPTOC Monitored data

Table 500: GSLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
I_SHAFT	FLOAT32	0.00...10.00	A	Amplitude of the measured shaft current
I_SHAFT_H1	FLOAT32	0.00...10.00	A	Amplitude of the fundamental component of the measured shaft current
I_SHAFT_H3	FLOAT32	0.00...10.00	A	Amplitude of the third harmonic component of the measured shaft current
I_SHAFT_H5	FLOAT32	0.00...10.00	A	Amplitude of the fifth harmonic component of the measured shaft current
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
GSLPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.12.10 Technical data

Table 501: GSLPTOC Technical data

Characteristics	Value
Operation accuracy	Depending on the frequency of the measured current f_n ±2 Hz
	±1.5% of the set value or ±0.03 × I_n
Start time [1, 2]	Typically 30ms
Reset time	<30 ms
Reset ratio	Typically 0.96
Retardation time	<50 ms
Operate time accuracy	±1.0% of the set value of ±20 ms

4.2 Earth-fault protection

4.2.1 Non-directional earth-fault protection EFxPTOC (ANSI 51G/51N-1, 51G/51N-2, 50G/50N)

4.2.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Non-directional earth-fault protection, low stage	EFLPTOC	Io>	51G/51N-1
Non-directional earth-fault protection, high stage	EFHPTOC	Io>>	51G/51N-2
Non-directional earth-fault protection, instantaneous stage	EFIPTOC	Io>>>	50G/50N

4.2.1.2 Function block

Figure 252: Function block

1 Current before fault = 0.0 x I_n, f_n = 50 Hz, nominal frequency fault current 1.1 x set *Start value* is injected, results based on statistical distribution of 1000 measurements
2 Includes the delay (≈0ms) of the static signal output (SSO)

4.2.1.3 Functionality

The non-directional earth-fault protection function EFxPTOC is used as non-directional earth-fault protection for feeders.

The function starts and operates when the residual current exceeds the set limit. The operate time characteristic for low stage EFLPTOC and high stage EFHPTOC can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The instantaneous stage EFIPTOC always operates with the DT characteristic.

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.2.1.4 Analog channel configuration

EFxPTOC has one analog group input which must be properly configured.

Table 502: Analog inputs

Input	Description
IRES	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of EFxPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

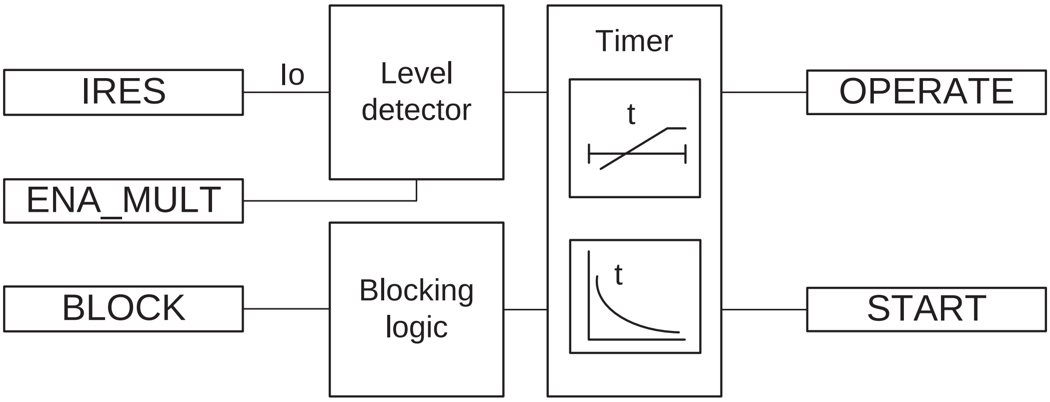


Figure 253: Functional module diagram

Level detector

The measured residual current is compared to the set *Start value*. If the measured value exceeds the set *Start value*, the level detector sends an enable-signal to the timer module. If the ENA_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

The start value multiplication is normally done when the inrush detection function (INRPHAR) is connected to the ENA_MULT input.

Timer

Once activated, the timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.2.1 IDMT curves for overcurrent protection* in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.1.6 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 503: Measurement modes supported by EFxPTOC stages

Measurement mode	EFLPTOC	EFHPTOC	EFIPTOC
RMS	x	x	
DFT	x	x	
Peak-to-Peak	x	x	x

For a detailed description of the measurement modes, see *Chapter 11.6 Measurement modes* in this manual.

4.2.1.7 Timer characteristics

EFxPTOC supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* and *Type of reset curve* settings.

When the DT characteristic is selected, it is only affected by the *Operate delay time* and *Reset delay time* settings.

The protection relay provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages.

Table 504: Timer characteristics supported by different stages

Operating curve type	EFLPTOC	EFHPTOC
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	x
(10) IEC Very Inverse	x	x
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	x
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable curve	x	x
(18) RI type	x	
(19) RD type	x	

EFIPTOC supports only definite time characteristics.

For a detailed description of timers, see *Chapter 11 General function block features* in this manual.

Table 505: Reset time characteristics supported by different stages

Reset curve type	EFLPTOC	EFHPTOC	Note
(1) Immediate	x	x	Available for all operate time curves
(2) Def time reset	x	x	Available for all operate time curves
(3) Inverse reset	x	x	Available only for ANSI and user programmable curves

The *Type of reset curve* setting does not apply to EFIPTOC or when the DT operation is selected. The reset is purely defined by the *Reset delay time* setting.

4.2.1.8 Application

EFxPTOC is designed for protection and clearance of earth faults in distribution and sub-transmission networks where the neutral point is isolated or earthed via a resonance coil or through low resistance. It also applies to solidly earthed networks and earth-fault protection of different equipment connected to the power systems, such as shunt capacitor bank or shunt reactors and for backup earth-fault protection of power transformers.

Many applications require several steps using different current start levels and time delays. EFxPTOC consists of three different protection stages.

- Low EFLPTOC
- High EFHPTOC
- Instantaneous EFIPTOC

EFLPTOC contains several types of time-delay characteristics. EFHPTOC and EFIPTOC are used for fast clearance of serious earth faults.

4.2.1.9 Signals

EFLPTOC Input signals

Table 506: EFLPTOC Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

EFHPTOC Input signals

Table 507: EFHPTOC Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

EFIPTOC Input signals

Table 508: EFIPTOC Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

EFLPTOC Output signals

Table 509: EFLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

EFHPTOC Output signals

Table 510: EFHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

EFIPTOC Output signals

Table 511: EFIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.1.10 Settings

EFLPTOC Settings

Table 512: EFLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...10.000	xIn	0.005	0.010	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table 513: EFLPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 514: EFLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 515: EFLPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

EFHPTOC Settings

Table 516: EFHPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 517: EFHPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 518: EFHPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 519: EFHPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

EFIPTOC Settings

Table 520: EFIPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	1.00...40.00	xIn	0.01	1.00	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Operate delay time	20...300000	ms	10	20	Operate delay time

Table 521: EFIPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 522: EFIPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.2.1.11 Monitored data

EFLPTOC Monitored data

Table 523: EFLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFLPTOC	Enum	1=on 2=blocked 3=test		Status

Name	Type	Values (Range)	Unit	Description
		4=test/blocked 5=off		

EFHPTOC Monitored data

Table 524: EFHPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFHPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

EFIPTOC Monitored data

Table 525: EFIPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
EFIPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.1.12 Technical data

Table 526: EFxPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
	EFLPTOC	±1.5% of the set value or ±0.002 × I_n		
	EFHPTOC and EFIPTOC	±1.5% of set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n)		
Start time [1]		Minimum	Typical	Maximum
	EFIPTOC [2]:			

Table continues on the next page

[1] *Measurement mode* = fault current in one phase with nominal frequency injected from random phase angle, results based onstatistical distribution of 1000 meas urements

Characteristic		Value		
	I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	8 ms 8 ms	11 ms 9 ms	14 ms 11 ms
	EFHPTOC and EFLPTOC [3]: I_{Fault} = 2 × set *Start value*	23 ms	26 ms	29 ms
Reset time		Typically <40 ms		
Reset ratio		Typically 0.96		
Retardation time		<30 ms		
Operate time accuracy in definite time mode [5]		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [4]		
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression		

4.2.1.13 Technical revision history

Table 527: EFLPTOC Technical revision history

Product connectivity level	Technical revision	Change
PCL4	I	Setting *Start value* maximum value extended to 10.000xIn.

4.2.2 Directional earth-fault protection DEFxPDEF (ANSI 67G/N-1 51G/N-1, 67G/N-1 51G/N-2)

4.2.2.1 Identification

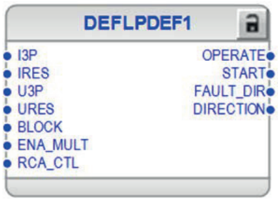
Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional earth-fault protection, low stage	DEFLPDEF	Io> ->	67G/N-1

Table continues on the next page

2 Measured with static signal output (SSO).
3 Includes the delay of the signal output contact (SO).
5 Start time of the function also included.
4 Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20.

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
			51G/N-1
Directional earth-fault protection, high stage	DEFHPDEF	Io>> ->	67G/N-1 51G/N-2

4.2.2.2 Function block



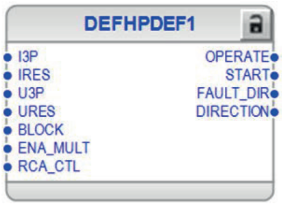


Figure 254: Function block

4.2.2.3 Functionality

The directional earth-fault protection function DEFxPDEF is used as directional earth-fault protection for feeders.

The function starts and operates when the operating quantity (current) and polarizing quantity (voltage) exceed the set limits and the angle between them is inside the set operating sector. The operate time characteristic for low stage (DEFLPDEF) and high stage (DEFHPDEF) can be selected to be either definite time (DT) or inverse definite minimum time (IDMT).

In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.2.2.4 Analog channel configuration

DEFxPDEF has four analog group inputs which must be properly configured.

Table 528: Analog inputs

Input	Description
I3P [1]	Three-phase currents, necessary when *Pol quantity* is set to "Neg. seq. volt."
IRES	Residual current (measured or calculated)

Table continues on the next page

[1] Can be connected to `GRPOFF` if *Pol quantity* is set to "Zero seq. volt" or *Directional mode* is set to "Nondirectional".

Input	Description
U3P [1]	Three-phase voltages, necessary when *Pol quantity* is set to "Neg. seq. volt."
URES [2]	Residual voltage (measured or calculated), necessary when *Pol quantity* is set to "Zero seq. volt."

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 529: Special conditions

Condition	Description
U3P connected real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.
URES calculated	Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DEFxPDEF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

[2] Can be connected to GRPOFF if *Pol quantity* is set to "Neg. seq. volt" or *Directional mode* is set to "Nondirectional".

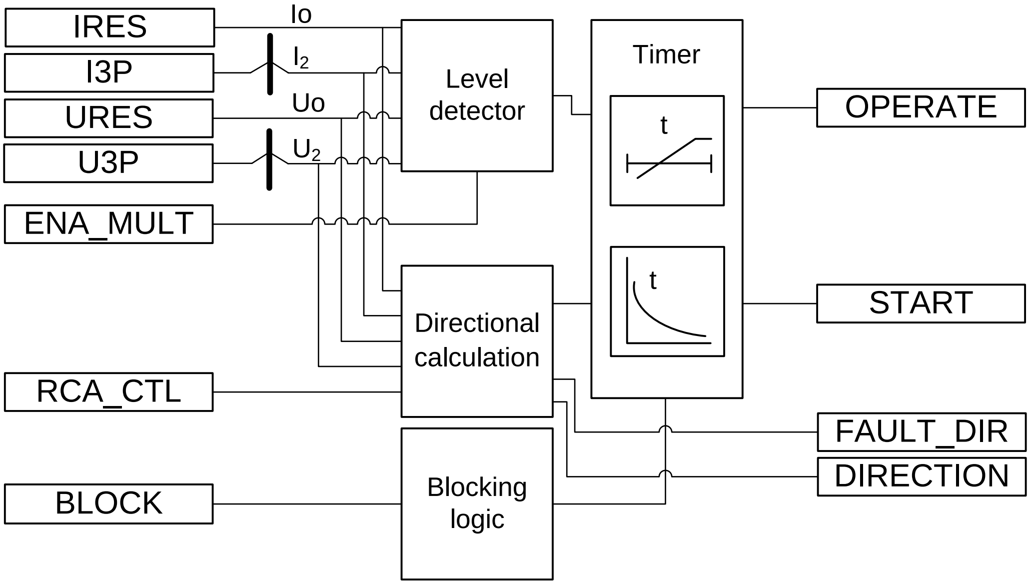


Figure 255: Functional module diagram

Level detector

The magnitude of the operating quantity is compared to the set *Start value* and the magnitude of the polarizing quantity is compared to the set *Voltage start value*. If both the limits are exceeded, the level detector sends an enabling signal to the timer module. When the *Enable voltage limit* setting is set to "False", *Voltage start value* has no effect and the level detection is purely based on the operating quantity. If the ENA_MULT input is active, the *Start value* setting is multiplied by the *Start value Mult* setting.

If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if the *Directional mode* was set to "Non-directional" or *Allow Non Dir* to "True". The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of these settings exceeds the *Start value* setting range.

Typically, the ENA_MULT input is connected to the inrush detection function INRHPAR. In case of inrush, INRPHAR activates the ENA_MULT input, which multiplies *Start value* by the *Start value Mult* setting.

Directional calculation

The directional calculation module monitors the angle between the polarizing quantity and operating quantity. Depending on the *Pol quantity* setting, the polarizing quantity can be the residual voltage (measured or calculated) or the negative sequence voltage. When the angle is in the operation sector, the module sends the enabling signal to the timer module.

The minimum signal level which allows the directional operation can be set with the *Min operate current* and *Min operate voltage* settings.

If *Pol quantity* is set to "Zero. seq. volt", the residual current and residual voltage are used for directional calculation.

If *Pol quantity* is set to "Neg. seq. volt", the negative sequence current and negative sequence voltage are used for directional calculation.

In the phasor diagrams representing the operation of DEFxPDEF, the polarity of the polarizing quantity (Uo or U2) is reversed, that is, the polarizing quantity in the phasor diagrams is either -Uo or -U2. Reversing is done by switching the polarity of the residual current measuring channel (see the connection in the Protection relay's physical connections section). Similarly the polarity of the calculated Io and I_2 is also switched.

For defining the operation sector, there are five modes available through the *Operation mode* setting.

Table 530: Operation modes

Operation mode	Description
Phase angle	The operating sectors for forward and reverse are defined with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* and *Max reverse angle*.
IoSin	The operating sectors are defined as "forward" when |Io| x sin (ANGLE) has a positive value and "reverse" when the value is negative. ANGLE is the angle difference between -Uo and Io.
IoCos	As "IoSin" mode. Only cosine is used for calculating the operation current.
Phase angle 80	The sector maximum values are frozen to 80 degrees respectively. Only *Min forward angle* and *Min reverse angle* are settable.
Phase angle 88	The sector maximum values are frozen to 88 degrees. Otherwise as "Phase angle 80" mode.

Polarizing quantity selection "Neg. seq. volt." is available only in the "Phase angle" operation mode.

The directional operation can be selected with the *Directional mode* setting. The alternatives are "Non-directional", "Forward" and "Reverse" operation. The operation criterion is selected with the *Operation mode* setting. By setting *Allow Non Dir* to "True", non-directional operation is allowed when the directional information is invalid, that is, when the magnitude of the polarizing quantity is less than the value of the *Min operate voltage* setting.

Typically, the network rotating direction is counter-clockwise and defined as "ABC". If the network rotating direction is reversed, meaning clockwise, that is, "ACB", the equation for calculating the negative sequence voltage component need to be changed. The network rotating direction is defined with a system parameter *Phase rotation*. The calculation of the component is affected but the angle difference calculation remains the same. When the residual voltage is used as the polarizing method, the network rotating direction change has no effect on the direction calculation.

The network rotating direction is set in the protection relay using the parameter in the HMI menu: **Configuration** > **System** > **Phase rotation**.

The default parameter value is "ABC".

If the *Enable voltage limit* setting is set to "True", the magnitude of the polarizing quantity is checked even if *Directional mode* is set to "Non-directional" or *Allow Non Dir* to "True".

The *Characteristic angle* setting is used in the "Phase angle" mode to adjust the operation according to the method of neutral point earthing so that in an isolated network the *Characteristic angle* (φ_{RCA}) = -90° and in a compensated network φ_{RCA} = 0°. In addition, the characteristic angle can be changed via the control signal RCA_CTL. RCA_CTL affects the *Characteristic angle* setting.

The *Correction angle* setting can be used to improve selectivity due the inaccuracies in the measurement transformers. The setting decreases the operation sector. The correction can only be used with the "IoCos" or "IoSin" modes.

The polarity of the polarizing quantity can be reversed by setting the *Pol reversal* to "True", which turns the polarizing quantity by 180 degrees.

For definitions of different directional earth-fault characteristics, see *Chapter 4.2.2.9 Directional earth-fault characteristics* in this manual.

The `DIRECTION` output indicates on which operating sector the operating quantity is measured. The `FAULT_DIR` output indicates in which operation sector the fault current is measured. The output is operational once the function is started.

The directional calculation module calculates several values which are presented in the monitored data.

Table 531: Monitored data values

Monitored data values	Description
ANGLE	Also called operating angle, shows the angle difference between the polarizing quantity (Uo, U_2) and operating quantity (Io, I_2).
ANGLE_RCA	The angle difference between the operating angle and Characteristic angle, that is, ANGLE_RCA = ANGLE – Characteristic angle.
I_OPER	The current that is used for fault detection. If the Operation mode setting is "Phase angle", "Phase angle 80" or "Phase angle 88", I_OPER is the measured or calculated residual current. If the Operation mode setting is "IoSin", I_OPER is calculated as follows I_OPER = Io x sin(ANGLE). If the Operation mode setting is "IoCos", I_OPER is calculated as follows I_OPER = Io x cos(ANGLE).

Timer

Once activated, the timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.2.1 IDMT curves for overcurrent protection* in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.2.6 Directional earth-fault principles

In many cases it is difficult to achieve selective earth-fault protection based on the magnitude of residual current only. To obtain a selective earth-fault protection scheme, it is necessary to take the phase angle of Io into account. This is done by comparing the phase angle of the operating and polarizing quantity.

Relay characteristic angle

The *Characteristic angle* setting, also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Angle (MTA), is used in the "Phase angle" mode to turn the directional characteristic if the expected fault current angle does not coincide with the polarizing quantity to produce the maximum torque. That is, RCA is the angle between the maximum torque line and polarizing quantity. If the polarizing quantity is in phase with the maximum torque line, RCA is 0 degrees. The angle is positive if the operating current lags the polarizing quantity and negative if it leads the polarizing quantity.

Example 1

The "Phase angle" mode is selected, compensated network (ϕRCA = 0 deg)

=> *Characteristic angle* = 0 deg

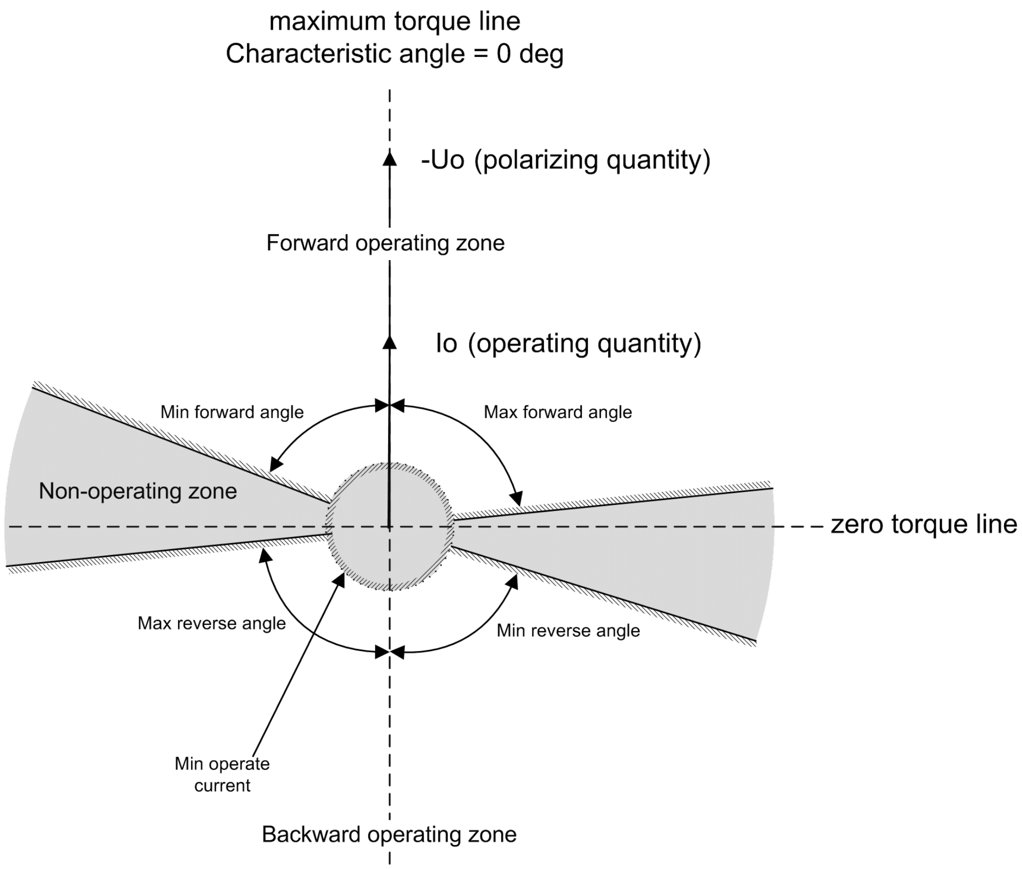


Figure 256: Definition of the relay characteristic angle, RCA=0 degrees in a compensated network

Example 2

The "Phase angle" mode is selected, solidly earthed network (ϕRCA = +60 deg)

=> *Characteristic angle* = +60 deg

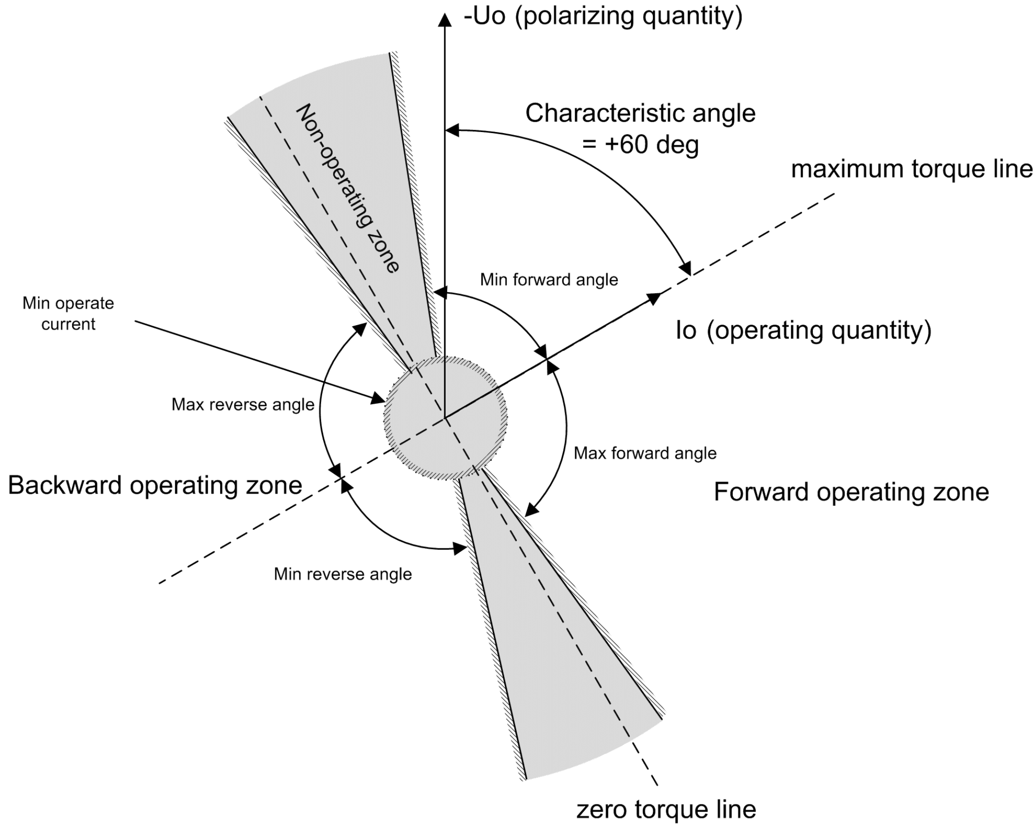


Figure 257: Definition of the relay characteristic angle, RCA=+60 degrees in a solidly earthed network

Example 3

The "Phase angle" mode is selected, isolated network (ϕRCA = -90 deg)

=> *Characteristic angle* = -90 deg

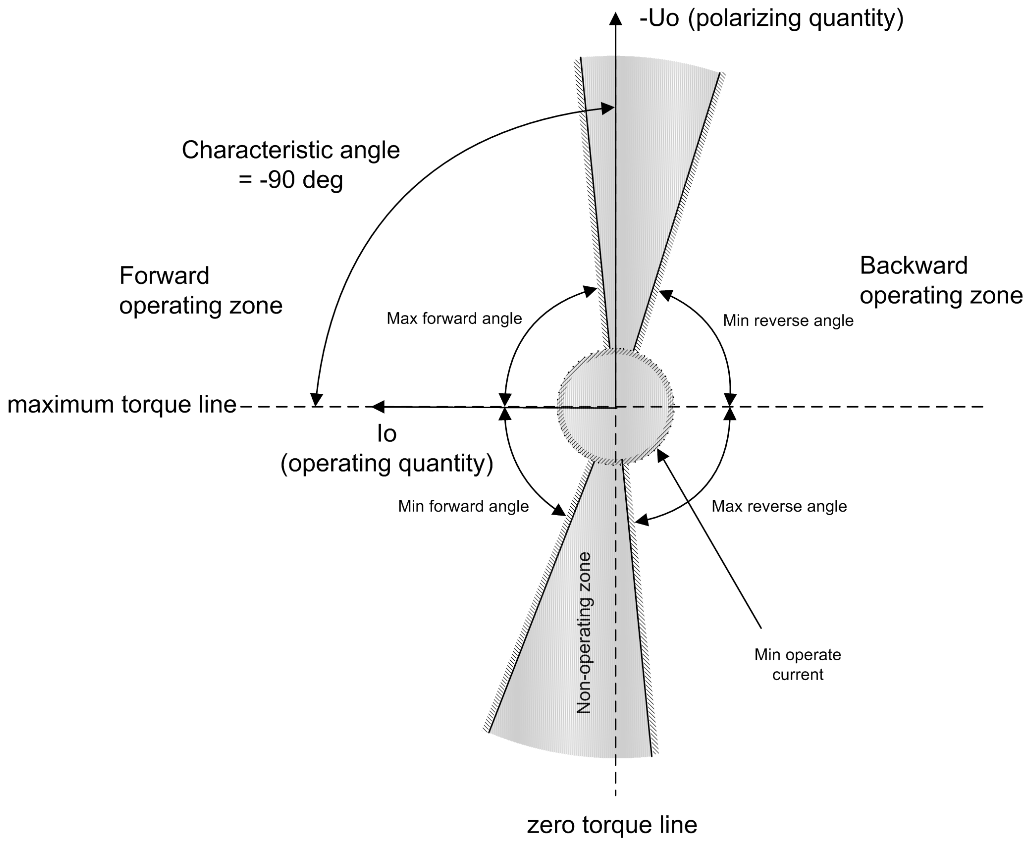


Figure 258: Definition of the relay characteristic angle, RCA=–90 degrees in an isolated network

Directional earth-fault protection in an isolated neutral network

In isolated networks, there is no intentional connection between the system neutral point and earth. The only connection is through the phase-to-earth capacitances (C_0) of phases and leakage resistances (R_0). This means that the residual current is mainly capacitive and has a phase shift of -90 degrees compared to the polarizing voltage. Consequently, the relay characteristic angle (RCA) should be set to -90 degrees and the operation criteria to "IoSin" or "Phase angle". The width of the operating sector in the phase angle criteria can be selected with the settings *Min forward angle*, *Max forward angle*, *Min reverse angle* or *Max reverse angle*. *Figure 259* illustrates a simplified equivalent circuit for an unearthed network with an earth fault in phase C.

For definitions of different directional earth-fault characteristics, see *Chapter 4.2.2.9 Directional earth-fault characteristics* .

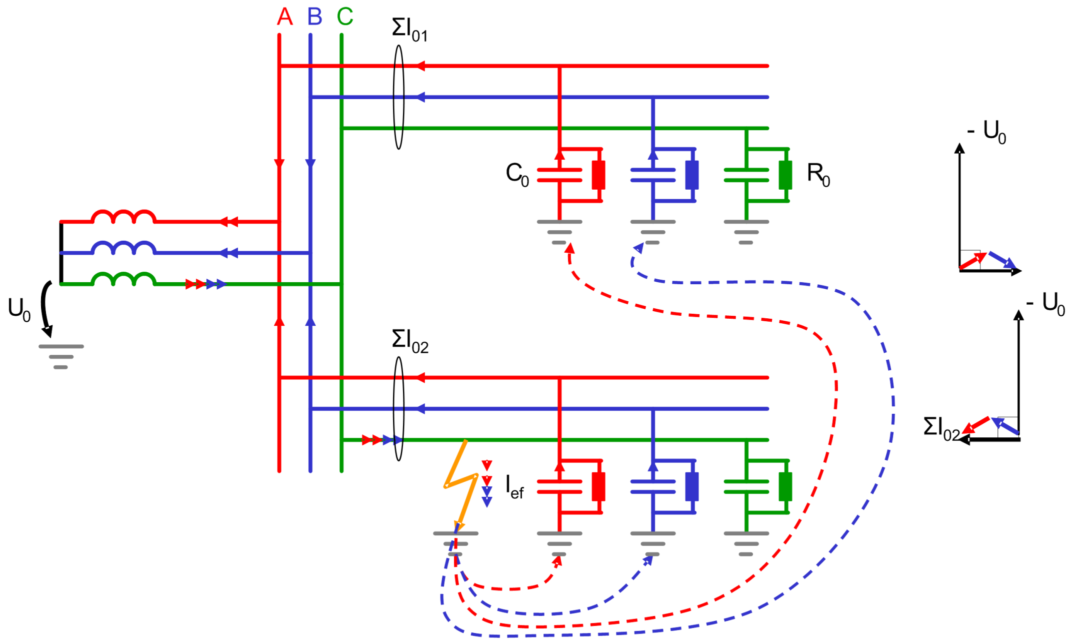


Figure 259: Earth-fault situation in an isolated network

Directional earth-fault protection in a compensated network

In compensated networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the protection relays. In this case, the selectivity is based on the measurement of the active current component. The magnitude of this component is often small and must be increased by means of a parallel resistor in the compensation equipment. When measuring the resistive part of the residual current, the *Operation mode* should be set to "Phase angle" and the relay characteristic angle (RCA) should be set to 0 degrees. Alternatively, the *Operation mode* can be set to "IoCos". *Figure 259* illustrates a simplified equivalent circuit for a compensated network with an earth fault in phase C.

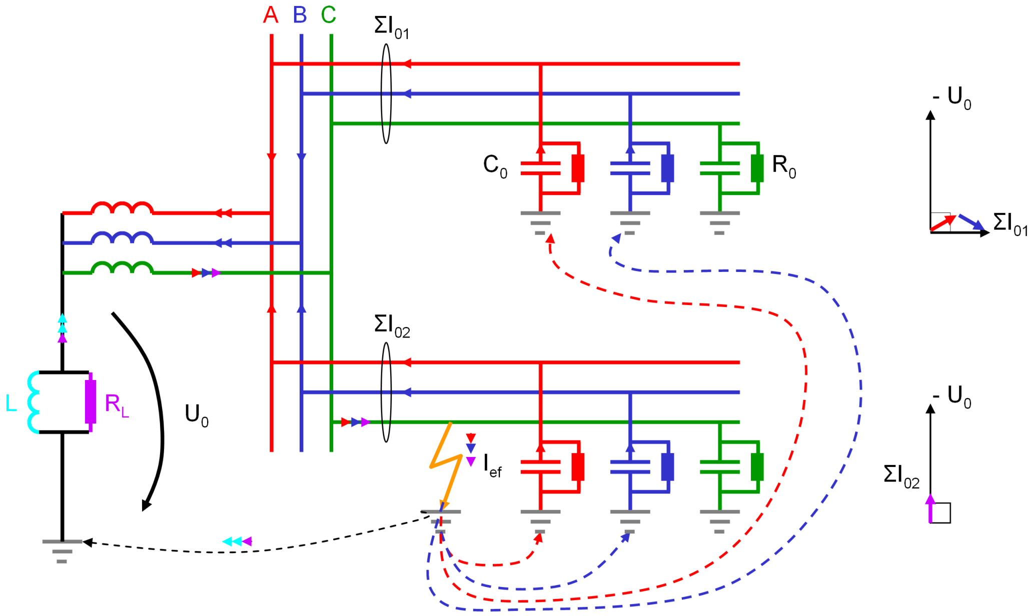


Figure 260: Earth-fault situation in a compensated network

The Petersen coil or the earthing resistor may be temporarily out of operation. To keep the protection scheme selective, it is necessary to update the *Characteristic angle* setting accordingly. This can be done with an auxiliary input in the protection relay which receives a signal from an auxiliary switch of the disconnector of the Petersen coil in compensated networks. As a result the characteristic angle is set automatically to suit the earthing method used. The RCA_CTL input can be used to change the operation criteria as described in Table 532 and Table 533.

Table 532: Relay characteristic angle control in Iosin(ϕ) and Iocos(ϕ) operation criteria

Operation mode **setting:**	**RCA_CTL = FALSE**	**RCA_CTL = TRUE**
Iosin	Actual operation mode: Iosin	Actual operation mode: Iocos
Iocos	Actual operation mode: Iocos	Actual operation mode: Iosin

Table 533: *Characteristic angle* control in phase angle operation mode

Characteristic angle **setting**	**RCA_CTL = FALSE**	**RCA_CTL = TRUE**
-90°	ϕ_{RCA} = -90°	ϕ_{RCA} = 0°
0°	ϕ_{RCA} = 0°	ϕ_{RCA} = -90°

Use of the extended phase angle characteristic

The traditional method of adapting the directional earth-fault protection function to the prevailing neutral earthing conditions is done with the *Characteristic angle* setting. In an unearthed network, *Characteristic angle* is set to -90 degrees and in a compensated network *Characteristic angle* is set to 0 degrees. In case the earthing method of the network is temporarily changed from compensated to unearthed due to the disconnection of the arc suppression coil, the *Characteristic angle* setting should be modified correspondingly. This can be done using the setting groups or the RCA_CTL input. Alternatively, the operating sector of the directional earth-fault protection function can be extended to cover the operating sectors of both neutral earthing principles. Such characteristic is valid for both unearthed and compensated network and does not require any modification in case the neutral earthing changes temporarily from the unearthed to compensated network or vice versa.

The extended phase angle characteristic is created by entering a value of over 90 degrees for the *Min forward angle* setting; a typical value is 170 degrees (*Min reverse angle* in case *Directional mode* is set to "Reverse"). The *Max forward angle* setting should be set to cover the possible measurement inaccuracies of current and voltage transformers; a typical value is 80 degrees (*Max reverse angle* in case *Directional mode* is set to "Reverse").

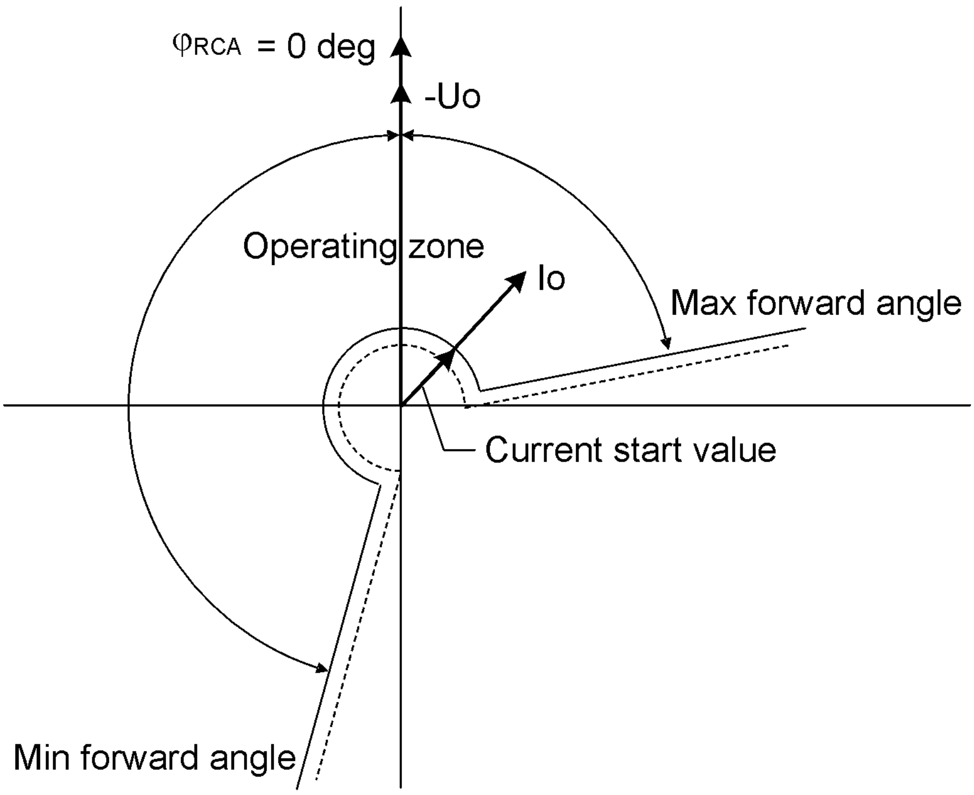


Figure 261: Extended operation area in directional earth-fault protection

4.2.2.7 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

Table 534: Measurement modes supported by DEFxPDEF stages

Measurement mode	DEFLPDEF	DEFHPDEF
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

For a detailed description of the measurement modes, see *Chapter 11.6 Measurement modes* in this manual.

4.2.2.8 Timer characteristics

DEFxPDEF supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* setting.

The protection relay provides 16 IDMT characteristics curves, of which seven comply with the IEEE C37.112 and six with the IEC 60255-3 standard. Two curves follow the special characteristics of ABB praxis and are referred to as RI and RD. In addition to this, a user programmable curve can be used if none of the standard curves are applicable. The user can choose the DT characteristic by selecting the *Operating curve type* values "ANSI Def. Time" or "IEC Def. Time". The functionality is identical in both cases.

The following characteristics, which comply with the list in the IEC 61850-7-4 specification, indicate the characteristics supported by different stages.

Table 535: Timer characteristics supported by different stages

Operating curve type	DEFLPDEF	DEFHPDEF
(1) ANSI Extremely Inverse	x	x
(2) ANSI Very Inverse	x	
(3) ANSI Normal Inverse	x	x
(4) ANSI Moderately Inverse	x	
(5) ANSI Definite Time	x	x
(6) Long Time Extremely Inverse	x	
(7) Long Time Very Inverse	x	
(8) Long Time Inverse	x	
(9) IEC Normal Inverse	x	
(10) IEC Very Inverse	x	
(11) IEC Inverse	x	
(12) IEC Extremely Inverse	x	
(13) IEC Short Time Inverse	x	
(14) IEC Long Time Inverse	x	
(15) IEC Definite Time	x	x
(17) User programmable curve	x	x
(18) RI type	x	
(19) RD type	x	

For a detailed description of the timers, see *Chapter 11 General function block features* in this manual.

Table 536: Reset time characteristics supported by different stages

Reset curve type	DEFLPDEF	DEFHPDEF	Note
(1) Immediate	x	x	Available for all operate time curves
(2) Def time reset	x	x	Available for all operate time curves
(3) Inverse reset	x	x	Available only for ANSI and user pro-grammable curves

4.2.2.9 Directional earth-fault characteristics

Phase angle characteristic

The operation criterion phase angle is selected with the *Operation mode* setting using the value "Phase angle".

When the phase angle criterion is used, the DIRECTION output indicates on which operating sector the operating quantity is measured. The FAULT_DIR output indicates in which operation sector the fault current is measured. The output is operational once the function is started.

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the clockwise sector and the *Min forward angle* setting correspondingly the counterclockwise sector, measured from the *Characteristic angle* setting.

In the reverse operation area, the *Max reverse angle* setting gives the clockwise sector and the *Min reverse angle* setting correspondingly the counterclockwise sector, measured from the complement of the *Characteristic angle* setting (180 degrees phase shift) .

The relay characteristic angle (RCA) is set to positive if the operating current lags the polarizing quantity. It is set to negative if it leads the polarizing quantity.

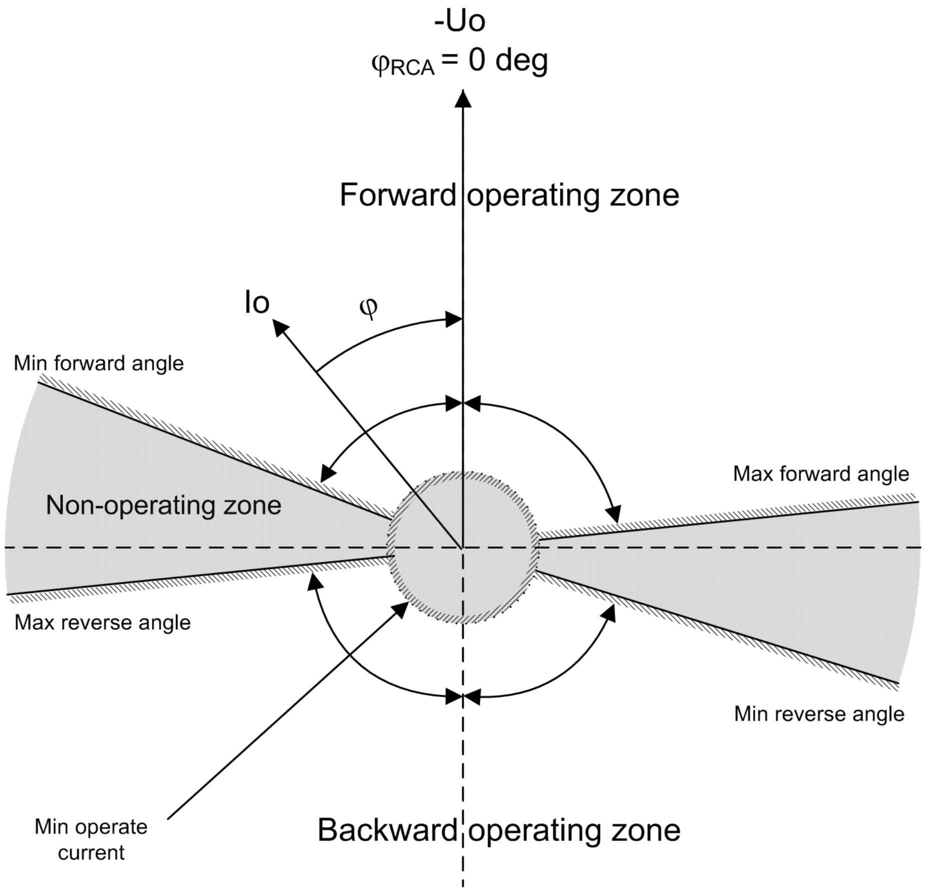


Figure 262: Configurable operating sectors in phase angle characteristic

Table 537: Momentary operating direction

Fault direction	The value for DIRECTION
Angle between the polarizing and operating quantity is not in any of the defined sectors.	0 = unknown
Angle between the polarizing and operating quantity is in the forward sector.	1= forward
Angle between the polarizing and operating quantity is in the reverse sector.	2 = backward
Angle between the polarizing and operating quantity is in both the forward and the reverse sectors, that is, the sectors are overlapping.	3 = both

If the *Allow Non Dir* setting is "False", the directional operation (forward, reverse) is not allowed when the measured polarizing or operating quantities are invalid, that is, their magnitude is below the set minimum values. The minimum values can be defined with the settings *Min operate current* and *Min operate voltage*. In case of low magnitudes, the `FAULT_DIR` and `DIRECTION` outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

Iosin(ϕ) and Iocos(ϕ) criteria

A more modern approach to directional protection is the active or reactive current measurement. The operating characteristic of the directional operation depends on the earthing principle of the network. The Iosin(ϕ) characteristics is used in an isolated network, measuring the reactive component of the fault current caused by the earth capacitance. The Iocos(ϕ) characteristics is used in a compensated network, measuring the active component of the fault current.

The operation criteria Iosin(ϕ) and Iocos(ϕ) are selected with the *Operation mode* setting using the values "IoSin" or "IoCos" respectively.

The angle correction setting can be used to improve selectivity. The setting decreases the operation sector. The correction can only be used with the Iosin(ϕ) or Iocos(ϕ) criterion. The `RCA_CTL` input is used to change the Io characteristic:

Table 538: Relay characteristic angle control in the IoSin and IoCos operation criteria

Operation mode:	RCA_CTL = "False"	RCA_CTL = "True"
IoSin	Actual operation criterion: Io-sin(ϕ)	Actual operation criterion: Io-cos(ϕ)
IoCos	Actual operation criterion: Io-cos(ϕ)	Actual operation criterion: Io-sin(ϕ)

When the Iosin(ϕ) or Iocos(ϕ) criterion is used, the component indicates a forward- or reverse-type fault through the `FAULT_DIR` and `DIRECTION` outputs, in which 1 equals a forward fault and 2 equals a reverse fault. Directional operation is not allowed (the *Allow non dir* setting is "False") when the measured polarizing or operating quantities are not valid, that is, when their magnitude is below the set minimum values. The minimum values can be defined with the *Min operate current* and *Min operate voltage* settings. In case of low magnitude, the `FAULT_DIR` and `DIRECTION` outputs are set to 0 = unknown, except when the *Allow non dir* setting is "True". In that case, the function is allowed to operate in the directional mode as non-directional, since the directional information is invalid.

The calculated Iosin(ϕ) or Iocos(ϕ) current used in direction determination can be read through the I_OPER monitored data. The value can be passed directly to a decisive element, which provides the final start and operate signals.

The I_OPER monitored data gives an absolute value of the calculated current.

The following examples show the characteristics of the different operation criteria:

Example 1.

Iosin(ϕ) criterion selected, forward-type fault

`=> FAULT_DIR = 1`

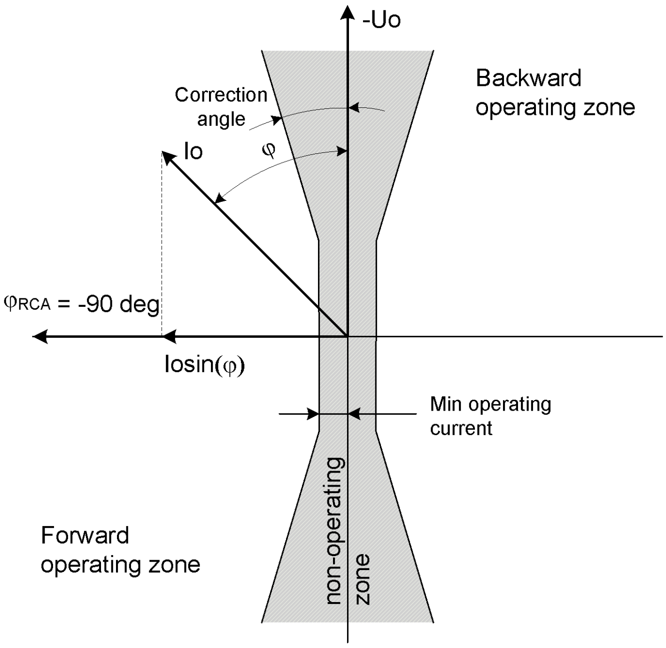


Figure 263: Operating characteristic Iosin(ϕ) in forward fault

The operating sector is limited by angle correction, that is, the operating sector is 180 degrees - 2*(angle correction).

Example 2.

Iosin(ϕ) criterion selected, reverse-type fault

```
=> FAULT_DIR = 2
```

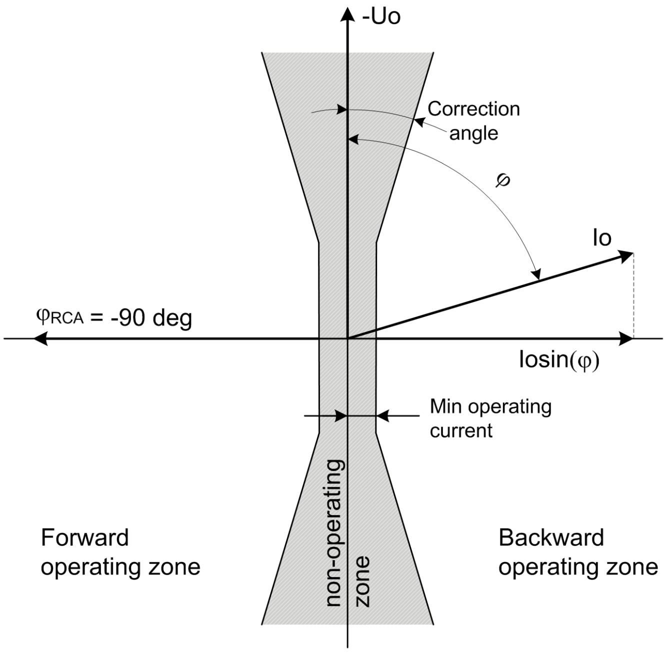


Figure 264: Operating characteristic Iosin(ϕ) in reverse fault

Example 3.

Iocos(ϕ) criterion selected, forward-type fault

`=> FAULT_DIR = 1`

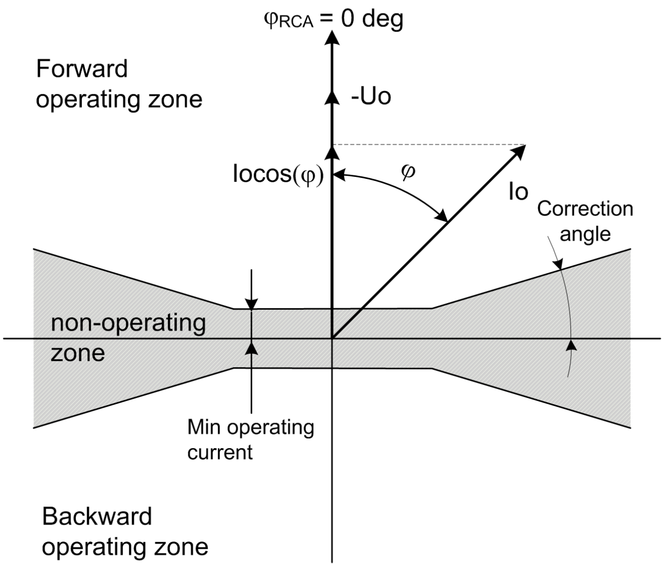


Figure 265: Operating characteristic Iocos(ϕ) in forward fault

Example 4.

Iocos(ϕ) criterion selected, reverse-type fault

`=> FAULT_DIR = 2`

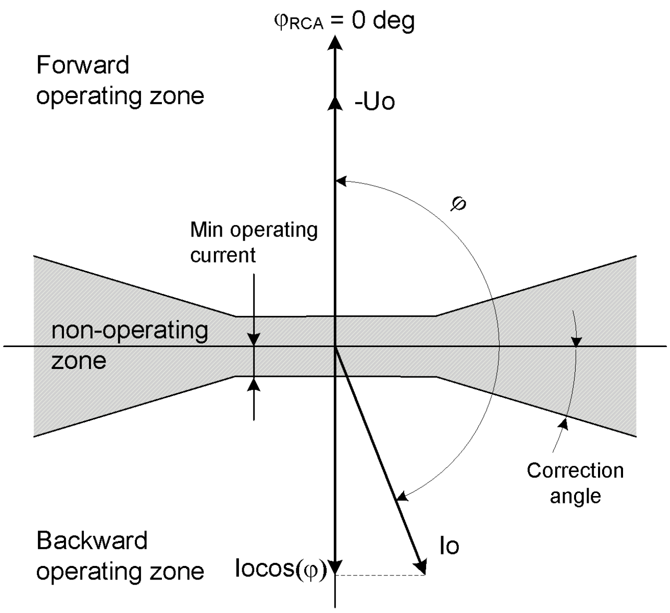


Figure 266: Operating characteristic Iocos(ϕ) in reverse fault

Phase angle 80

The operation criterion phase angle 80 is selected with the *Operation mode* setting by using the value "Phase angle 80".

Phase angle 80 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 80 degrees
- The sector limits of the fixed sectors are rounded.

The sector rounding is used for cancelling the CT measurement errors at low current amplitudes. When the current amplitude falls below three percent of the nominal current, the sector is reduced to 70 degrees at the fixed sector side. This makes the protection more selective, which means that the phase angle measurement errors do not cause faulty operation.

There is no sector rounding on the other side of the sector.

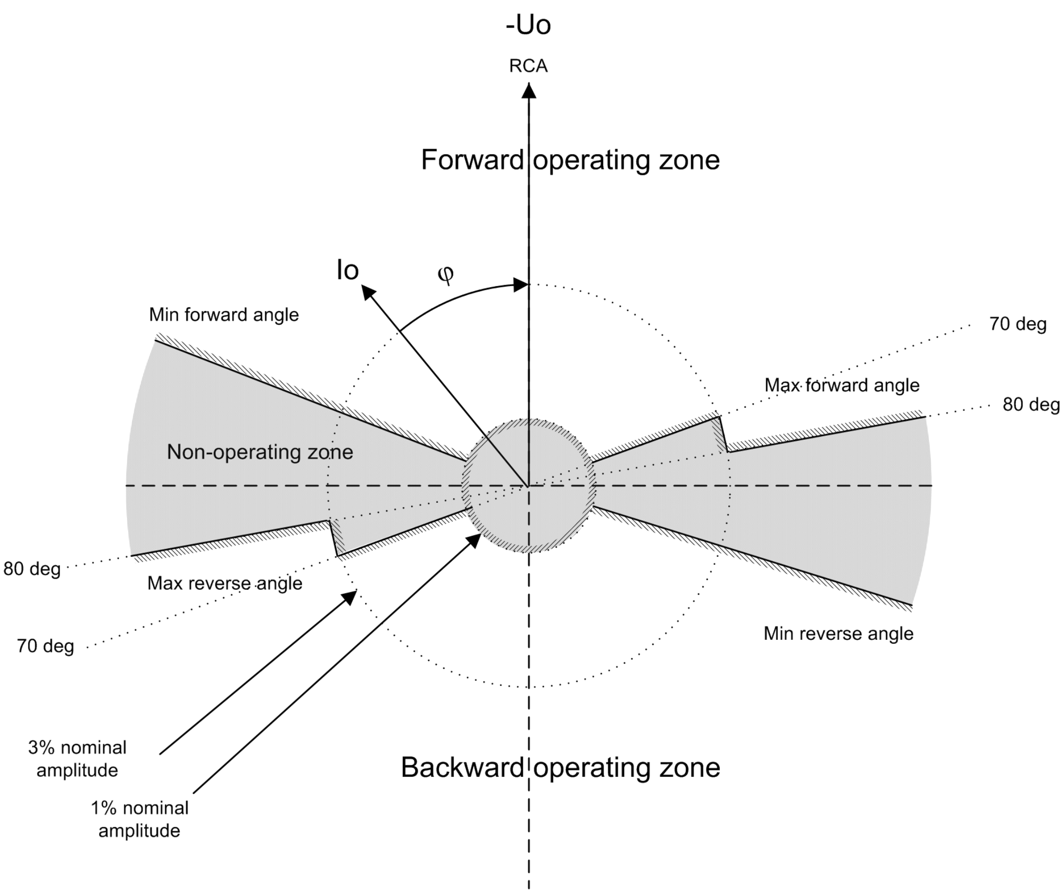


Figure 267: Operating characteristic for phase angle 80

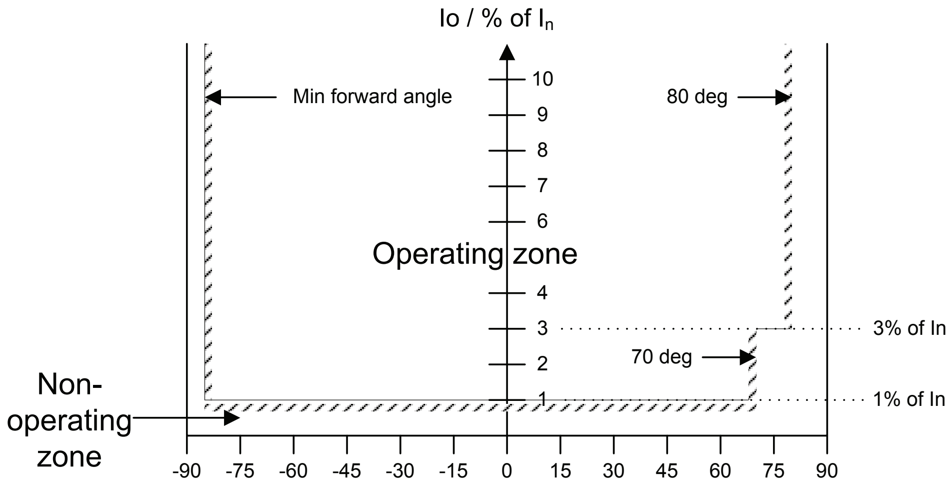


Figure 268: Phase angle 80 amplitude (Directional mode = Forward)

Phase angle 88

The operation criterion phase angle 88 is selected with the *Operation mode* setting using the value "Phase angle 88".

Phase angle 88 implements the same functionality as the phase angle but with the following differences:

- The *Max forward angle* and *Max reverse angle* settings cannot be set but they have a fixed value of 88 degrees
- The sector limits of the fixed sectors are rounded.

Sector rounding in the phase angle 88 consists of three parts.

- If the current amplitude is between 1...20 percent of the nominal current, the sector limit increases linearly from 73 degrees to 85 degrees
- If the current amplitude is between 20...100 percent of the nominal current, the sector limit increases linearly from 85 degrees to 88 degrees
- If the current amplitude is more than 100 percent of the nominal current, the sector limit is 88 degrees.

There is no sector rounding on the other side of the sector.

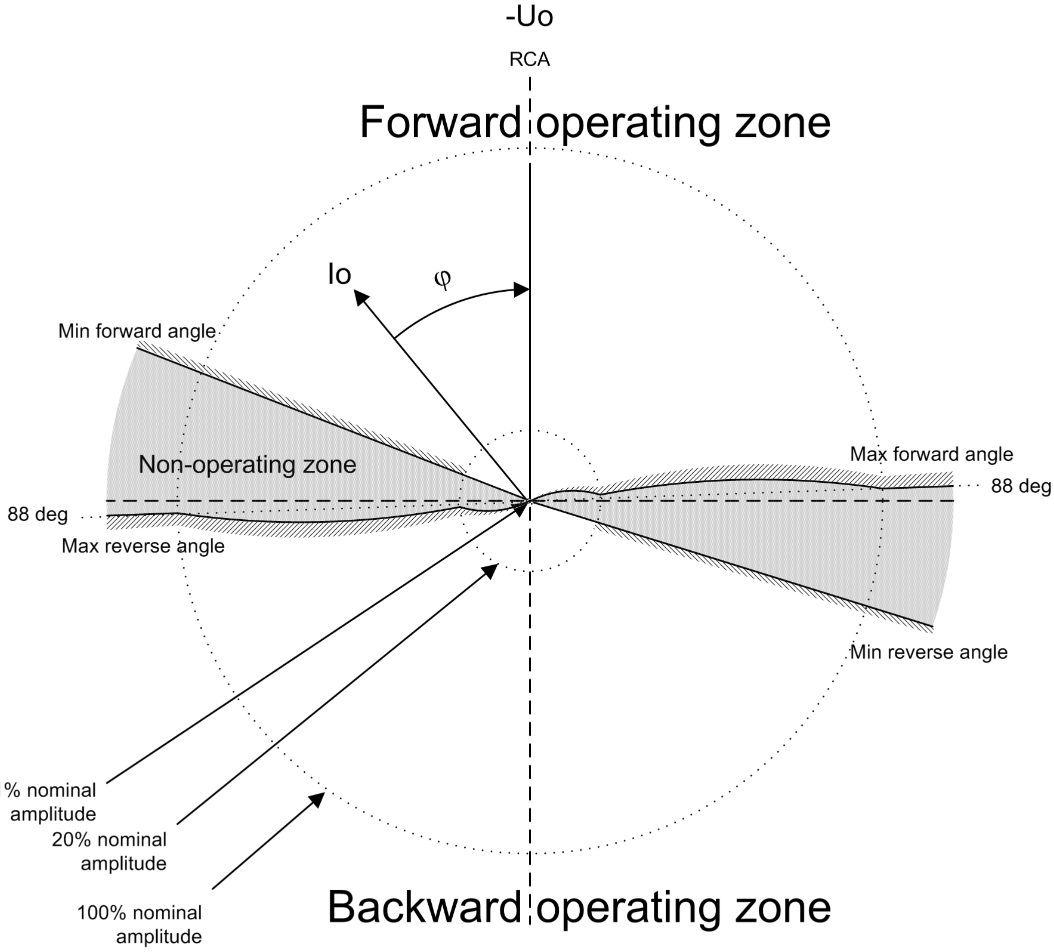


Figure 269: Operating characteristic for phase angle 88

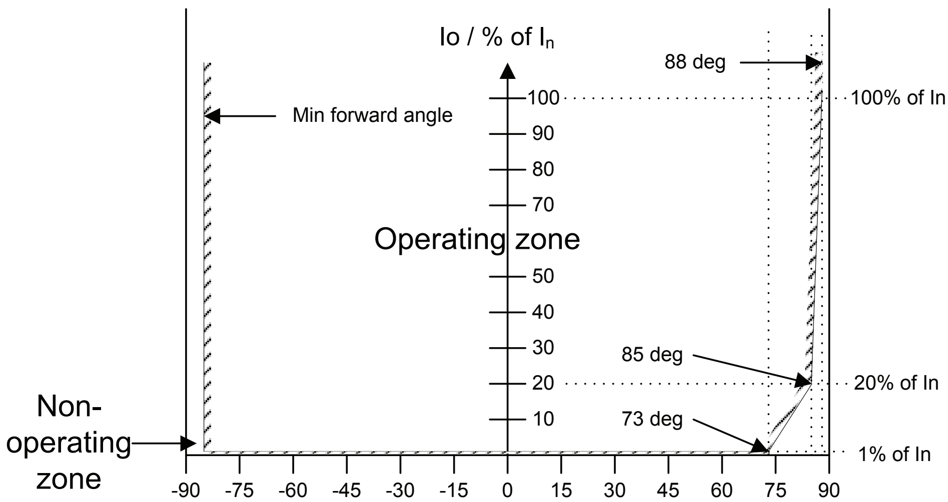


Figure 270: Phase angle 88 amplitude (Directional mode = Forward)

4.2.2.10 Application

The directional earth-fault protection DEFxPDEF is designed for protection and clearance of earth faults and for earth-fault protection of different equipment connected to the power systems, such as shunt capacitor banks or shunt reactors, and for backup earth-fault protection of power transformers.

Many applications require several steps using different current start levels and time delays. DEFxPDEF consists of two different stages.

- Low DEFLPDEF
- High DEFHPDEF

DEFLPDEF contains several types of time delay characteristics. DEFHPDEF is used for fast clearance of serious earth faults.

The protection can be based on the phase angle criterion with extended operating sector. It can also be based on measuring either the reactive part Iosin(φ) or the active part Iocos(φ) of the residual current. In isolated networks or in networks with high impedance earthing, the phase-to-earth fault current is significantly smaller than the short-circuit currents. In addition, the magnitude of the fault current is almost independent of the fault location in the network.

The function uses the residual current components Iocos(φ) or Iosin(φ) according to the earthing method, where φ is the angle between the residual current and the reference residual voltage (-Uo). In compensated networks, the phase angle criterion with extended operating sector can also be used. When the relay characteristic angle RCA is 0 degrees, the negative quadrant of the operation sector can be extended with the *Min forward angle* setting. The operation sector can be set between 0 and -180 degrees, so that the total operation sector is from +90 to -180 degrees. In other words, the sector can be up to 270 degrees wide. This allows the protection settings to stay the same when the resonance coil is disconnected from between the neutral point and earth.

System neutral earthing is meant to protect personnel and equipment and to reduce interference for example in telecommunication systems. The neutral earthing sets challenges for protection systems, especially for earth-fault protection.

In isolated networks, there is no intentional connection between the system neutral point and earth. The only connection is through the line-to-earth capacitances (C_0) of phases and leakage resistances (R_0). This means that the residual current is mainly capacitive and has -90 degrees phase shift compared to the residual voltage (-Uo). The characteristic angle is -90 degrees.

In resonance-earthed networks, the capacitive fault current and the inductive resonance coil current compensate each other. The protection cannot be based on the reactive current measurement, since the current of the compensation coil would disturb the operation of the relays. In this case, the selectivity is based on the measurement of the active current component. This means that the residual current is mainly resistive and has zero phase shift compared to the residual voltage (-Uo) and the characteristic angle is 0 degrees. Often the magnitude of this component is small, and must be increased by means of a parallel resistor in the compensation equipment.

In networks where the neutral point is earthed through low resistance, the characteristic angle is also 0 degrees (for phase angle). Alternatively, Iocos(φ) operation can be used.

In solidly earthed networks, the *Characteristic angle* is typically set to +60 degrees for the phase angle. Alternatively, Iosin(φ) operation can be used with a reversal polarizing quantity. The polarizing quantity can be rotated 180 degrees by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires. Although the Iosin(ϕ) operation can be used in solidly earthed networks, the phase angle is recommended.

Connection of measuring transformers in directional earth fault applications

The residual current Io can be measured with a core balance current transformer or the residual connection of the phase current signals. If the neutral of the network is either isolated or earthed with high impedance, a core balance current transformer is recommended to be used in earth-fault protection. To ensure sufficient accuracy of residual current measurements and consequently the selectivity of the scheme, the core balance current transformers should have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended.

Attention should be paid to make sure the measuring transformers are connected correctly so that DEFxPDEF is able to detect the fault current direction without failure. As directional earth fault uses residual current and residual voltage (-Uo), the poles of the measuring transformers must match each other and also the fault current direction. Also the earthing of the cable sheath must be taken into notice when using core balance current transformers. The following figure describes how measuring transformers can be connected to the protection relay.

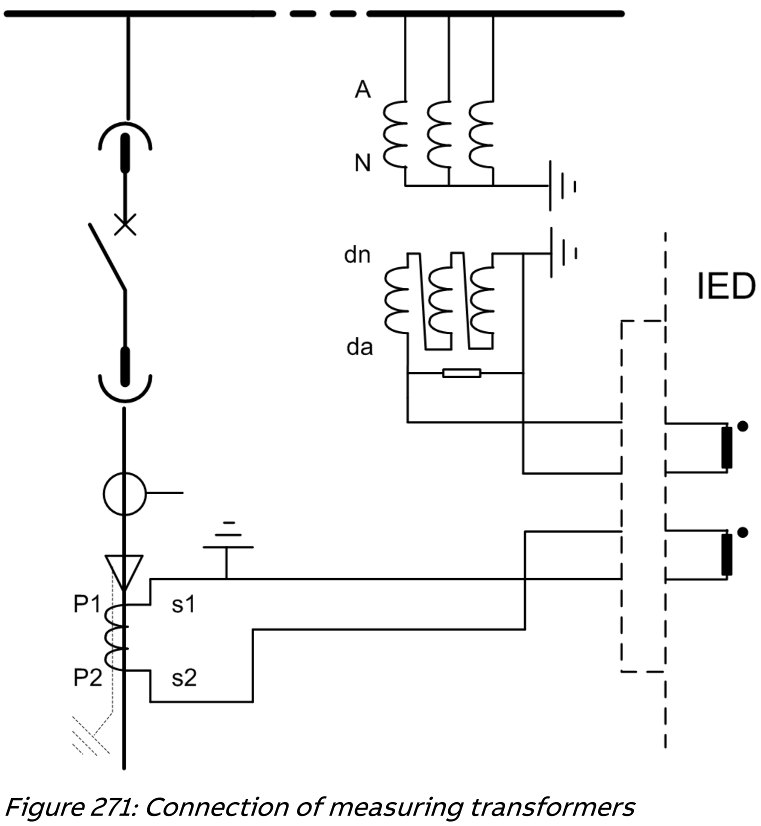


Figure 271: Connection of measuring transformers

4.2.2.11 Signals

DEFLPDEF Input signals

Table 539: DEFLPDEF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

DEFHPDEF Input signals

Table 540: DEFHPDEF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

DEFLPDEF Output signals

Table 541: DEFLPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
FAULT_DIR	Enum	Detected fault direction
DIRECTION	Enum	Direction information

DEFHPDEF Output signals

Table 542: DEFHPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
FAULT_DIR	Enum	Detected fault direction
DIRECTION	Enum	Direction information

4.2.2.12 Settings

DEFLPDEF Settings

Table 543: DEFLPDEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...10.000	xIn	0.005	0.010	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	50...300000	ms	10	50	Operate delay time
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Max forward angle	0...180	deg	1	80	Maximum phase angle in forward direction

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Max reverse angle	0...180	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...180	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...180	deg	1	80	Minimum phase angle in reverse direction
Voltage start value	0.010...1.000	xUn	0.001	0.010	Voltage start value

Table 544: DEFLPDEF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

Table 545: DEFLPDEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 546: DEFLPDEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	50...60000	ms	1	50	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS			2=DFT	Selects used measurement mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=DFT 3=Peak-to-Peak				
Min operate current	0.5...100.0	%In	0.1	0.5	Minimum operating current
Min operate voltage	1.0...100.0	%Un	0.1	1.0	Minimum operating voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Characteristic correction angle in IoCos and IoSin mode
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Pol quantity	3=Zero seq. volt. 4=Neg. seq. volt.			3=Zero seq. volt.	Reference quantity used to determine fault direction

DEFHPDEF Settings

Table 547: DEFHPDEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.10...40.00	xIn	0.01	0.10	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 15=IEC Def. Time 17=Programmable			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	40...300000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Max forward angle	0...180	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...180	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...180	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...180	deg	1	80	Minimum phase angle in reverse direction
Voltage start value	0.010...1.000	xUn	0.001	0.010	Voltage start value

Table 548: DEFHPDEF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate			1=Immediate	Selection of reset curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Def time reset 3=Inverse reset				
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

Table 549: DEFHPDEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 550: DEFHPDEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode
Min operate current	0.5...100.0	%In	0.1	0.5	Minimum operating current
Min operate voltage	1.00...100.00	%Un	1.00	1.00	Minimum operating voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Characteristic correction angle in IoCos and IoSin mode
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Pol quantity	3=Zero seq. volt. 4=Neg. seq. volt.			3=Zero seq. volt.	Reference quantity used to determine fault direction

4.2.2.13 Monitored data

DEFLPDEF Monitored data

Table 551: DEFLPDEF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
I_OPER	FLOAT32	0.00...40.00	xIn	Calculated operating current
DEFLPDEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

DEFHPDEF Monitored data

Table 552: DEFHPDEF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
I_OPER	FLOAT32	0.00...40.00	xIn	Calculated operating current
DEFHPDEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.2.14 Technical data

Table 553: DEFxPDEF Technical data

Characteristic		Value
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz
	DEFLPDEF	Current: ±1.5% of the set value or ±0.002 × I_n

Table continues on the next page

Characteristic		Value		
		Voltage ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°		
	DEFHPDEF	Current: ±1.5% of the set value or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0% of the set value (at currents in the range of 10…40 × I_n) Voltage: ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°		
Start time [1, 2]		Minimum	Typical	Maximum
	DEFHPDEF I_{Fault} = 2 × set *Start value*	42 ms	46 ms	49 ms
	DEFLPDEF I_{Fault} = 2 × set *Start value*	58 ms	62 ms	66 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<30 ms		
Operate time accuracy in definite time mode [4]		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [3]		
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression		

1 *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.
2 Includes the delay of the signal output contact.
4 Start time of the function also included.
3 Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20.

4.2.2.15 Technical revision history

Table 554: DEFLPDEF Technical revision history

Product connectivi ty level	Technical revision	Change
PCL4	H	Setting *Start value* maximum value extended to 10.000xIn.

4.2.3 Transient-intermittent earth-fault protection INTRPTEF (ANSI 67NTEF/NIEF)

4.2.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Transient/intermittent earth-fault protection	INTRPTEF	Io> -> IEF	67NTEF/NIEF

4.2.3.2 Function block

Figure 272: Function block

4.2.3.3 Functionality

The transient/intermittent earth-fault protection function INTRPTEF is a function designed for the protection and clearance of permanent and intermittent earth faults in distribution and sub-transmission networks. Fault detection is done from the residual current and residual voltage signals by monitoring the transients.

The operating time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.2.3.4 Analog channel configuration

INTRPTEF has two analog group inputs which must be properly configured.

Table 555: Analog inputs

Input	Description
IRES	Residual current (measured or calculated)
URES	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 556: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected for calculating the residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of INTRPTEF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

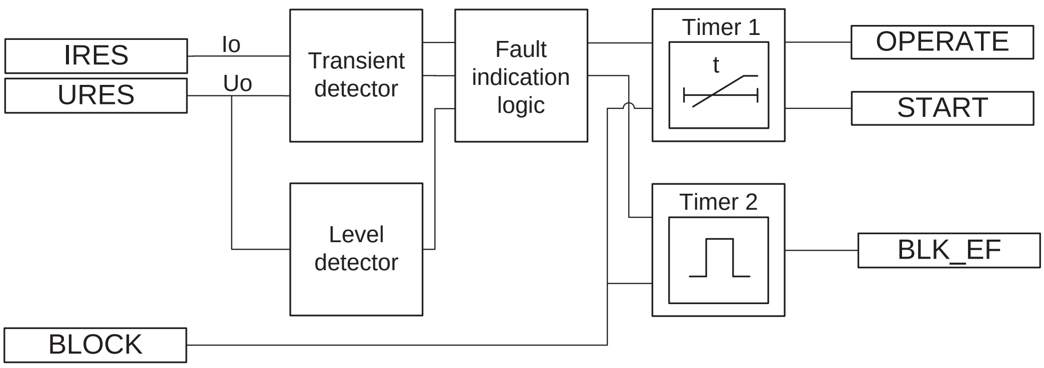


Figure 273: Functional module diagram

Level detector

The Level detector module is used only when selected *Operation mode* is "Transient EF". The module compares the measured residual voltage to the set *Voltage start* value. If the measured value exceeds the set *Voltage start* value, the module reports the exceeding of the value to the Fault indication logic.

Transient detector

The Transient detector module is used for detecting transients in the residual current and residual voltage signals.

The transient detection is supervised with a settable current threshold. With a special filtering technique, the setting *Min operate current* is based on the fundamental frequency current. This setting should be set based on the value of the parallel resistor of the coil, with security margin. For example, if the resistive current of the parallel resistor is 10 A, then a value of 0.7×10 A = 7 A could be used. The same setting is also applicable in case the coil is disconnected and the network becomes unearthed. Generally, a smaller value should be used and it must never exceed the value of the parallel resistor in order to allow operation of the faulted feeder.

Fault indication logic

Depending on the set *Operation mode*, INTRPTEF has two independent modes for detecting earth faults. The "Transient EF" mode is intended to detect all kinds of earth faults. The "Intermittent EF" mode is dedicated for detecting intermittent earth faults in cable networks.

To satisfy the sensitivity requirements, basic earth-fault protection (based on fundamental frequency phasors) should always be used in parallel with the INTRPTEF function.

The Fault indication logic module determines the direction of the fault. The fault direction determination is secured by multi-frequency neutral admittance measurement and special filtering techniques. This enables fault direction determination which is not sensitive to disturbances in measured Io and Uo signals, for example, switching transients.

When *Directional mode* setting "Forward" is used, the protection operates when the fault is in the protected feeder. When *Directional mode* setting "Reverse" is used, the protection operates when the fault is outside the protected feeder (in the background network). If the direction has no importance, the value "Non-directional" can be selected. The detected fault direction (FAULT_DIR) is available in the monitored data view.

In the "Transient EF" mode, when the start transient of the fault is detected and the Uo level exceeds the set *"Voltage start value"*, Timer 1 is activated. Timer 1 is kept activated until the Uo level exceeds the set value or in case of a drop-off, the drop-off duration is shorter than the set *Reset delay time*.

In the "Intermittent EF" mode, when the start transient of the fault is detected and the Uo level exceeds the set *Voltage start value*, the Timer 1 is activated. When a required number of intermittent earth-fault transients set with the *Peak counter limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), the START output is activated. The Timer 1 is kept activated as long as transients are occurring during the drop-off time defined by setting *Reset delay time*.

Timer 1

The time characteristic is according to DT.

In the "Transient EF" mode, the OPERATE output is activated after *Operate delay time* if the residual voltage exceeds the set *"Voltage start value"*. The *Reset delay time* starts to elapse when residual voltage falls below *Voltage start value*. If there is no OPERATE activation, for example, the fault disappears momentarily, START stays activated until the the *Reset delay time* elapses. After OPERATE activation, START and OPERATE signals are reset as soon as Uo falls below *Voltage start value*.

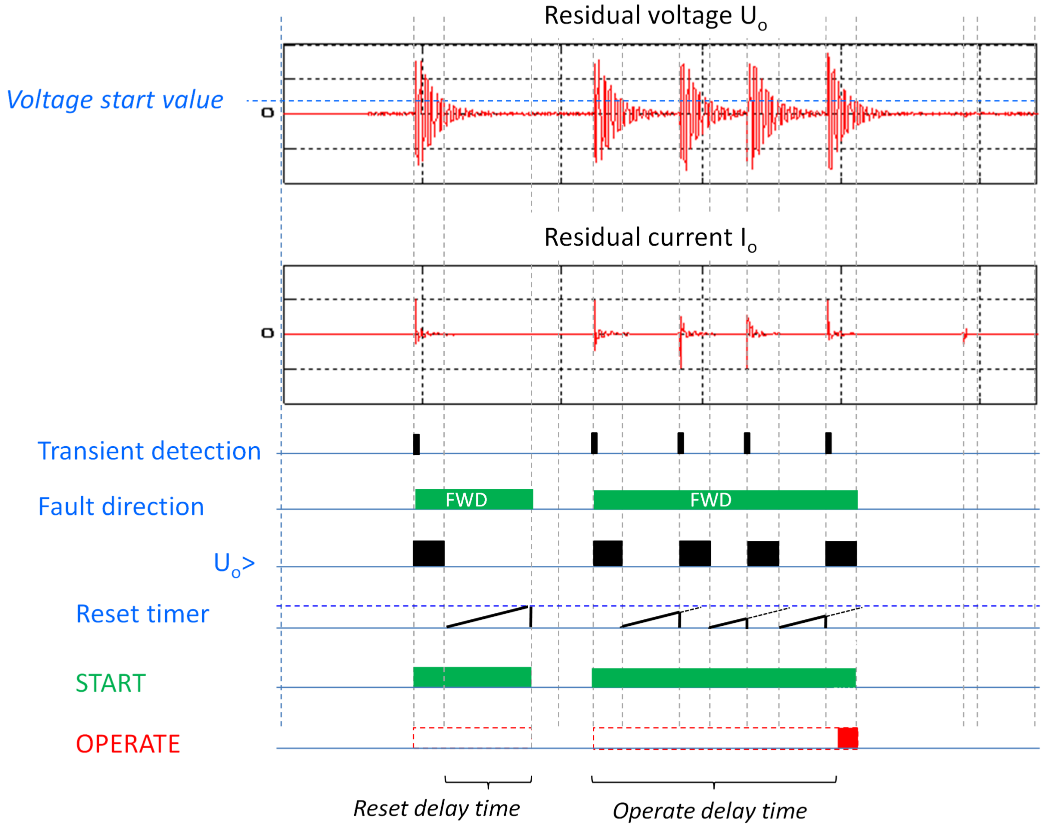


Figure 274: Example of INTRPTEF operation in ”Transient EF” mode in the faulty feeder

In the "Intermittent EF" mode the OPERATE output is activated when the following conditions are fulfilled:

- the number of transients that have been detected exceeds the *Peak counter limit* setting
- the timer has reached the time set with the *Operate delay time*
- and one additional transient is detected during the drop-off cycle

The *Reset delay time* starts to elapse from each detected transient (peak). In case there is no OPERATE activation, for example, the fault disappears momentarily START stays activated until the *Reset delay time* elapses, that is, reset takes place if time between transients is more than *Reset delay time*. After OPERATE activation, a fixed pulse length of 100 ms for OPERATE is given, whereas START is reset after *Reset delay time* elapses

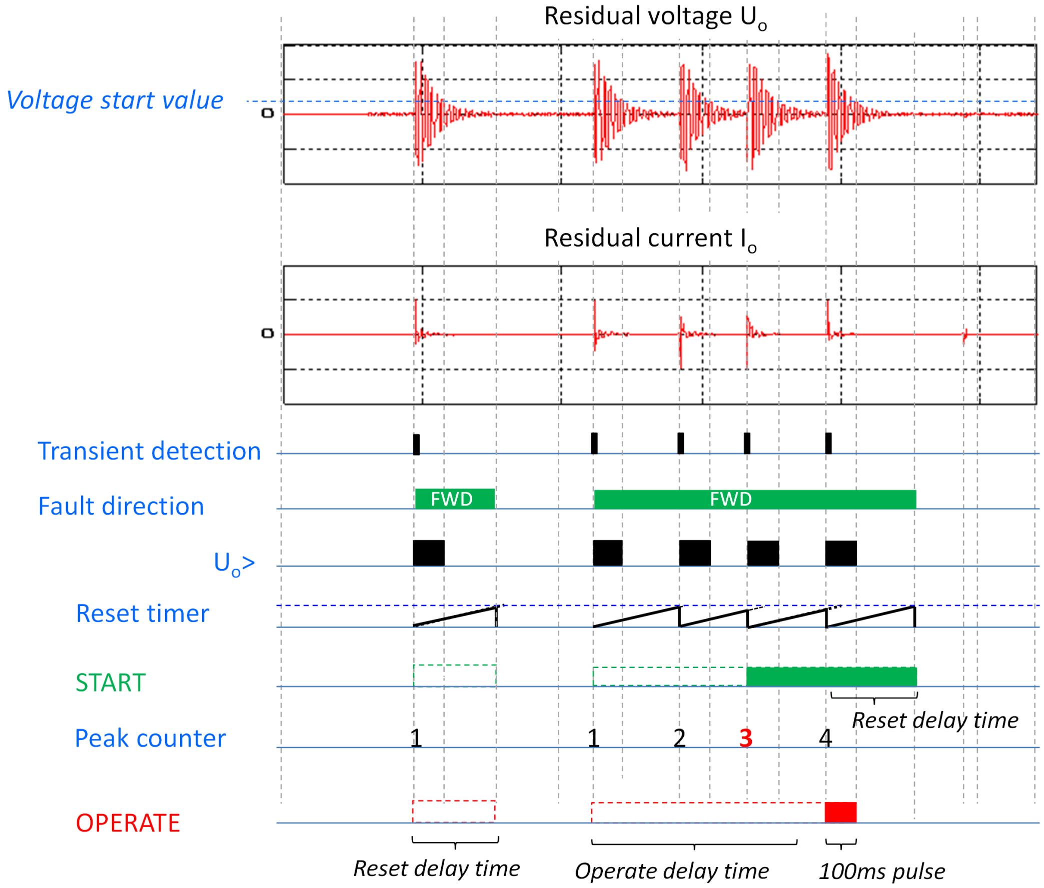


Figure 275: Example of INTRPTEF operation in "Intermittent EF" mode in the faulty feeder, Peak counter limit=3

The timer calculates the start duration value START_DUR which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Timer 2

If the function is used in the directional mode and an opposite direction transient is detected, the BLK_EF output is activated for the fixed delay time of 25 ms. If the START output is activated when the BLK_EF output is active, the BLK_EF output is deactivated.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.3.6 Application

INTRPTEF is an earth-fault function dedicated to operate in intermittent and permanent earth faults occurring in distribution and sub-transmission networks. Fault detection is done from the residual current and residual voltage signals by monitoring the transients with predefined criteria. As the function has a dedicated purpose for the fault types, fast detection and clearance of the faults can be achieved.

Intermittent earth fault

Intermittent earth fault is a special type of fault that is encountered especially in compensated networks with underground cables. A typical reason for this type of fault is the deterioration of cable insulation either due to mechanical stress or due to insulation material aging process where water or moisture gradually penetrates the cable insulation. This eventually reduces the voltage withstand of the insulation, leading to a series of cable insulation breakdowns. The fault is initiated as the phase-to-earth voltage exceeds the reduced insulation level of the fault point and mostly extinguishes itself as the fault current drops to zero for the first time, as shown in *Figure 276*. As a result, very short transients, that is, rapid changes in the form of spikes in residual current (Io) and in residual voltage (Uo), can be repeatedly measured. Typically, the fault resistance in case of an intermittent earth fault is only a few ohms.

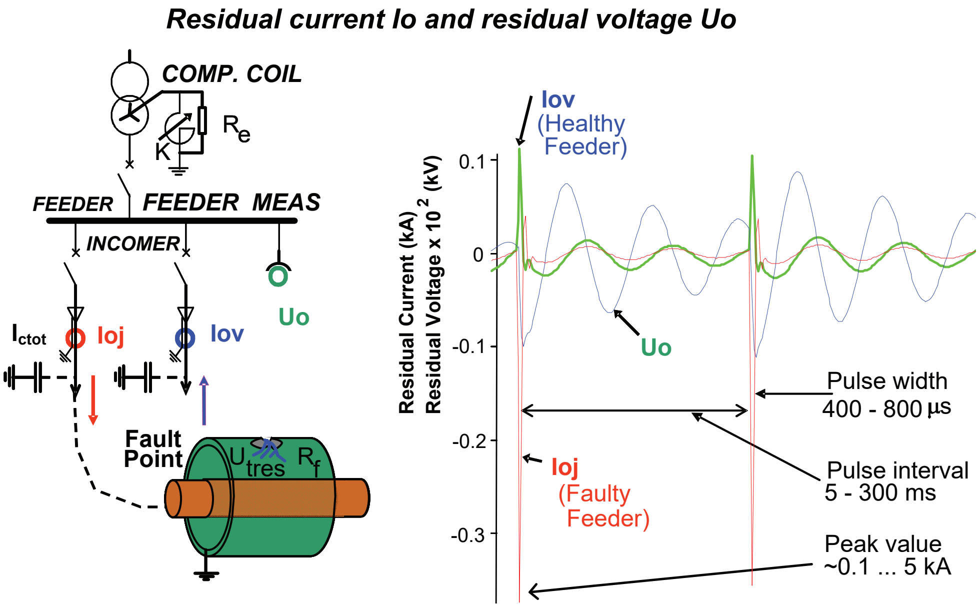


Figure 276: Typical intermittent earth-fault characteristics

Earth-fault transients

In general, earth faults generate transients in currents and voltages. There are several factors that affect the magnitude and frequency of these transients, such as the fault moment on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. In the fault initiation, the voltage of the faulty phase decreases and the corresponding capacitance is discharged to earth (→ discharge transients). At the same time, the voltages of the healthy phases increase and the related capacitances are charged (→ charge transient).

If the fault is permanent (non-transient) in nature, only the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients.

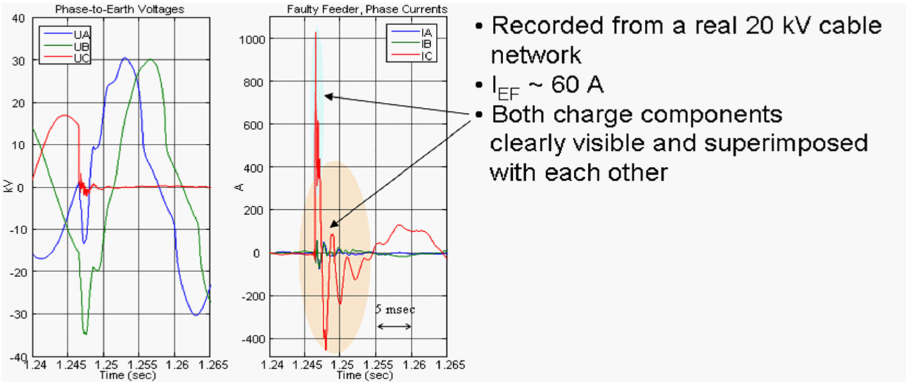


Figure 277: Example of earth-fault transients, including discharge and charge transient components, when a permanent fault occurs in a 20 kV network in phase C

4.2.3.7 Signals

INTRPTEF Input signals

Table 557: INTRPTEF Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

INTRPTEF Output signals

Table 558: INTRPTEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite direction peaks

4.2.3.8 INTRPTEF Settings

Table 559: INTRPTEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Operate delay time	40...1200000	ms	10	500	Operate delay time
Voltage start value	0.05...0.50	xUn	0.01	0.20	Voltage start value

Table 560: INTRPTEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Intermittent EF 2=Transient EF			1=Intermittent EF	Operation criteria

Table 561: INTRPTEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	40...60000	ms	1	500	Reset delay time
Peak counter limit	2...20		1	2	Min requirement for peak counter before start in IEF mode
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current for transi-ent detector

4.2.3.9 INTRPTEF Monitored data

Table 562: INTRPTEF Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / op-erate time
INTRPTEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.3.10 Technical data

Table 563: INTRPTEF Technical data

Characteristic	Value
Operation accuracy (Uo criteria with transient protection)	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × U_o
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5

4.2.4 Admittance-based earth-fault protection EFPADM (ANSI 21NY)

4.2.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Admittance-based earth-fault protection	EFPADM	Yo> ->	21NY

4.2.4.2 Function block

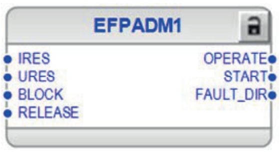


Figure 278: Function block

4.2.4.3 Functionality

The admittance-based earth-fault protection function EFPADM provides a selective earth-fault protection function for high-resistance earthed, unearthed and compensated networks. It can be applied for the protection of overhead lines as well as with underground cables. It can be used as an alternative solution to traditional residual current-based earth-fault protection functions, such as the IoCos mode in DEFxPDEF. Main advantages of EFPADM include a versatile applicability, good sensitivity and easy setting principles.

EFPADM is based on evaluating the neutral admittance of the network, that is, the quotient:

$$\underline{Yo} = \underline{Io} / -\underline{Uo}$$

(Equation 56)

The measured admittance is compared to the admittance characteristic boundaries in the admittance plane. The supported characteristics include overadmittance, oversusceptance, overconductance or any combination of the three. The directionality of the oversusceptance and overconductance criteria can be defined as forward, reverse or non-directional, and the boundary lines can be tilted if required by the application. This allows the optimization of the shape of the admittance characteristics for any given application.

EFPADM supports two calculation algorithms for admittance. The admittance calculation can be set to include or exclude the prefault zero-sequence values of Io and Uo. Furthermore, the calculated admittance is recorded at the time of the trip and it can be monitored for post-fault analysis purposes.

To ensure the security of the protection, the admittance calculation is supervised by a residual overvoltage condition which releases the admittance protection during a fault condition. Alternatively, the release signal can be provided by an external binary signal.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.2.4.4 Analog channel configuration

EFPADM has two analog group inputs which must be properly configured.

Table 564: Analog inputs

Input	Description
IRES	Residual current (measured or calculated)
URES	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 565: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected. Setting *VT connection* must be "Wye" in that particular UTVTR..

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of EFPADM can be described using a module diagram. All the modules in the diagram are explained in the next sections.

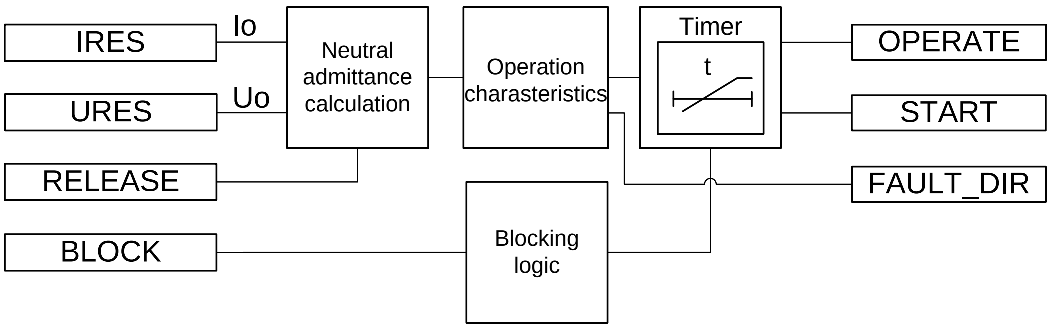


Figure 279: Functional module diagram

Neutral admittance calculation

When the residual voltage exceeds the set threshold *Voltage start value*, an earth fault is detected and the neutral admittance calculation is released.

To ensure a sufficient accuracy for the Io and Uo measurements, it is required that the residual voltage exceeds the value set by *Min operate voltage*. If the admittance calculation mode is "Delta", the minimum change in the residual voltage due to a fault must be 0.01 × Un to enable the operation. Similarly, the residual current must exceed the value set by *Min operate current*.

The polarity of the polarizing quantity Uo can be changed, that is, rotated by 180 degrees, by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires.

As an alternative for the internal residual overvoltage-based start condition, the neutral admittance protection can also be externally released by utilizing the RELEASE input.

When *Admittance Clc mode* is set to "Delta", the external logic used must be able to give RELEASE in less than 0.1 s from fault initiation. Otherwise the collected pre-fault values are overwritten with fault time values. If it is slower, *Admittance Clc mode* must be set to “Normal”.

Neutral admittance is calculated as the quotient between the residual current and residual voltage (polarity reversed) fundamental frequency phasors. The *Admittance Clc mode* setting defines the calculation mode.

Admittance Clc mode = "Normal"

$$\underline{Yo} = \frac{\underline{Io}_{fault}}{-\underline{Uo}_{fault}}$$

(Equation 57)

Admittance Clc mode = "Delta"

$$\underline{Yo} = \frac{\underline{Io}_{fault} - \underline{Io}_{prefault}}{-(\underline{Uo}_{fault} - \underline{Uo}_{prefault})} = \frac{\Delta \underline{Io}}{-\Delta \underline{Uo}}$$

(Equation 58)

$\underline{Y}o$	Calculated neutral admittance [Siemens]
$\underline{I}o_{fault}$	Residual current during the fault [Amperes]
$\underline{U}o_{fault}$	Residual voltage during the fault [Volts]
$\underline{I}o_{prefault}$	Prefault residual current [Amperes]
$\underline{U}o_{prefault}$	Prefault residual voltage [Volts]
$\Delta \underline{I}o$	Change in the residual current due to fault [Amperes]
$\Delta \underline{U}o$	Change in the residual voltage due to fault [Volts]

Traditionally, admittance calculation is done with the calculation mode "Normal", that is, with the current and voltage values directly measured during the fault. As an alternative, by selecting the calculation mode "Delta", the prefault zero-sequence asymmetry of the network can be removed from the admittance calculation. Theoretically, this makes the admittance calculation totally immune to fault resistance, that is, the estimated admittance value is not affected by fault resistance. Utilization of the change in Uo and Io due to a fault in the admittance calculation also mitigates the effects of the VT and CT measurement errors, thus improving the measuring accuracy, the sensitivity and the selectivity of the protection.

Calculation mode "Delta" is recommended in case a high sensitivity of the protection is required, if the network has a high degree of asymmetry during the healthy state or if the residual current measurement is based on sum connection, that is, the Holmgren connection.

Neutral admittance calculation produces certain values during forward and reverse faults.

Fault in reverse direction, that is, outside the protected feeder.

$$\underline{Y}o = -\underline{Y}_{Fdtot}$$

(Equation 59)

$$\approx -j \cdot \frac{I_{eFd}}{U_{ph}}$$

(Equation 60)

$\underline{Y}_{Fdtot}$	Sum of the phase-to-earth admittances ($\underline{Y}_{FdA}$, $\underline{Y}_{FdB}$, $\underline{Y}_{FdC}$) of the protected feeder
I_{eFd}	Magnitude of the earth-fault current of the protected feeder when the fault resistance is zero ohm
U_{ph}	Magnitude of the nominal phase-to-earth voltage of the system

Equation 59 shows that in case of outside faults, the measured admittance equals the admittance of the protected feeder with a negative sign. The measured admittance is dominantly reactive; the small resistive part of the measured admittance is due to the leakage losses of the feeder. Theoretically, the measured admittance is located in the third quadrant in the admittance plane close to the im($\underline{Y}$o) axis, see *Figure 280*.

The result of *Equation 59* is valid regardless of the neutral earthing method. In compensated networks the compensation degree does not affect the result. This enables a straightforward setting principle for the neutral admittance protection: admittance characteristic is set to cover the value $\underline{Y}o = -\underline{Y}_{Fdtot}$ with a suitable margin.

Due to inaccuracies in voltage and current measurement, the small real part of the calculated neutral admittance may appear as positive, which brings the measured admittance in the fourth quadrant in the admittance plane. This should be considered when setting the admittance characteristic.

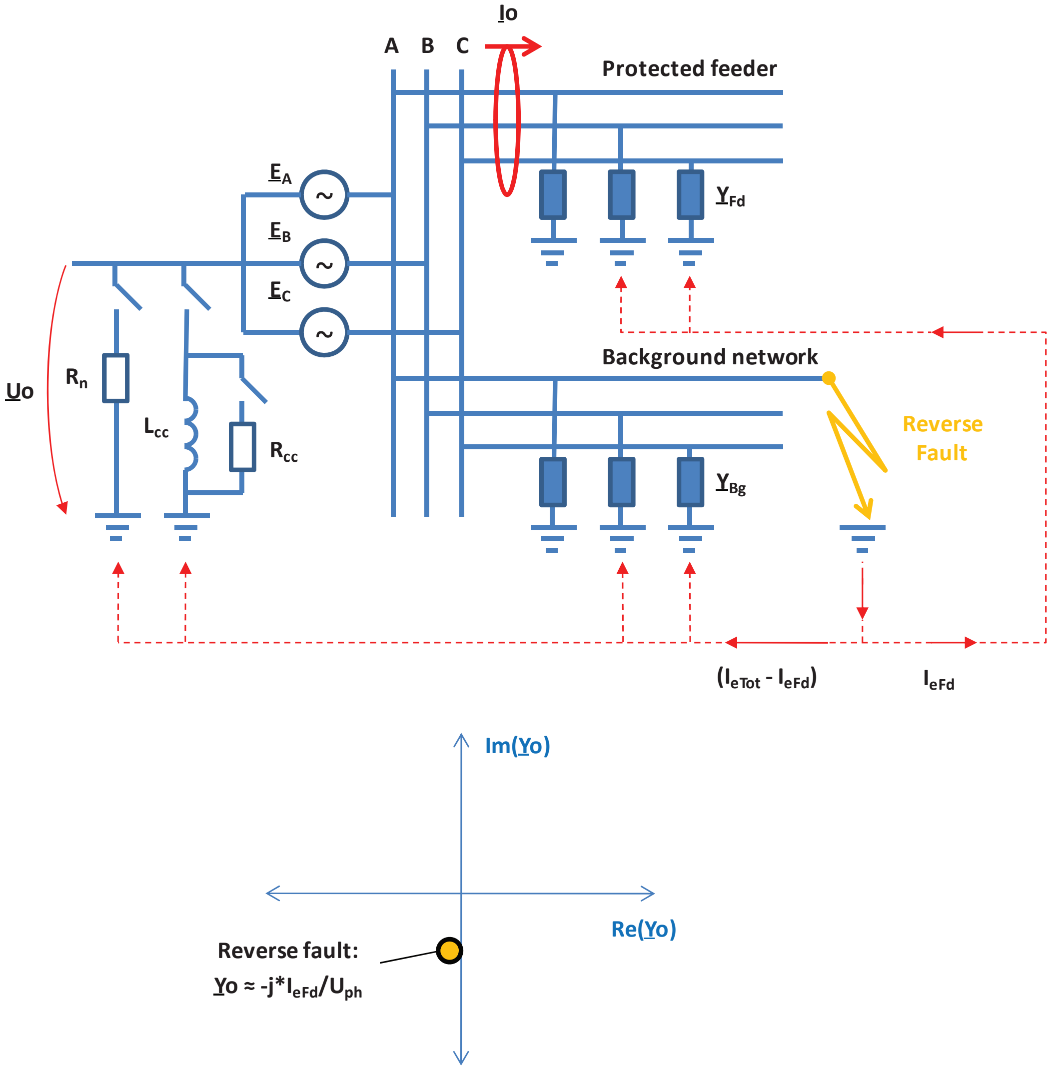


Figure 280: Admittance calculation during a reverse fault

R_{CC}	Resistance of the parallel resistor
L_{CC}	Inductance of the compensation coil
R_n	Resistance of the neutral earthing resistor
$\underline{Y}_{Fd}$	Phase-to-earth admittance of the protected feeder
$\underline{Y}_{Bg}$	Phase-to-earth admittance of the background network

For example, in a 15 kV compensated network with the magnitude of the earth-fault current in the protected feeder being 10 A (Rf = 0 Ω), the theoretical value for the measured admittance during an earth fault in the reverse direction, that is, outside the protected feeder, can be calculated.

$$\underline{Y}o \approx -j \cdot \frac{I_{eFd}}{U_{ph}} = -j \cdot \frac{10A}{15/\sqrt{3}kV} = -j \cdot 1.15 \text{ milliSiemens}$$

(Equation 61)

The result is valid regardless of the neutral earthing method.

In this case, the resistive part of the measured admittance is due to leakage losses of the protected feeder. As they are typically very small, the resistive part is close to zero. Due to inaccuracies in the voltage and current measurement, the small real part of the apparent neutral admittance may appear positive. This should be considered in the setting of the admittance characteristic.

Fault in the forward direction, that is, inside the protected feeder.

Unearthed network:

$$\underline{Y}o = \underline{Y}_{Bgtot}$$

(Equation 62)

$$\approx j \cdot \left(\frac{I_{eTot} - I_{eFd}}{U_{ph}} \right)$$

(Equation 63)

Compensated network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC}$$

(Equation 64)

$$\approx \frac{I_{Rcc} + j \cdot \left(I_{eTot} \cdot (1 - K) - I_{eFd} \right)}{U_{ph}}$$

(Equation 65)

High-resistance earthed network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{Rn}$$

(Equation 66)

$$\approx \frac{I_{Rn} + j \cdot \left(I_{eTot} - I_{eFd} \right)}{U_{ph}}$$

(Equation 67)

$\underline{Y}_{Bgtot}$	Sum of the phase-to-earth admittances ($\underline{Y}_{BgA}$, $\underline{Y}_{BgB}$, $\underline{Y}_{BgC}$) of the background network
$\underline{Y}_{CC}$	Admittance of the earthing arrangement (compensation coil and parallel resistor)
I_{Rcc}	Rated current of the parallel resistor

Table continues on the next page

I_{eFd}	Magnitude of the earth-fault current of the protected feeder when the fault resistance is zero ohm
I_{eTot}	Magnitude of the uncompensated earth-fault current of the network when Rf is zero ohm
K	Compensation degree, K = 1 full resonance, K<1 undercompensated, K>1 overcompensated
I_{Rn}	Rated current of the neutral earthing resistor

Equation 62 shows that in case of a fault inside the protected feeder in unearthed networks, the measured admittance equals the admittance of the background network. The admittance is dominantly reactive; the small resistive part of the measured admittance is due to the leakage losses of the background network. Theoretically, the measured admittance is located in the first quadrant in the admittance plane, close to the im(Yo) axis, see *Figure 281*.

Equation 64 shows that in case of a fault inside the protected feeder in compensated networks, the measured admittance equals the admittance of the background network and the coil including the parallel resistor. Basically, the compensation degree determines the imaginary part of the measured admittance and the resistive part is due to the parallel resistor of the coil and the leakage losses of the background network and the losses of the coil. Theoretically, the measured admittance is located in the first or fourth quadrant in the admittance plane, depending on the compensation degree, see *Figure 281*.

Before the parallel resistor is connected, the resistive part of the measured admittance is due to the leakage losses of the background network and the losses of the coil. As they are typically small, the resistive part may not be sufficiently large to secure the discrimination of the fault and its direction based on the measured conductance. This and the rating and the operation logic of the parallel resistor should be considered when setting the admittance characteristic in compensated networks.

Equation 66 shows that in case of a fault inside the protected feeder in high-resistance earthed systems, the measured admittance equals the admittance of the background network and the neutral earthing resistor. Basically, the imaginary part of the measured admittance is due to the phase-to-earth capacitances of the background network, and the resistive part is due to the neutral earthing resistor and the leakage losses of the background network. Theoretically, the measured admittance is located in the first quadrant in the admittance plane, see *Figure 281*.

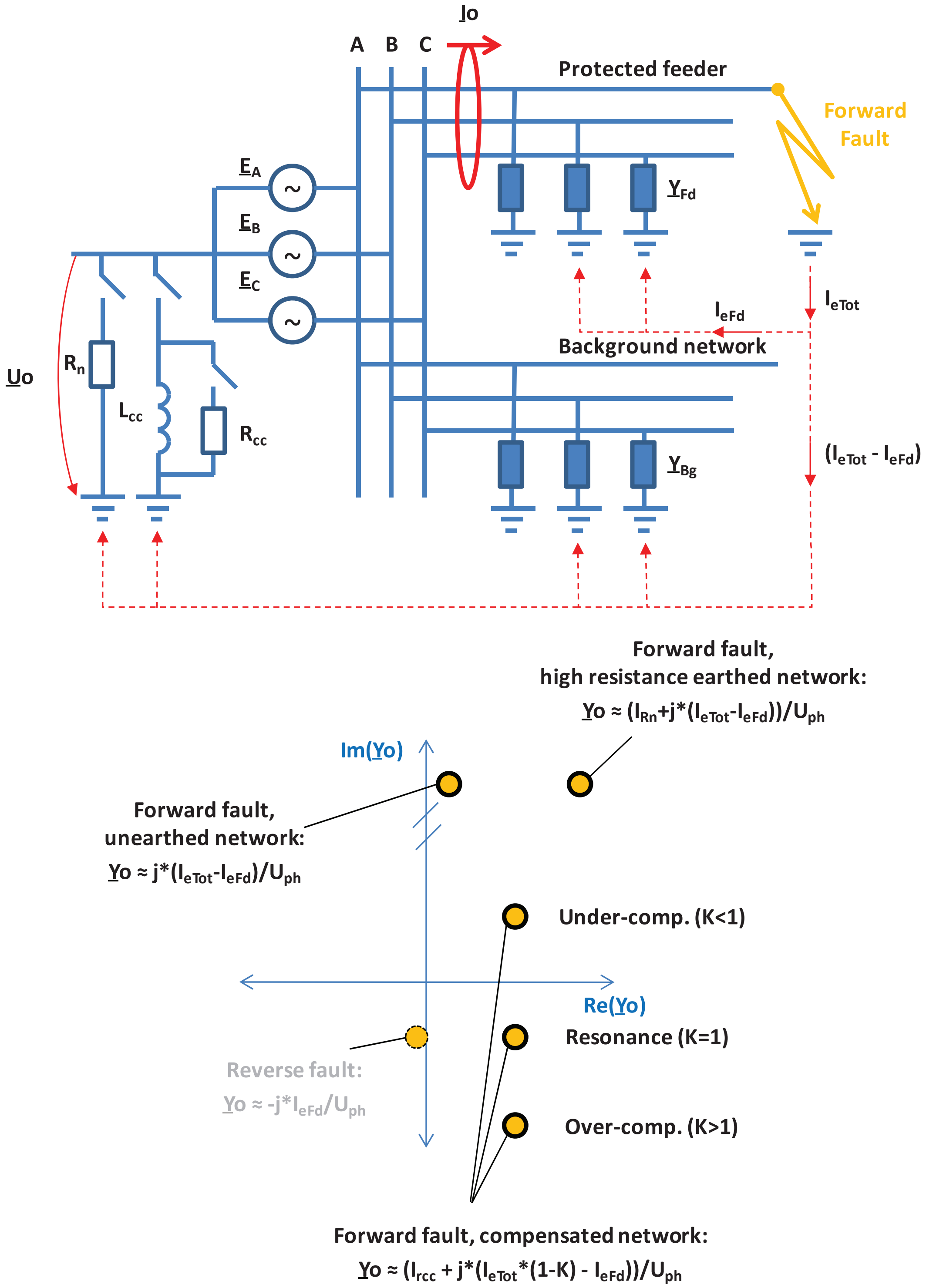


Figure 281: Admittance calculation during a forward fault

When the network is fully compensated in compensated networks, theoretically during a forward fault, the imaginary part of the measured admittance equals the susceptance of the protected feeder with a negative sign. The discrimination between a forward and reverse fault must therefore be based on the real part of the measured admittance, that is, conductance. Thus, the best selectivity is achieved when the compensated network is operated either in the undercompensated or overcompensated mode.

For example, in a 15 kV compensated network, the magnitude of the earth-fault current of the protected feeder is 10 A (Rf = 0 Ω) and the magnitude of the network is 100 A (Rf = 0 Ω). During an earth fault, a 15 A resistor is connected in parallel to the coil after a 1.0 second delay. Compensation degree is overcompensated, K = 1.1.

During an earth fault in the forward direction, that is, inside the protected feeder, the theoretical value for the measured admittance after the connection of the parallel resistor can be calculated.

$$\underline{Y}o \approx \frac{I_{Rcc} + j \cdot (I_{eTot} \cdot (1-K) - I_{eFd})}{U_{ph}}$$

$$= \frac{15A + j \cdot (100A \cdot (1-1.1) - 10A)}{15kV/\sqrt{3}} \approx (1.73 - j \cdot 2.31) \text{ milliSiemens}$$

(Equation 68)

Before the parallel resistor is connected, the resistive part of the measured admittance is due to the leakage losses of the background network and the losses of the coil. As they are typically small, the resistive part may not be sufficiently large to secure the discrimination of the fault and its direction based on the measured conductance. This and the rating and the operation logic of the parallel resistor should be considered when setting the admittance characteristic.

When a high sensitivity of the protection is required, the residual current should be measured with a cable/ring core CT, that is, the Ferranti CT. Also the use of the sensitive `Io` input should be considered. The residual voltage measurement should be done with an open delta connection of the three single pole-insulated voltage transformers.

The sign of the admittance characteristic settings should be considered based on the location of characteristic boundary in the admittance plane. All forward-settings are given with positive sign and reverse-settings with negative sign.

Operation characteristic

After the admittance calculation is released, the calculated neutral admittance is compared to the admittance characteristic boundaries in the admittance plane. If the calculated neutral admittance $\underline{Y}o$ moves outside the characteristic, the enabling signal is sent to the timer.

EFPADM supports a wide range of different characteristics to achieve the maximum flexibility and sensitivity in different applications. The basic characteristic shape is selected with the *Operation mode* and *Directional mode* settings. *Operation mode* defines which operation criterion or criteria are enabled and *Directional mode* defines if the forward, reverse or non-directional boundary lines for that particular operation mode are activated. The `FAULT_DIR` output indicates which operation sector the fault is measured. The output is operational once the function is started.

Table 566: Operation criteria

Operation mode	Description
Yo	Admittance criterion
Bo	Susceptance criterion
Go	Conductance criterion
Yo, Go	Admittance criterion combined with the conductance criteri-on
Yo, Bo	Admittance criterion combined with the susceptance criteri-on
Go, Bo	Conductance criterion combined with the susceptance crite-rion
Yo, Go, Bo	Admittance criterion combined with the conductance and susceptance criterion

The options for the *Directional mode* setting are "Non-directional", "Forward" and "Reverse".

Figure 282, *Figure 283* and *Figure 284* illustrate the admittance characteristics supported by EFPADM and the settings relevant to that particular characteristic. The most typical characteristics are highlighted and explained in details in *Chapter 4.2.4.6 Neutral admittance characteristics*. Operation is achieved when the calculated neutral admittance $\underline{Y}o$ moves outside the characteristic (the operation area is marked with gray).

The settings defining the admittance characteristics are given in primary milliSiemens (mS). The conversion equation for the admittance from secondary to primary is:

$$Y_{pri} = Y_{sec} \cdot \frac{ni_{CT}}{nu_{VT}}$$

(Equation 69)

ni_{CT}	CT ratio for the residual current Io
nu_{VT}	VT ratio for the residual voltage Uo

Example: Admittance setting in the secondary is 5.00 milliSiemens. The CT ratio is 100/1 A and the VT ratio is 11547/100 V. The admittance setting in the primary can be calculated.

$$Y_{pri} = 5.00\ mS \cdot \frac{\frac{100}{1}A}{\frac{11547}{100}V} = 4.33\ mS$$

(Equation 70)

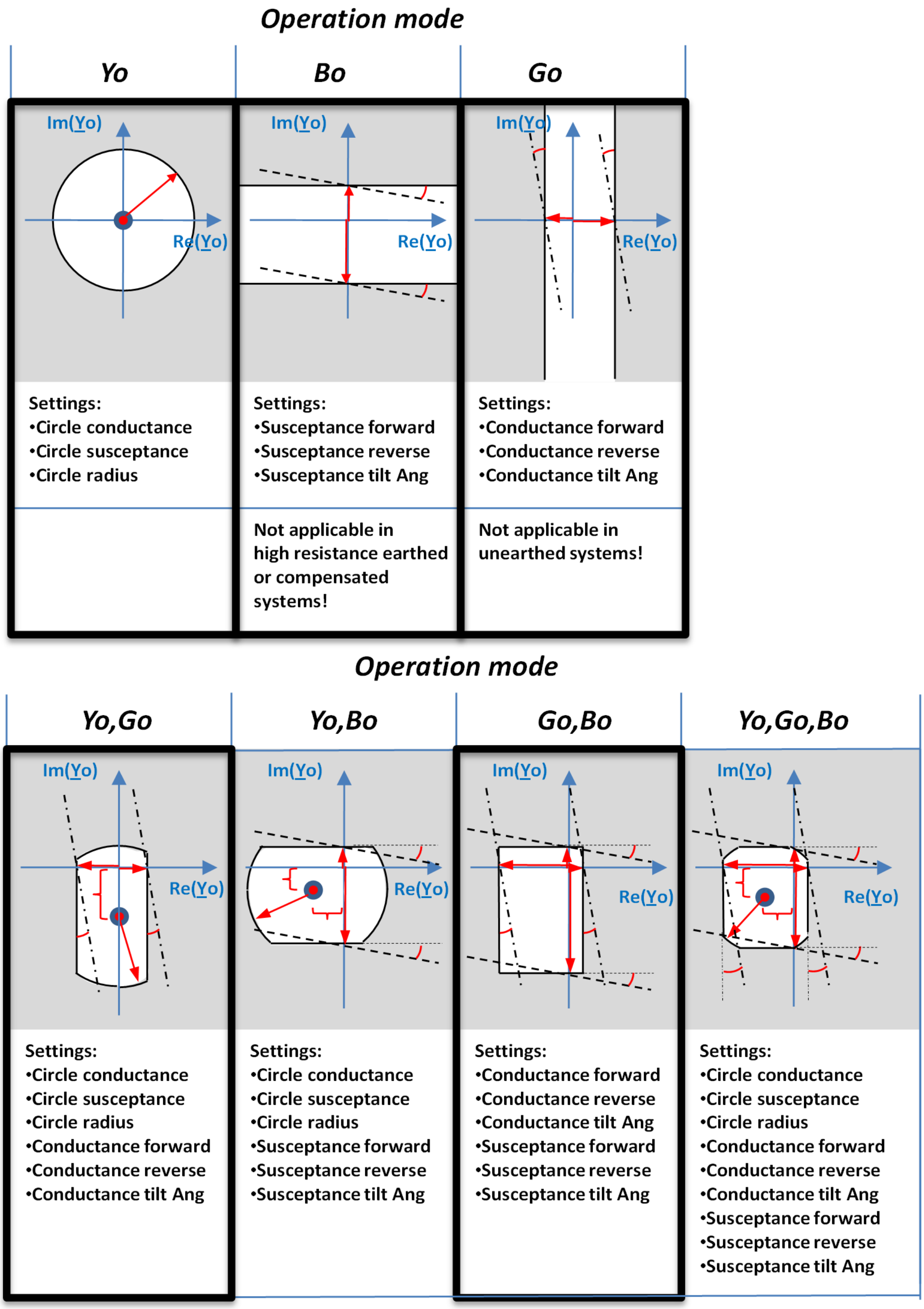


Figure 282: Admittance characteristic with different operation modes when Directional mode = "Non-directional"

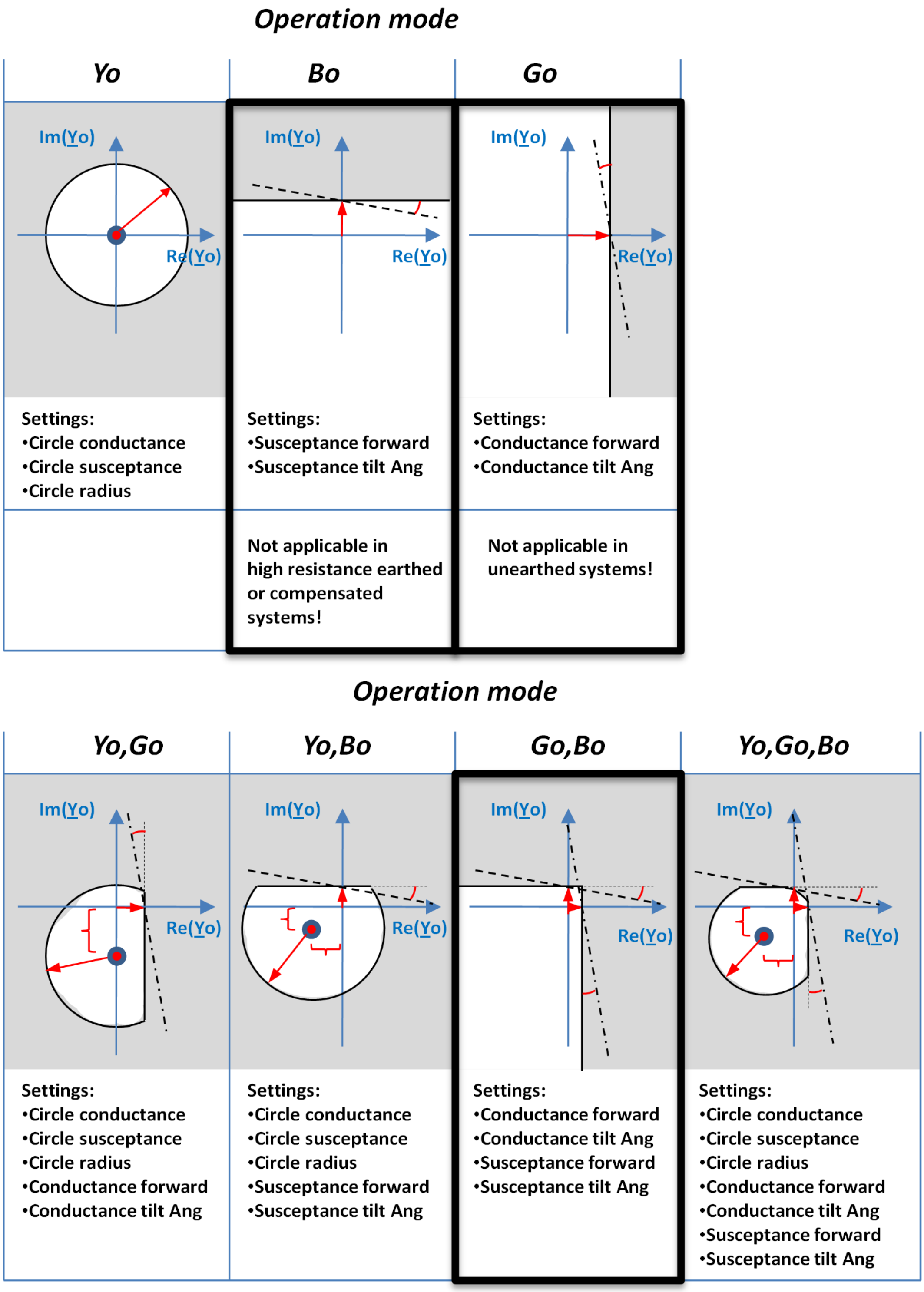


Figure 283: Admittance characteristic with different operation modes when Directional mode = "Forward"

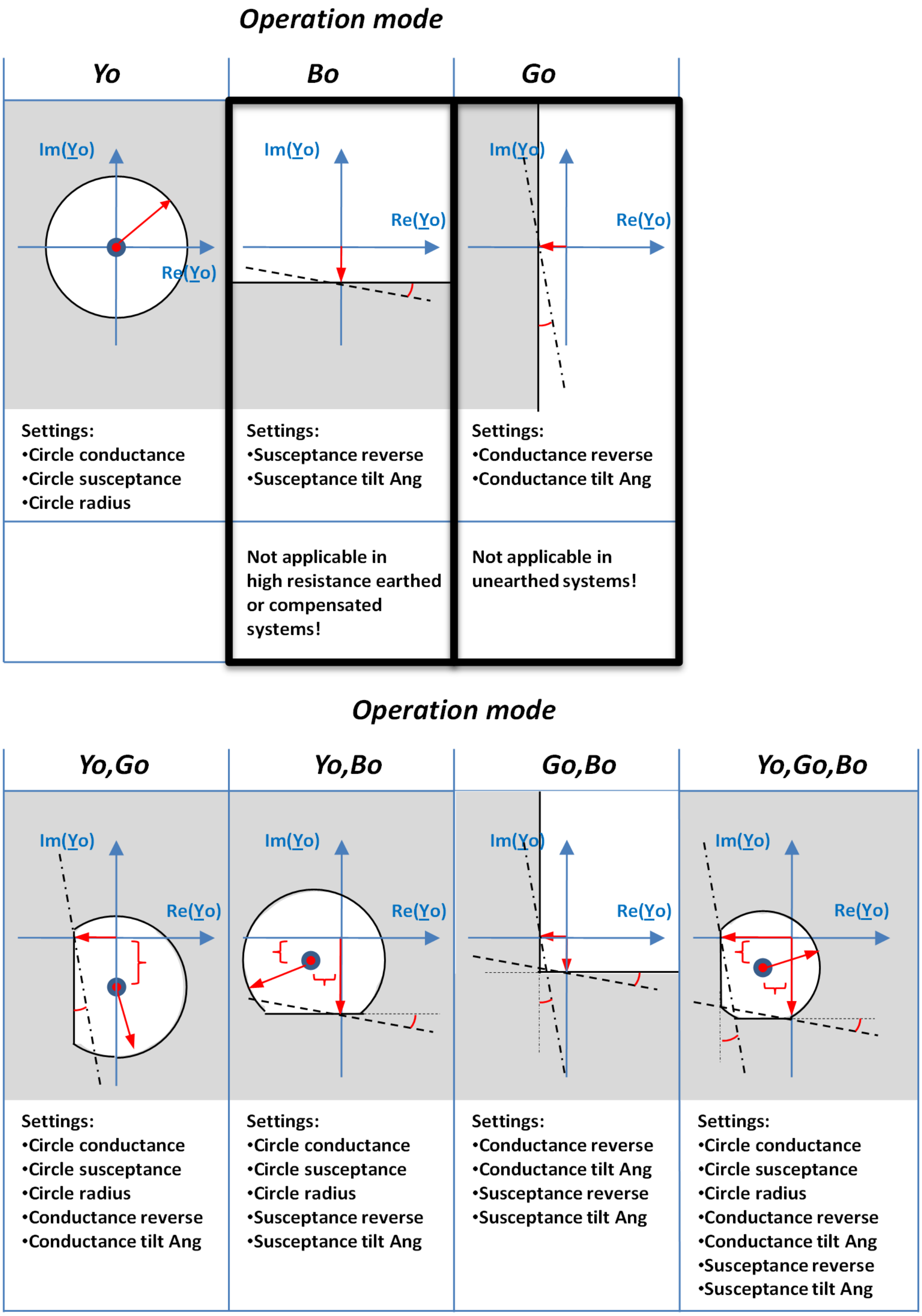


Figure 284: Admittance characteristic with different operation modes when Directional mode = "Reverse"

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set with the *Operate delay time* setting, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set with the *Reset delay time* setting, the operation timer resets and the START output is deactivated. The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.2.4.6 Neutral admittance characteristics

The applied characteristic should always be set to cover the total admittance of the protected feeder with a suitable margin. However, more detailed setting value selection principles depend on the characteristic in question.

The settings defining the admittance characteristics are given in primary milliSiemens.

The forward and reverse boundary settings should be set so that the forward setting is always higher than the reverse setting and that there is space between them.

Overadmittance characteristic

The overadmittance criterion is enabled with the setting *Operation mode* set to "Yo". The characteristic is a circle with the radius defined with the *Circle radius* setting. For the sake of application flexibility, the midpoint of the circle can be moved away from the origin with the *Circle conductance* and *Circle susceptance* settings. Default values for *Circle conductance* and *Circle susceptance* are 0.0 mS, that is, the characteristic is an origin-centered circle.

Operation is achieved when the measured admittance moves outside the circle.

The overadmittance criterion is typically applied in unearthed networks, but it can also be used in compensated networks, especially if the circle is set off from the origin.

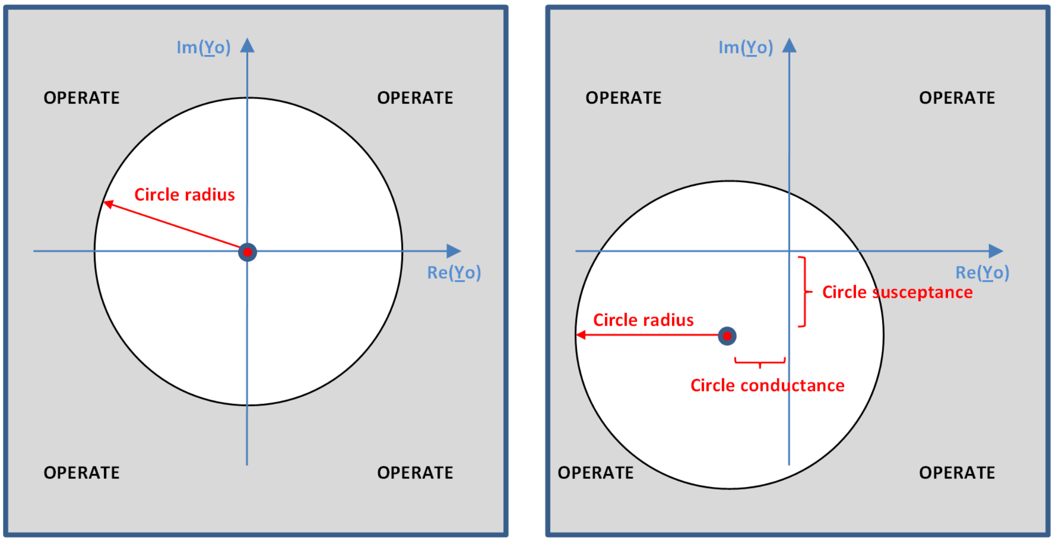


Figure 285: Overadmittance characteristic. Left figure: classical origin-centered admittance circle. Right figure: admittance circle is set off from the origin.

Non-directional overconductance characteristic

The non-directional overconductance criterion is enabled with the *Operation mode* setting set to "Go" and *Directional mode* to "Non-directional". The characteristic is defined with two overconductance boundary lines with the *Conductance forward* and *Conductance reverse* settings. For the sake of application flexibility, the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a vertical line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the vertical axis.

In case of non-directional conductance criterion, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward*.

Operation is achieved when the measured admittance moves over either of the boundary lines.

The non-directional overconductance criterion is applicable in high-resistance earthed and compensated networks. It must not be applied in unearthed networks.

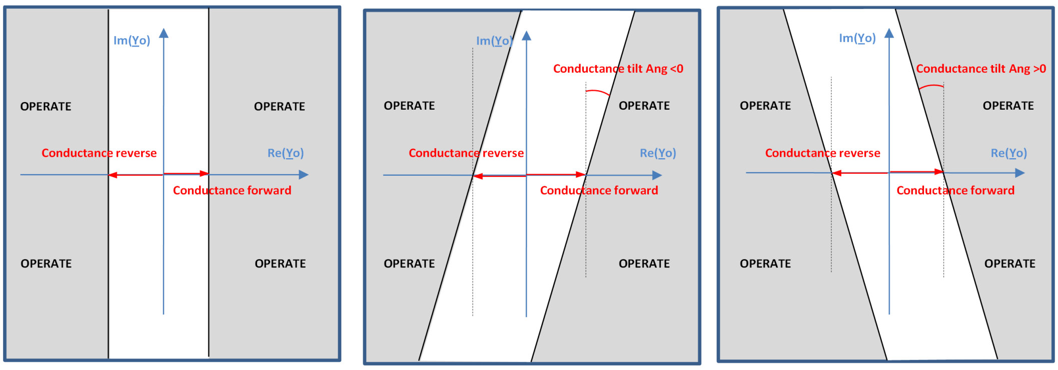


Figure 286: Non-directional overconductance characteristic. Left figure: classical non-directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

Forward directional overconductance characteristic

The forward directional overconductance criterion is enabled with the *Operation mode* setting set to "Go" and *Directional mode* set to "Forward". The characteristic is defined by one overconductance boundary line with the *Conductance forward* setting. For the sake of application flexibility, the boundary line can be tilted with the angle defined with the *Conductance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a vertical line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the vertical axis.

Operation is achieved when the measured admittance moves over the boundary line.

The forward directional overconductance criterion is applicable in high-resistance earthed and compensated networks. It must not be applied in unearthed networks.

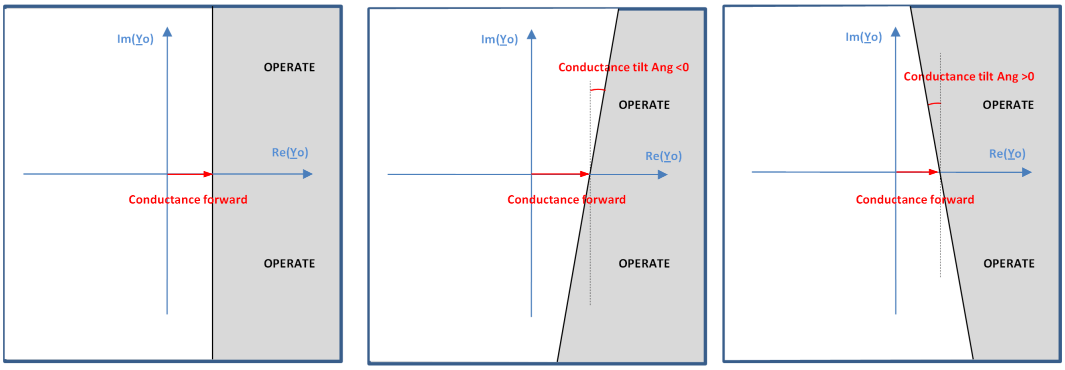


Figure 287: Forward directional overconductance characteristic. Left figure: classical forward directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

Forward directional oversusceptance characteristic

The forward directional oversusceptance criterion is enabled with the *Operation mode* setting set to "Bo" and *Directional mode* to "Forward". The characteristic is defined by one oversusceptance boundary line with the *Susceptance forward* setting. For the sake of application flexibility, the boundary line can be tilted by the angle defined with the *Susceptance tilt Ang* setting. By default, the tilt angle is zero degrees, that is, the boundary line is a horizontal line in the admittance plane. A positive tilt value rotates the boundary line counterclockwise from the horizontal axis.

Operation is achieved when the measured admittance moves over the boundary line.

The forward directional oversusceptance criterion is applicable in unearthed networks. It must not be applied to compensated networks.

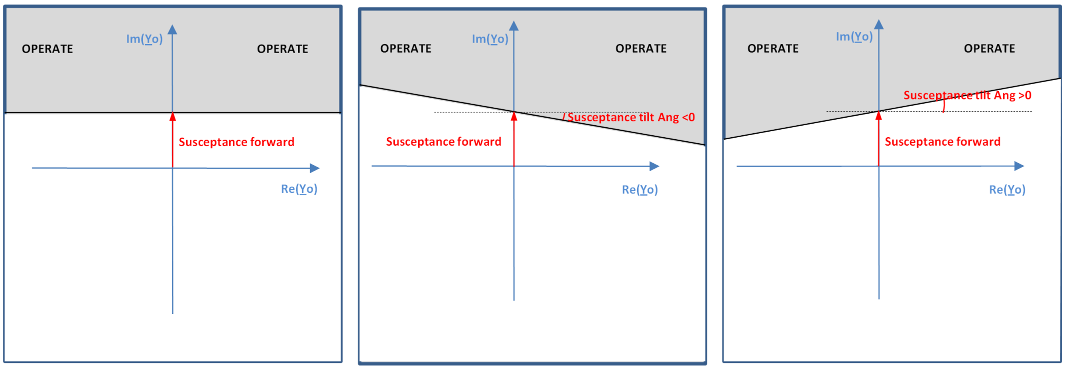


Figure 288: Forward directional oversusceptance characteristic. Left figure: classical forward directional oversusceptance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

Combined overadmittance and overconductance characteristic

The combined overadmittance and overconductance criterion is enabled with the *Operation mode* setting set to "Yo, Go" and *Directional mode* to "Non-directional". The characteristic is a combination of a circle with the radius defined with the *Circle radius* setting and two overconductance boundary lines with the settings *Conductance forward* and *Conductance reverse*. For the sake of application flexibility, the midpoint of the circle can be moved from the origin with the *Circle conductance* and *Circle susceptance* settings. Also the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* setting. By default, the *Circle conductance* and *Circle susceptance* are 0.0 mS and *Conductance tilt Ang* equals zero degrees, that is, the characteristic is a combination of an origin-centered circle with two vertical overconductance boundary lines. A positive tilt value for the *Conductance tilt Ang* setting rotates boundary lines counterclockwise from the vertical axis.

In case of the non-directional conductance criterion, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward*.

Operation is achieved when the measured admittance moves outside the characteristic.

The combined overadmittance and overconductance criterion is applicable in unearthed, high-resistance earthed and compensated networks or in systems where the system earthing may temporarily change during normal operation from compensated network to unearthed system.

Compared to the overadmittance criterion, the combined characteristic improves sensitivity in high-resistance earthed and compensated networks. Compared to the non-directional overconductance criterion, the combined characteristic enables the protection to be applied also in unearthed systems.

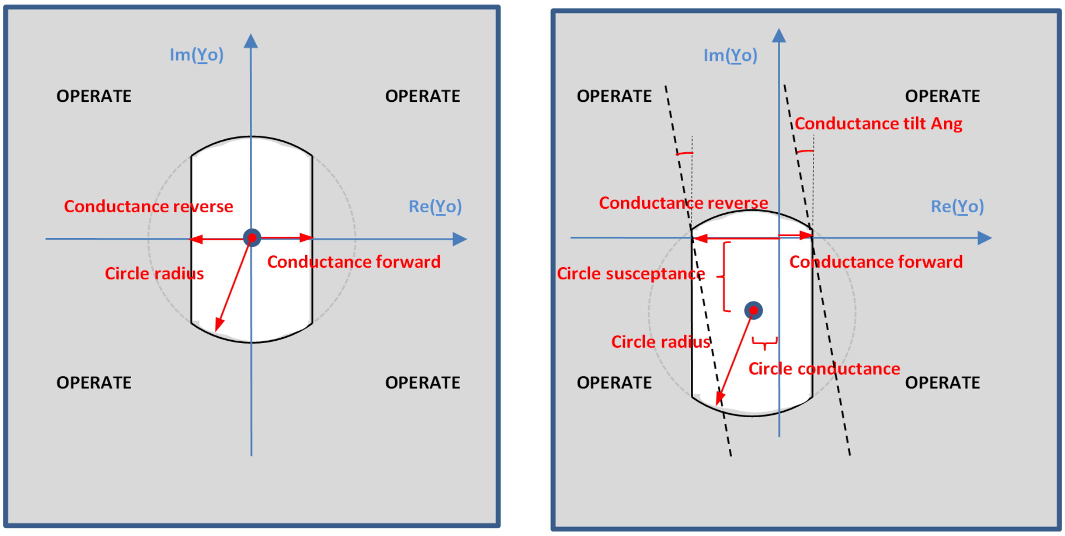


Figure 289: Combined overadmittance and overconductance characteristic. Left figure: classical origin-centered admittance circle combined with two overconductance boundary lines. Right figure: admittance circle is set off from the origin.

Combined overconductance and oversusceptance characteristic

The combined overconductance and oversusceptance criterion is enabled with the *Operation mode* setting set to "Go, Bo".

By setting *Directional mode* to "Forward", the characteristic is a combination of two boundary lines with the settings *Conductance forward* and *Susceptance forward*. See *Figure 290*.

By setting *Directional mode* to "Non-directional", the characteristic is a combination of four boundary lines with the settings *Conductance forward, Conductance reverse*, *Susceptance forward* and *Susceptance reverse*. See *Figure 291*.

For the sake of application flexibility, the boundary lines can be tilted by the angle defined with the *Conductance tilt Ang* and *Susceptance tilt Ang* settings. By default, the tilt angles are zero degrees, that is, the boundary lines are straight lines in the admittance plane. A positive *Conductance tilt Ang* value rotates the overconductance boundary line counterclockwise from the vertical axis. A positive *Susceptance tilt Ang* value rotates the oversusceptance boundary line counterclockwise from the horizontal axis.

In case of the non-directional conductance and susceptance criteria, the *Conductance reverse* setting must be set to a smaller value than *Conductance forward* and the *Susceptance reverse* setting must be set to a smaller value than *Susceptance forward*.

Operation is achieved when the measured admittance moves outside the characteristic.

The combined overconductance and oversusceptance criterion is applicable in high-resistance earthed, unearthed and compensated networks or in the systems where the system earthing may temporarily change during normal operation from compensated to unearthed system.

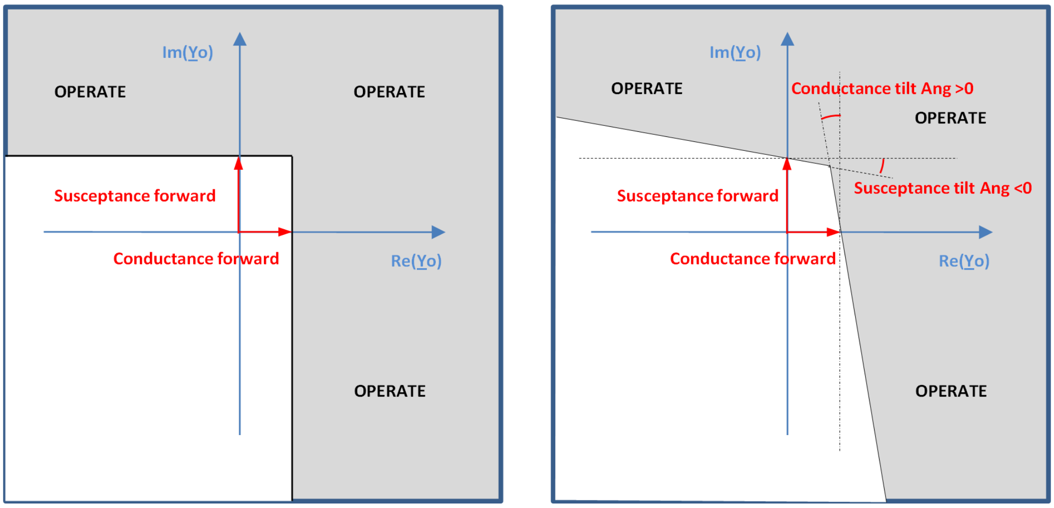


Figure 290: Combined forward directional overconductance and forward directional oversusceptance characteristic. Left figure: the Conductance tilt Ang and Susceptance tilt Ang settings equal zero degrees. Right figure: the setting Conductance tilt Ang > 0 degrees and the setting Susceptance tilt Ang < 0 degrees.

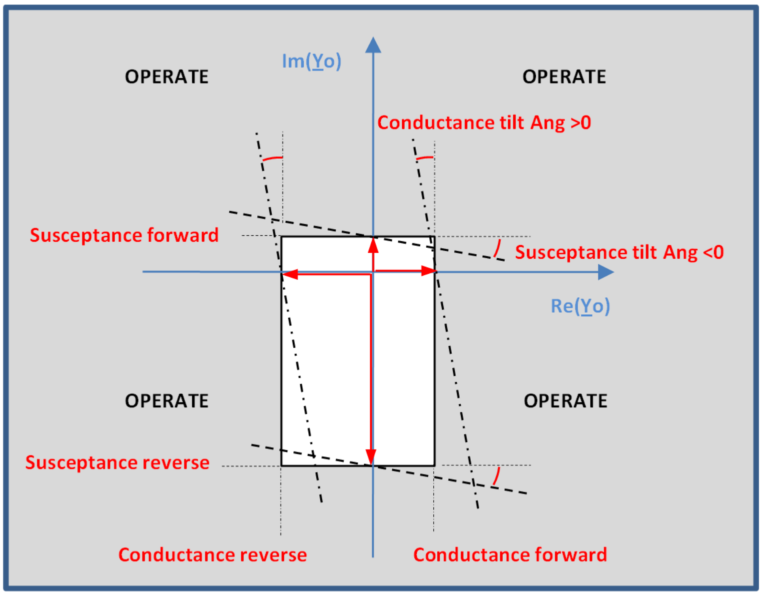


Figure 291: Combined non-directional overconductance and non-directional oversusceptance characteristic

The non-directional overconductance and non-directional oversusceptance characteristic provides a good sensitivity and selectivity when the characteristic is set to cover the total admittance of the protected feeder with a proper margin.

The sign of the admittance characteristic settings should be considered based on the location of characteristic boundary in the admittance plane. All forward-settings are given with positive sign and reverse-settings with negative sign.

4.2.4.7 Application

Admittance-based earth-fault protection provides a selective earth-fault protection for high-resistance earthed, unearthed and compensated networks. It can be applied for the protection of overhead lines as well as with underground cables. It can be used as an alternative solution to traditional residual current-based earth-fault protection functions, for example the IoCos mode in DEFxPDEF. Main advantages of EFPADM include versatile applicability, good sensitivity and easy setting principles.

Residual overvoltage condition is used as a start condition for the admittance-based earth-fault protection. When the residual voltage exceeds the set threshold *Voltage start value*, an earth fault is detected and the neutral admittance calculation is released. In order to guarantee a high security of protection, that is, avoid false starts, the *Voltage start value* setting must be set above the highest possible value of Uo during normal operation with a proper margin. It should consider all possible operation conditions and configuration changes in the network. In unearthed systems, the healthy-state Uo is typically less than 1%×Uph (Uph = nominal phase-to-earth voltage). In compensated networks, the healthy-state Uo may reach values even up to 30%×Uph if the network includes large parts of overheadlines without a phase transposition. Generally, the highest Uo is achieved when the compensation coil is tuned to the full resonance and when the parallel resistor of the coil is not connected.

The residual overvoltage-based start condition for the admittance protection enables a multistage protection principle. For example, one instance of EFPADM could be used for alarming to detect faults with a high fault resistance using a relatively low value for the *Voltage start value* setting. Another instance of EFPADM could then be set to trip with a lower sensitivity by selecting a higher value of the *Voltage start value* setting than in the alarming instance (stage).

To apply the admittance-based earth-fault protection, at least the following network data are required:

- System earthing method
- Maximum value for Uo during the healthy state
- Maximum earth-fault current of the protected feeder when the fault resistance Rf is zero ohm
- Maximum uncompensated earth-fault current of the system (Rf = 0 Ω)
- Rated current of the parallel resistor of the coil (active current forcing scheme) in the case of a compensated neutral network
- Rated current of the neutral earthing resistor in the case of a high-resistance earthed system
- Knowledge of the magnitude of Uo as a function of the fault resistance to verify the sensitivity of the protection in terms of fault resistance

Figure 292 shows the influence of fault resistance on the residual voltage magnitude in unearthed and compensated networks. Such information should be available to verify the correct *Voltage start value* setting, which helps fulfill the requirements for the sensitivity of the protection in terms of fault resistance.

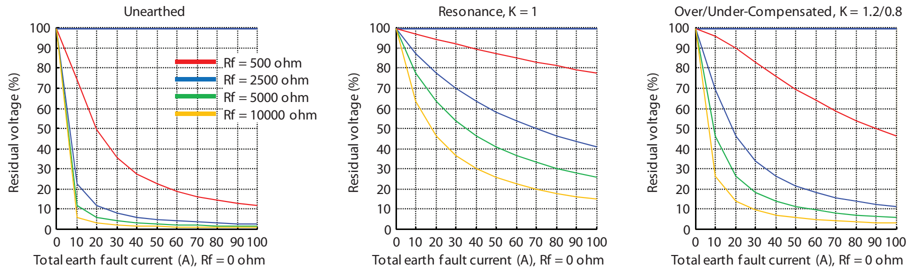


Figure 292: Influence of fault resistance on the residual voltage magnitude in 10 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times higher than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

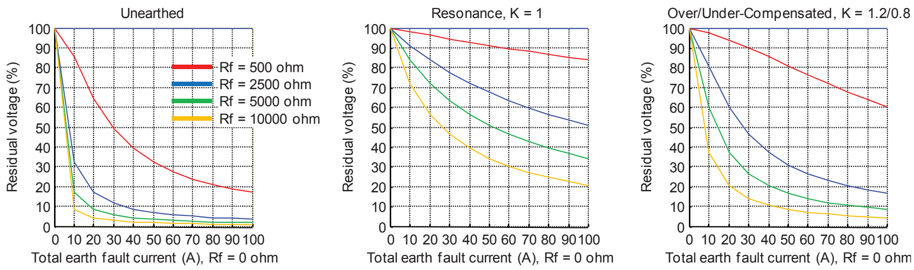


Figure 293: Influence of fault resistance on the residual voltage magnitude in 15 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times higher than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

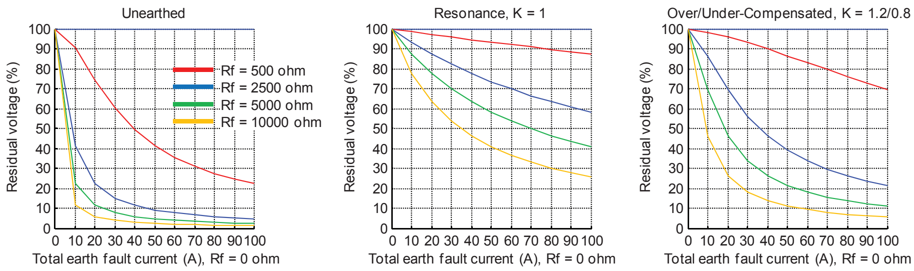


Figure 294: Influence of fault resistance on the residual voltage magnitude in 20 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times higher than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

Example

In a 15 kV, 50 Hz compensated network, the maximum value for Uo during the healthy state is 10%×Uph. Maximum earth-fault current of the system is 100 A. The maximum earth-fault current of the protected feeder is 10 A (Rf = 0 Ω). The applied active current forcing scheme uses a 15 A resistor (at 15 kV), which is connected in parallel to the coil during the fault after a 1.0 second delay.

Solution: As a start condition for the admittance-based earth-fault protection, the internal residual overvoltage condition of EFPADM is used. The *Voltage start value* setting must be set above the maximum healthy-state Uo of 10%×Uph with a suitable margin.

Voltage start value = 0.15 × Un

According to *Figure 293*, this selection ensures at least a sensitivity corresponding to a 2000 ohm fault resistance when the compensation degree varies between 80% and 120%. The greatest sensitivity is achieved when the compensation degree is close to full resonance.

An earth-fault current of 10 A can be converted into admittance.

$$\underline{Y}_{Fdtot} = \frac{10A}{15kV/\sqrt{3}} \approx j \cdot 1.15 \text{ mS}$$

(Equation 71)

A parallel resistor current of 15 A can be converted into admittance.

$$G_{cc} = \frac{15A}{15kV/\sqrt{3}} \approx 1.73 \text{ mS}$$

(Equation 72)

According to *Equation 59*, during an outside fault EFPADM measures the following admittance:

$$\underline{Y}o = -\underline{Y}_{Fdtot} \approx -j \cdot 1.15 \text{ mS}$$

(Equation 73)

According to *Equation 62*, during an inside fault EFPADM measures the admittance after the connection of the parallel resistor:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC} \approx (1.73 + j \cdot B) \text{ mS}$$

(Equation 74)

Where the imaginary part of the admittance, B, depends on the tuning of the coil (compensation degree).

The admittance characteristic is selected to be the combined overconductance and oversusceptance characteristic ("Box"-characteristics) with four boundary lines:

Operation mode = "Go, Bo"

Directional mode = "Non-directional"

The admittance characteristic is set to cover the total admittance of the protected feeder with a proper margin, see *Figure 295*. Different setting groups can be used to allow adaptation of protection settings to different feeder and network configurations.

Conductance forward

This setting should be set based on the parallel resistor value of the coil. It must be set to a lower value than the conductance of the parallel resistor, in order to enable dependable operation. The selected value should move the boundary line from origin to include some margin for the admittance operation point due to CT/VT-errors, when fault is located outside the feeder.

Conductance forward: 15 A/(15 kV/sqrt(3)) * 0.2 = +0.35 mS corresponding to 3.0 A (at 15 kV). The selected value provides margin considering also the effect of CT/VT-errors in case of outside faults.

In case of a lower rated value of the parallel resistor, for example, 5 A (at 15 kV), the recommended security margin should be higher, for example 0.7, so that sufficient margin for CT/VT-errors can be achieved.

Susceptance forward

By default, this setting should be based on the minimum operate current of 1 A.

Susceptance forward: 1 A/(15 kV/sqrt(3)) = +0.1 mS

Susceptance reverse

This setting should be set based on the value of the maximum earth-fault current produced by the feeder (considering possible feeder topology changes) with a security margin. This ensures that the admittance operating point stays inside the "Box"-characteristics during outside fault. The recommended security margin should not be lower than 1.5.

Susceptance reverse: - (10 A * 1.5)/ (15 kV/sqrt(3)) = -1.73 mS

Conductance reverse

This setting is used to complete the non-directional characteristics by closing the "Box"-characteristic. In order to keep the shape of the characteristic reasonable and to allow sufficient margin for the admittance operating point during outside fault, it is recommended to use the same value as for setting Susceptance reverse.

Conductance reverse = -1.73 mS

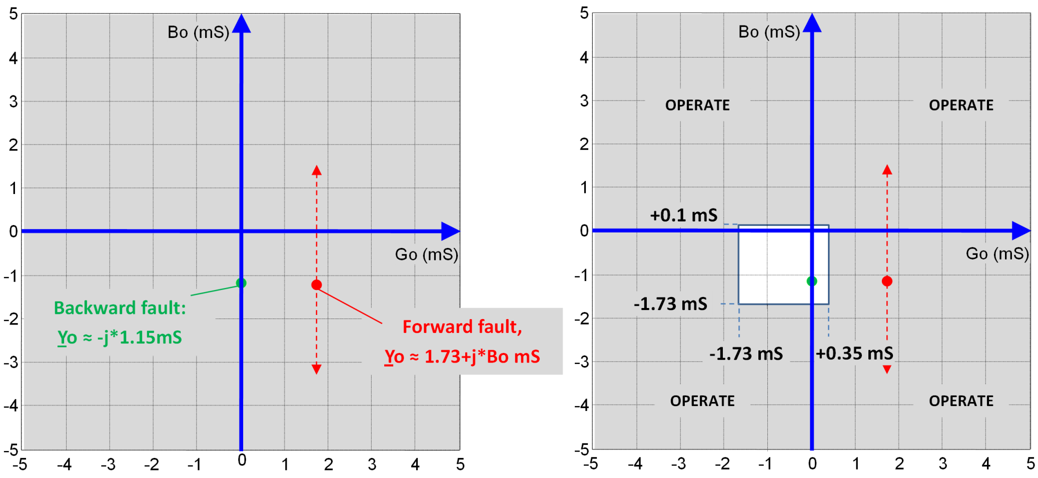


Figure 295: Admittances of the example

4.2.4.8 Signals

EFPADM Input signals

Table 567: EFPADM Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RELEASE	BOOLEAN	0=False	External trigger to release neutral admittance protection

EFPADM Output signals

Table 568: EFPADM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
FAULT_DIR	Enum	Detected fault direction

4.2.4.9 EFPADM Settings

Table 569: EFPADM Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.01...2.00	xUn	0.01	0.15	Voltage start value
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Operation mode	1=Yo 2=Go 3=Bo 4=Yo, Go 5=Yo, Bo 6=Go, Bo 7=Yo, Go, Bo			1=Yo	Operation criteria
Operate delay time	60...300000	ms	10	60	Operate delay time
Circle radius	0.05...500.00	mS	0.01	1.00	Admittance circle radius
Circle conductance	-500.00...500.00	mS	0.01	0.00	Admittance circle midpoint, conductance
Circle susceptance	-500.00...500.00	mS	0.01	0.00	Admittance circle midpoint, susceptance

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Conductance forward	-500.00...500.00	mS	0.01	1.00	Conductance threshold in forward direction
Conductance reverse	-500.00...500.00	mS	0.01	-1.00	Conductance threshold in reverse direction
Susceptance forward	-500.00...500.00	mS	0.01	1.00	Susceptance threshold in forward direction
Susceptance reverse	-500.00...500.00	mS	0.01	-1.00	Susceptance threshold in reverse direction

Table 570: EFPADM Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Conductance tilt Ang	-30...30	deg	1	0	Tilt angle of conductance boundary line
Susceptance tilt Ang	-30...30	deg	1	0	Tilt angle of susceptance boundary line

Table 571: EFPADM Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 572: EFPADM Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Admittance Clc mode	1=Normal 2=Delta			1=Normal	Admittance calculation mode
Reset delay time	0...60000	ms	1	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

4.2.4.10 EFPADM Monitored data

Table 573: EFPADM Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
COND_RES	FLOAT32	-1000.00...1000.00	mS	Real part of calculated neutral admittance
SUS_RES	FLOAT32	-1000.00...1000.00	mS	Imaginary part of calculated neutral admittance
EFPADM	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

4.2.4.11 Technical data

Table 574: EFPADM Technical data

Characteristic	Value		
Operation accuracy [1]	At the frequency f = f_n		
	±1.0% or ±0.01 mS (In range of 0.5...100 mS)		
Start time [2]	Minimum	Typical	Maximum
	56 ms	60 ms	64 ms
Reset time	40 ms		
Operate time accuracy	±1.0% of the set value of ±20 ms		
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.2.5 Rotor earth-fault protection, injection method MREFPTOC (ANSI 64R)

4.2.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Rotor earth-fault protection, injection method	MREFPTOC	Io>R	64R

4.2.5.2 Function block

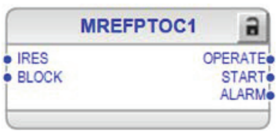


Figure 296: Function block

4.2.5.3 Functionality

The rotor earth-fault protection, injection method, function MREFPTOC is used to detect an earth fault in the rotor circuit of synchronous machines. MREFPTOC is used with the injection device REK510, which requires a secured 58, 100 or 230 V AC

[1] $U_o = 1.0 \times U_n$.
[2] Includes the delay of the signal output contact, results based on statistical distribution of 1000 measurements.

50/60 Hz input source and injects a 100 V AC voltage via its coupling capacitors to the rotor circuit towards earth.

MREFPTOC consists of independent alarm and operating stages. The operating time characteristic is according to definite time (DT) for both stages.

MREFPTOC contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.2.5.4 Analog channel configuration

MREFPTOC has one analog group input which must be properly configured.

Table 575: Analog signals

Input	Description
IRES	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of MREFPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

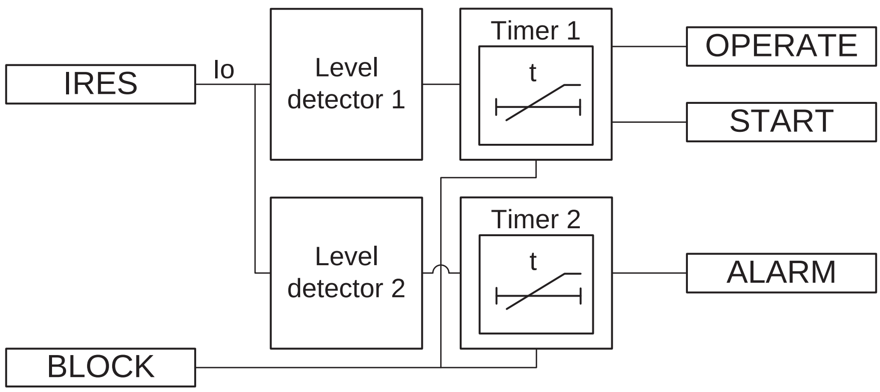


Figure 297: Functional module diagram

Level detector 1

The measured rotor earth-fault current (DFT value) is compared to the *Operate start value* setting. If the measured value exceeds that of the *Operate start value* setting, Level detector 1 sends a signal to start the Timer 1 module.

Level detector 2

The measured rotor earth-fault current (DFT value) is compared to the set *Alarm start value*. If the measured value exceeds that of the *Alarm start value* setting, Level detector 2 sends a signal to start the Timer 2 module.

For MREFPTOC, the earth-fault current is the current that flows due to the voltage injected by the injection device in the rotor circuit when an earth fault arises.

A considerable amount of harmonics, mainly 3rd and 6th, can occur in the excitation current under normal no-fault conditions, especially with the thyristor excitation and rotating diode rectifier systems. MREFPTOC uses DFT value calculation to filter DC and harmonic components which could otherwise give out false alarms or trips.

Timer 1

Once activated, the Timer activates the `START` output. The timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time* in the DT mode, the `OPERATE` output is activated. If a drop-off situation occurs, that is, a fault suddenly disappears before the operating delay is exceeded, the timer reset state is activated. The reset time depends on the *Reset delay time* setting.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets the internal timers.

Timer 2

Once activated, the Timer activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time* in the DT mode, the `ALARM` output is activated. If a drop-off situation occurs, that is, a fault suddenly disappears before the alarm delay is exceeded, the timer reset state is activated. The reset time depends on the *Alm reset delay time* setting.

The binary input `BLOCK` can be used to block the function. The activation of the `BLOCK` input deactivates all outputs and resets the internal timers.

4.2.5.6 Application

The rotor circuit of synchronous machines is normally isolated from the earth. The rotor circuit can be exposed to an abnormal mechanical or thermal stress due to, for example, vibrations, overcurrent and choked cooling medium flow. This can result in the breakdown of the insulation between the field winding and the rotor iron at the point exposed to excessive stress. If the isolation resistance is decreased significantly, this can be seen as an earth fault. For generators with slip rings, the rotor insulation resistance is sometimes reduced due to the accumulated carbon dust layer produced by the carbon brushes. As the circuit has a high impedance to earth, a single earth fault does not lead to any immediate damage because the fault current is small due to a low voltage. There is, however, a risk that a second earth fault appears, creating a rotor winding interturn fault and causing severe magnetic imbalance and heavy rotor vibrations that soon lead to a severe damage.

Therefore, it is essential that any occurrence of an insulation failure is detected and that the machine is disconnected as soon as possible. Normally, the device is tripped after a short time delay.

A 50/60 Hz voltage is injected via the injection device REK 510 to the rotor field winding circuit of the synchronous machine as shown in *Figure 298*. The injected voltage is 100 V AC via the coupling capacitors. A coupling capacitor prevents a DC current leakage through the injection device.

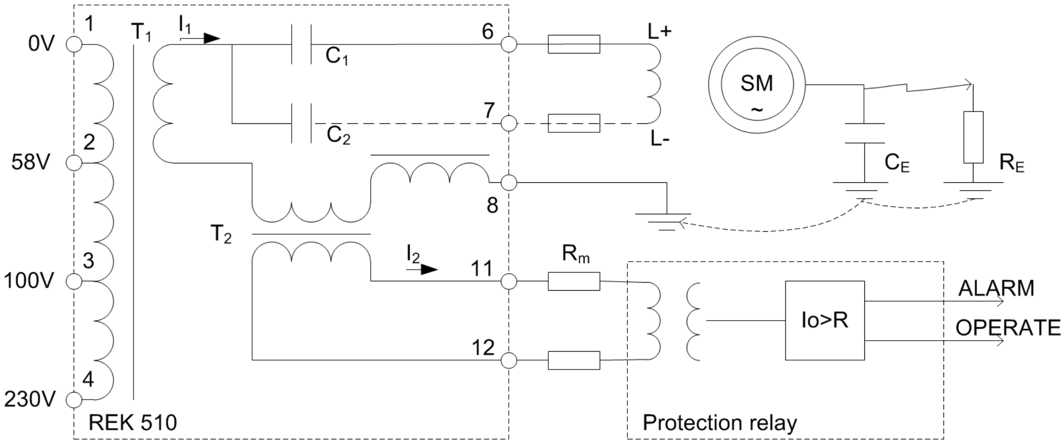


Figure 298: Principle of the rotor earth-fault protection with the current injection device

The auxiliary AC voltage forms a small charging current I_1 to flow via the coupling capacitors, resistances of the brushes and the leakage capacitance between the field circuit and earth. The field-to-earth capacitance C_E affects the level of the resulting current to an extent which is a few milliamperes during normal no-fault operating conditions.

If an earth fault arises in the rotor field circuit, this current increases and can reach a level of 130 mA at a fully developed earth fault (fault resistance R_E = 0, one coupling capacitor C_1 = 2µF is used). The integrated current transformer of the injection device REK 510 then amplifies this current with the ratio of 1:10 to a measurable level. MREFPTOC is used to measure this current.

An example of the measured curves with various field-to-earth leakage capacitance values is given in *Figure 299*.

It is recommended that the alarm and operation stages of MREFPTOC are both used. The alarm stage for giving an indication for weakly developed earth faults with a start value setting corresponds to a 10 kΩ fault resistance with a 10-second delay. The operation stage for a protection against fully developed earth faults with a start value setting corresponds to a 1...2 kΩ fault resistance with a 0.5-second delay.

The current setting values corresponding to the required operating fault resistances can be tested by connecting an adjustable fault simulating resistor between the excitation winding poles and the earth. Whether only one of the coupling capacitors or both should be used in a parallel connection should be determined on a case-by-case basis, taking into consideration the consequences of a possibly excessive current at a direct earth fault.

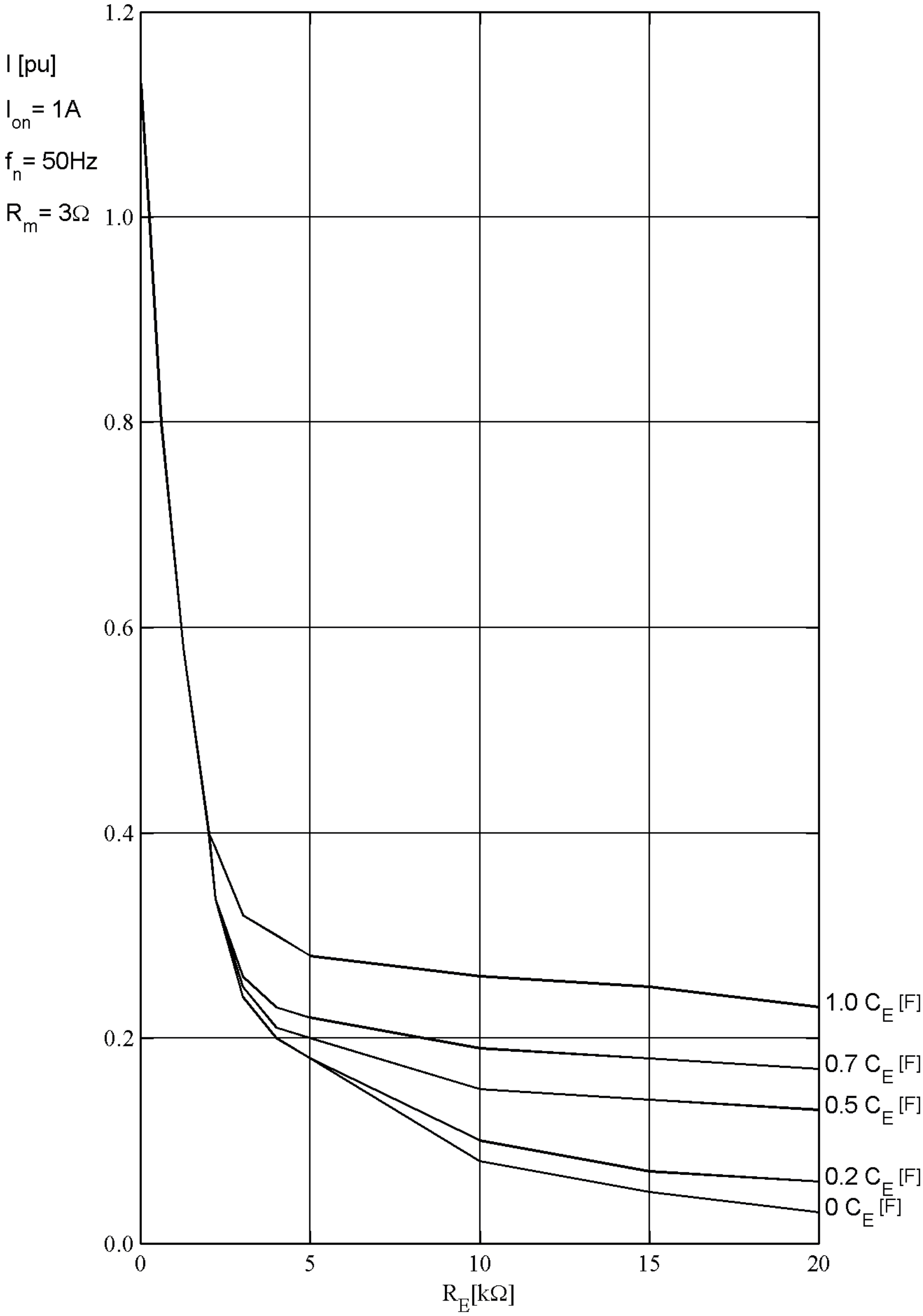


Figure 299: Measured current as a function of the rotor earth-fault resistance with various field-to-earth capacitance values with the measuring circuit resistance Rm = 3.0 Ω, fn = 50 Hz. Only one coupling capacitor is used.

4.2.5.7 Signals

MREFPTOC Input signals

Table 576: MREFPTOC Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

MREFPTOC Output signals

Table 577: MREFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.2.5.8 MREFPTOC Settings

Table 578: MREFPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate start value	0.010...2.000	xIn	0.001	0.010	Operate start value
Alarm start value	0.010...2.000	xIn	0.001	0.010	Alarm start value
Operate delay time	40...20000	ms	1	500	Operate delay time
Alarm delay time	40...200000	ms	1	10000	Alarm delay time

Table 579: MREFPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 580: MREFPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Alm reset delay time	0...60000	ms	1	20	Alarm reset delay time

4.2.5.9 MREFPTOC Monitored data

Table 581: MREFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
MREFPTOC	Enum	1=on 2=blocked		Status

Name	Type	Values (Range)	Unit	Description
		3=test 4=test/blocked 5=off		

4.2.5.10 Technical data

Table 582: MREFPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]	I_{Fault} = 1.2 × set *Start value*	Minimum	Typical	Maximum
		30 ms	34 ms	38 ms
Reset time		<50 ms		
Reset ratio		Typically 0.96		
Retardation time		<50 ms		
Operate time accuracy		±1.0% of the set value of ±20 ms		
Suppression of harmonics		-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.2.6 Harmonics-based earth-fault protection HAEFPTOC (ANSI 51NH)

4.2.6.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Harmonics-based earth-fault protection	HAEFPTOC	Io>HA	51NH

4.2.6.2 Function block

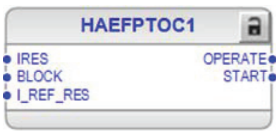


Figure 300: Function block

4.2.6.3 Functionality

The harmonics-based earth-fault protection function HAEFPTOC is used instead of a traditional earth-fault protection in networks where a fundamental frequency component of the earth-fault current is low due to compensation.

1 Current before fault = 0.0 × I_n, f_n = 50 Hz, earth-fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.
2 Includes the delay of the signal output contact.

By default, HAEFPTOC is used as a standalone mode. Substation-wide application can be achieved using horizontal communication where the detection of a faulty feeder is done by comparing the harmonics earth-fault current measurements.

The function starts when the harmonics content of the earth-fault current exceeds the set limit. The operation time characteristic is either definite time (DT) or inverse definite minimum time (IDMT). If the horizontal communication is used for the exchange of current values between the protection relays, the function operates according to the DT characteristic.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.2.6.4 Analog channel configuration

HAEFPTOC has one analog group input which must be properly configured.

Table 583: Analog signals

Input	Description
IRES	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.6.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of HAEFPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

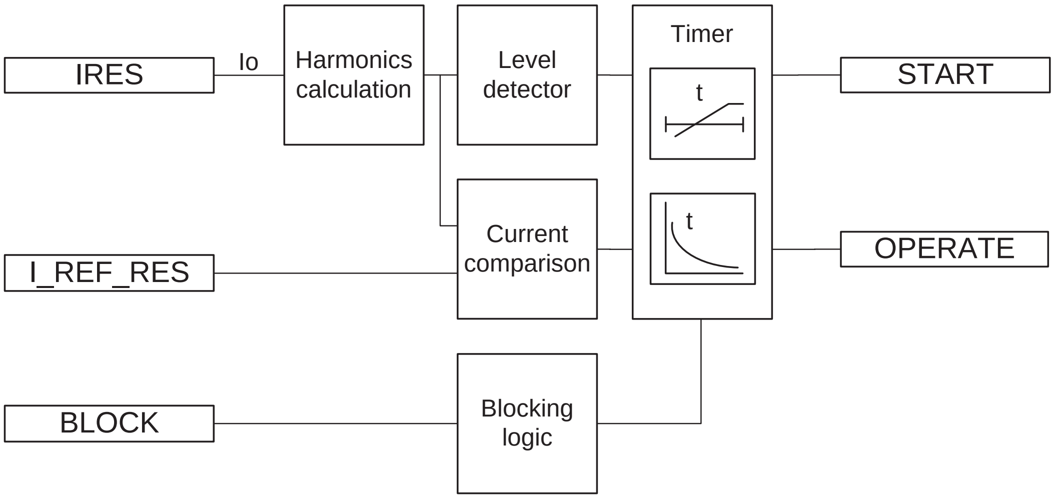


Figure 301: Functional module diagram

Harmonics calculation

This module feeds the measured residual current to the high-pass filter, where the frequency range is limited to start from two times the fundamental frequency of the network (for example, in a 50 Hz network the cutoff frequency is 100 Hz), that is, summing the harmonic components of the network from the second harmonic. The output of the filter, later referred to as the harmonics current, is fed to the Level detector and Current comparison modules.

The harmonics current I_HARM_RES is available in the monitored data view. The value is also sent over horizontal communication to the other protection relays on the parallel feeders configured in the protection scheme.

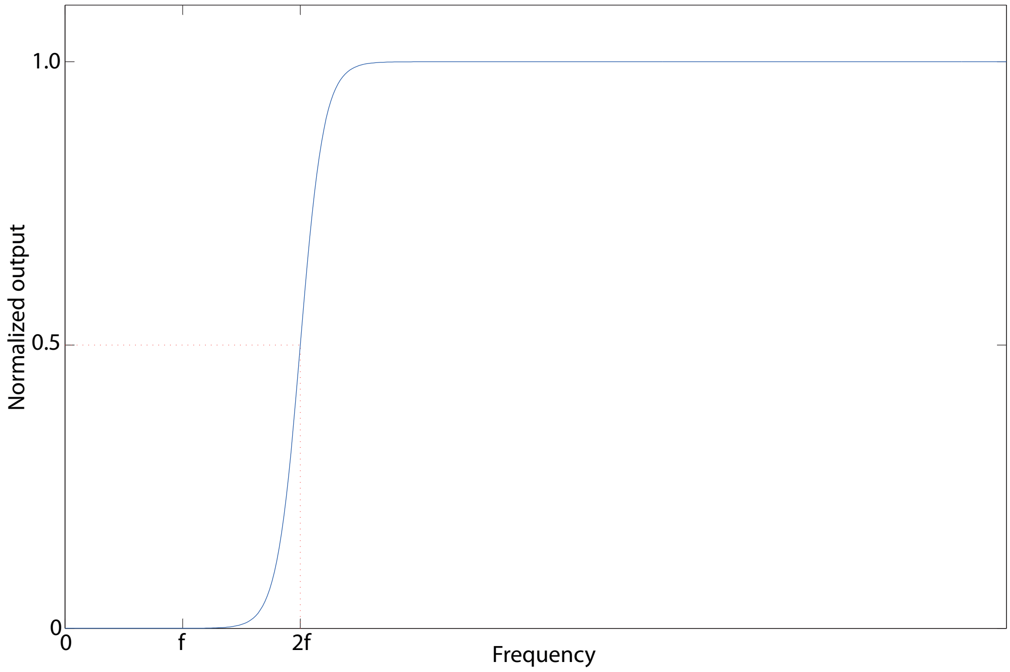


Figure 302: High-pass filter

Level detector

The harmonics current is compared to the *Start value* setting. If the value exceeds the value of the *Start value* setting, Level detector sends an enabling signal to the Timer module.

Current comparison

The maximum of the harmonics currents reported by other parallel feeders in the substation, that is, in the same busbar, is fed to the function through the `I_REF_RES` input. If the locally measured harmonics current is higher than `I_REF_RES`, the enabling signal is sent to Timer.

If the locally measured harmonics current is lower than `I_REF_RES`, the fault is not in that feeder. The detected situation blocks Timer internally, and simultaneously also the `BLKD_I_REF` output is activated.

The module also supervises the communication channel validity which is reported to the Timer.

Timer

The `START` output is activated when Level detector sends the enabling signal. Functionality and the time characteristics depend on the selected value of the *Enable reference use* setting.

Table 584: Values of the Enable reference use setting

Enable reference use		**Functionality**
Standalone		In the standalone mode, depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of the *Operate delay time* setting in the DT mode or the value defined by the inverse time curve, the OPERATE output is activated.
Reference use	Communication valid	When using the horizontal communication, the function is forced to use the DT characteristics. When the operation timer has reached the value of the *Minimum operate time* setting and simultaneously the enabling signal from the Current comparison module is active, the OPERATE signal is activated.
	Communication invalid	Function operates as in the standalone mode.

The *Enable reference use* setting forces the function to use the DT characteristics where the operating time is set with the *Minimum operate time* setting.

If the communication for some reason fails, the function switches to use the *Operation curve type* setting, and if DT is selected, *Operate delay time* is used. If the IDMT curve is selected, the time characteristics are according to the selected curve and the *Minimum operate time* setting is used for restricting too fast an operation time.

In case of a communication failure, the start duration may change substantially depending on the user settings.

When the programmable IDMT curve is selected, the operation time characteristics are defined with the *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E* parameters.

If a drop-off situation happens, that is, a fault suddenly disappears before the operation delay is exceeded, the Timer reset state is activated. The functionality of Timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the value of the *Reset delay time* setting is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. If the drop-off situation continues, the reset timer is reset and the START output is deactivated.

The "Inverse reset" selection is only supported with ANSI or the programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operation and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operation time for IDMT. The setting is applicable only when the IDMT curves are used

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve but always at least the value of the *Minimum operate time* setting. More information can be found in *Chapter 11.2.1 IDMT curves for overcurrent protection*.

Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation, and the set operating time, which can be either according to DT or IDMT. The value is available in the monitored data view.

More information can be found in *Chapter 11 General function block features*.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the *Block OPERATE output* mode, the function operates normally but the OPERATE output is not activated.

4.2.6.6 Application

During an earth fault, HAEFPTOC calculates the maximum current for the current feeder. The value is sent over an analog GOOSE to other protection relays of the busbar in the substation. At the configuration level, all the values received over the analog GOOSE are compared through the MAX function to find the maximum value. The maximum value is sent back to HAEFPTOC as the I_REF_RES input. The operation of HAEFPTOC is allowed in case I_REF_RES is lower than the locally measured harmonics current. If I_REF_RES exceeds the locally measured harmonics current, the operation of HAEFPTOC is blocked.

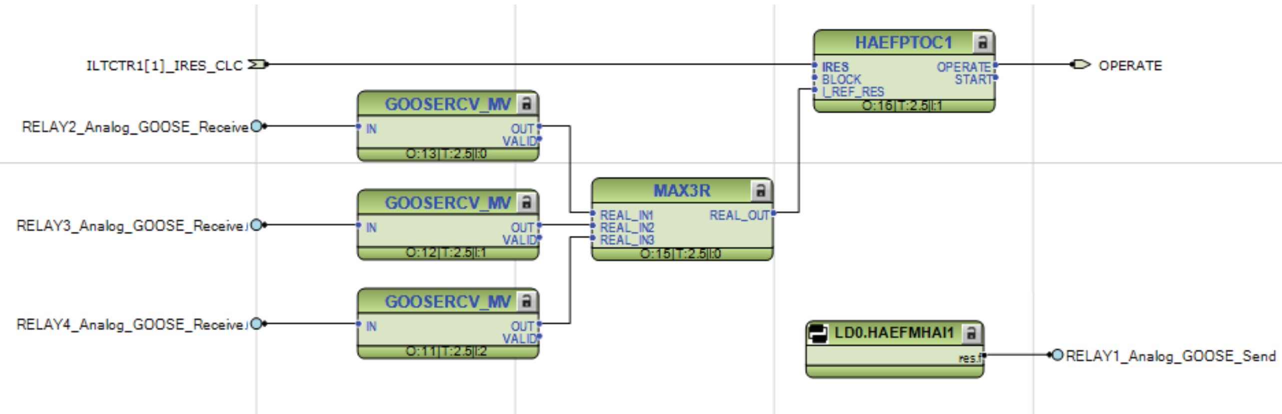


Figure 303: Protection scheme based on the analog GOOSE communication with three analog GOOSE receivers

4.2.6.7 Signals

HAEFPTOC Input signals

Table 585: HAEFPTOC Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
I_REF_RES	FLOAT32	0.0	Reference current

HAEFPTOC Output signals

Table 586: HAEFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.6.8 HAEFPTOC Settings

Table 587: HAEFPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.10	Start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	100...300000	ms	10	600	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type

Table 588: HAEFPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	100...200000	ms	10	500	Minimum operate time for IDMT curves
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Enable reference use	0=False 1=True			0=False	Enable using current reference from other IEDs instead of stand-alone

Table 589: HAEFPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 590: HAEFPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

4.2.6.9 HAEFPTOC Monitored data

Table 591: HAEFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
I_HARM_RES	FLOAT32	0.0...30000.0	A	Calculated harmonics current
BLKD_I_REF	BOOLEAN	0=False 1=True		Current comparison status indicator
HAEFPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.6.10 Technical data

Table 592: HAEFPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±5% of the set value or ±0.004 × I_n
Start time ,	Typically 77 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode [3]	±1.0% of the set value or ±20 ms
Operate time accuracy in IDMT mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = f_n
	-3 dB at f = 13 × f_n

4.2.7 Wattmetric-based earth-fault protection WPWDE (ANSI 32N)

4.2.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Wattmetric-based earth-fault protection	WPWDE	Po> ->	32N

4.2.7.2 Function block

Figure 304: Function block

4.2.7.3 Functionality

The wattmetric-based earth-fault protection function WPWDE can be used to detect earth faults in unearthed networks, compensated networks (Petersen coil-earthed networks) or networks with a high-impedance earthing. It can be used as an alternative solution to the traditional residual current-based earth-fault protection functions, for example, the IoCos mode in the directional earth-fault protection function DEFxPDEF.

[1] Fundamental frequency current = 1.0 × I_n, harmonics current before fault = 0.0 × I_n, harmonics fault current 2.0 × *Start value*, results based on statistical distribution of 1000 measurements.
[2] Includes the delay of the signal output contact.
[3] Start time of the function also included.
[4] Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 2...20.

WPWDE measures the earth-fault power 3UoIoCosφ and gives an operating signal when the residual current Io, residual voltage Uo and the earth-fault power exceed the set limits and the angle (φ) between the residual current and the residual voltage is inside the set operating sector, that is, forward or backward sector. The operating time characteristic can be selected to be either definite time (DT) or a special wattmetric-type inverse definite minimum type (wattmetric type IDMT).

The wattmetric-based earth-fault protection is very sensitive to current transformer errors and it is recommended that a core balance CT is used for measuring the residual current.

WPWDE contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.2.7.4 Analog channel configuration

WPWDE has two analog group inputs which must be properly configured.

Table 593: Analog inputs

Input	Description
IRES	Residual current (measured or calculated)
URES	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 594: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected for calculating the residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.7.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

For WPWDE, certain notations and definitions are used.

Residual voltage Uo = (UA+UB+UC)/3 = U_0, where U_0 = zero-sequence voltage

Residual current Io = -(IA+IB+IC) = 3×- I_0, where I_0 = zero-sequence current

The minus sign (-) is needed to match the polarity of calculated and measured residual currents.

The operation of WPWDE can be described with a module diagram. All the modules in the diagram are explained in the next sections.

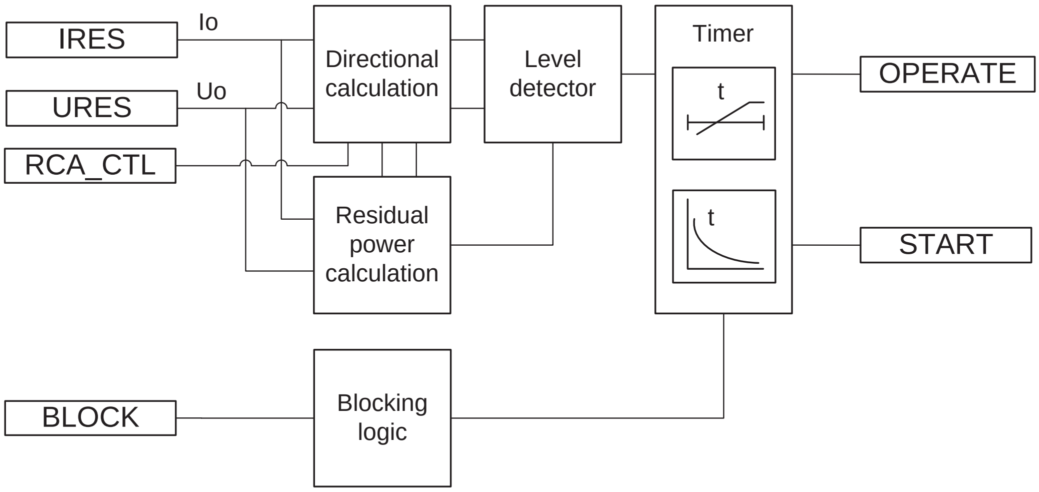


Figure 305: Function module diagram

Directional calculation

The Directional calculation module monitors the angle between the operating quantity (residual current Io) and polarizing quantity (residual voltage Uo). The operating quantity can be selected with the setting *Io signal Sel*. The selectable options are “Measured Io” and “Calculated Io”. The polarizing quantity can be selected with the setting *Pol signal Sel*. The selectable options are “Measured Uo” and “Calculated Uo”. When the angle between operating quantity and polarizing quantity after considering the *Characteristic angle* setting is in the operation sector, the module sends an enabling signal to Level detector. The directional operation is selected with the *Directional mode* setting. Either the “Forward” or “Reverse” operation mode can be selected. The direction of fault is calculated based on the phase angle difference between the operating quantity Io and polarizing quantity Uo, and the value (ANGLE) is available in the monitored data view.

In the phasor diagrams representing the operation of WPWDE, the polarity of the polarizing quantity (residual voltage Uo) is reversed. Reversing is done by switching the polarity of the residual current measuring channel (see the connection in the Protection relay's physical connections section).

If the angle difference lies between -90° to 0° or 0° to +90°, a forward-direction fault is considered. If the phase angle difference lies within -90° to -180° or +90° to +180°, a reverse-direction fault is detected. Thus, the normal width of a sector is 180°.

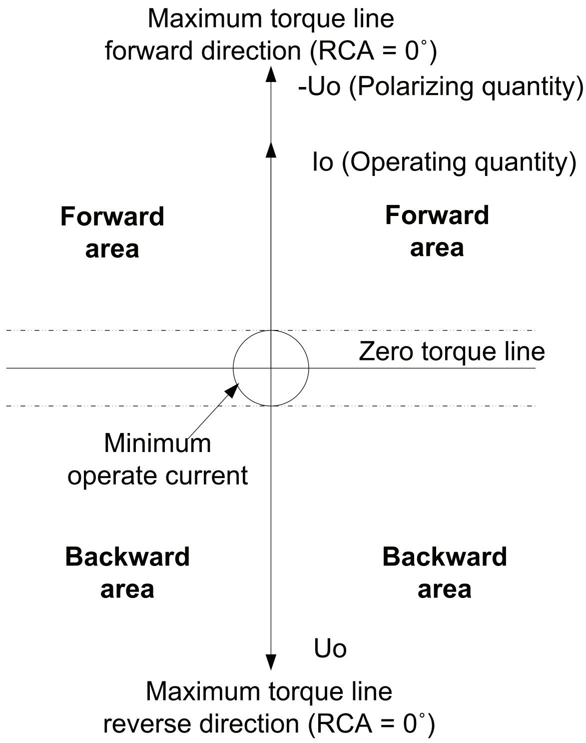


Figure 306: Definition of the relay characteristic angle

The phase angle difference is calculated based on the *Characteristic angle* setting (also known as Relay Characteristic Angle (RCA) or Relay Base Angle or Maximum Torque Angle (MTA)). The *Characteristic angle* setting is done based on the method of earthing employed in the network. For example, in case of an unearthed network, the *Characteristic angle* setting is set to -90°, and in case of a compensated network, the *Characteristic angle* setting is set to 0°. In general, *Characteristic angle* is selected so that it is close to the expected fault angle value, which results in maximum sensitivity. *Characteristic angle* can be set anywhere between -179° to +180°. Thus, the effective phase angle (ϕ) for calculating the residual power considering characteristic angle is according to the equation.

$$\phi = \left(\angle(-Uo) - \angle Io - Characteristic\ angle \right)$$

(Equation 75)

In addition, the characteristic angle can be changed via the control signal RCA_CTL. The RCA_CTL input is used in the compensated networks where the compensation coil sometimes is temporarily disconnected. When the coil is disconnected, the compensated network becomes isolated and the *Characteristic angle* setting must be changed. This can be done automatically with the RCA_CTL input, which results in the addition of -90° in the *Characteristic angle* setting.

The value (ANGLE_RCA) is available in the monitored data view.

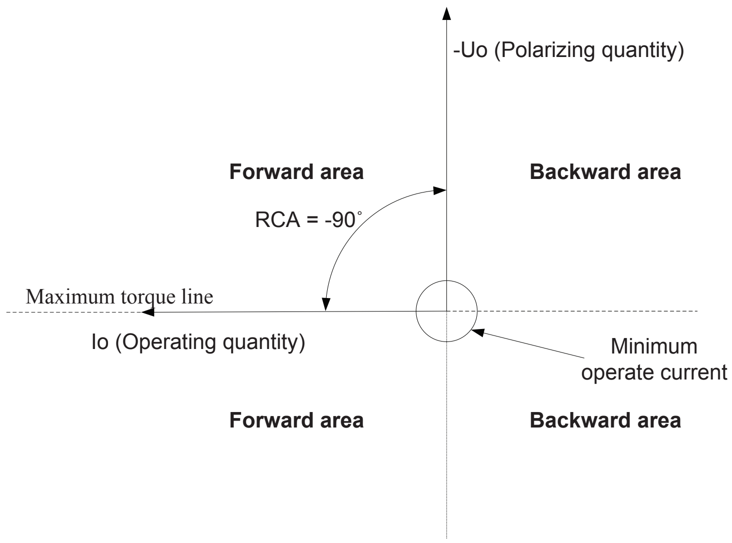


Figure 307: Definition of relay characteristic angle, RCA = -90° in an isolated network

Characteristic angle should be set to a positive value if the operating signal lags the polarizing signal and to a negative value if the operating signal leads the polarizing signal.

Type of network	Recommended characteristic angle
Compensated network	0°
Unearthed network	-90°

In unearthed networks, when the characteristic angle is -90°, the measured residual power is reactive (varmetric power).

The fault direction is also indicated `FAULT_DIR` (available in the monitored data view), which indicates 0 if a fault is not detected, 1 for faults in the forward direction and 2 for faults in the backward direction.

The direction of the fault is detected only when the correct angle calculation can be made. If the magnitude of the operating quantity or polarizing quantity is not high enough, the direction calculation is not reliable. Hence, the magnitude of the operating quantity is compared to the *Min operate current* setting and the magnitude of the polarizing quantity is compared to *Min operate voltage*, and if both the operating quantity and polarizing quantity are higher than their respective limit, a valid angle is calculated and the residual power calculation module is enabled.

The *Correction angle* setting can be used to improve the selectivity when there are inaccuracies due to the measurement transformer. The setting decreases the operation sector. The *Correction angle* setting should be done carefully as the phase angle error of the measurement transformer varies with the connected burden as well as with the magnitude of the actual primary current that is being measured. An example of how *Correction angle* alters the operating region is as shown:

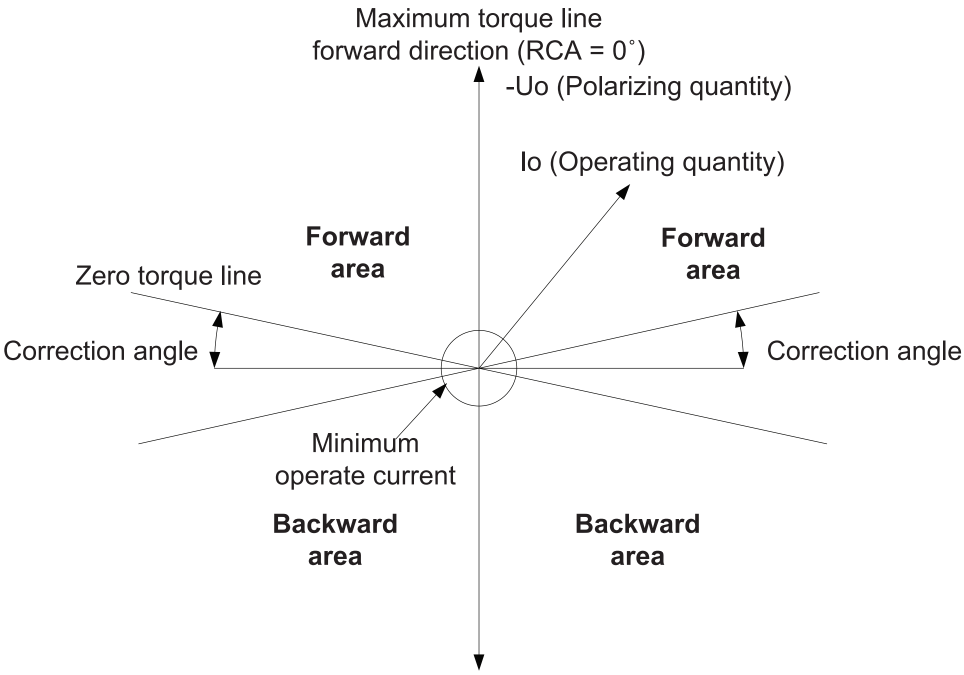


Figure 308: Definition of correction angle

The polarity of the polarizing quantity can be changed (rotated by 180°) by setting *Pol reversal* to "True" or by switching the polarity of the residual voltage measurement wires.

Residual power calculation

The Residual power calculation module calculates the magnitude of residual power 3UoIoCosϕ. Angle ϕ is the angle between the operating quantity and polarizing quantity, compensated with a characteristic angle. The angle value is received from the Directional calculation module. The Directional calculation module enables the residual power calculation only if the minimum signal levels for both operating quantity and polarizing quantity are exceeded. However, if the angle calculation is not valid, the calculated residual power is zero. Residual power (RES_POWER) is calculated continuously and it is available in the monitored data view. The power is given in relation to nominal power calculated as Pn = Un × In, where Un and In are obtained from the entered voltage transformer and current transformer ratios entered.

Level detector

Level detector compares the magnitudes of the measured operating quantity (residual current Io), polarizing quantity (residual voltage Uo) and calculated residual power to the set *Current start value* (×In), *Voltage start value* (×Un) and *Power start value* (×Pn) respectively. When all three quantities exceed the limits, Level detector enables the Timer module.

As nominal power is the result of the multiplication of the nominal current and the nominal voltage Pn = Un × In, the calculation of the setting value for *Power start value* (×Pn) depends on whether Io and Uo are measured or calculated from the phase quantities.

Timer

Once activated, Timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or wattmetric IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated. If a drop-off situation happens, that is, a fault suddenly disappears before the operating delay is exceeded, the timer reset state is activated. The reset time is identical for both DT or wattmeter IDMT. The reset time depends on the *Reset delay time* setting.

Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the *Block OPERATE output* mode, the function operates normally but the `OPERATE` output is not activated.

4.2.7.6 Timer characteristics

In the wattmetric IDMT mode, the `OPERATE` output is activated based on the timer characteristics:

$$t[s] = \frac{k * P_{ref}}{P_{cal}}$$

(Equation 76)

t[s]	operation time in seconds
k	set value of *Time multiplier*
P_{ref}	set value of *Reference power*
P_{cal}	calculated residual power

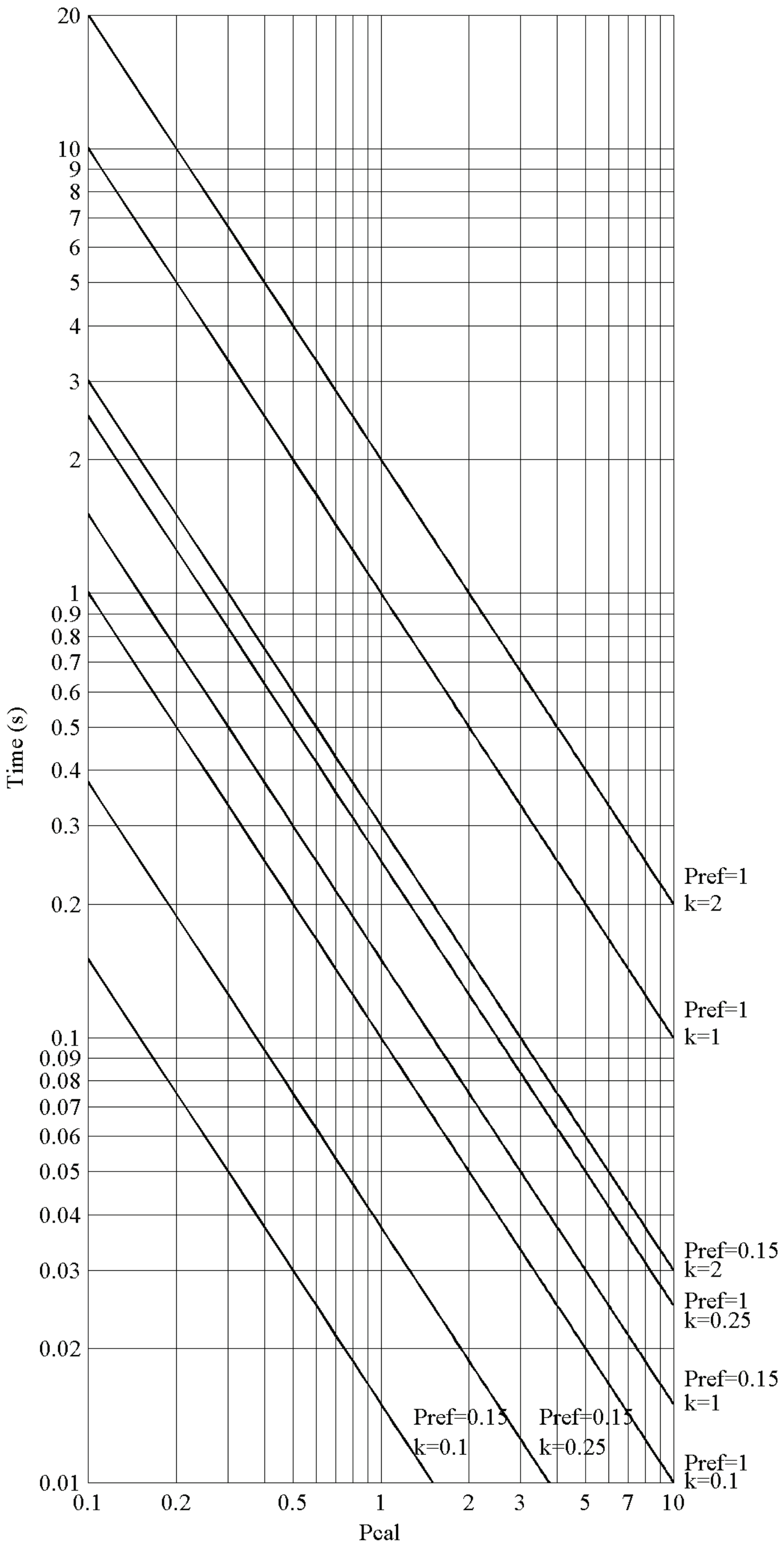


Figure 309: Operation time curves for wattmetric IDMT for S ref set at 0.15 xPn

4.2.7.7 Measurement modes

The function operates on three alternative measurement modes: "RMS", "DFT" and "Peak-to-Peak". The measurement mode is selected with the *Measurement mode* setting.

4.2.7.8 Application

The wattmetric method is one of the commonly used directional methods for detecting the earth faults especially in compensated networks. The protection uses the residual power component 3UoIoCosφ (φ is the angle between the polarizing quantity and operating quantity compensated with a relay characteristic angle).

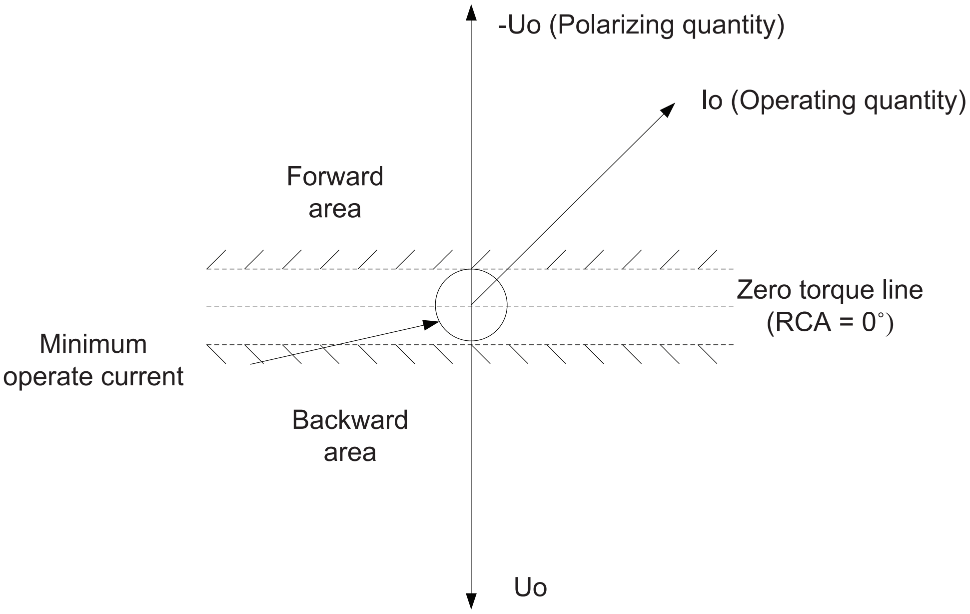


Figure 310: Characteristics of wattmetric protection

In a fully compensated radial network with two outgoing feeders, the earth-fault currents depend mostly on the system earth capacitances (C_0) of the lines and the compensation coil (L). If the coil is tuned exactly to the system capacitance, the fault current has only a resistive component. This is due to the resistances of the coil and distribution lines together with the system leakage resistances (R_0). Often a resistor (R_L) in parallel with the coil is used for increasing the fault current.

When a single phase-to-earth fault occurs, the capacitance of the faulty phase is bypassed and the system becomes unsymmetrical. The fault current is composed of the currents flowing through the earth capacitances of two healthy phases. The protection relay in the healthy feeder tracks only the capacitive current flowing through its earth capacitances. The capacitive current of the complete network (sum of all feeders) is compensated with the coil.

A typical network with the wattmetric protection is an undercompensated network where the coil current $I_L = I_{Ctot} - I_{Cfd}$ (I_{Ctot} is the total earth-fault current of the network and I_{Cfd} is the earth-fault current of the healthy feeder).

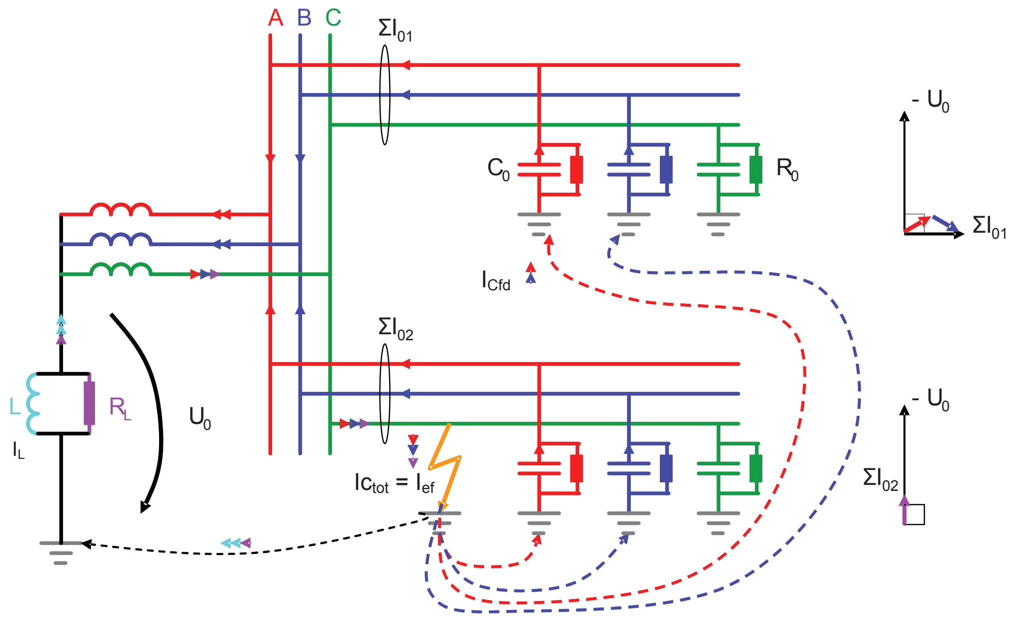


Figure 311: Typical radial compensated network employed with wattmetric protection

The wattmetric function is activated when the residual active power component exceeds the set limit. However, to ensure a selective operation, it is also required that the residual current and residual voltage also exceed the set limit.

It is highly recommended that core balance current transformers are used for measuring Io when using the wattmetric method. When a low transformation ratio is used, the current transformer can suffer accuracy problems and even a distorted secondary current waveform with some core balance current transformers. Therefore, to ensure a sufficient accuracy of the residual current measurement and consequently a better selectivity of the scheme, the core balance current transformer should preferably have a transformation ratio of at least 70:1. Lower transformation ratios such as 50:1 or 50:5 are not recommended, unless the phase displacement errors and current transformer amplitude are checked first.

It is not recommended to use the directional wattmetric protection in case of a ring or meshed system as the wattmetric requires a radial power flow to operate.

The relay characteristic angle needs to be set based on the system earthing. In an unearthed network, that is, when the network is only coupled to earth via the capacitances between the phase conductors and earth, the characteristic angle is chosen as -90°.

In compensated networks, the capacitive fault current and inductive resonance coil current compensate each other, meaning that the fault current is mainly resistive and has zero phase shift compared to the residual voltage. In such networks, the characteristic angle is chosen as 0°. Often the magnitude of an active component is small and must be increased by means of a parallel resistor in a compensation coil. In networks where the neutral point is earthed through a low resistance, the characteristic angle is always 0°.

As the amplitude of the residual current is independent of the fault location, the selectivity of the earth-fault protection is achieved with time coordination.

The use of wattmetric protection gives a possibility to use the dedicated inverse definite minimum time characteristics. This is applicable in large high-impedance earthed networks with a large capacitive earth-fault current.

In a network employing a low-impedance earthed system, a medium-size neutral point resistor is used. Such a resistor gives a resistive earth-fault current component of about 200...400 A for an excessive earth fault. In such a system, the directional residual power protection gives better possibilities for selectivity enabled by the inverse time power characteristics.

4.2.7.9 Signals

WPWDE Input signals

Table 595: WPWDE Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

WPWDE Output signals

Table 596: WPWDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.7.10 WPWDE Settings

Table 597: WPWDE Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Directional mode	2=Forward 3=Reverse			2=Forward	Directional mode
Current start value	0.010...5.000	xIn	0.001	0.010	Minimum operate residual current for deciding fault di-rection
Voltage start value	0.010...1.000	xUn	0.001	0.010	Start value for re-sidual voltage
Power start value	0.003...1.000	xSn	0.001	0.003	Start value for re-sidual active power
Reference power	0.050...1.000	xSn	0.001	0.150	Reference value of residual power for Wattmetric IDMT curves

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Time multiplier	0.025...2.000		0.005	1.000	Time multiplier for Wattmetric IDMT curves
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 20=Wattmetric IDMT			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	60...300000	ms	10	60	Operate delay time for definite time

Table 598: WPWDE Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 599: WPWDE Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used current measurement mode
Correction angle	0.0...10.0	deg	0.1	2.0	Angle correction
Min operate current	0.010...1.000	xIn	0.001	0.010	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Reset delay time	0...60000	ms	1	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity

4.2.7.11 WPWDE Monitored data

Table 600: WPWDE Monitored data

Name	Type	Values (Range)	Unit	Description
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
DIRECTION	Enum	0=unknown 1=forward 2=backward 3=both		Direction information
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
RES_POWER	FLOAT32	-160.000...160.000	xPn	Calculated residual active power
WPWDE	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.7.12 Technical data

Table 601: WPWDE Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Current and voltage: ±1.5% of the set value or ±0.002 × I_n Power: ±3% of the set value or ±0.002 × P_n
Start time [1, 2]	Typically 63 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode [3]	±1.0% of the set value or ±20 ms
Operate time accuracy in IDMT mode	±5.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2,3,4,5,…

4.2.8 Third harmonic based stator earth-fault protection H3EFPSEF (ANSI 64TN)

4.2.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Third harmonic-based stator earth-fault protection	H3EFPSEF	dUo>/Uo3H	64TN

[1] Io varied during the test, U_o = 1.0 × U_n = phase-to-earth voltage during earth fault in compensated or unearthed network, the residual power value before fault = 0.0 pu, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
[2] Includes the delay of the signal output contact.
[3] Start time of the function also included.

4.2.8.2 Function block

Figure 312: Function block

4.2.8.3 Functionality

The third harmonic-based stator earth-fault protection H3EFPSEF is used to detect stator earth fault at the neutral point and at least up to 15...20% from the neutral point along the stator winding. H3EFPSEF compares the third harmonic voltages produced by the generator itself at both neutral and terminal side of the generator for detecting earth fault.

H3EFPSEF provides two alternative protection methods:

- Differential of the third harmonic component measured both at generator neutral and terminal side
- Neutral side third harmonic undervoltage

H3EFPSEF operates with the definite time DT characteristics.

H3EFPSEF contains a blocking functionality. Blocking deactivates all outputs and reset timers.

4.2.8.4 Analog channel configuration

H3EFPSEF has three analog group inputs which must be properly configured.

Table 602: Analog inputs

Input	Description
U3P [1]	Three-phase voltages Necessary when *Voltage selection* is set to "Uo", "Phase A", "Phase B" or "Phase C"
URES [2]	Residual voltage (measured or calculated) Necessary when *Voltage selection* is set to "Uo"
UNEUT	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources. The `GRPOFF` signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

[1] Can be connected to `GRPOFF` if *Voltage selection* is set to "No voltage" or "Uo".
[2] Can be connected to `GRPOFF` if *Voltage selection* is other than "Uo".

Table 603: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with at least one voltage channel connected.
URES calculated	The function requires that all three voltage channels from the terminal side are connected to calculate residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.
UNEUT calculated	The function requires that all three voltage channels from the neutral side are connected to calculate residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.8.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of the third harmonic-based stator earth-fault protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

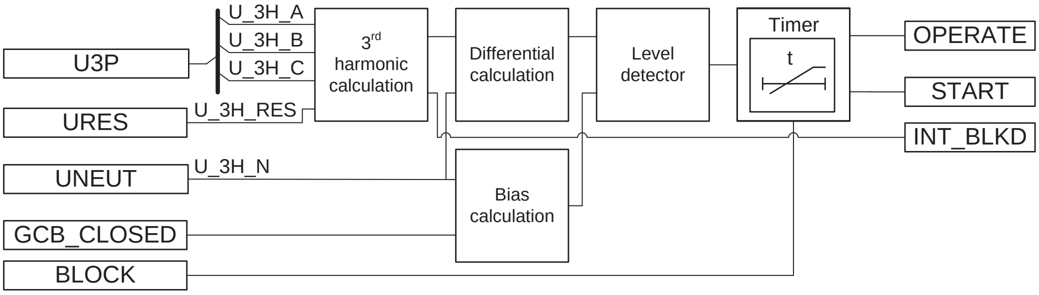


Figure 313: Functional module diagram

3rd harmonic calculation (terminal side)

3rd harmonic calculation calculates the magnitude and phase angle of the third harmonic voltage at the generator terminal $\bar{U}_{3H\_T}$. Calculation of the third harmonic voltage depends on the availability of terminal side voltage and is specified by the *Voltage selection* setting.

- *Voltage selection* setting is set to "No voltage" if phase-to-earth voltages are not available at the terminal side. Even in a situation where only phase-to-phase voltages are available, *Voltage selection* is set to "No Voltage" because phase-to-phase voltages do not contain a third harmonic component. With *Voltage* *selection* set to "No Voltage", third harmonic-based earth-fault protection is based on third harmonic neutral side undervoltage protection.

- *Voltage selection* setting is set to "Measured Uo" if the third harmonic voltage is measured directly from an open-delta voltage connection of the voltage transformer or the third harmonic voltage is calculated using all three phase-to-earth voltages. If the terminal side voltage is fed from an open-delta voltage connection of the voltage transformer, the terminal side third harmonic voltage Û3H_T is the same as the measured open-delta voltage Û3H_RES.

$$\bar{U}_{3H\_T} = \bar{U}_{3H\_RES}$$

(Equation 77)

If all three phase-to-earth voltages are available, the terminal side third harmonic voltage is calculated as a vector average of the third harmonic voltages of all three phases.

$$\bar{U}_{3H\_T} = \frac{1}{3} \times (\bar{U}_{3H\_A} + \bar{U}_{3H\_B} + \bar{U}_{3H\_C})$$

(Equation 78)

- If only one phase-to-earth voltage is available, the *Voltage selection* setting is set to the respective phase, that is, "Phase A" or "Phase B" or "Phase C" based on the available phase. In this case, the magnitude of the terminal side third harmonic voltage is assumed to be equal to the third harmonic voltage of the phase available.

$$\bar{U}_{3H\_T} = \bar{U}_{3H\_A} \text{ or } \bar{U}_{3H\_B} \text{ or } \bar{U}_{3H\_C}$$

(Equation 79)

The function is internally blocked if the magnitude of calculated $\bar{U}_{3H\_T}$ is lower than the set *Voltage block value*. This also activates the `INT_BLKD` output.

Differential calculation

The amplitude of the third harmonic differential voltage can be calculated using the following equation.

$$UD_{3H} = \left| \bar{U}_{3H\_T} + \bar{U}_{3H\_N} \right|$$

(Equation 80)

UD_{3H}	Magnitude of the third harmonic differential voltage
$\bar{U}_{3H\_T}$	Terminal side third harmonic voltage phasor
$\bar{U}_{3H\_N}$	Neutral side third harmonic voltage phasor

The magnitude of the third harmonic differential voltage `UD_3H` and the phase angle difference between the terminal side and neutral side third harmonic voltage `U_3HANGL_T_N` are available in the Monitored data view.

Bias calculation

The amplitude of the third harmonic bias voltage can be calculated using the following equation.

$$UB_{3H} = Beta \times \left| \overline{U}_{3H\_N} \right|$$

(Equation 81)

UB_{3H}	Magnitude of the third harmonic bias voltage
Beta	Setting to achieve the required degree of security under healthy conditions
$\bar{U}_{3H\_N}$	Neutral side third harmonic voltage phasor

The third harmonic bias voltage calculation shown in *Equation 81* is valid under all operating conditions if there is no generator circuit breaker between generator and transformer. But if the generator circuit breaker is used, it is needed to reduce the sensitivity of the protection when it is open. The use of the generator circuit breaker is defined by *Generator CB used* setting set to "Yes" and the open position is sensed when the binary input GCB_CLOSED available is FALSE.

With the generator breaker in the open position, function desensitizes the protection by multiplying the value of the *Beta* setting with the set constant *CB open factor* setting.

$$UB_{3H} = CB\ open\ factor \times Beta \times \left| \overline{U}_{3H\_N} \right|$$

(Equation 82)

Neutral side third harmonic voltage is measured via a voltage transformer between the generator neutral point and the earth. The magnitude of the third harmonic biased voltage UB_3H is available in the Monitored data view.

Level detector

In the third harmonic differential method, Level detector compares the third harmonic differential voltage with the third harmonic bias voltage. If the differential voltage exceeds the biased voltage, the module sends an enabling signal to start the timer.

If the terminal voltage is not available, that is, *Voltage selection* is set to "No voltage" the module compares the neutral side third harmonic voltage U_3H_N to the set *Voltage N 3.H Lim*.

Timer

Once activated, Timer activates the START output. The Timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

Timer calculates the start duration START_DUR value, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers.

4.2.8.6 Application

Mechanical and thermal stress deteriorates stator winding insulation, which can eventually cause an earth fault between the winding and stator core.

The fault current magnitude in case of stator earth fault depends on the grounding type. Common practice in most countries is to earth the generator neutral side through a resistor. The resistor is selected such as to limit the maximum earth-fault current in the range of 5...10 A. The same can be done by connecting a single phase voltage transformer between the neutral side and earth, and with an equivalent resistor on the secondary side of the transformer.

In a normal operating condition, that is, when there is no earth fault, the residual voltage is close to zero with no zero-sequence current flowing in the generator. When a phase-to-earth fault occurs, the residual voltage increases and the current flows through the neutral. The simplest way to protect the stator winding against an earth fault is by providing residual overvoltage protection (or residual/neutral overcurrent protection). However, at best these simple schemes can protect only 95% of the stator winding, leaving 5% of the neutral end unprotected. This is because the voltage generated in the faulted winding decreases as the fault point becomes closer to the neutral point and it is not enough to drive the protection. Under certain unfavorable conditions, the blind zone may extend up to 20% from the neutral point.

An earth fault close to the neutral point is not dangerous, but an undetected fault may develop into an interturn fault or phase-to-phase fault. Also an undetected earth fault near the neutral point is bypassing the high-impedance grounding, and then another earth fault at the terminal results in a catastrophic situation.

Therefore, it is important to extend the protection to full 100%. The third harmonic voltage-based protection is one such protection which provides effective protection during an earth fault at the neutral point, and at least in the range up to 15...20% from the neutral point along the stator winding.

To achieve a complete stator earth-fault protection, two protection functions should always run in parallel.

- Fundamental frequency-based residual overvoltage protection ROVPTOV
- Third harmonic-based stator earth-fault protection H3EFPSEF

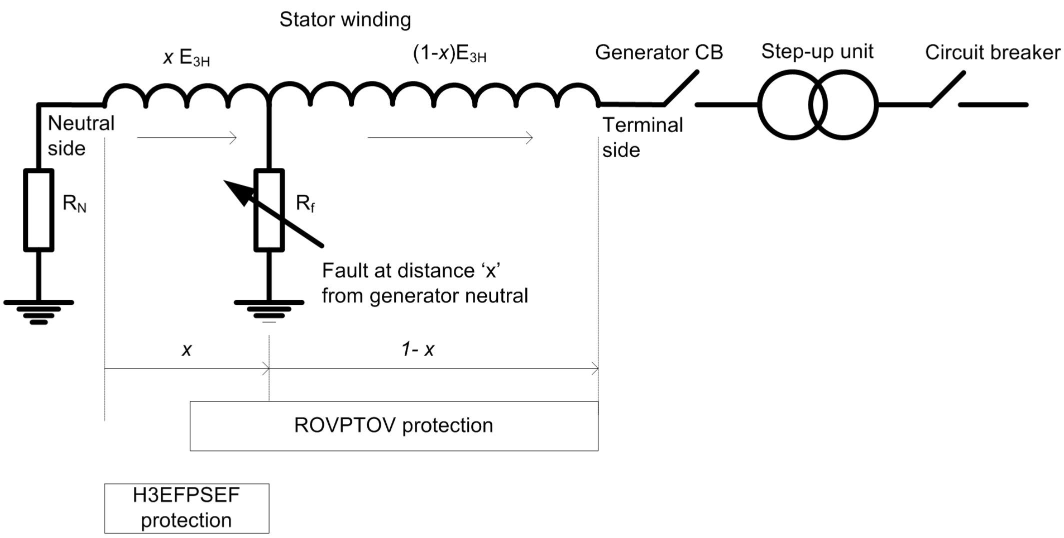


Figure 314: Complete stator earth-fault protection

Third harmonic voltage-based differential protection

The voltage generated by a generator is not a perfect sinusoidal wave but contains triplen harmonics voltages. These triplen harmonics appear in each phase with the same magnitude and angle, due to which they do not sum to zero and thus also appear in the neutral side of the generator as a zero-sequence quantity. Among all the triplen harmonics voltages generated, the third harmonic voltage has the highest magnitude with the magnitude varying between 1% and 10% of the terminal voltage, depending on the generator design philosophy. However, for a particular generator the magnitude of third harmonics on the neutral side and terminal side depends also on the active power generated.

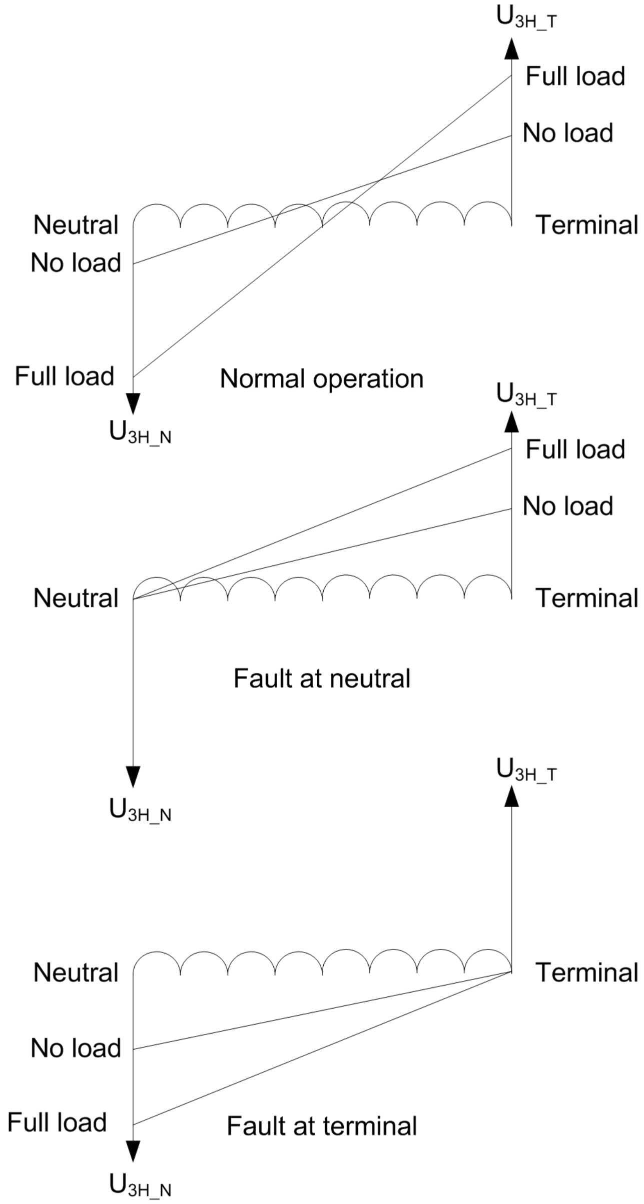


Figure 315: Typical example of the third-harmonic voltage measured at the generator neutral and terminals under different conditions

The operating equation of the protection is described in the following equation.

$$\left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right| - Beta \times \left|\bar{U}_{3H\_N}\right| = 0$$

(Equation 83)

The third harmonic voltages $\bar{U}_{3H\_T}$ and $\bar{U}_{3H\_N}$ are the phasor with its real and imaginary parts. $\bar{U}_{3H\_T}$ is approximately in the opposite direction to that of the $\bar{U}_{3H\_N}$, however the actual no-fault angle between those two phasors depends on the type of generator earthing. For example, the angle is about 145 degrees for a high-resistance-earthed unit generator.

The equation defines the "operate" and "restrain" regions of the protection. The third harmonic differential protection operates according to the following equation.

$$\left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right| \geq Beta \times \left|\bar{U}_{3H\_N}\right|$$

(Equation 84)

$\bar{U}_{3H\_N}$	Neutral side third harmonic voltage phasor
$\bar{U}_{3H\_T}$	Terminal side third harmonic voltage phasor
Beta	Setting to achieve a required degree of security under healthy conditions
$\lvert\bar{U}_{3H\_T}+\bar{U}_{3H\_N}\rvert$	Magnitude of the third harmonic differential voltage
$Beta \cdot \lvert\bar{U}_{3H\_N}\rvert$	Magnitude of the third harmonic bias (restrain) voltage

Factor *Beta*, which is a setting, can be determined from the condition.

$$\frac{Beta \times \left|\bar{U}_{3H\_N}\right|}{\left|\bar{U}_{3H\_T} + \bar{U}_{3H\_N}\right|} = K$$

(Equation 85)

K is the security factor, for example K = 1.5. Equation 85 must be satisfied in the normal, healthy condition of the protected generator, with a high enough value for K, so that no unwanted operation of the protection should be expected, regardless the load on the generator.

To assure a reliable functioning of the protection, it is necessary that the generator produces third harmonic voltage which is at least 1% of the generator rated voltage.

As phase-to-phase voltages do not contain a third harmonic component, in situations where the VTs on the terminal side are connected between phase-to-phase, the differential protection in Equation 85 cannot work. In such case, the *Voltage selection* setting is set to "No Voltage" and H3EFPSEF operates as a simple neutral side third harmonic undervoltage protection.

When H3EFPSEF is reduced to function as only a third harmonic neutral point undervoltage protection, it is necessary to block the function during start-up and shutdown of generator and also when there is no sufficient voltage.

Calculating Beta value

The setting *Beta* gives the proportion of the third harmonic voltage in the neutral point of the generator to be used as bias quantity. *Beta* must be set so that there is no risk of trip during the normal, non-faulted operation of the generator. If *Beta* is set high, this limits the portion of the stator winding covered by the protection. In most cases, the default setting “3.00” gives an acceptable sensitivity for an earth fault near the neutral point of the stator winding. However, to assure the best performance, measurements during the normal operation of the generator are to be made during commissioning.

1. The value of the *Beta* setting must be set to “1.00”.
2. Loading of the generator is done at 5 to 10 different load points and the third harmonic differential and bias voltage are measured. Both quantities can be obtained from the Monitored data view of the function.
3. A graph indicating differential and bias voltages as a functions of the load on the generator must be plotted.
4. Based on the graph, such value of the *Beta* setting must be selected that the bias voltage, even in the worst condition, is at least 30% to 50% higher than the differential voltage.

The angle between the third harmonic voltage phasors $\bar{U}_{3H\_T}$ and $\bar{U}_{3H\_N}$ is 150°, and with the *Beta* setting value "1.0", protection guarantees a stability margin of 25%. This requires the value of *Beta* to be increased so as to increase the stability of protection. The recommended value of the *Beta* setting is at least “1.2”.

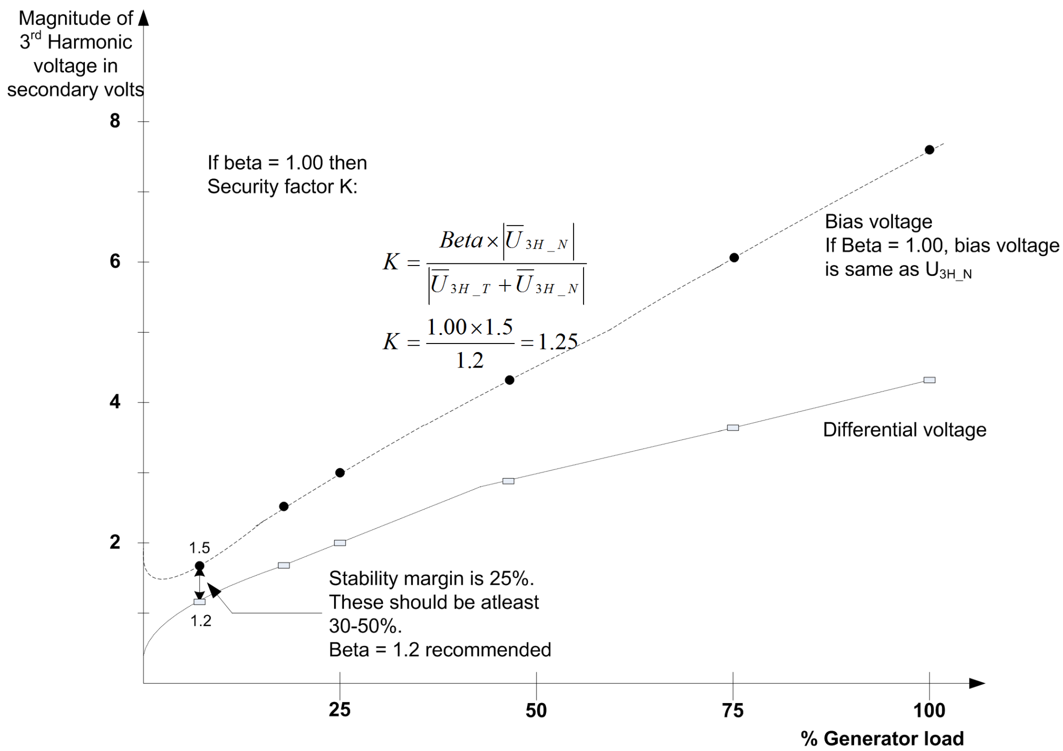


Figure 316: Typical example of variation of the bias voltage and differential voltage with a change in the active generated load (the angle between the third harmonic terminal and neutral voltage is 150°)

Calculating CB Open factor

One of the factors, though not major, governing the magnitude of the generated third harmonic voltage is the generator terminal capacitance. If there is no generator breaker, the capacitive coupling to earth is the same under all operating conditions. However, the generator breaker normally exists between the protected generator and its power transformer.

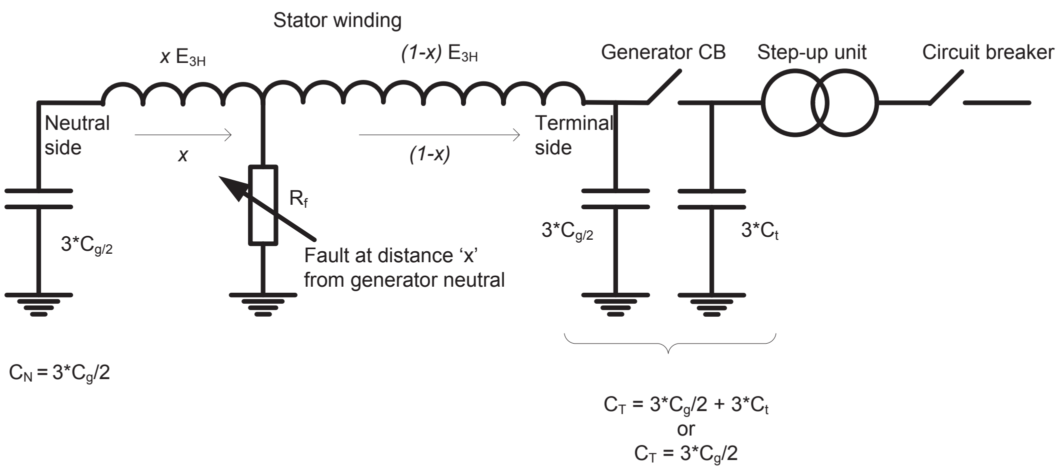


Figure 317: Capacitance seen at generator terminal and neutral side

C_g	Phase capacitance of generator stator winding
C_t	Total external phase capacitance of the system as seen from the generator
C_N	Phase-to-ground lumped capacitance of the generator stator winding, between the earth-fault location and the generator neutral
C_T	Phase-to-ground lumped capacitance of the generator stator winding, between the generator terminal and earth-fault location

When there is a generator breaker, the capacitive coupling to earth differs between the operating conditions when the generator is running with the generator breaker open (before synchronization) and with the circuit breaker closed.

With the generator breaker open, the total capacitance is smaller compared to normal operating conditions. This means that the neutral side third harmonic voltage is reduced compared to the normal operating condition. Therefore, there is a need to reduce the sensitivity of the protection. When generator breaker is open, H3EFPSEF desensitizes the protection by multiplying the *Beta* setting with a set constant *CB open factor* setting.

$$\left|\overline{U}_{3H\_T} + \overline{U}_{3H\_N}\right| \geq \text{CB open factor} \times \text{Beta} \times \left|\overline{U}_{3H\_N}\right|$$

(Equation 86)

The *CB Open factor* setting is obtained during commissioning.

1. For a particular value of *Beta* the third harmonic neutral voltage is measured with the generator in the no-load condition and the circuit breaker in the closed position.
2. With the same condition, the third harmonic neutral voltage with the circuit breaker in the open position is measured.
3. *CB Open factor* should be set equal to the ratio of the third harmonic neutral voltage measured with the circuit breaker in the closed position to that in the open.

4.2.8.7 Signals

H3EFPSEF Input signals

Table 604: H3EFPSEF Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
UNEUT	SIGNAL	-	Analog input
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
GCB_CLOSED	BOOLEAN	0=False	Generator CB in closed position

H3EFPSEF Output signals

Table 605: H3EFPSEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
INT_BLKD	BOOLEAN	Protection internally blocked

4.2.8.8 H3EFPSEF Settings

Table 606: H3EFPSEF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Beta	0.50...10.00		0.01	3.00	Portion of neutral side 3rd harmonic used as bias
Voltage N 3.H Lim	0.005...0.200	xUn	0.001	0.010	Start value for 3rd harmonic residual undervoltage protection
Operate delay time	20...300000	ms	10	20	Operate delay time

Table 607: H3EFPSEF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage selection	1=No voltage 2=Uo 4=Phase A 5=Phase B 6=Phase C			2=Uo	Type of voltage connection available at generator terminal
CB open factor	1.00...10.00		0.01	1.00	Multiplication factor for beta when CB is in open condition

Table 608: H3EFPSEF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 609: H3EFPSEF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage block value	0.010...0.100	xUn	0.001	0.010	Low level blocking for 3rd harmonic differential protection
Generator CB used	0=No 1=Yes			0=No	Defines if generator circuit breaker exists
Reset delay time	0...60000	ms	1	20	Reset delay time

4.2.8.9 H3EFPSEF Monitored data

Table 610: H3EFPSEF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
UD_3H	FLOAT32	0.00...40.00	xUn	3rd harmonic differential voltage amplitude
UB_3H	FLOAT32	0.00...40.00	xUn	3rd harmonic bias voltage amplitude
U_3H_T	FLOAT32	0.00...40.00	xUn	Terminal side 3rd harmonic voltage amplitude
U_3H_N	FLOAT32	0.00...40.00	xUn	Neutral side 3rd harmonic voltage amplitude
U_3H_N	FLOAT32	0.00...40.00	xUn	Neutral side 3rd harmonic voltage amplitude
U_3HANGL_T_N	FLOAT32	-180.00...180.00	deg	Phase angle between 3rd harmonic terminal and neutral voltage
H3EFPSEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.8.10 Technical data

Table 611: H3EFPSEF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±2 Hz
	±5% of the set value or ±0.004 × U_n
Start time [1, 2]	Typically 35 ms
Reset time	Typically 35 ms
Reset ratio	Typically 0.96 (differential mode) Typically 1.04 (under voltage mode)
Operate time accuracy	±1.0% of the set value of ±20 ms

4.2.9 Multifrequency admittance-based earth-fault protection MFADPSDE (ANSI 67NYH)

4.2.9.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multifrequency admittance-based earth-fault protection	MFADPSDE	Io> ->Y	67NYH

4.2.9.2 Function block

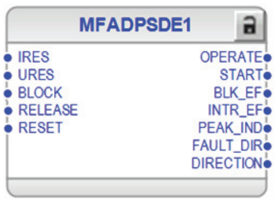


Figure 318: Function block

4.2.9.3 Functionality

The multifrequency admittance-based earth-fault protection function MFADPSDE provides selective directional earth-fault protection for high-impedance earthed networks, that is, for compensated, unearthed and high-resistance earthed systems. It can be applied for the earth-fault protection of overhead lines and underground cables, regardless of the earth-fault type (continuous, transient or

[1] f_n = 50 Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

intermittent) or the fault resistance value (low or high ohmic). MFADPSDE replaces traditional sensitive directional earth-fault protection (such as Iocos) and transient earth-fault protection (such as Wischer principle) combining the same functionality into a single function block (see *Table 612*).

Table 612: Comparison of the MFADPSDE functionality with traditional methods in resonant earthed networks

	Earth-fault type				
	Transient	Continuous	Restriking/ Intermitten t	Low-ohmic	High-ohmic
Traditional Iocos		x		x	x
Traditional Wischer	x		x	x	
MFADPSDE	x	x	x	x	x

As shown by numerous practical field tests, MFADPSDE provides better sensitivity and selectivity compared with traditional methods with less complexity in settings and configuration. MFADPSDE provides enhanced earth-fault protection performance, especially in networks with cable feeders where distributed compensation coils are applied and the earth-fault type is typically intermittent. It is applicable in feeders with distributed compensation regardless of the size or localization of distributed coils. Selective protection can be achieved also in case of overcompensated feeders.

The neutral point in compensated networks is earthed via a controllable centralized arc suppression coil located typically in the primary substation. Additionally, (fixed) distributed compensation coils can be used, which are installed in relevant locations along the protected feeders.

In unearthed networks, the neutral point in the primary substation is not connected to earth. However, in unearthed networks (fixed) distributed compensation coils can also be used to compensate a part of the total capacitive earth-fault current. Typically, the resulting compensation degree is less than 50 percent. Thus, unearthed networks with or without distributed compensation coils are generally referred to as unearthed networks in this manual.

MFADPSDE operation is based on multifrequency neutral admittance measurement using the cumulative phasor summing technique. This concept provides extremely secure, dependable and selective earth-fault protection also when the residual quantities are highly distorted and contain non-fundamental frequency components.

The sensitivity that can be achieved is comparable with traditional fundamental frequency based methods such as IoCos/IoSin (DEFxPTOC), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

MFADPSDE can detect faults with dominantly fundamental frequency content as well as transient, intermittent and restriking earth faults. The function can be used as an alternative solution to transient or intermittent function INTRPTEF.

MFADPSDE supports fault direction indication both in operate and in non-operate direction, which can be used during fault location process. The in-built transient detector can be used to identify restriking or intermittent earth faults, and discriminate them from permanent or continuous earth faults.

The operation characteristic is defined by a tilted operation sector, which is universally valid for unearthed and compensated networks.

The operating time characteristic is according to the definite time (DT).

MFADPSDE contains a blocking functionality to block function outputs, timers or the function itself.

4.2.9.4 Analog channel configuration

MFADPSDE has two analog group inputs which must be properly configured.

Table 613: Analog inputs

Input	Description
IRES	Residual current (measured or calculated)
URES	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 614: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected for calculating the residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.9.5 Operation principle

The *Operation* setting is used to enable or disable the function. The corresponding parameter values are "on" and "off".

The operation of MFADPSDE can be described using a module diagram. All the modules in the diagram are explained in the following sections.

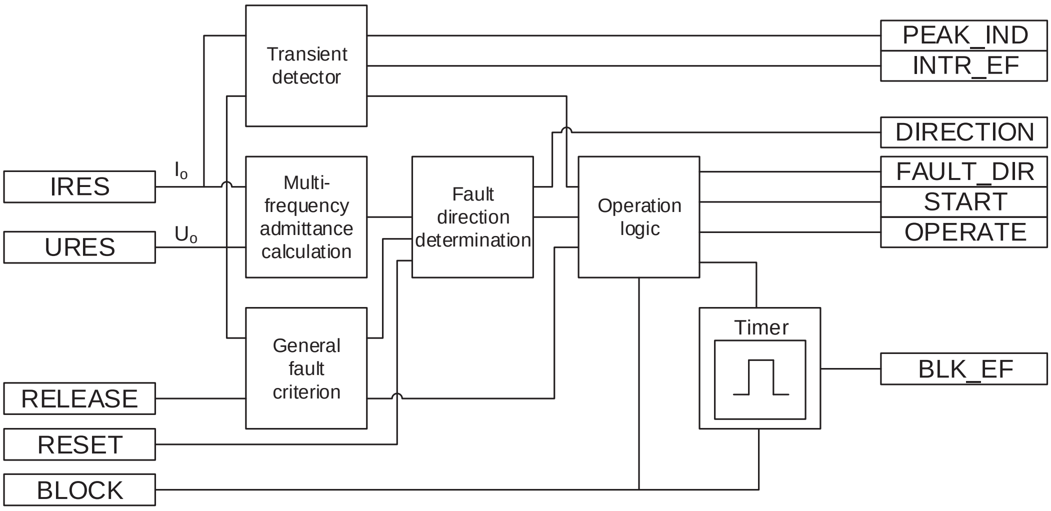


Figure 319: Functional module diagram

General fault criterion

The General fault criterion (GFC) module monitors the presence of earth faults in the network and it is based on the value of the fundamental frequency zero-sequence voltage defined as the vector sum of fundamental frequency phase voltage phasors divided by three.

$$\overline{U_0^1} = \frac{\left(\overline{U_A^1} + \overline{U_B^1} + \overline{U_C^1}\right)}{3}$$

(Equation 87)

MFADPSDE supports zero-sequence voltage monitoring based on measurement (from open-delta winding) or calculated (derived from phase-to-earth voltages).

When the magnitude of $\underline{U}_o^1$ exceeds setting *Voltage start value*, an earth fault is detected. The GFC module reports the exceeded value to the Fault direction determination module and Operation logic. The reporting is referenced as General Fault Criterion release.

The setting *Voltage start value* defines the basic sensitivity of MFADPSDE. To avoid unselective start or operation, *Voltage start value* must always be set above the maximum healthy-state zero-sequence voltage value, considering network topology changes, compensation coil and parallel resistor switching status and compensation degree variations. The setting *Voltage start value* can be easily selected based on the resonance curve calculated by the coil controller in corresponding network conditions (see *Figure 320*).

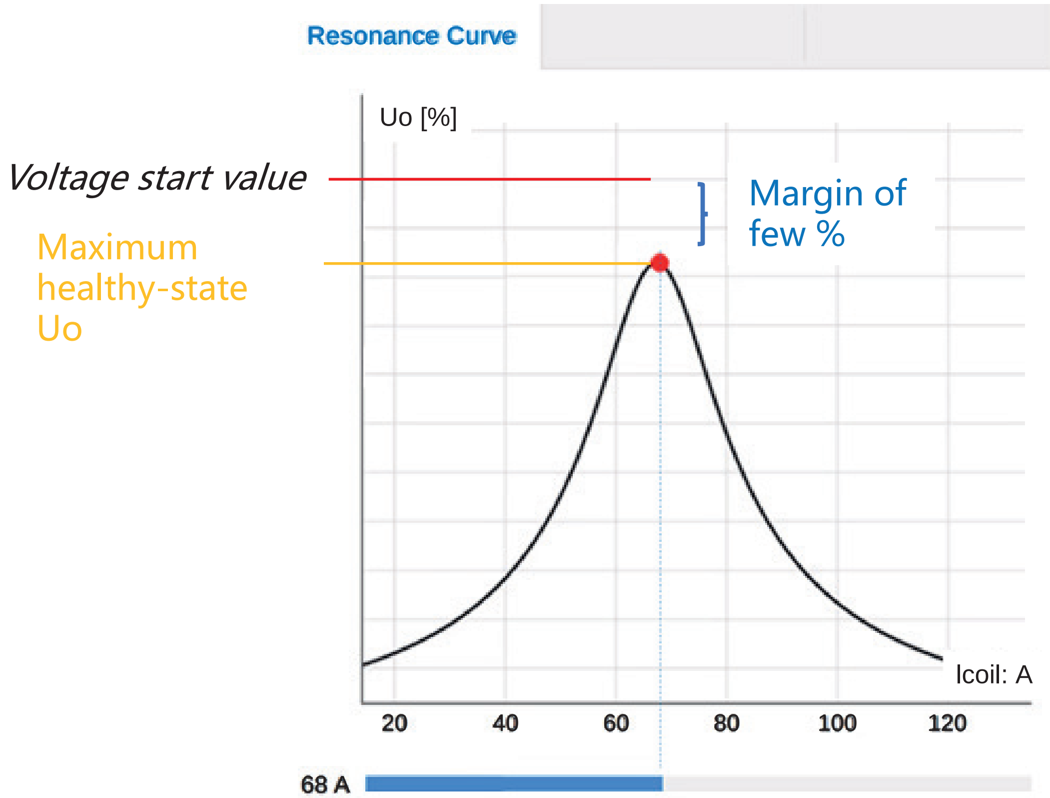


Figure 320: Example of selection of setting Voltage start value to maximize the earth-fault detection sensitivity based on the resonance curve calculated by the coil controller

There are three MFADPSDE instances (stages) available. The sensitivity of different stages should be selected differently. For example, stage 1 could have the highest *Voltage start value* and the shortest *Operate delay time*. Thus it would fulfill the requirements for protection operation speed by providing fast operation for low-ohmic earth faults. Stage 2 should have lower *Voltage start value* and longer *Operate delay time* compared with stage 1. This stage would fulfill the requirements for protection sensitivity (in terms of fault resistance value). Stage 3 could be used to detect high-ohmic earth faults and generate alarms for them. To maximize the earth-fault detection sensitivity of stage 3, *Voltage start value* should be selected based on the network's resonance curve (see *Figure 320*).

Such coordination of different protection stages enables:

- Indication (but no tripping) of transient, self-extinguishing earth faults, where the zero-sequence voltage may temporarily rise to a high value and then decay slowly away. This can be achieved by monitoring the `START` outputs. Delayed operation times of stages 1 and 2 avoid unnecessary breaker operations during self-extinguishing earth faults.
- Fast tripping of low-ohmic permanent earth faults regardless of their type (continuous or intermittent), stage 1
- Delayed tripping of higher-ohmic permanent earth faults regardless of their type (continuous or intermittent), stage 2

- Alarms (but no tripping) about high-ohmic earth faults in order to monitor the insulation status of the network and provide early indication of evolving faults before they cause tripping (by stages 1 or 2), stage 3.

Besides the internal start condition based on residual zero-sequence overvoltage, MFADPSDE can also be externally released by using the RELEASE input. In this case, the external release signal overrides the *Voltage start value* setting and sets the internal limit to the minimum value.

Multi-frequency admittance calculation

The Multi-frequency admittance calculation module calculates neutral admittances using fundamental frequency and the 2nd, 3rd, 5th, 7th and 9th harmonic components of residual current and zero-sequence voltage. The fundamental frequency admittance (conductance and susceptance) is calculated if the magnitude of a harmonic in residual current and zero-sequence voltage is measurable by the relay.

$$\overline{Y_0^1} = \frac{3 \cdot \overline{I_0^1}}{-\overline{U_0^1}} = G_o^1 + j \cdot B_o^1$$

(Equation 88)

$\overline{Y_0^1}$	Fundamental frequency neutral admittance phasor
$\overline{I_0^1}$	Fundamental frequency zero-sequence current phasor $\left(= \frac{(\overline{I_A^1} + \overline{I_B^1} + \overline{I_C^1})}{3}\right)$
$\overline{U_0^1}$	Fundamental frequency zero-sequence voltage phasor $\left(= \frac{(\overline{U_A^1} + \overline{U_B^1} + \overline{U_C^1})}{3}\right)$
G_o^1	Fundamental frequency conductance, $\mathrm{Re}\left(\overline{Y_0^1}\right)$
B_o^1	Fundamental frequency susceptance, $\mathrm{Im}\left(\overline{Y_0^1}\right)$

$$\mathrm{Im}\left[\overline{Y_0^n}\right] = \mathrm{Im}\left[\frac{3 \cdot \overline{I_0^n}}{-\overline{U_0^n}}\right] = j \cdot B_o^n$$

(Equation 89)

where n = 2, 3, 5, 7 and 9

$\overline{Y_0^n}$	nth harmonic frequency neutral admittance phasor
$\overline{I_0^n}$	nth harmonic frequency zero-sequence current phasor

Table continues on the next page

$\overline{U_0^n}$ nth harmonic frequency zero-sequence voltage phasor

B_o^n nth harmonic frequency susceptance, $\mathrm{Im}\left(\overline{Y_0^n}\right)$

For fault direction determination, the fundamental frequency admittance and harmonic susceptances are summed together in phasor format. The result is the sum admittance phasor defined as

$$\overline{Y}_{osum} = \mathrm{Re}\left[\overline{Y_0^1}\right] + j \cdot \mathrm{Im}\left[\overline{Y_0^1} + \sum_{n=2}^{9} \overline{Y_0^n}\right] = G_o^1 + j \cdot B_{osum}$$

(Equation 90)

The polarity of the polarizing quantity (residual voltage) can be changed (rotated by 180 degrees) by setting the *Pol reversal* parameter to "True" or by switching the polarity of the residual voltage measurement wires.

Fault direction determination

If an earth fault is detected by the GFC module, the fault direction is evaluated based on the calculated sum admittance phasor $\overline{Y}_{osum}$ obtained from the Multi-frequency admittance calculation module. To obtain dependable and secure fault direction determination regardless of the fault type (transient, intermittent, restriking, permanent, high or low ohmic), the fault direction is calculated using a special filtering algorithm, Cumulative Phasor Summing (CPS) technique. This filtering method is advantageous during transient, intermittent and restriking earth faults with dominantly non-sinusoidal or transient content. It is equally valid during continuous (stable) earth faults.

The concept of CPS is illustrated in *Figure 321*. It is the result of adding the values of the measured sum admittance phasors together in phasor format in chronological order during the fault. Using the discrete sum admittance phasors $\overline{Y}_{osum}$ in different time instants (t_1...t_5), the corresponding accumulated sum admittance phasor $\overline{Y}_{osum\_CPS}$ is calculated. This phasor is used as directional phasor in determining the direction of the fault.

$$\overline{Y}_{osum\_CPS}(t_1) = \overline{Y}_{osum}(t_1)$$

(Equation 91)

$$\overline{Y}_{osum\_CPS}(t_2) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2)$$

(Equation 92)

$$\overline{Y}_{osum\_CPS}(t_3) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3)$$

(Equation 93)

$$\overline{Y}_{osum\_CPS}(t_4) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3) + \overline{Y}_{osum}(t_4)$$

(Equation 94)

$$\overline{Y}_{osum\_CPS}(t_5) = \overline{Y}_{osum}(t_1) + \overline{Y}_{osum}(t_2) + \overline{Y}_{osum}(t_3) + \overline{Y}_{osum}(t_4) + \overline{Y}_{osum}(t_5)$$

(Equation 95)

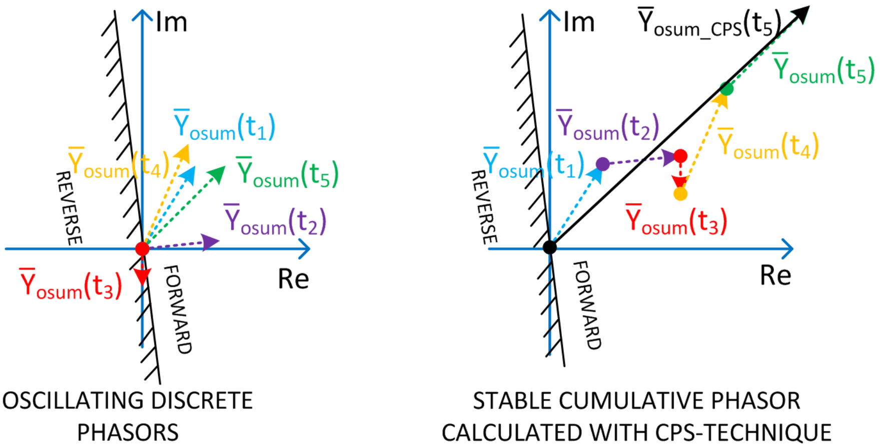


Figure 321: Principle of Cumulative Phasor Summing (CPS)

The CPS technique provides a stable directional phasor quantity despite individual phasors varying in magnitude and phase angle in time due to an unstable fault type such as a restriking or intermittent earth fault. This is also true for harmonic components included in the sum admittance phasor. Harmonics typically have a highly fluctuating character.

Harmonic components provide a more distinctive directional determination in compensated networks than the fundamental frequency component. With higher frequencies, the compensation coil appears as very high impedance and the harmonics are not affected by compensation coil and degree of compensation. When harmonics are present, they cause the sum admittance phasor to behave as in case of an unearthed network, where directional phasors point in opposite directions in the faulty and healthy feeder.

The direction of MFADPSDE is defined with setting *Directional mode* as "Forward" or "Reverse". The operation characteristic is defined by a tilted operation sector as illustrated in *Figure 322*. The characteristic provides universal applicability, that is, it is valid in both compensated and unearthed networks even if the compensation coil is temporarily switched off. The tilt of the operation sector is defined with setting *Tilt angle* to compensate the measurement errors of residual current and voltage transformers. The typical setting value of 5 degrees is recommended, but it should always reflect the maximum expected measurement errors.

In case of unearthed network operation, adequate tilt angle must be allowed to ensure dependable operation of MFADPSDE.

In *Figure 322*, phasors 1...4 demonstrate the behavior of the directional phasor in different network fault conditions.

- Phasor 1 depicts the direction of the accumulated sum admittance phasor in case of earth fault outside the protected feeder (assuming that the admittance of the protected feeder is dominantly capacitive). The result is valid regardless of the fault type (low ohmic, high(er) ohmic, permanent, intermittent or restriking). If harmonic components are present in the fault quantities, they turn the phasor alignment to the negative Im(Yo) axis.
- Phasor 2 depicts the direction of accumulated sum admittance phasor in case of earth fault inside the protected feeder when the network is unearthed. The result is also valid in compensated networks when there are harmonic components in the fault quantities (typically low-ohmic permanent, intermittent or restriking fault). In this case, the result is valid regardless of network's actual compensation degree. Harmonics would turn the phasor align to the positive Im(Yo) axis.
- Phasors 3 and 4 depict the direction of accumulated sum admittance phasor in case of higher-ohmic earth fault in the protected feeder without harmonics in the fault quantities when the network is compensated. As no harmonic components are present, the phase angle of the accumulated phasor is determined by the compensation degree of the network. With a high degree of overcompensation, the phasor turns towards the negative Im(Yo) axis (as phasor 4).

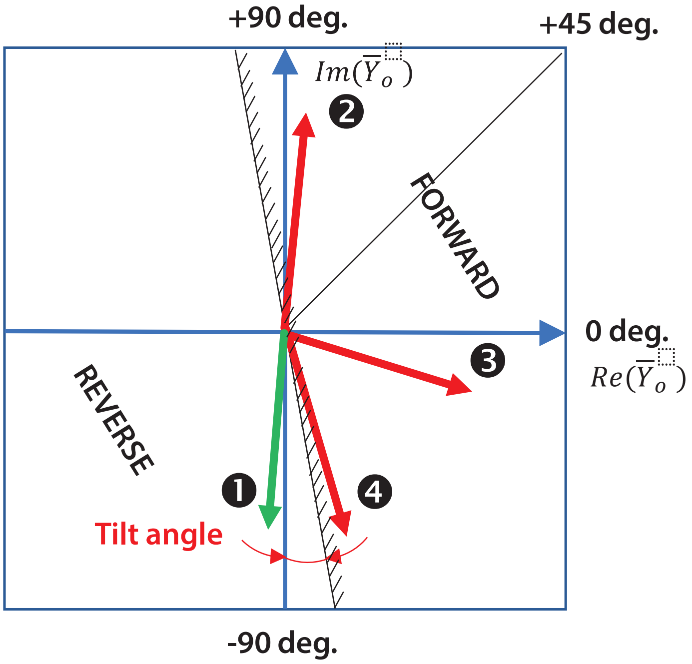


Figure 322: Directional characteristic of MFADPSDE

The residual current should be measured with accurate Core Balance Current Transformer (CBCT) to minimize the measurement errors, especially phase displacement. This is especially important when high sensitivity of protection is targeted.

The characteristic *Tilt angle* should reflect the measurement errors, that is, the larger the measurement errors, the higher the *Tilt angle* setting should be. A typical setting value of 5 degrees is recommended.

The maximum value for characteristic *Tilt angle* depends on the ratio of the resistive and reactive component in the measured residual current Io. The operation point moves away from the operation sector mid-point; the lower is the ratio of the resistive and reactive component in the measured residual current Io. The phase angle of operation point in the faulted feeder can be approximated with equation

$$\varphi = atan\left(\frac{I_{EFFd} + I_{detuning}}{I_{damping}}\right)$$

(Equation 96)

I_{EFFd}	Earth-fault current produced by the protected feeder [A]
$I_{detuning}$	Detuning of the arc suppression coil [A]
$I_{damping}$	System damping [A]

Example 1:

I_{EFFd} = 30 A, $I_{detuning}$ = +10 A and $I_{damping}$ = 10 A. From *Equation 96*, j = 76 deg. Thus *Tilt angle* should not exceed ~10 deg.

Example 2:

I_{EFFd} = 50 A, $I_{detuning}$ = +10 A and $I_{damping}$ = 5 A. From *Equation 96*, j = 85 deg. Thus *Tilt angle* should not exceed ~3 deg. However, such a low Tilt angle setting may endanger the security of protection due to measurement errors of the CBCTs. In this case, the phase angle of operation point should be increased by considering:

1. System damping increase by increasing the current value of the parallel resistor of the coil.
2. Reduction of the earth-fault current produced by the protected feeder by, for example, installation of distributed compensation coils or by change of the feeder topology.
3. Reduction of overcompensation of the network. The recommendation is to use the undercompensation mode.

The `DIRECTION` output indicates on which operating sector the current is measured. The `FAULT_DIR` output indicates in which operation sector the fault current is measured. The output is operational once the function is started.

To adapt the fault direction determination to possible fault direction change during the fault, for example, during manual fault location process, a cyclic accumulation of sum admittance phasors is conducted. The duration of this directional evaluation cycle is 1.2 · *Reset delay time* (minimum of 600 ms). If the fault direction based on the cyclic phasor accumulation is opposite to the function direction output for *Reset delay time* or 500 ms (minimum of 500 ms), the function is reset and fault direction calculation of MFADPSDE is restarted.

If the earth-fault protection generates alarms, MFADPSDE also includes a `RESET` input which can be used to externally re-trigger the fault direction determination if reevaluation of fault direction during a persistent earth fault is required.

It is also recommended to connect the start signal of non-directional earth fault protection (EFxPTOC), set to operate in case of a cross-country fault, to `RESET` input or `BLOCK` input of MFADPSDE to reset phasor accumulation during a cross-country fault. MFADPSDE can then adapt to a fault direction change more rapidly if a singlephase earth fault persists in the system after the other faulty feeder has been tripped (the cross-country fault has been transformed into a single-phase earth fault).

The direction of MFADPSDE is supervised by a settable current magnitude threshold, setting *Min operate current*. The operate current used in the magnitude supervision is measured with a special filtering method, which provides a stable residual current estimate regardless of the fault type. This estimate is the result of the fundamental frequency admittance calculation using the CPS technique. The stabilized current value is obtained (after conversion) from the corresponding admittance value by multiplying it by the system nominal phase-to-earth voltage value. The equations for calculating the stabilized values of the fundamental frequency admittance and the corresponding current are given below.

$$\overline{Y^1_{o\ stab}} = \frac{3 \cdot \overline{I^1_{0\,CPS}}}{-\overline{U^1_{0\,CPS}}} = \mathrm{Re}\left[\overline{Y^1_{o\ stab}}\right] + j \cdot \mathrm{Im}\left[\overline{Y^1_{o\ stab}}\right] = G^1_{ostab} + j \cdot B^1_{ostab}$$

(Equation 97)

$\overline{Y^1_{o\ stab}}$	Stabilized fundamental frequency admittance estimate, which is result from fundamental frequency admittance calculation utilizing the Cumulative Phasor Summing (CPS) technique.
$\overline{I^1_{0\,CPS}}$	Fundamental frequency zero-sequence current phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.
$\overline{U^1_{0\,CPS}}$	Fundamental frequency zero-sequence voltage phasor calculated utilizing the Cumulative Phasor Summing (CPS) technique.
G^1_{ostab}	Real-part of stabilized fundamental frequency conductance estimate.
B^1_{ostab}	Imaginary part of stabilized fundamental frequency susceptance estimate.

$$\overline{I^1_{o\ stab}} = (G^1_{ostab} + j \cdot B^1_{ostab}) \cdot U_{baseres} = I^1_{oCosstab} + j \cdot I^1_{oSinstab}$$

(Equation 98)

$\overline{I^1_{o\ stab}}$	Stabilized fundamental frequency residual current estimate, which is obtained (after conversion) from the corresponding admittance value by multiplying it with the system nominal phase-to-earth voltage value.
$\overline{I^1_{o\ Cosstab}}$	Real-part of stabilized fundamental frequency residual current estimate.
$\overline{I^1_{o\ Sinstab}}$	Imaginary part of stabilized fundamental frequency residual current estimate.
$U_{baseres}$	System nominal phase-to-earth voltage value.

The main advantage of the filtering method is that due to the admittance calculation, the resulting current value does not depend on the fault resistance value, that is, the estimated current magnitude equals the value that is measured during a solid earth fault (Rf = 0 Ω). Another advantage of the method is that it can estimate correct current magnitude also during intermittent or restriking faults.

The setting *Min operate current* defines the minimum operate current which must be exceeded for the function to start or operate.

Setting *Operating quantity* defines whether the current magnitude supervision is based on the “Adaptive”, “Amplitude” or “Resistive” methods.

Table 615: Comparison of Operating quantity of MFADPSDE with traditional methods

Traditional method	Setting Operating quantity of MFADPSDE		
	Adaptive	Amplitude	Resistive
Iosin		x	
Iocos			x
Iosin/Iocos	x		

When Operating quantity is set to "Adaptive", the method adapts the principle of current magnitude supervision to the system earthing condition. This is done by monitoring the phase angle of accumulated sum admittance phasor, (see Figure 323).

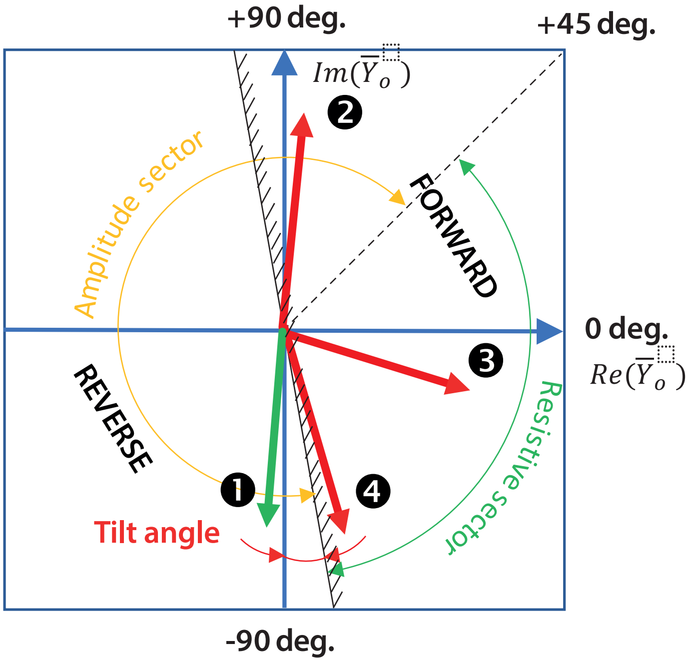


Figure 323: Automatic adaptation of current magnitude supervision condition (setting Min operate current) to either resistive part or amplitude of I1 ostab based on the phase angle of accumulated sum admittance phasor, when setting Operating quantity = "Adaptive". Directional mode = "Forward"

If the phase angle of accumulated sum admittance phasor is greater than 45 degrees, current magnitude supervision is based on the amplitude of $\overline{I^1_{o\,stab}}$, which must exceed the set minimum operate current threshold. If the phase angle of accumulated sum admittance phasor is below 45 degrees, current magnitude supervision is based on the resistive part of $\overline{I^1_{o\,stab}}$, which must exceed the set minimum operate current threshold. This automatic adaptation of the magnitude supervision condition enables secure and dependable directional determination in compensated networks, and it is also valid when the network is unearthed (compensation coil is switched off).

If operation direction is set to reverse, the resistive and amplitude sectors are mirrored in the operation characteristics.

Setting *Operating quantity* should be set to "Adaptive" in resonant earthed systems, except when protected feeders are overcompensated by distributed coils. In such a case, *Operating quantity* should be set to "Resistive".

Setting *Operating quantity* to "Adaptive" enables secure and dependable directional determination in compensated networks, which is also valid when the compensation coil is switched off and the network becomes unearthed. In case of an unearthed network, *Min operate current* is automatically compared to the amplitude of $\overline{I^1_{o\,stab}}$. In case of restriking earth-faults, harmonics created by the fault type make the accumulated sum admittance phasor behave as in case of an unearthed network. Therefore, operation can be achieved without the need for resistive part of $\overline{I^1_{o\,stab}}$. This also means that in compensated networks during earth faults with rich harmonic content in residual quantities, operation can be achieved without the parallel resistor of the centralized compensation coil.

When *Operating quantity* is set to "Resistive", the set minimum operate current threshold (setting Min operate current) is compared to the resistive component of $\overline{I^1_{o\,stab}}$ in the whole defined operate sector (see *Figure 324*).

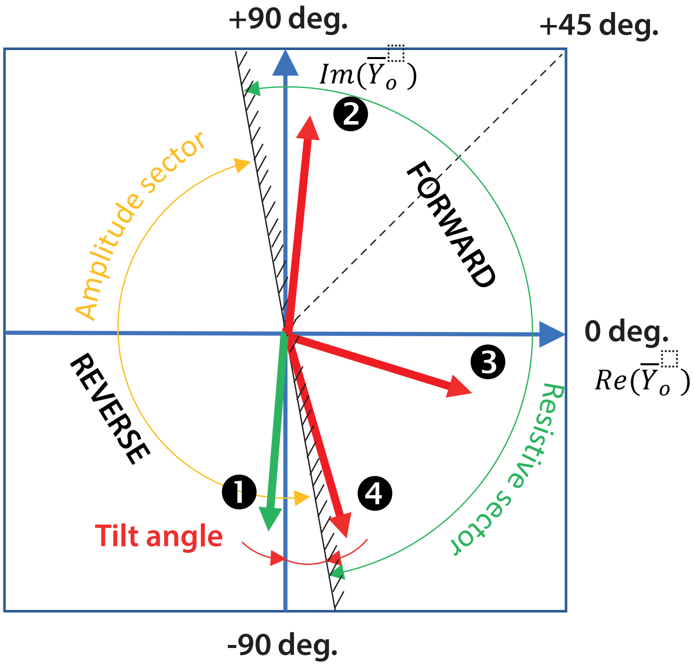


Figure 324: Operating quantity = "Resistive" and Directional mode = "Forward"

The resistive mode is valid for resonant earthed networks and high-resistance earthed systems, but not in case of unearthed networks. The resistive mode must be selected when there is a risk of local overcompensation of a protected feeder, that is, when the earth-fault current is compensated with distributed compensation coils and their inductive current exceeds the amount of capacitive current produced by the phase-to-earth capacitances of the feeder.

In compensated networks, where distributed compensation coils are also used to compensate earth-fault current, setting *Operating quantity* should be set to "Resistive". This enables secure and dependable directional determination also in case of local overcompensation where the earth-fault current produced by the healthy feeder can become inductive.

When *Operating quantity* is set to "Amplitude", the set minimum operate current threshold (setting *Min operate current*) is compared to the amplitude of $\overline{I}^{1}_{o\,stab}$ in the whole defined operate sector (see *Figure 325*). This selection can be used in unearthed networks.

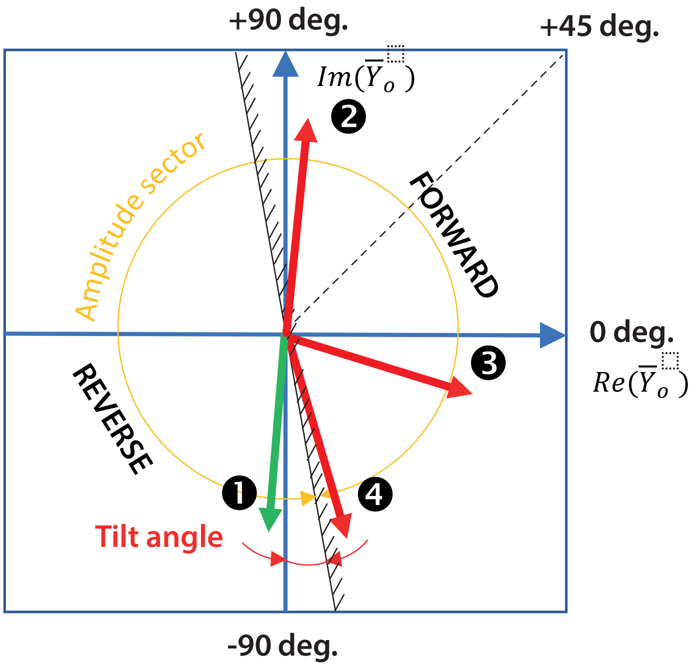


Figure 325: Operating quantity = "Amplitude" and Directional mode = "Forward"

If the “Adaptive” or “Resistive” operating quantity is selected, the setting *Min operate current* should be set to value:

$$[pu] < p \cdot IRtot$$

(Equation 99)

[pu]	Min operate current
IRtot	Total resistive earth-fault current of the network corresponding to the resistive current of the parallel resistor of the coil and the natural losses of the system (typically in order of 1...5 % of the total capacitive earth-fault current of the network).
p	security factor = 0.5...0.7

It must be set to a value which is lower than the total resistive earth-fault current in order to enable dependable operation.

Estimation of the total resistive earth-fault current of the network including the parallel resistor of the coil and the network losses can be obtained from the network calculation results of the coil controller in resonant earthed networks. In Petersen coil controller, this value is denoted as ‘I_DAMPING’ [A]. When evaluating this numerical value, the connection status of the parallel resistor of the coil must be considered. See the example in *Figure 326*. In this case, the parallel resistor of the coil has value 8.6 A and it is permanently connected. The total system damping is calculated as 11.29 A. Thus the natural network losses including the losses of the coil are 11.29 A - 8.6 A = 2.69 A.

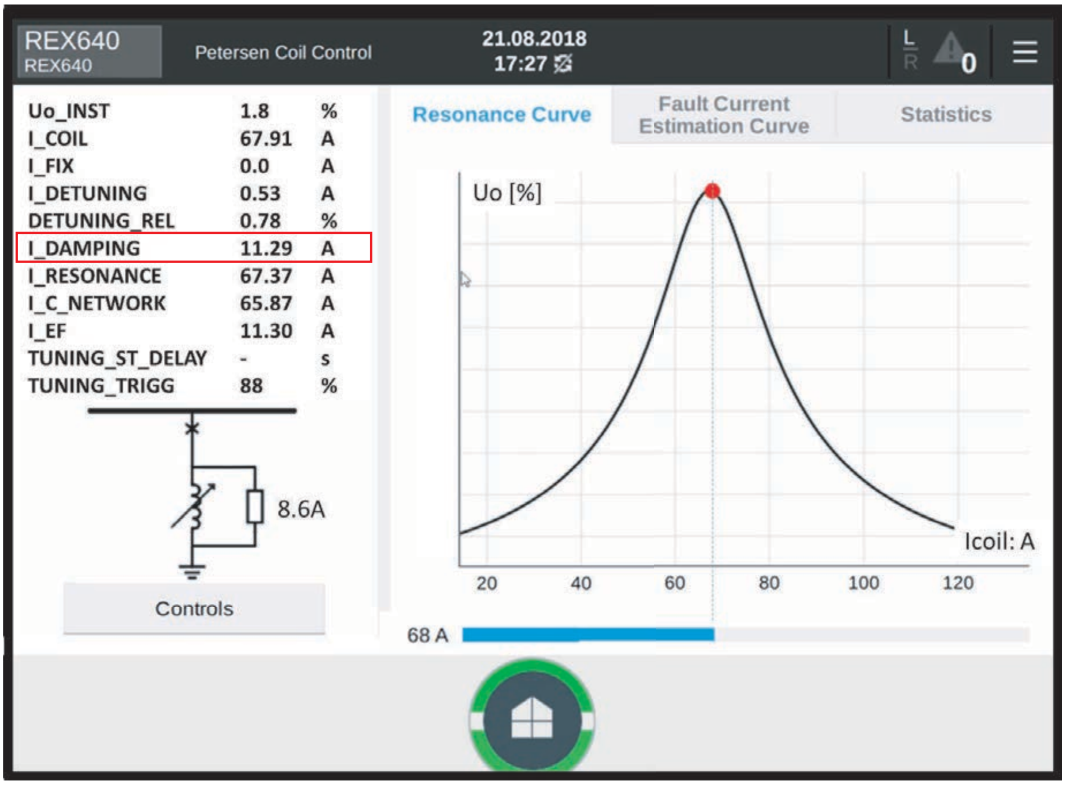


Figure 326: Example of interpretation of network damping value, I_DAMPING, calculated by the coil controller

For example, if the resistive current of the parallel resistor is 10 A (at primary voltage level), then a value of 0.5 · 10 A = 5 A could be used for setting *Min operate current*.

The network damping value, I_DAMPING, calculated by the coil controller can be used as a base for setting *Min operate current*.

If *Operating quantity* is set to "Adaptive", the setting value *Min operate current* is also applicable if the coil is disconnected and the network becomes unearthed. In this case, the current magnitude supervision is automatically based on the amplitude of $\overline{I}^{1}_{o\ stab}$). The selected setting value must never exceed the ampere value of the parallel resistor in order to allow operation in the faulty feeder. In case of smaller ampere value of the parallel resistor, for example 5 A, the recommended security factor should be higher, for example 0.7, so that sufficient margin for CT and VT errors can be achieved.

If *Operating quantity* is set to "Amplitude", the *Min operate current* setting should be selected based on the capacitive earth-fault current values produced by the background network in case of a solid earth fault with a security margin.

The main task of the current magnitude supervision module is to secure the correct directional determination of an earth fault so that only the faulty feeder is disconnected or generates alarms. Therefore, the threshold value *Min operate current* should be selected carefully and should not be set too high as this can inhibit the disconnection of the faulty feeder.

The residual current should be measured with an accurate CBCT to minimize the measurement errors, especially phase displacement.

The parallel resistor should be kept connected during the healthy state so that in case of a fault, earth-fault protection can immediately see sufficient value of resistive component for operation. If the parallel resistor is kept disconnected during the healthy state, it should be immediately connected when the earth fault is detected. This enables the earth-fault protection to operate without delay.

Transient detector

The Transient detector module is used for detecting transients in the residual current and zero-sequence voltage signals. Whenever transient is detected, this is indicated with the PEAK_IND output. When the number of detected transients equals or exceeds the *Peak counter limit* setting (without the function being reset, depending on the drop-off time set with the *Reset delay time* setting), INTR_EF output is activated. This indicates detection of restriking or intermittent earth fault in the network.

Transient detector affects the operation of MFADPSDE (START and OPERATE outputs) when operation mode is “Intermittent EF”. For other operation modes, (“General EF”, “Alarming EF”), PEAK_IND and INTR_EF outputs can be used for monitoring purposes. The operation of the Transient detector is illustrated in *Figure 327*.

Several factors affect the magnitude and frequency of fault transients, such as the fault inception angle on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. If the fault is permanent (non-transient), the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients. The practical sensitivity of transient detection is limited to approximately a few hundreds of ohms of fault resistance. Therefore the application of transient detection is limited to low-ohmic earth faults.

Transient detector is a non-directional function. Thus, if detection of restriking or intermittent earth faults is wanted only in the faulted feeder, the START and INTR_EF outputs must be ANDed in the configuration.

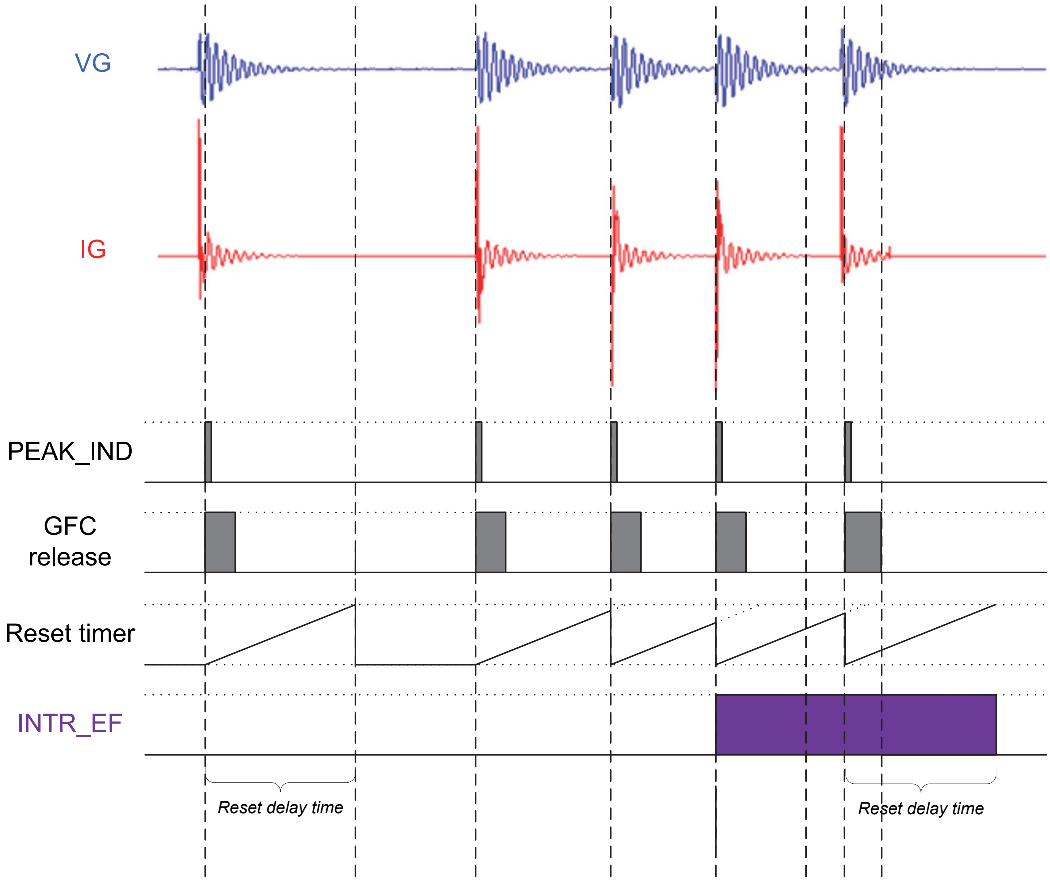


Figure 327: Example of operation of Transient detector: indication of detected transient by PEAK_IND output and detection of restriking or intermittent earth fault by INTR_EF output (setting Peak counter limit = 3)

Operation logic

MFADPSDE supports four operation modes selected with setting Operation mode: "General EF", "Alarming EF", "Intermittent EF" and "Transient EF".

General EF

Operation mode “General EF” is applicable to various earth faults in high-impedance earthed networks, that is, in compensated, unearthed and high-resistance earthed networks. It detects earth faults regardless of their type (transient, intermittent or restriking, permanent, high or low ohmic) and provides definite operate time for protection regardless of the fault type.

In “General EF” mode, the operate timer is started in the following conditions.

- Earth fault is detected by the GFC
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current $\overline{I_{o\ stab}^{1}}$ exceeds the set *Min operate current* level which is applied in current magnitude threshold supervision, and which is further defined with setting *Operating quantity* (available options are "Adaptive", "Amplitude" and "Resistive").

The START output is activated once *Start delay time* has elapsed. OPERATE output is activated once *Operate delay time* has elapsed and the above three conditions are valid. Reset timer is started if any of the above three conditions is not valid. If the fault is transient and self-extinguishes, START output stays activated until the elapse of reset timer (setting Reset delay time). After OPERATE output activation, START and OPERATE outputs are reset immediately, if any of the above three conditions is not valid. The start duration value START_DUR, available in the Monitored data view, indicates the percentage ratio of the start situation and the set operating time.

If detection of temporary earth faults is not desired, the activation of START output can be delayed with setting *Start delay time*. The same setting can also be used to avoid restarting of the function during long lasting post-fault oscillations, if time constant of post-fault oscillations is very long (network losses and damping is low).

To keep the operate timer activated between current spikes during intermittent or restriking earth fault, the *Reset delay time* should be set to a value exceeding the maximum expected time interval between fault spikes (obtained at full resonance condition). Recommended value is at least 300 ms.

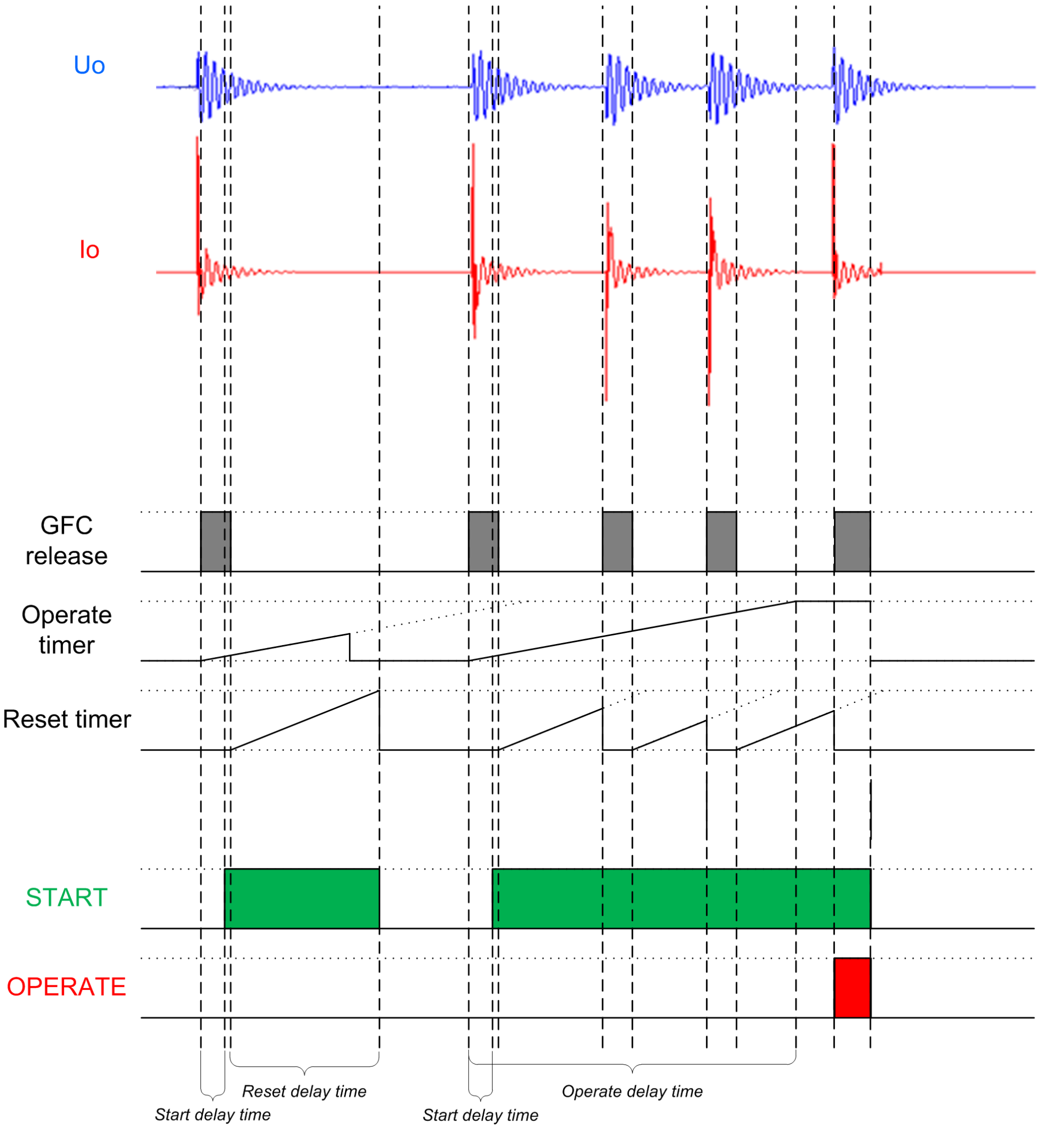


Figure 328: Operation in "General EF" mode

Alarming EF

Operation mode "Alarming EF" is applicable in all kinds of earth faults in high-impedance earthed networks, that is, in compensated, unearthed and high resistance earthed networks, where fault detection is only alarming. It is intended to detect earth faults regardless of their type (transient, intermittent or restriking, permanent, high or low ohmic).

In "Alarming EF" mode, the operate timer is started during the following conditions.

- Earth fault is detected by the GFC
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current $\overline{I_{o\,stab}^{1}}$ exceeds the set *Min operate current* level, which is applied in current magnitude threshold supervision, and which is further defined with setting *Operating quantity* (available options are "Adaptive", "Amplitude" and "Resistive").

The START output is activated once *Start delay time* has elapsed. OPERATE output is not valid in the "Alarming EF" mode. Reset timer is started if any of the above three conditions are not valid. In case the fault is transient and self-extinguishes, START output stays activated until the elapse of reset timer (setting *Reset delay time*).

If detection of temporary earth faults is not desired, the activation of START output can be delayed with setting *Start delay time*.

To keep the operate timer activated between current spikes during intermittent or restriking earth fault, the *Reset delay time* should be set above the maximum expected time interval between fault spikes (obtained at full resonance condition). The recommended value is at least 300 ms.

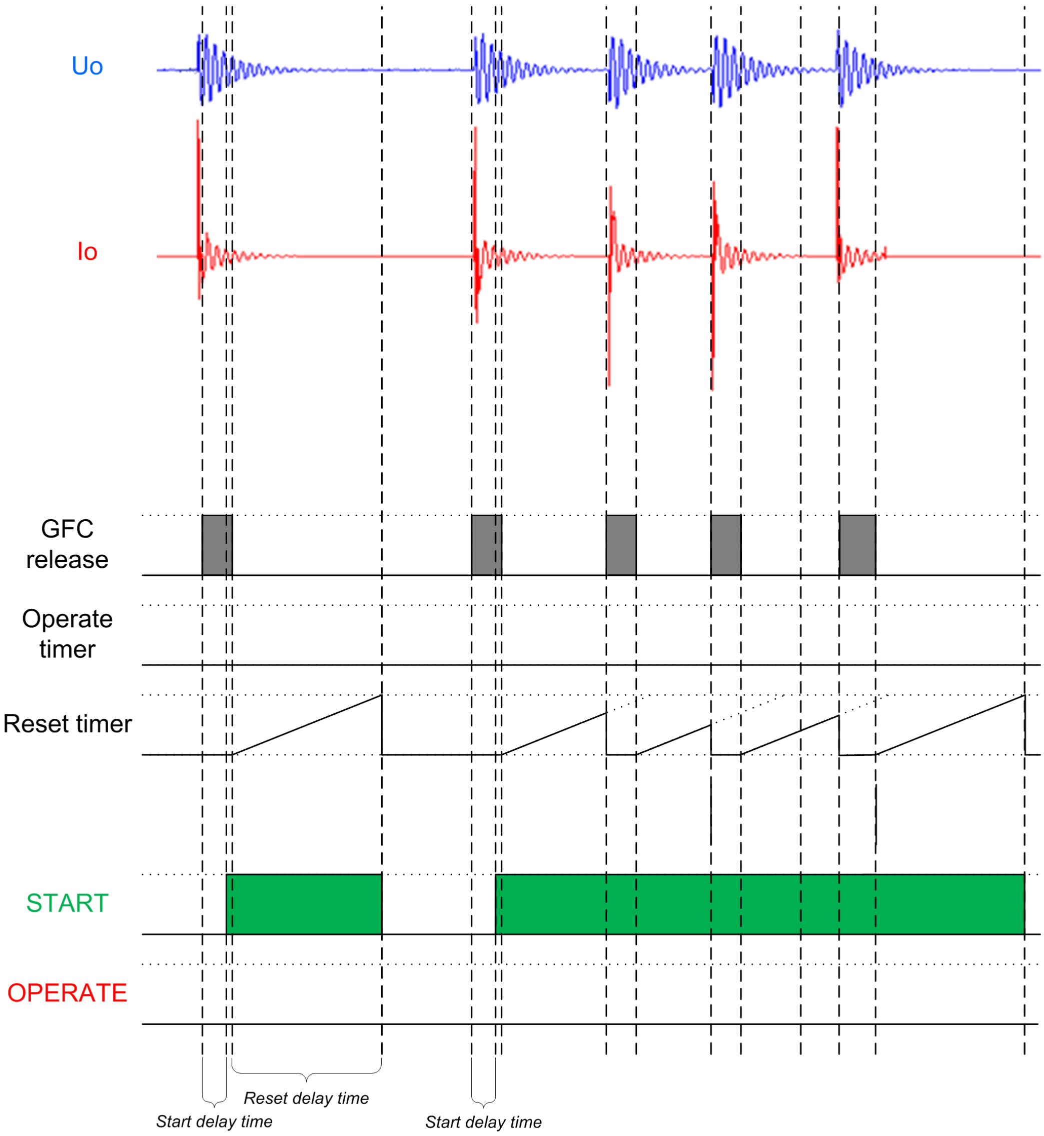


Figure 329: Operation in "Alarming EF" mode

Intermittent EF

Operation mode “Intermittent EF” is used to detect restriking or intermittent earth faults. A required number of intermittent earth fault transients set with the *Peak counter limit* setting must be detected for operation. Therefore, transient faults or permanent faults with only initial fault ignition transient are not detected in this mode. The application of “Intermittent EF” mode is limited to low ohmic intermittent or restriking earth faults.

In the “Intermittent EF” mode, the operate timer is started when the following conditions are met.

- Transient is detected by the Transient detector (indicated with PEAK_IND output)
- Earth fault is detected by the GFC at time of transient
- Fault direction equals *Directional mode* setting
- Estimated stabilized fundamental frequency residual current $\overline{I}^{1}_{o\,stab}$ exceeds the set *Min operate current* level, which is applied in current magnitude threshold supervision, and which is further defined with setting *Operating quantity* (available options are "Adaptive", "Amplitude" and "Resistive").

When a required number of intermittent earth-fault transients set with the *Peak counter limit* setting are detected without the function being reset (depends on the drop-off time set with the *Reset delay time* setting), the START output is activated. The INTR_EF output is activated to indicate the fault type is intermittent or restriking earth fault. The operate timer is kept activated as long as transients occur during the drop-off time defined by setting *Reset delay time*.

The OPERATE output is activated when *Operate delay time* has elapsed, required number of transients has been detected, earth fault is detected by the GFC, fault direction matches the *Directional mode* setting and estimated stabilized fundamental frequency residual current exceeds set *Minimum operate current* setting.

Reset delay time starts to elapse from each detected transient. Function is reset if time between current peaks is more that *Reset delay time* or if the General Fault Criterion release is reset. After OPERATE output activation, START and OPERATE outputs are reset immediately at the falling edge of General Fault Criterion release, that is, when zero-sequence voltage falls below *Voltage start value*. This should be considered if “Intermittent EF" mode is applied in case earth faults are only alarmed to avoid repetitive start and operate events.

Peak counter limit setting should not be set below 3 in order to provide secure indication of intermittent/restriking earth faults. This is due to the fact that sometimes the fault ignition transient is characterized by highly distorted waveform, which may result in multiple transient detection at time of fault ignition. By increasing the value of *Peak counter limit* setting, the security of correct fault type identification is increased.

To keep the operate timer activated between current spikes during intermittent or restriking earth faults, *Reset delay time* should be set above the maximum expected time interval between fault spikes (obtained at full resonance condition). The recommended value is at least 300 ms.

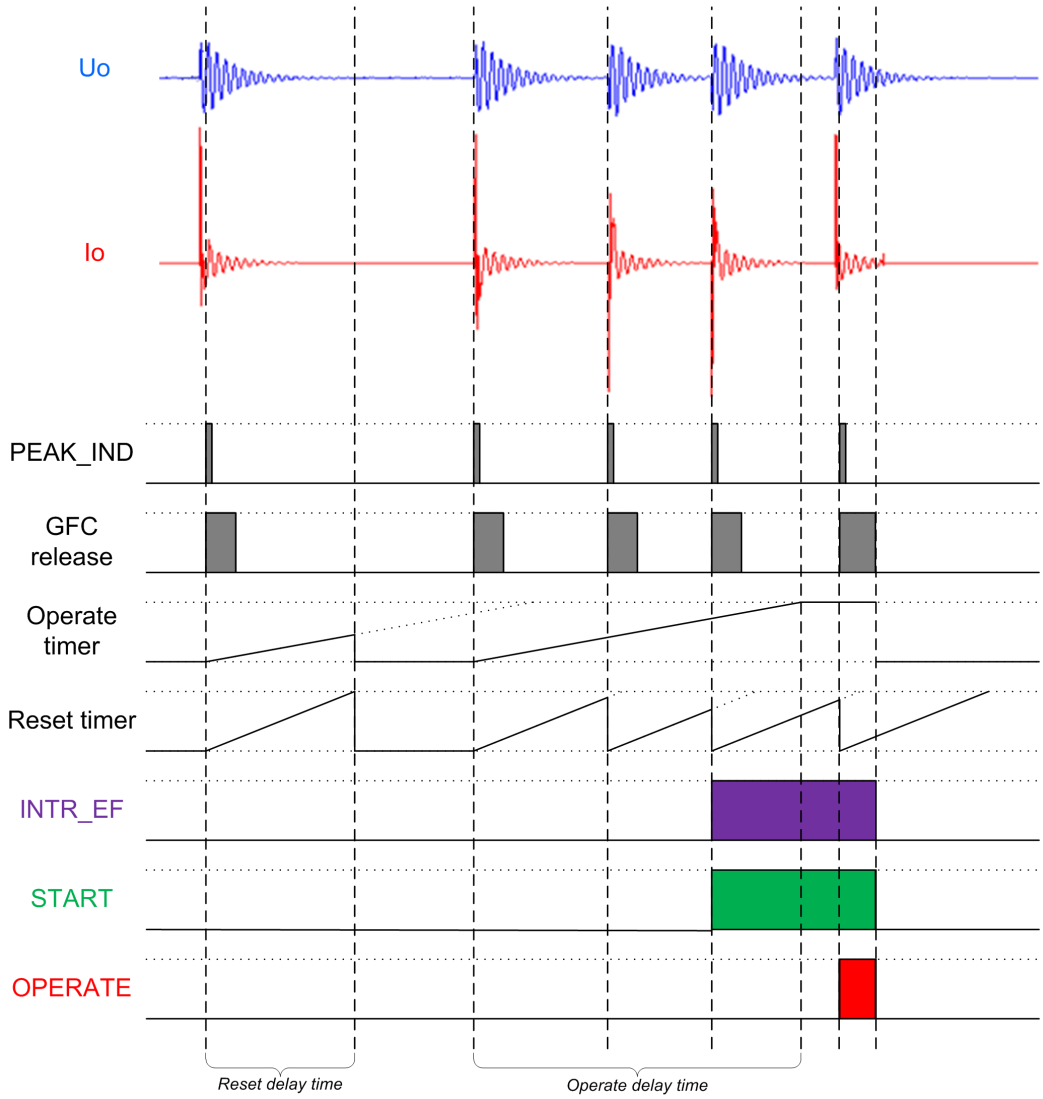


Figure 330: Operation in "Intermittent EF" mode, Peak counter limit = 3

Transient EF

Operation mode "Transient EF" is dedicated for detecting fast transient faults where the fault current stays on only for a very short time. It is recommended method in networks, where network damping has very small value or when parallel resistor of the coil is not used, for example in sub-transmission networks.

In the "Transient EF" mode, the fault direction is determined from the beginning of the fault and is held until earth-fault is detected by GFC.

In the "Transient EF" mode, the operate timer is started when the following conditions are met.

- Earth fault is detected by the GFC
- Fault direction equals Directional mode setting and fault direction detection is done only at the beginning of the fault

- Estimated stabilized fundamental frequency residual current $\overline{I^{1}_{o\,stab}}$ exceeds the set Min operate current level, which is applied in current magnitude threshold supervision, and which is further defined with setting Operating quantity (available options are "Adaptive", "Amplitude" and "Resistive").

In the “Transient EF” mode, the START output is activated immediately when start conditions are met.

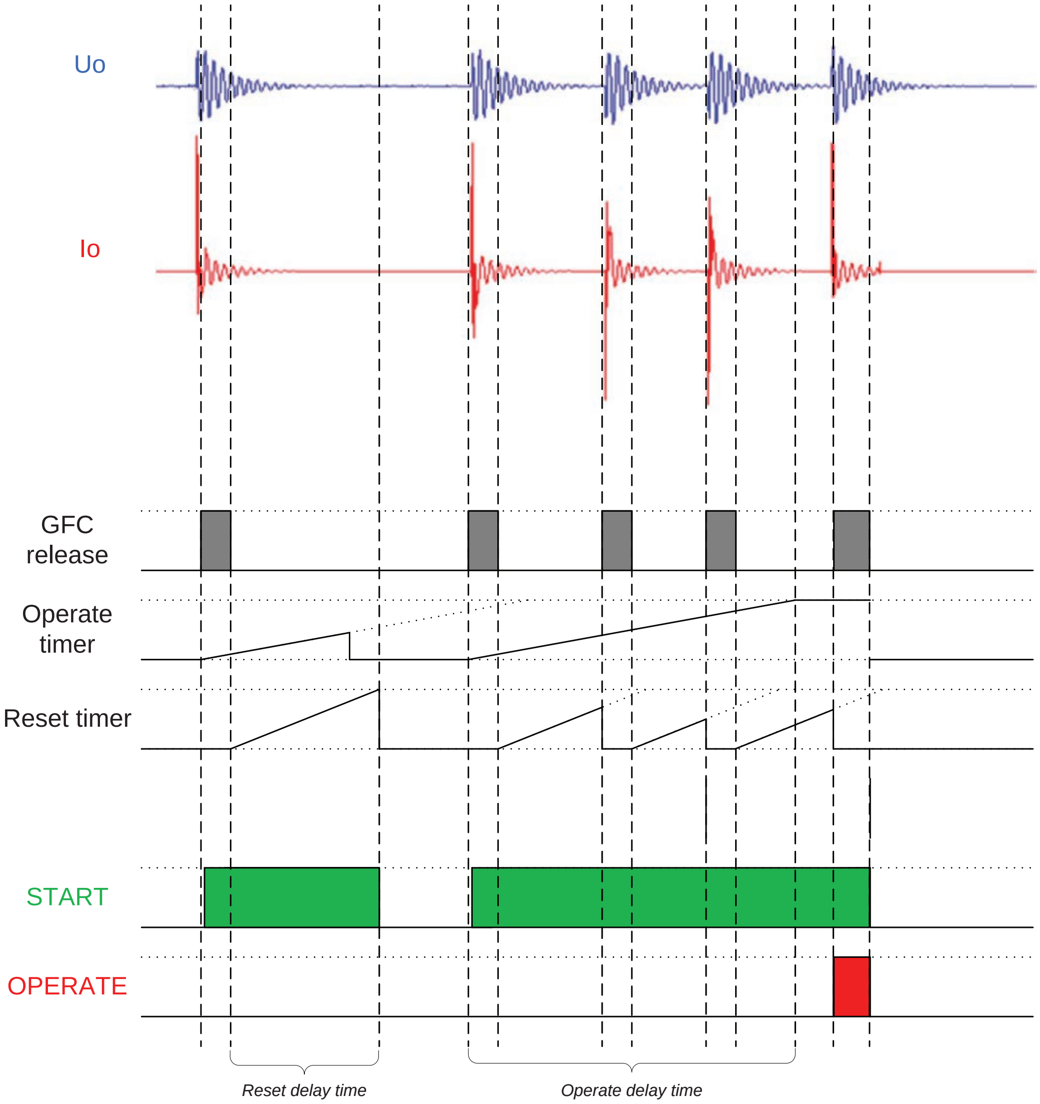


Figure 331: Operation in “Transient EF” mode

When operation mode “Transient EF” is selected, *Operating quantity* should be set to "Resistive" and *Min operate current* to the minimum value. *Tilt angle* should be 10 degrees especially if the residual current is measured with Holmgreen (sum) connection of phase current CTs.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

If the BLOCK input of MFADPSDE is used in the configuration, then "Block all" mode is recommended.

Recommended uses of the BLOCK input of MFADPSDE are:

1. Connecting the start signal of non-directional earth fault protection (EFxPTOC), set to operate in case of a cross-country fault, to BLOCK input of MFADPSDE to reset phasor accumulation during a cross-country fault. MFADPSDE can then adapt to a fault direction change more rapidly if a single-phase earth fault persists in the system after the other faulty feeder has been tripped (the cross-country fault has been transformed into a single-phase earth fault).
2. Connecting the ‘Auto-Reclose in progress’ output (INPRO) from DARREC to BLOCK input of MFADPSDE to allow faster reset of MFADPSDE during high-speed auto-reclosing cycle HSAR when setting *Reset delay time* equals or is higher than the dead time of high-speed auto-reclosing cycle HSAR.
3. In case of a network with distributed coils but no centralized arc suppression coil at the primary substation (unearthed network), it is recommended to add an additional logic to protection configuration, which blocks MFADPSDE if the frequency of measured Uo and Io becomes lower than nominal. Such condition is valid in network when earth fault becomes disconnected and a phenomenon called ‘post-fault oscillation’ is initiated.
4. If the parallel resistor of the coil has long connection delay, it is recommended to add an additional logic to protection configuration to enable the release of MFADPSDE at the time of the parallel resistor switching.

The logic to release MFADPSDE at time of resistor (re)connection is illustrated in *Figure 332*.

- Detection of earth fault from residual overvoltage, ROVPTOV
- Delay of release MFADPSDE using TONGAPC connected to the BLOCK input of MFA (inversed)
- Delay of release (TONGAPC: On delay time (ms)) based on known time delays in resistor connection
- Protection operate delay time to be set smaller than the resistor connection duration.

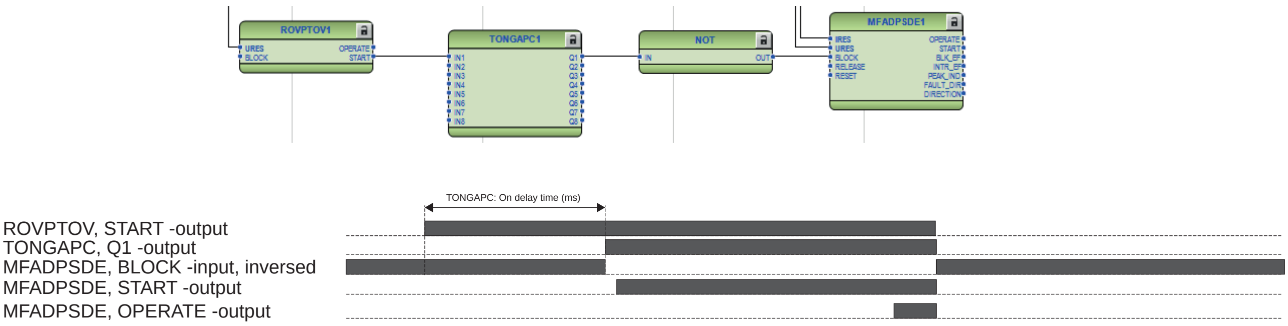


Figure 332: Logic to release MFADPSDE at the time of resistor (re)connection

The logic enables exact operate time of MFADPSDE elapsed from time of resistor (re)connection.

In the configuration, equal *Reset delay time* and *Voltage start value* must be used for ROVPTOV and MFADPSDE.

The release delay should be based on known delays in resistor (re)connection:

- Logic OFF-ON-OFF: *Switch on delay* of the parallel resistor.
- Logic ON-OFF-ON: *Switch off delay* + *Time off* time of the parallel resistor.

The resulting total protection operate time is defined as follows:

- Logic OFF-ON-OFF: *Switch on delay* of the parallel resistor + set *Operate delay time* of MFADPSDE.
- Logic ON-OFF-ON: *Switch off delay* + *Time off* time of the parallel resistor + set *Operate delay time* of MFADPSDE.
- Set *Operate delay time* of MFADPSDE smaller than the connection duration time of the resistor.

If earth faults are only alarmed, the external logic is not needed.

When the proposed logic is used and indication of transient earth faults is needed, the START output from INTRPTEF can be used.

Timer

If the detected fault direction is opposite to the set directional mode and GFC release is active, BLK_EF output is activated once *Start delay time* has elapsed. Reset timer is activated at the falling edge of GFC release, that is, when zero-sequence voltage falls below *Voltage start value*. BLK_EF is reset once the reset delay time elapses. Activation of the BLOCK input deactivates the BLK_EF output and resets Timer.

BLK_EF output is activated when the following conditions are met:

- Earth fault is detected by the GFC
- Fault direction is opposite to *Directional mode* setting

The estimated stabilized fundamental frequency residual current $\overline{I^{1}_{o\,stab}}$ exceeds the internally fixed threshold, which is 1% of In. This current magnitude threshold supervision is based on the “Amplitude” method.

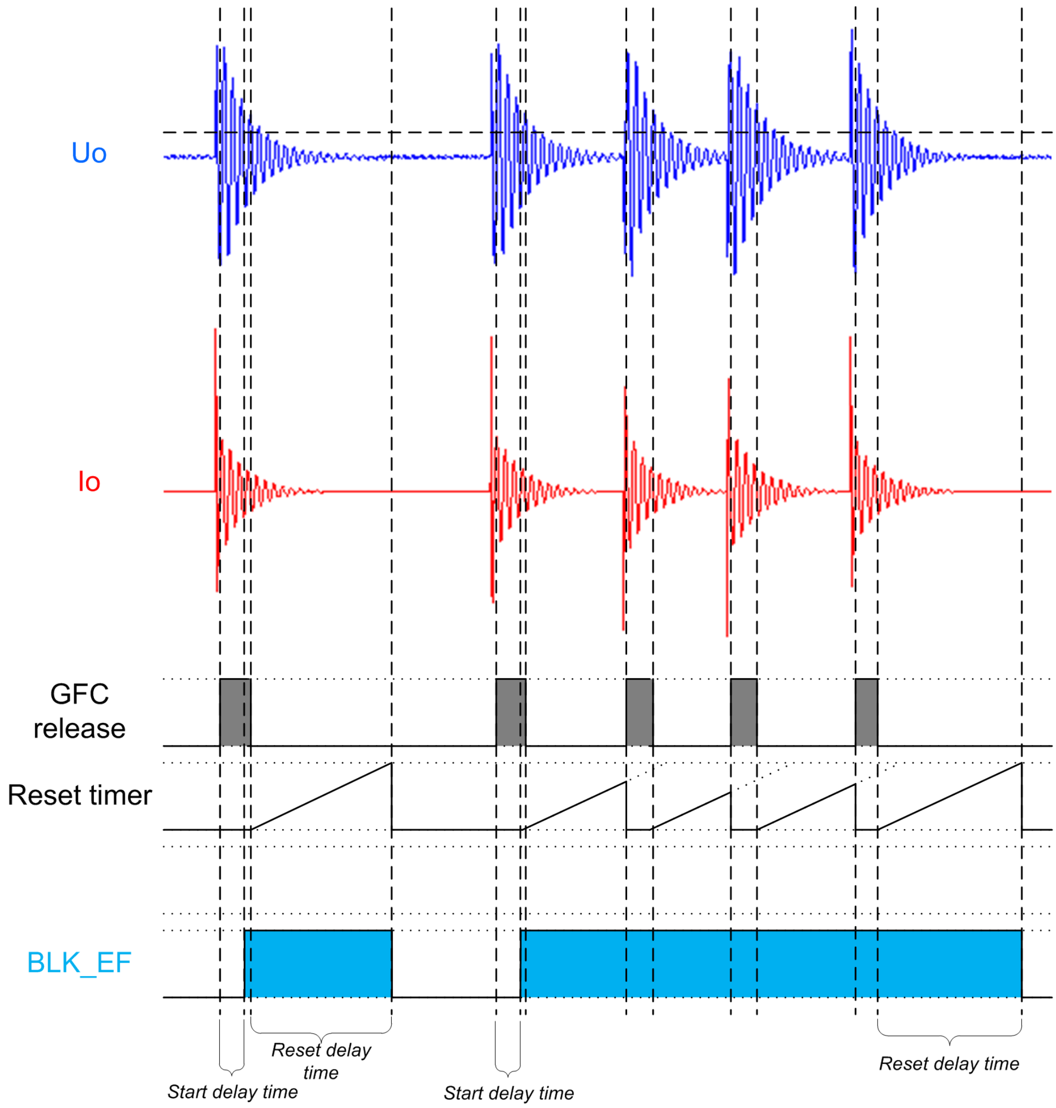


Figure 333: Activation of BLK_EF output (indication that fault is located opposite to the set operate direction)

4.2.9.6 Application

MFADPSDE provides selective directional earth-fault protection for high-impedance earthed networks, that is, for compensated, unearthed and high-resistance earthed systems. It can be applied for the earth-fault protection of overhead lines and underground cables, regardless of the earth-fault type (continuous, transient or intermittent) or the fault resistance value (low or high ohmic). MFADPSDE replaces traditional sensitive directional earth-fault protection (such as Iocos) and transient earth-fault protection (such as Wischer principle) combining the same functionality into a single function block (see *Table 616*).

Table 616: Comparison of the MFADPSDE functionality with traditional methods in resonant earthed networks

	Earth-fault type				
	Transient	Continuous	Restriking / Intermittent	Low-ohmic	High-ohmic
Traditional Iocos		x		x	x
Traditional Wischer	x		x	x	
New MFADPSDE	x	x	x	x	x

As shown by numerous practical field tests, MFADPSDE provides better sensitivity and selectivity compared with traditional methods with less complexity in settings and configuration. MFADPSDE provides enhanced earth-fault protection performance, especially in networks with cable feeders where distributed compensation coils are applied and earth-fault type is typically intermittent. It is applicable in feeders with distributed compensation regardless of the size or localization of distributed coils. Selective protection can be achieved also in case of overcompensated feeders.

MFADPSDE operation is based on multifrequency neutral admittance measurement using the cumulative phasor summing technique. This concept provides extremely secure, dependable and selective earth-fault protection also when the residual quantities are highly distorted and contain non-fundamental frequency components. MFADPSDE is well-suited for compensated networks where measurement signals may have such characteristics, for example, during intermittent earth faults.

MFADPSDE can operate with both low-ohmic and higher-ohmic earth faults, where the sensitivity limit is defined with the residual overvoltage condition. This allows earth faults with several kilohms of fault resistance to be detected in a symmetrical system. The achieved sensitivity is comparable with traditional fundamental frequency based methods such as the IoCos/IoSin (DEFxPTOC), Watt/Varmetric (WPWDE) and neutral admittance (EFPADM).

MFADPSDE can detect faults with dominantly fundamental frequency content as well as transient, intermittent or restriking earth faults. MFADPSDE can be used as an alternative solution to transient or intermittent function INTRPTEF.

MFADPSDE supports fault direction indication in operate and non-operate directions which can be used during fault location process. The in-built transient detector can be used to identify restriking or intermittent earth faults, and discriminate them from permanent or continuous earth faults.

The direction of MFADPSDE can be set as forward or reverse. The operation characteristic is defined by a tilted operation sector, which is universally valid both in unearthed and compensated networks. The tilt of the operation sector should be selected based on the measurement errors of the applied residual current and voltage measurement transformers.

The operating time characteristic is according to the definite time (DT).

The function contains a blocking functionality to block function outputs, timers or the function itself.

MFADPSDE supports both tripping and alarming operation modes. For the alarming earth-fault protection application, the function contains a dedicated operation mode. MFADPSDE provides reliability and sensitivity of protection with a single function. This enables a protection scheme implementation that is simpler than separate fault type dedicated earth-fault functions which need to be coordinated. Other advantages of MFADPSDE include versatile applicability, good selectivity, good sensitivity and easy setting principles.

Three instances (stages) of MFADPSDE are available.

4.2.9.7 Signals

MFADPSDE Input signals

Table 617: MFADPSDE Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RELEASE	BOOLEAN	0=False	External trigger to release neutral admittance protection
RESET	BOOLEAN	0=False	External trigger to reset direction calculatio

MFADPSDE Output signals

Table 618: MFADPSDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite direction peaks
INTR_EF	BOOLEAN	Intermittent earth-fault indication
PEAK_IND	BOOLEAN	Current transient detection indication
FAULT_DIR	Enum	Detected fault direction
DIRECTION	Enum	Direction information

4.2.9.8 MFADPSDE Settings

Table 619: MFADPSDE Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Directional mode	2=Forward			2=Forward	Directional mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Reverse				
Voltage start value	0.01...1.00	xUn	0.01	0.10	Voltage start value
Operate delay time	60...1200000	ms	10	500	Operate delay time

Table 620: MFADPSDE Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operating quantity	1=Adaptive 2=Amplitude 3=Resistive			1=Adaptive	Operating quantity selection
Min operate current	0.005...5.000	xIn	0.001	0.010	Minimum operate current
Tilt angle	2.0...20.0	deg	0.1	5.0	Characteristic tilt angle

Table 621: MFADPSDE Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Intermittent EF 2=Transient EF 3=General EF 4=Alarming EF			3=General EF	Operation criteria

Table 622: MFADPSDE Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Peak counter limit	2...20		1	2	Peak counter limit for restriking EF
Start delay time	30...60000	ms	1	30	Start delay time
Reset delay time	0...60000	ms	1	500	Reset delay time
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity

4.2.9.9 MFADPSDE Monitored data

Table 623: MFADPSDE Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ANGLE	FLOAT32	-180.00...180.00	deg	Angle between polarizing and operating quantity
I_OPER	FLOAT32	0.000...40.000	xIn	Calculated operating current
MFADPSDE	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.9.10 Technical data

Table 624: MFADPSDE Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × U_n
Start time [1]	Typically 35 ms
Reset time	Typically 40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms

4.2.10 Touch voltage based earth-fault current protection IFPTOC (ANSI 46SNQ/59N)

4.2.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Touch voltage based earth-fault current protection	IFPTOC	IFPTOC	46SNQ/59N

4.2.10.2 Function block

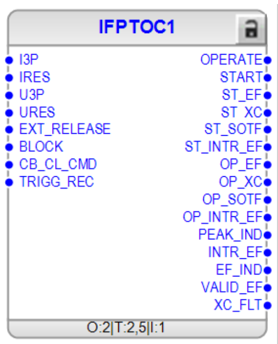


Figure 334: Function block

4.2.10.3 Functionality

The touch voltage-based earth-fault current protection function IFPTOC provides selective earth-fault protection for single-phase earth faults in high-impedance earthed networks, that is, in compensated, unearthed and high resistance earthed

[1] Includes the delay of the signal output contact, results based on statistical distribution of 1000 measurements.

systems. It can be applied for the earth-fault protection of overhead lines and underground cables, regardless of actual earth-fault type (continuous or intermittent) or fault resistance value (low or high ohmic). Operation time of IFPTOC can either be definite time or inverse time. In case of inverse time operation, operation time becomes automatically adapted to estimated single-phase earth-fault current or touch-voltage magnitude.

Traditional directional, sensitive earth-fault protection functions applied in high-impedance earthed networks are typically based on residual quantities (U_o, I_o). In high-impedance earthed networks residual current does not accurately match the fault current flowing at fault location. This is since the capacitive current contribution of the faulted feeder itself is not measurable using residual current. The higher is the capacitive current contribution of the faulted feeder, the greater is the mismatch of true fault current and residual current (I_o). This is the root reason, why operate time cannot be based on measured magnitude of current (I_o). Therefore, in traditional directional sensitive earth-fault protection functions operate time must be pre-defined and it is thus based on *assumed* magnitude of fault current. *Actual* fault current magnitude depends on e.g. the prevailing detuning degree of the network during an earth fault, which depends on the actual values of network shunt capacitance and coil inductance. In modern networks with increased degree of cabling, switching operations may result into large variations of network capacitance. On the other hand, typical practical arrangement for adjustment of coil inductance involves mechanical movement of air gap in the iron core, which is a time-consuming process. In case there is great mismatch between the assumed and true fault current magnitude, the fulfillment of electrical safety regulations is questionable. It should be noted that the time constant of coil tuning is much longer than requirements for protection operate time. In modern networks, high temporary detuning conditions are possible due to increase of use of underground cables, which increase feeder total phase-to-earth capacitance enormously.

However, operation of IFPTOC is not based on traditional residual quantities (U_o, I_o), but on accurate estimation of earth-fault (EF) current flowing at the fault location. Estimation of earth-fault current is done in real-time utilizing changes in phase currents measured at the beginning of the feeder due to a single-phase earth fault.

Thanks to its novel operation principle, the method has several advantages over the traditional state-of-art earth-fault protection methods such as the wattmetric method:

- The method enables automatic, real-time adaptation of protection operation speed according to the prevailing (estimated) single-phase earth-fault current magnitude. The estimated earth-fault current magnitude can be converted into corresponding touch voltage or earth potential rise (EPR) value, which enables direct compliance of protection operation speed according to standard EN50522. As another option, IFPTOC enables protection operation speed according to standard IEEE80. This operation mode can also be used when maximum allowed earth potential rise vs. operation speed follows a relationship such as 750V/ $\sqrt{t}$[*sec*].
- The harmonic content of fault current can be included into fault current magnitude estimate, which further enhances the accuracy and practicality of the novel protection method.
- IFPTOC enables significant improvement on safety and overall dependability of the protection schemes used today in compensated networks. IFPTOC provides unique advantages, for example during the following practical network conditions:
  - On feeders with high capacitive earth-fault current contribution (e.g. long cable feeders), where traditional earth-fault protection is challenged by the

fact that the phase angle difference between U_o and I_o increases as the capacitive earth-fault current contribution increases. Phase angle difference may become so high that correct operation of traditional protection functions is endangered. This is not the case for IFPTOC, as fault current estimate is not affected by the capacitive earth-fault current contribution of the protected feeder itself.
  - In case earth fault occurs during abnormal network topologies, or when fault current compensation is temporarily not effective or when network is operated heavily over- or under-compensated.
- Magnitude of true fault current is estimated without need on any pre-defined information on the network topology.
- Also, the effect of fault resistance can be considered and compensated in the estimated earth-fault current magnitude applying dedicated fault resistance compensation method. This functionality allows acceleration of protection operation speed during high(er) ohmic earth fault when actual fault current magnitude is low.

IFPTOC includes also dedicated protection functionality for important practical earth-fault scenarios such as switch onto fault (SOTF) condition, for intermittent earth faults and for high current cross-country earth-faults. Each of such fault condition can be tripped with individually defined operation criteria enabling high application flexibility and reliability.

4.2.10.4 Analog channel configuration

IFPTOC has four analog group inputs which must be properly configured.

Table 625: Analog inputs

Input	Description
I3P	Three phase currents
IRES	Residual current (measured or calculated)
U3P	Three phase voltages
URES	Measured or calculated residual voltage

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 626: Special conditions

Condition	Description
U3P connected real meas-urements	Recommendation to connect all three phase-to-earth voltage channels. Alternative is at least two phase-to-earth / phaseto-phase voltages and measured residual voltage (URES).
URES calculated	Three phase-to-earth voltages must be connected for calcu-lating the residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.2.10.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected “on” the function is enabled and respectively “off” means function is disabled.

The operation of *Touch voltage-based earth-fault current protection IFPTOC* can be described by using a module diagram (see figure below). All the modules in the diagram are explained in the next sections.

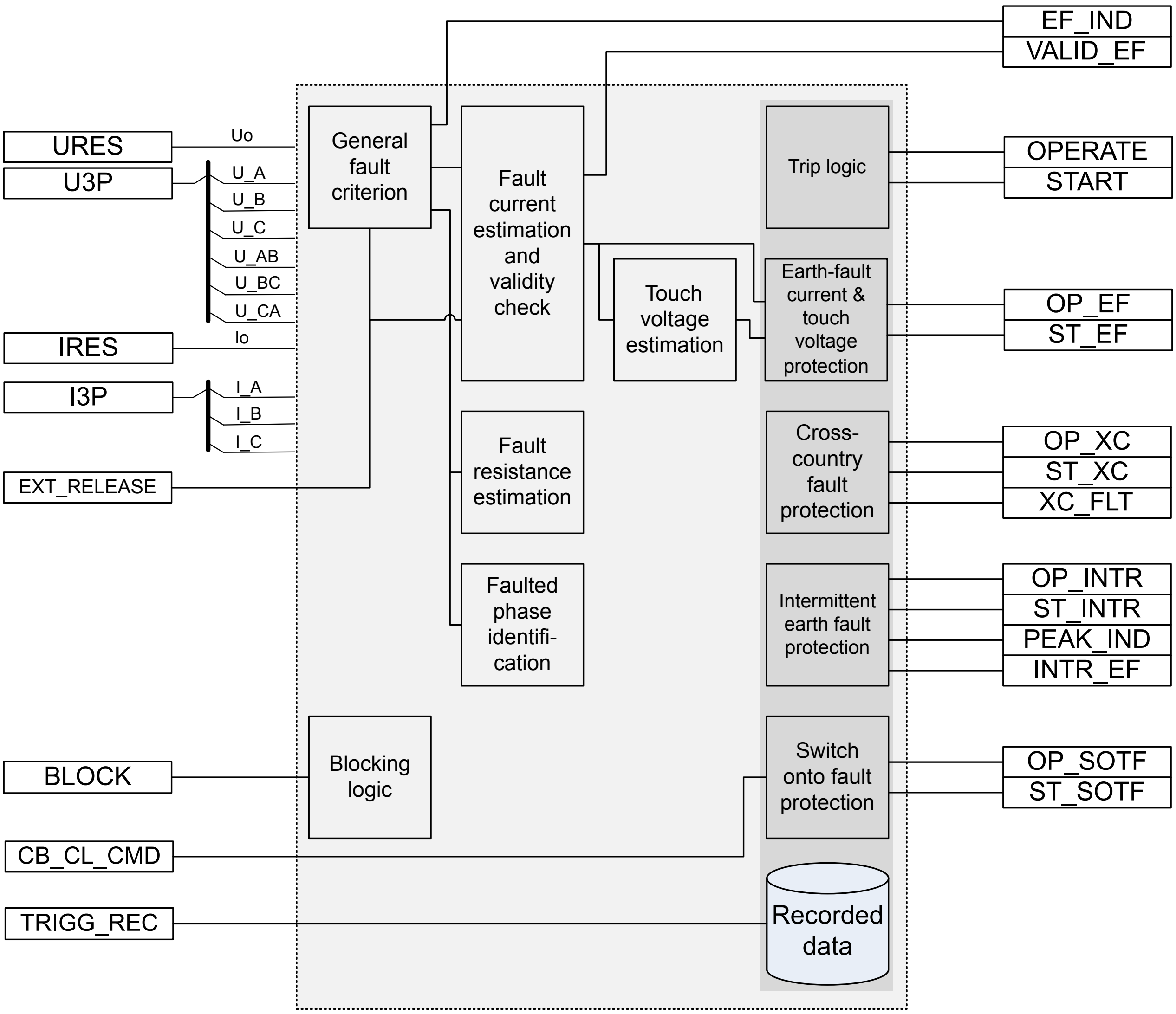


Figure 335: Functional module diagram

General fault criterion

The General fault criterion (GFC) module monitors the presence of earth fault in the network. It is based on the value of the fundamental frequency residual voltage $\underline{U}_o$

defined as the vector sum of fundamental frequency phase voltage phasors divided by three.

$$\underline{U}_o = (\underline{U}_A + \underline{U}_B + \underline{U}_C)/3$$

(Equation 100)

When the magnitude of U_o exceeds setting *Voltage start value*, an earth fault is detected and EF_IND output is set to TRUE. Setting value *Voltage start value* is given in per unit format with system nominal phase-to-earth value (U_{n_PE}) as reference.

IFPTOC supports fundamental frequency residual voltage monitoring based on measured U_o from open-delta winding or internally calculated U_o derived from connected phase-to-earth voltages.

Input EXT_RELEASE is alternative method for internal GFC and validity check modules to indicate the presence of earth fault in the protected feeder and to release the calculation of IFPTOC function. Activation of EXT_RELEASE will also override earth-fault validity check criterion i.e. earth-fault current estimate is considered as valid when EXT_RELEASE is activated. It is therefore mandatory that EXT_RELEASE is based on start of directional earth-fault detection function, such as MFADPSDE or DEFxPDEF.

The setting *Voltage start value* defines the basic sensitivity of the IFPTOC function in terms of fault resistance. Fault detection sensitivity in terms of fault resistance can be estimated using the equation below:

$$R_F[ohm] \leq \frac{U_{PE} \cdot \left(\sqrt{I_d^2 + I_v^2 - I_v^2 \cdot U_{o\_pu}^2} - I_d \cdot U_{o\_pu}\right)}{(I_d^2 + I_v^2) \cdot U_{o\_pu}}$$

(Equation 101)

where U_{PE} is the system phase-to-earth voltage [V], I_d is the total system damping [A], I_v is the network detuning value [A] and U_{o_pu} is setting *Voltage start value* in per unit.

In compensated networks the minimum value for the setting *Voltage start value* can be easily selected based on the resonance curve calculated by the coil controller considering different network topologies and conditions, refer to *Figure 336*.

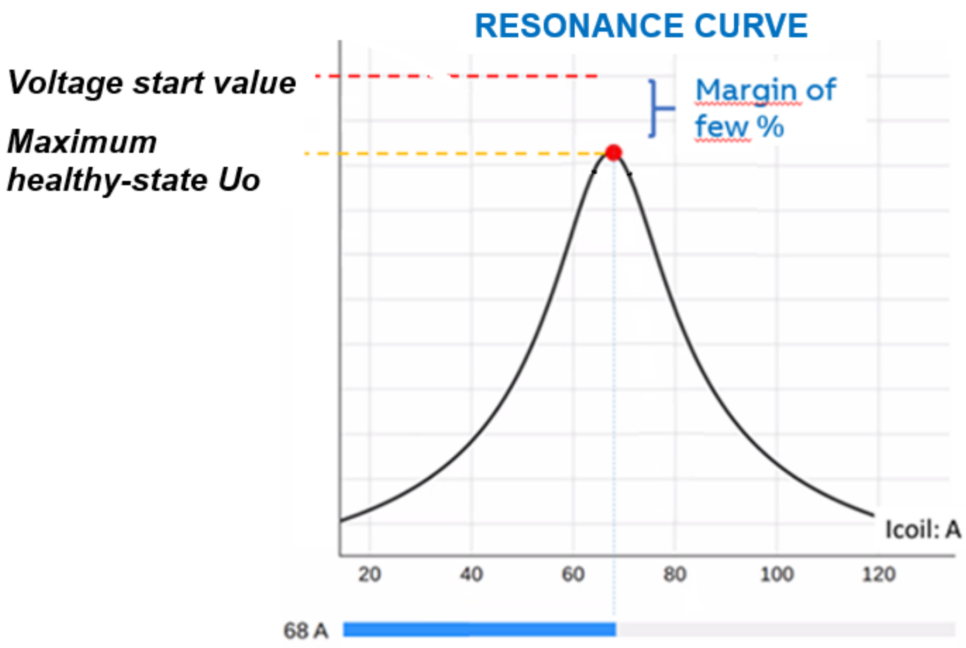


Figure 336: Example of selection of setting Voltage start value in order to maximize the earth-fault detection sensitivity of IFPTOC based on the resonance curve calculated by the coil controller

To avoid unselective start or operation of IFPTOC, *Voltage start value* must always be set to a value which exceeds the maximum healthy-state residual voltage value, taking into consideration of possible network topology changes (variation in unbalance), compensation coil and parallel resistor switching status (variation in damping) and compensation degree variations (variation in detuning).

Activation of `EF_IND` output is determined to be the time instant when the earth fault is detected. This information is needed as the IFPTOC utilizes “delta” calculation i.e. changes in phase currents due to earth fault. For example, the change of phase A current phasor due to earth fault can be written as:

$$\Delta \underline{I}_A = \underline{I}_A(t_{FLT}) - \underline{I}_A(t_{PRE\_FLT})$$

(Equation 102)

Where:

t_{FLT} is the time during the detected earth fault

t_{PRE_FLT} is the time prior to detected earth fault occurrence and it represents time during pre-fault or healthy-state conditions. This pre-fault operation point is determined based on user setting *Revert time* as follows:

$$t_{PRE\_FLT} = t_{FLT}(1) - \text{Revert time}$$

(Equation 103)

where $t_{FLT}(1)$ equals the first time instant, when earth fault is detected by the GFC-module. Pre-fault time moment is at least *Revert time* before earth fault occurrence moment.

Revert time setting should be set high enough (default value is 300 ms), because during a high(er) ohmic fault the increase speed (gradient) of the magnitude of U_o may be slow, refer to example in *Figure 337*, where earth-fault occurs at time 0 ms. Earth fault is detected by GFC module slightly after that, at time instant $t_{FLT}(1)$ marked with red dot, when magnitude of U_o exceeds setting *Voltage start value*. As an indication of detected earth-fault output `EF_IND` is activated.

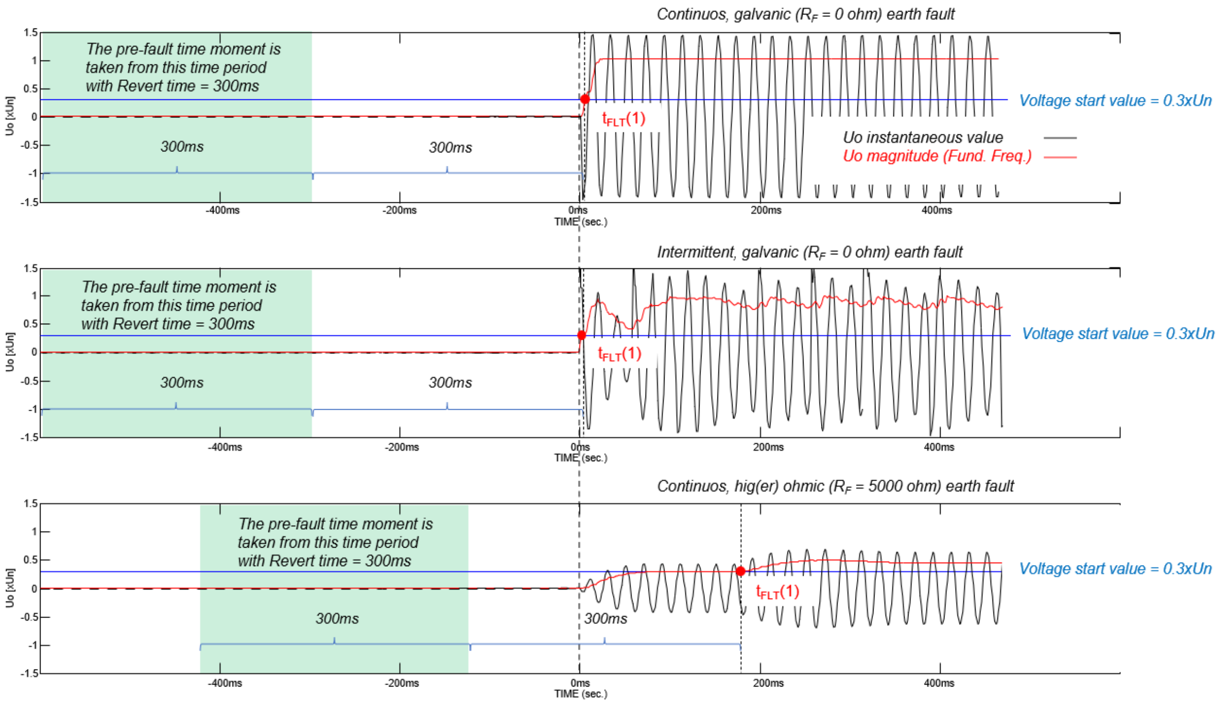


Figure 337: Illustration of operation of General Fault Criterion (GFC) module and the meaning of setting Revert time

In case of secondary testing of IFPTOC function, the pre-fault time in the test file must be longer than *2xRevert time*. For example, if *Revert time* = 300 ms, then pre-fault time in the test file must be longer than 600 ms.

Indication of detected earth fault is available in Recorded data: *EF indication*.

Fault current estimation and validity check

Operation of IFPTOC is based on estimating the magnitude of earth-fault current flowing in the fault spot, or on touch voltage magnitude derived from the earth-fault current estimate.

In compensated network, the magnitude of fundamental frequency earth-fault current depends on the network damping (I_d), detuning (I_v), voltage (U_{PE}) and fault resistance (R_F) and can be written as:

$$I_F^1 = \sqrt{\frac{(I_d^2+I_v^2)\cdot U_{PE}^2}{(I_d^2+I_v^2)\cdot R_F^2+2\cdot I_d\cdot R_F\cdot U_{PE}+U_{PE}^2}}$$

(Equation 104)

Maximum fault current value is obtained when fault resistance (R_F) is zero, in case of *Equation 104* can be written as:

$$\max(I_F^1) = \sqrt{I_d^2 + I_v^2}$$

(Equation 105)

Interpretation of *Equation 105* is that fault current has resistive part due to network damping and imaginary part due to network detuning. Fault current magnitude increases when damping or detuning increases.

The effect of fault resistance to fault current magnitude can be written as:

$$I_F^1 = \max(I_F^1)\cdot U_{o_{pu}} = \sqrt{I_d^2 + I_v^2}\cdot U_{o_{pu}}$$

(Equation 106)

where

$$U_{o_{pu}} = \left|\frac{U_{PE}}{R_F\cdot(I_d - j\cdot I_v)+U_{PE}}\right|$$

(Equation 107)

Interpretation of *Equation 106* is that effect of fault resistance to fault current magnitude is proportional to scaling the fault current magnitude at zero fault resistance with the per unit value of residual voltage ($U_{o_{pu}}$) due to fault resistance.

Minimum fault current magnitude is always obtained at resonance, when detuning (I_v) is zero, in case *Equation 104* can be written as:

$$\min(I_F^1) = \sqrt{\frac{I_d^2\cdot U_{PE}^2}{(I_d\cdot R_F + U_{PE})^2}}$$

(Equation 108)

At resonance, fault current is only due to system resistive shunt losses i.e. due to network damping (I_d) and possible harmonic components.

In case of unearthed network, detuning value (I_v) equals the uncompensated earth-fault current due to total network phase-to-earth capacitance value. In case of high resistance earthed network detuning value (I_v) equals the uncompensated earth-fault current due to total network phase-to-earth capacitance value and the network damping (I_d) value includes losses due to the neutral point resistor.

Estimation of earth-fault current and methods for ensuring its validity are explained next.

Fault current estimation

In IFPTOC the estimation of earth-fault current flowing at the fault location is done utilizing changes in phase currents measured due to an earth fault.

To estimate the earth-fault current magnitude, change in threefold negative-sequence component due to earth fault is calculated (phase A as reference, phase rotation: ABC):

$$\underline{I}_F^{est} = 3 \cdot \underline{I}_2 = \underline{I}_A + \underline{a}^2 \cdot \underline{I}_B + \underline{a} \cdot \underline{I}_C$$

(Equation 109)

$$\underline{I}_F^{est} = 3 \cdot \Delta\underline{I}_2 = \Delta\underline{I}_A + \underline{a}^2 \cdot \Delta\underline{I}_B + \underline{a} \cdot \Delta\underline{I}_C$$

(Equation 110)

$$I_F^{est} = abs(\underline{I}_F^{est})$$

(Equation 111)

Where

$\underline{I}_F^{est}$ = Earth-fault current estimate (phasor)

I_F^{est} = Earth-fault current estimate (magnitude)

$\Delta\underline{I}_A = \underline{I}_A(t_{FLT}) - \underline{I}_A(t_{PRE\_FLT})$ = change of phase A current phasor due to earth fault

$\Delta\underline{I}_B = \underline{I}_B(t_{FLT}) - \underline{I}_B(t_{PRE\_FLT})$ = change of phase B current phasor due to earth fault

$\Delta\underline{I}_C = \underline{I}_C(t_{FLT}) - \underline{I}_C(t_{PRE\_FLT})$ = change of phase C current phasor due to earth fault

$\Delta\underline{I}_2 = \underline{I}_2(t_{FLT}) - \underline{I}_2(t_{PRE\_FLT})$ = change of negative sequence-current phasor due to earth fault

$\underline{a}$ = Phase rotation operator = cos(120°) + j·sin(120°)

Applying the “delta” calculation i.e. change in phase currents due to earth fault removes the healthy-state negative-sequence component from earth-fault current estimate, which may exist due to the practical unbalances in load currents and capacitive charging currents. Pre-fault negative-sequence current value is typically rather low in magnitude and constant in time domain, which enables good estimation accuracy regardless of load current level variations, or in case of uncertainty in the exactness of the pre-fault value (e.g. during auto-reclosing cycle).

The validity of memorized pre-fault negative-sequence component value that is utilized in delta calculation becomes poorer in time. There is thus a maximum time defined by the user that delta calculation is valid. This is given with setting

Max Dur delta Calc (maximum duration for delta calculation). After this time is elapsed from initial fault detection moment, then the validity of delta-calculation is not considered to be valid anymore and thus fault current estimation is done without delta calculation i.e. based on real time measurement of threefold negative-sequence component (Equation 109). The memorized pre-fault negative-sequence component values are reset when function is reset.

In practical compensated networks, earth-fault current may include a large share of harmonic components, especially during low ohmic faults. In IFPTOC the estimation of earth-fault (EF) current can be done with or without harmonic components. Refer to Figure 5 for illustrating the effect of harmonics on earth-fault current estimate. Measurement of harmonic components can be enabled with setting *Enable harmonics* = “Enable”, “Disable”.

Fundamental frequency component is always included into fault current magnitude estimation, even when setting *Enable harmonics* = “Disable”.

When setting *Enable harmonics* = “Enable”, the included harmonics are (if their magnitudes are sufficient for an accurate measurement): 2nd, 3rd, 5th, 7th and 9th.

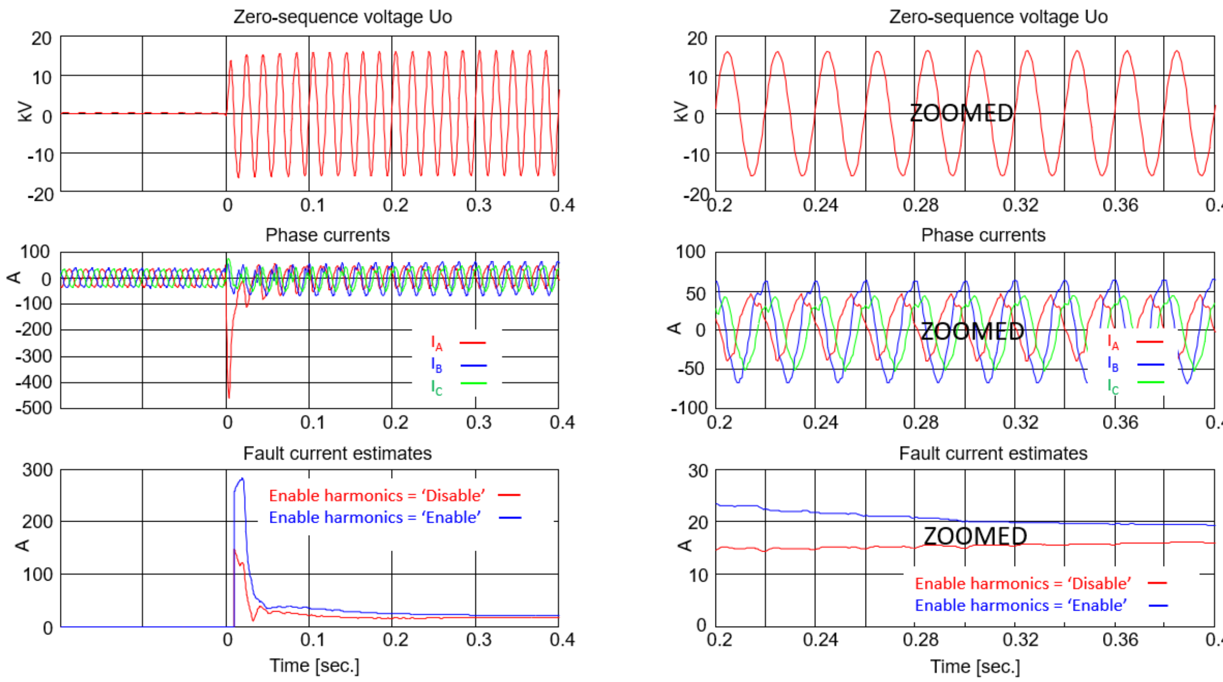


Figure 338: Illustration of earth-fault current estimate with and without harmonics calculation enabled (zoomed view on right hand column)

The harmonic components are only included in the earth-fault current estimate if their magnitudes are sufficient for an accurate measurement i.e. their values exceed minimum predefined value (0.3% from I_n). Also, the effect of harmonics is only taken into account, if the magnitude of fundamental frequency fault current estimate or touch voltage exceeds set start thresholds.

For the earth-fault current estimate magnitude, I_F^{est}, can be written:

When setting *Enable harmonics* = “Disable”:

$$I_F^{est} = \Delta 3 I_2^1$$

(Equation 112)

When setting *Enable harmonics* = “Enable”:

$$I_F^{est} = \sqrt{(\Delta 3 I_2^1)^2 + (\Delta 3 I_2^2)^2 + (\Delta 3 I_2^3)^2 + (\Delta 3 I_2^5)^2 + (\Delta 3 I_2^7)^2 + (\Delta 3 I_2^9)^2}$$

(Equation 113)

Where I_2^n is the magnitude of the n^{th} harmonic negative-sequence current component (n = 1, 2, 3, 5, 7 and 9).

In case of frequency adaptive system measurements, only 2^{nd}, 3^{rd} and 5^{th} harmonics are calculated.

In case there is fault resistance included in the fault current path, the effect of fault resistance is to decrease the value of earth-fault current as shown by *Equation 106*.

The downscaling of fault current magnitude can be estimated to be proportional to the magnitude of per unit value of residual voltage, refer to *Equation 106*. With setting *Ena RF Compensation* = “Enable”, user can compensate the effect of fault resistance and then earth-fault current estimate becomes independent of actual fault resistance value. This is done by dividing the fault current estimate with per unit value of residual voltage (< 1pu):

Estimate for “fault resistance compensated” earth-fault current, $I_F^{est\_Rfcomp}$:

$$I_F^{est\_Rfcomp} = I_F^{est}[A]/Uo[pu]$$

(Equation 114)

This means that with setting *Ena RF Compensation* = “Enable”, regardless of actual fault resistance magnitude, the earth-fault current estimate matches the value that would be valid if the fault would be a galvanic one (fault resistance equals zero). Thanks to this feature the fault is always seen and treated as a galvanic fault regardless of possible fault resistance. This functionality allows acceleration of protection operation speed during high(er) ohmic earth fault when fault current magnitude is low.

In case IFPTOC is used to detect high(er) ohmic earth faults, all start thresholds (*Voltage start value*, *EF current Str Val* or *Touch Vol Str Val*) must be set according to sensitivity requirements. Otherwise *Ena RF Compensation* may not be effective during actual high(er) ohmic earth fault.

In case of setting *Ena RF Compensation* = “Enable”, the effect of harmonics are not taken into account i.e. fault current estimation is based only on fundamental frequency component.

Figure 339 illustrates this concept: In the left-hand column is shown residual voltage, phase currents and fault current estimate during a galvanic earth fault (R_F = 0 ohm). During a galvanic fault U_o equals system nominal phase-to-earth voltage and has thus value of 1. 0pu (xU_{n_PE}, U_{n_PE} = Nominal phase-to-earth voltage). In the middle column is shown residual voltage, phase currents and fault current estimate during a higher ohmic earth fault (R_F = 3000 ohm). During a higher ohmic earth fault U_o reduces and thus also the magnitude of fault current is reduced. But the magnitude of fault current is reduced proportionally to residual voltage. In the right-hand column the effect of fault resistance is compensated by scaling the fault current estimate by dividing it with the per unit value of residual voltage. With fault resistance compensation, the operation speed of IFPTOC can be accelerated during high(er) ohmic earth faults.

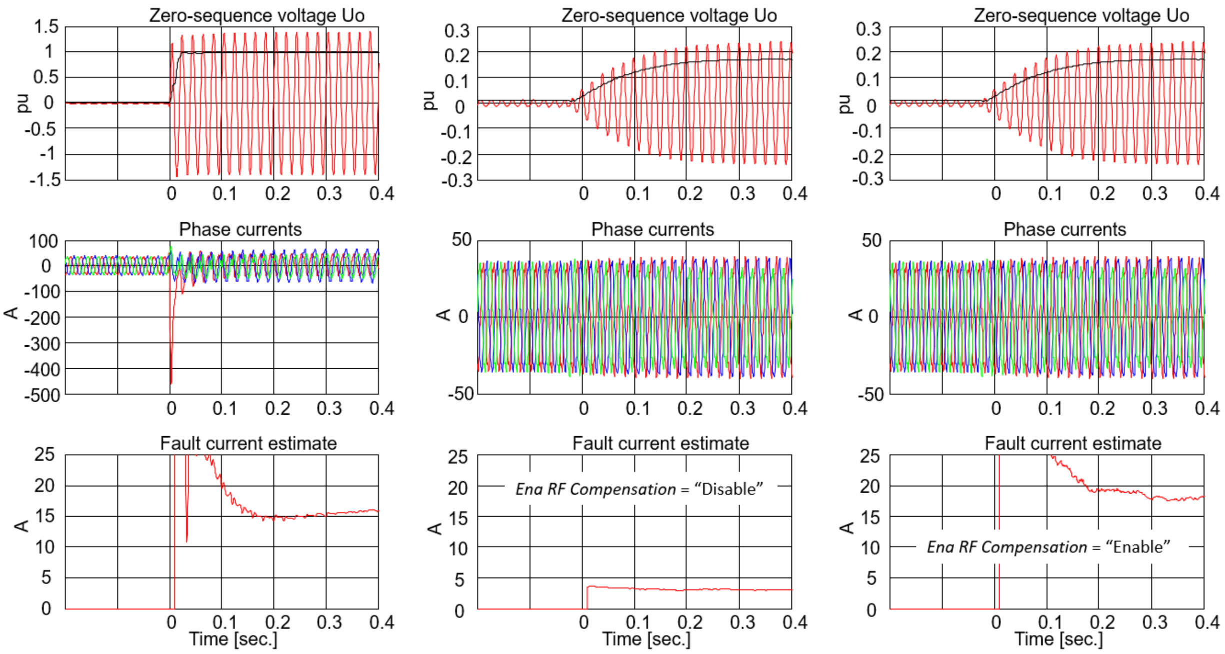


Figure 339: Illustration of fault resistance compensation functionality in IFPTOC. Left-hand column: galvanic earth fault (R_F = 0 ohm). Middle column: a higher ohmic earth fault (R_F = 3000 ohm) with setting Ena R_F Compensation = "Disable". Right-hand column: a higher ohmic earth fault (R_F = 3000 ohm) with setting Ena R_F Compensation = "Enable".

Note that it is the "effective" earth-fault current estimate which determines operation of IFPTOC. "Effective" earth-fault current includes the effect of user setting *Reduction factor*:

Effective earth-fault current estimate, $I_F^{est\_eff}$:

$$I_F^{est\_eff} = I_F^{est} \cdot Reduction\ factor$$

(Equation 115)

Setting *Reduction factor* is a user defined reduction factor, which can be used to scale down the estimated earth-fault current magnitude. Setting *Reduction factor* allows e.g. consideration that not all the earth-fault current (I_F) will flow back through "remote" earth. See illustration in Figure 7. A portion of the earth-fault current (I_{SCR}) may have alternative return paths, e.g. through cable sheaths/screens. Only current which flows through earth (I_E) will introduce rise of earth potential (earth potential rise, EPR, also called as ground potential rise GPR), which must be considered from electrical safety perspective. Setting *Reduction factor* = 1.00 means that 100% of earth-fault current flows back through “remote” earth and thus 100% of earth-fault current will introduce rise of earth potential.

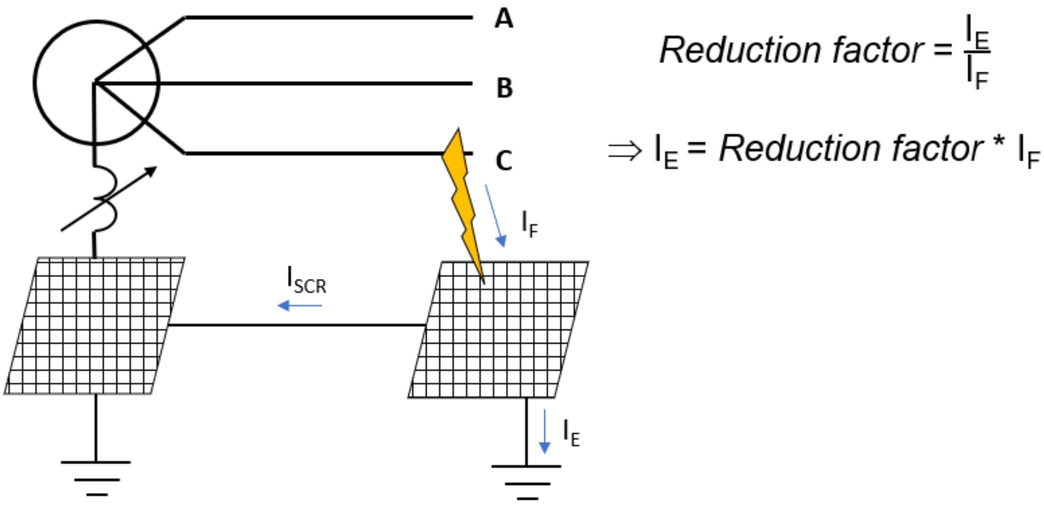


Figure 340: Simplified illustration and explanation of setting Reduction factor. Only fault current which flows through earth (I_E) will introduce rise of earth potential (earth potential rise, EPR, also called as ground potential rise, GPR).

Magnitude of the estimated effective earth-fault current is given in Recorded data:

- *Fault current* (fundamental frequency magnitude)
- *Fault current rms* (rms-value).

In Monitored data the magnitude of estimated effective earth-fault current is given in as:

- *FLT_CURRENT* (fundamental frequency magnitude)
- *FLT_CURR_RMS* (rms-value).

In case of setting *Ena RF Compensation* = “Enable”, actual earth-fault current value affected by fault resistance is then not available in Monitored/Recorded data, but the monitored/recorded current value is fault resistance compensated.

Validity check

Validity of earth-fault current estimate is defined with settings *EF validity Op mode* and *EF validity Min Curr*. *EF validity Op mode* has three options “Resistive”, “Resistive, Reactive” and “No Validity”.

Validity of earth-fault current estimate is based on evaluating the polarity of the measured admittance ($\underline{Y}_o = \underline{I}_o/\underline{U}_o$) at fault ignation. The accuracy of $\underline{I}_o$ and $\underline{U}_o$ should be therefore as good as possible. Especially the measurement of $\underline{I}_o$ should be based on accurate Core Balance CT (CBCT).

The validity of earth-fault current estimate is based on evaluating the polarity of the measured admittance ($\underline{Y}_o = \underline{I}_o/\underline{U}_o$) during the fault ignition moment (during the transient phase of fault). Admittance is calculated utilizing cumulative phasor summing technique (CPS). The measured “transient admittance” is converted into equivalent current value by multiplying it with nominal phase-to-earth voltage value and then compared with setting *EF validity Min Curr*. The current values used in validity check are called as transient resistive and reactive components and noted as *Transient Ris Comp* and *Transient React Comp* in Recorded data and TR_RIS_COMP and TR_REACT_COMP in Monitored Data.

Validity of earth-fault current estimate is indicated by VALID_EF = TRUE.

In case *EF validity Op mode* = 'Resistive', then validity of earth-fault current estimate is confirmed by evaluating the polarity of the resistive part of measured admittance (real($\underline{Y}_o$) = real($\underline{I}_o$/$\underline{U}_o$)) during the fault ignition moment (during the transient phase of fault). The measured "transient admittance" is converted into equivalent current value by multiplying it with nominal phase-to-earth voltage value and then compared with setting *EF validity Min Curr*. *EF validity Op mode* = 'Resistive' is valid in compensated systems regardless of compensation degree and also in high resistance earthed systems. Note that situation, when the compensation coil becomes unintentionally disconnected, may result to condition where measured resistive component is not sufficient for validity confirmation. In such case *EF validity Op mode* should be selected as 'Resistive, Reactive'.

In case *EF validity Op mode* = 'Resistive, Reactive', then validity of earth-fault current estimate is confirmed by evaluating the polarity of the resistive (real($\underline{Y}_o$) = real($\underline{I}_o$/$\underline{U}_o$)) and reactive (imaginary) part (imag($\underline{Y}_o$) = imag($\underline{I}_o$/$\underline{U}_o$)) of measured admittance during the fault ignition moment (during the transient phase of fault). The measured "transient admittance" is converted into equivalent current value by multiplying it with nominal phase-to-earth voltage value and then compared with setting *EF validity Min Curr*. Either one, resistive or reactive part of measured admittance is used to confirm validity of earth-fault current estimate. *EF validity Op mode* = 'Resistive, Reactive' is valid in compensated, unearthed and in high resistance earthed systems. In compensated systems this criterion is applicable unless the protected feeder is over-compensated i.e. earth-fault current produced by protected feeder is inductive. In such case *EF validity Op mode* must be set to 'Resistive'.

In case *EF validity Op mode* = 'No validity", then validity of earth-fault current estimate is not confirmed and protection operates based on estimated earth-fault current or touch voltage magnitude. *EF validity Op mode* = 'No validity' can be applied e.g. when current measurement is at incomer and when compensation coil with parallel resistor is located at dedicated earthing transformer bay. In this case, during an earth fault in the network, residual current at incomer is zero and thus validity evaluation based on resistive or reactive component is not possible. Thus in order to apply IFPTOC at the incomer, *EF validity Op mode* = 'No validity', must be selected.

Setting *EF validity Min Curr* is given in per unit format with residual current channel primary current as base value. The value should be selected based on following principles:

- In compensated networks *EF validity Min Curr* should be selected based on the known system damping value, in practice e.g. based on the ampere value of the parallel resistor of the coil. For example, if parallel resistor of the coil has rating of 10A, then *EF validity Min Curr* should be smaller than this value with margin, for example 5A. Based on practical experience, value of 3A is found to be suitable for most applications. The value of *EF validity Min Curr* should also be set higher than the transient resistive component generated by the protected feeder during post-fault oscillation to avoid false activations of validity check module in healthy feeders during an earth fault.

  Transient resistive component can be approximated with following equation:

$$real\left(\underline{Y}_o^{Tr}\right) = real\left(\frac{I_o}{-\underline{U}_o}\right) = G_{oTot} \cdot \frac{\left|B_{oFdTot}\right|}{\left|B_{oTot}\right|} - G_{oFdTot}$$

(Equation 116)

where

G_{oTot} = Conductance representing the total system shunt losses, i.e. losses of the coil(s), the parallel resistor and the total network shunt losses.

$|B_{oFdTot}|$ = The sum of absolute values of capacitive and inductive susceptances of the protected feeder. This term represents the energy stored in the LC-branches of the feeder. For example, if the capacitive susceptance of the feeder equals $20A^{cap}$ and the inductive susceptance of the distributed coils at the feeder equal $20A^{ind}$, then the sum of absolute values of susceptances of the feeder equal 40A.

$|B_{oTot}|$ = The sum of absolute values of capacitive and inductive susceptances of the network. This term represents the energy stored in the LC-branches of the total network. For example if capacitive susceptance of the network equal $100A^{cap}$ and the inductive susceptance of the central and distributed coils equal $100A^{ind}$, then the sum of absolute values of susceptances of the network equal 200A.

G_{oFdTot} = Conductance representing the total shunt losses of protected feeder i.e. losses of the coil(s) located at the feeder and natural shunt losses of the feeder.

- In unearthed networks *EF validity Min Curr* should be selected based on the earth-fault current of connected feeders. Value must be smaller than the capacitive earth-fault current due to parallel feeders. Based on practical experience, value of 3A is found to be suitable for most applications.
- In resistance earthed networks *EF validity Min Curr* should be selected based on the value of earthing resistor. Value must be smaller than the ampere value of earthing resistor.

To adapt the earth-fault current validity determination to a possible fault direction change during the fault, for example during manual fault location process, a cyclic accumulation of admittance phasor can be enabled with setting *Ena cyclic reset* = “Enable”. The duration of this evaluation cycle is only few fundamental cycles so that function can rapidly adapt to changes in fault direction. Evaluation is based on monitoring the sign of the accumulation of admittance phasor compared with sign of transient admittance stored at fault ignation. In case change of polarity is detected, and duration of polarity change exceeds setting *Intr EF reset time* and a cyclic accumulation of admittance (real- or imaginary part converted into equivalent current value) exceeds *EF validity Min Curr*, the validity evaluation of earth-fault current estimate is reset and restarted. As default, setting *Ena cyclic reset* = “Enable”.

Information about the validity of earth-fault current estimate is also available in *Recorded data: Valid EF detection*.

Magnitude of transient resistive or reactive current component used in evaluation of earth-fault current validity is given in recorded data as *Transient Ris Comp* and *Transient React Comp* (fundamental frequency magnitude) and in Monitored data as `TR_RIS_COMP` and `TR_REACT_COMP` (fundamental frequency magnitude). Positive value means that fault is seen inside the protected feeder, negative value means that fault is seen outside the protected feeder.

Touch voltage estimation

After estimate for earth-fault current is calculated and its validity confirmed, then conversion of fault current estimate I_F^{est} into earth potential rise estimate U_{EPR}^{est} is derived using equations below:

Effective earth potential rise estimate:

$$U_{EPR}^{est} = Maximum\ earthing\ Ris \cdot Reduction\ factor \cdot I_F^{est}$$

(Equation 117)

with *Equation 115*, *Equation 117* can also be written as:

$$U_{EPR}^{est} = Maximum\ earthing\ Ris \cdot I_F^{est\_eff}$$

(Equation 118)

Where

Setting *Maximum earthing Ris* is a user defined maximum earthing resistance value encountered in the earthings located at the protected feeder. Higher earthing resistance results in higher earth potential rise and touch voltage during the fault.

For estimating the hazardous touch voltage at fault location, U_{TF}^{est}, the estimate of the effective earth potential rise is used:

$$U_{TF}^{est} = U_{EPR}^{est}$$

(Equation 119)

Setting *Reduction factor* enables down scaling of the estimated earth potential rise, which determines operation speed of IFPTOC:

- In case *Reduction factor* = 1, it is assumed that touch voltage equals 100% of earth potential rise.
- In case *Reduction factor* < 1, then it is assumed that touch voltage equals only part of earth potential rise. In this case the value of setting *Reduction factor* depends e.g. on actual reduction effect in the return path of earth-fault current and properties of earthing systems in the protected feeder.

Magnitude of estimated touch voltage is given in Recorded data:

- *Touch voltage* (fundamental frequency magnitude)
- *Touch voltage rms* (rms-value).

In Monitored data the magnitude of estimated touch voltage is given in as:

- `TCH_VOLTAGE` (fundamental frequency magnitude)
- `TCH_VOLT_RMS` (rms-value).

Earth-fault current and touch voltage protection

Based on the practical experience from real earth faults, some faults have re-striking/intermittent characteristics, where the voltage and current waveforms generated by earth fault are rich with harmonics and non-sinusoidal content. In such fault type the operation of IFPTOC can alternatively be based on the counted number of transients instead of estimated fault current or touch voltage. Dedicated functionality to allow this type of operation is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.

Principle based on earth fault current estimate

The operation of IFPTOC based on earth-fault current estimate is described next. In case *Operation principle* = “EF current based”, then operation is based on the estimated effective earth-fault current magnitude taking account the effect of *Reduction factor*. The harmonic content of fault current can be included into estimate with setting *Enable harmonics* = “Enable”.

Operation time can be either definite time or inverse time, selected with setting *Operating curve type* = “Definite time”, “Inverse time EN50522” or “Inverse time IEEE80”.

When *Operating curve type* = “Definite time” is selected, then

- Operate time is according to definite time (DT) operation
- START and ST_EF outputs are activated when estimated earth-fault current magnitude (considering the effect of settings *Reduction factor* and *Enable harmonics*) exceeds setting *EF current Str Val* and earth fault is detected, and earth-fault current estimate is validated. Note that *Ena RF Compensation* = “Enable” does not affect this start condition. It is important to set setting *EF current Str Val* according to required protection sensitivity.
- OPERATE and OP_EF outputs are activated after operation timer has elapsed, defined with setting *DT stage Op time*.
- Reset timer is started if any of the above conditions for START is not anymore valid. START and ST_EF outputs stay activated until the reset timer expires (setting *Reset delay time*). After OPERATE output activation, START, ST_EF, OPERATE and OP_EF outputs are reset immediately i.e. reset delay time is no longer valid.
- During re-striking/intermittent earth faults, in case operation should be based preferably on counted number of transients, then setting *Reset delay time* should be set to low value, say 20-40 ms, thus definite time operation is ineffective during re-striking/intermittent earth faults as DT-timer becomes reset between re-strikes. Dedicated intermittent earth-fault protection functionality based on counted number of transients is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.
- Applicable settings are: *Reduction factor, EF current Str Val, DT stage Op time* and *Reset delay time*.
- Note that setting *CB Delay Comp* (circuit breaker delay compensation) is not applicable in definite time operation, but it must be taken into account in setting *DT stage Op time*.

Minimum practical value for setting *EF current Str Val* is 0.5% from CT primary current. For example, in case CT primary current is 200 A, then minimum practical value for setting *EF current Str Val* is 0.5%*200A = 1 A. For CT with 400 A primary current, then minimum practical value for setting *EF current Str Val* is 0.5%*400A = 2 A. The lower setting *EF current Str Val* is used, the higher sensitivity in terms of fault resistance can be obtained. Sensitivity in terms of fault resistance depends also on the network parameters (nominal voltage, damping and detuning) as described by equation below:

$$R_F[ohm] \leq \frac{U_{PE} \cdot \left(\sqrt{I_d^4 + 2I_d^2 \cdot I_v^2 - I_F^2 \cdot I_v^2 + I_v^4} - I_d \cdot I_F\right)}{(I_d^2 + I_v^2) \cdot I_F}$$

(Equation 120)

where U_{PE} is the nominal phase-to-earth voltage [V], I_d is the total system damping [A], I_v is the detuning [A], I_F is setting *EF current Str Val* in primary amperes.

Consider next the following example:

Example 1. Definite time operation of IFPTOC, when Operation principle = "EF current based", *Operating curve type* = "Definite time" is illustrated in *Figure 341*. In the example, setting *EF current Str Val* = 0.04*In (4 A with primary 100 A) and *DT stage Op time* = 400 ms. *Reduction factor* =1.0. IFPTOC starts when estimated fault current exceeds 4 A and operates after 400 ms, if start conditions are met. For illustrating possible operating speed requirements of protection, limits of touch voltage and earth potential rise durations defined in standard EN50522 scaled into corresponding earth-fault current requirements using the maximum earthing resistance R_{Emax} (setting *Maximum earthing Ris*) encountered in protected feeder are shown for reference.

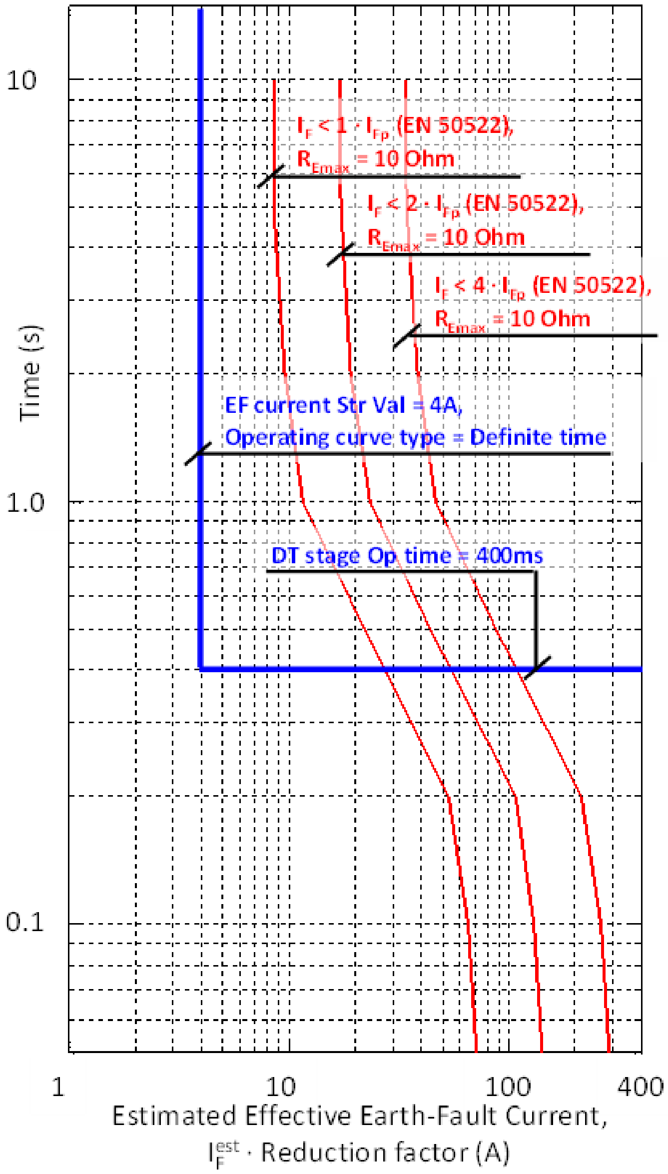


*Figure 341: Example of definite time operation of IFPTOC, when Operation principle = "EF current based", Operating curve type = "Definite time". Settings EF current Str Val = 0.04*In (4A) and DT stage Op time = 400ms. Reduction factor = 1.0. Maximum earthing Ris = 10ohm.*

When *Operating curve type* = "Inverse time EN50522" is selected, then

- Operate time is inverse time according to standard EN50522:

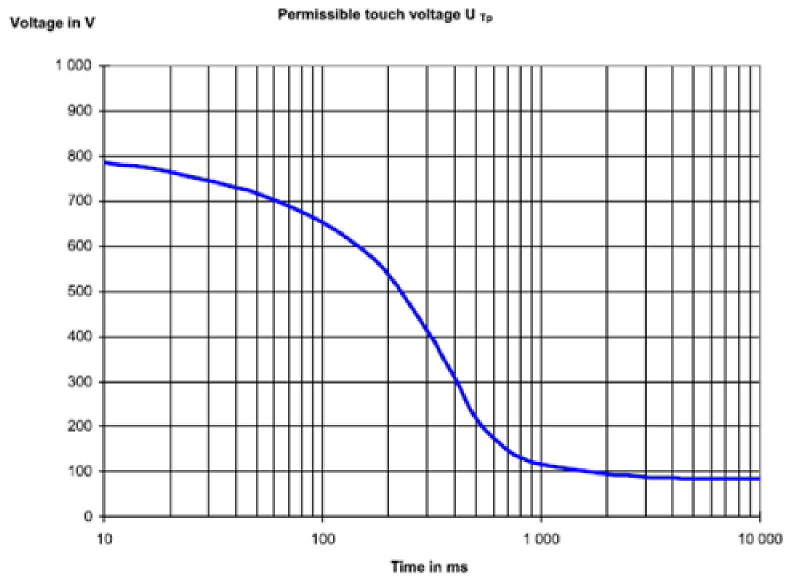


Figure 342: Permissible time-touch voltage characteristics given in standard EN 50522

- Time margin for practical circuit-breaker operate time can be applied with setting *CB delay Comp*. Default time margin is 0 ms.
- START and ST_EF outputs are activated when estimated effective earth-fault current magnitude (considering the effect of settings *Reduction factor* and *Enable harmonics*) exceeds setting *EF current Str Val* and earth fault is detected, and earth-fault current estimate is validated. Note that *Ena RF Compensation* = "Enable" does not affect this start condition.
- OPERATE and OP_EF outputs are activated according to the operate time - touch voltage and earth potential rise requirements defined in standard EN 50522. i.e. operate time is inversely proportional to the estimated fault current.
- Reset timer is started if any of the above conditions for START is not anymore valid. START and ST_EF outputs stay activated until the reset timer expires (setting *Reset delay time*). After OPERATE output activation, START, ST_EF, OPERATE and OP_EF outputs are reset immediately i.e. reset delay time is no longer valid. During re-striking/intermittent earth faults, the very high current transient may result to very fast operation times. In case longer operation time during re-striking/intermittent earth faults is preferred and operation should be based preferably on counted number of transients, then setting *Reset delay time* should be set to low value, say 20-40 ms. Dedicated intermittent earth-fault protection functionality based on counted number of transients is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.
- Applicable settings are: *Reduction factor, EF current Str Val, CB delay Comp, UTp multiplier, Maximum earthing Ris, IDMT stage Min Op Tm, IDMT stage Max Op Tm, Reset delay time*.

It is important to note, that:

1. Setting *Maximum earthing Ris* is used to scale the touch voltage and earth potential rise requirements defined in standard EN 50522 into corresponding earth-fault current requirements.
2. Setting *UTp multiplier* enables operation based on permissible earth potential rise U_E, by scaling of the permissible time-touch voltage characteristics given in standard EN 50522 with Setting *UTp multiplier*, see table below.

Table 627: Permissible touch voltages U_{Tp} and earth potential rise U_E values given in standard EN50522 converted into equivalent permissible earth-fault current I_{Fp} values as a function of the fault duration t_f. Conversion is made with parameter R_{Emax}, which is the setting *Maximum earthing Ris* in primary ohms i.e. the maximum earthing resistance encountered in protected feeder.

Fault duration t_f [sec.]	Permissible touch voltage, U_{Tp} converted into corresponding permissible fault current, I_{Fp}, U_{Tp} multiplier = 1.0 [A]	Permissible earth potential rise, U_E converted into corresponding permissible fault current, I_{Fp}, U_{Tp} multiplier = 2.0 [A]	Permissible earth potential rise, U_E converted into corresponding permissible fault current, I_{Fp}, U_{Tp} multiplier = 4.0 [A]
0.05	716 V/R_{Emax}	1432 V/R_{Emax}	2864 V/R_{Emax}
0.10	654 V/R_{Emax}	1308 V/R_{Emax}	2616 V/R_{Emax}
0.20	537 V/R_{Emax}	1074 V/R_{Emax}	2148 V/R_{Emax}
0.50	220 V/R_{Emax}	440 V/R_{Emax}	880 V/R_{Emax}
1.00	117 V/R_{Emax}	234 V/R_{Emax}	468 V/R_{Emax}
2.00	96 V/R_{Emax}	192 V/R_{Emax}	384 V/R_{Emax}
5.00	86 V/R_{Emax}	172 V R_{Emax}	344 V/R_{Emax}
10.00	85 V/R_{Emax}	170 V/R_{Emax}	340 V/R_{Emax}

3. Minimum effective earth-fault current magnitude (considering the effect of setting *Reduction factor*), which must be exceeded for the function to start, is defined with setting *EF current Str Val*. It is important to set this value according to required protection sensitivity.
4. With *IDMT stage Min Op Tm* setting user can define minimum allowed operate time for IFPTOC i.e. this is the minimum allowed operate time of IFPTOC.
5. With *IDMT stage Max Op Tm* setting user can define maximum allowed operate time for IFPTOC i.e. this is the maximum allowed operate time of IFPTOC although IDMT timer would define slower operate time.

Parameter defining maximum earthing resistance, setting *Maximum earthing Ris* must be always set in case *Operation principle* = “EF current based” and *Operating curve type* = “Inverse time EN50522” is selected. Setting *Maximum earthing Ris* is needed to scale the touch voltage and earth potential rise requirements defined in standard EN 50522 into corresponding earth-fault current requirements.

Setting *Reduction factor* considers the fact that only part of the earth-fault current (I_F) will flow back through “remote” earth and introduces earth potential rise and touch voltages.

Minimum practical value for setting *EF current Str Val* is 0.5% from CT primary current. For example, in case CT primary current is 200A, then minimum practical value for setting *EF current Str Val* is 0.5%*200 A = 1 A. For CT with 400 A primary current, then minimum practical value for setting *EF current Str Val* is 0.5%*400 A = 2 A. The lower setting *EF current Str Val* is used, the higher sensitivity in terms of fault resistance can be obtained. Sensitivity in terms of fault resistance depends also on the network parameters (nominal voltage, damping and detuning) as described by *Equation 120*.

When *Operating curve type* = “Inverse time EN50522” is selected, then the protection operate time as a function of estimated effective earth-fault current I_F^{est} (taking into account the effect of settings *Reduction factor* and *Enable harmonics*) is according to equation below:

$$t = 0.29 \times e^{\ln\left(-\frac{722.8-\left(\frac{I_F^{est} \times Reduction\ factor \times Maximum\ earthing\ Ris}{UTp\ multiplier}\right)}{85.3-\left(\frac{I_F^{est} \times Reduction\ factor \times Maximum\ earthing\ Ris}{UTp\ multiplier}\right)}\right)/2.39} - CB\ delay\ Comp\ [s]$$

(Equation 121)

In IFPTOC function, the preferred presentation of operation timer characteristics is by plotting the protection operate time as a function of permissible/estimated earth-fault current as illustrated in figures from *Figure 343*, *Figure 344* and *Figure 345*.

Consider next three examples with *Operating curve type* = “Inverse time EN50522”:

Table 628: Comparison of operation times given in EN50522 with IFPTOC. The theoretical operate time of IFPTOC has been calculated assuming CB delay Comp = 0 s

EN50522, U_{tp} [V]	EN50522, t_f [sec]	IFPTOC, t_f Theoretical [sec]
716	0.05	0.04
654	0.1	0.12
537	0.2	0.20
220	0.5	0.50
117	1	1.00
96	2	1.59
86	5	5.02
85	10	8.48

Example 2a. Inverse time operation of IFPTOC, when *Operation principle* = “EF-current based” and *Operating curve type* = “Inverse time EN50522” is illustrated in *Figure 343*. Start value for operation is set to be 0.02*In (2 A if primary 100 A). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms. Setting *UTp multiplier* is 1.0 and setting *Maximum earthing Ris* is 10 ohms. Reduction factor = 1.0. For illustrating the operating speed requirement of protection, limits of touch voltage durations defined in standard EN50522 scaled the into corresponding earth-fault current requirements using the maximum earthing resistance R_{Emax} (setting *Maximum earthing Ris*) encountered in protected feeder are shown for reference.

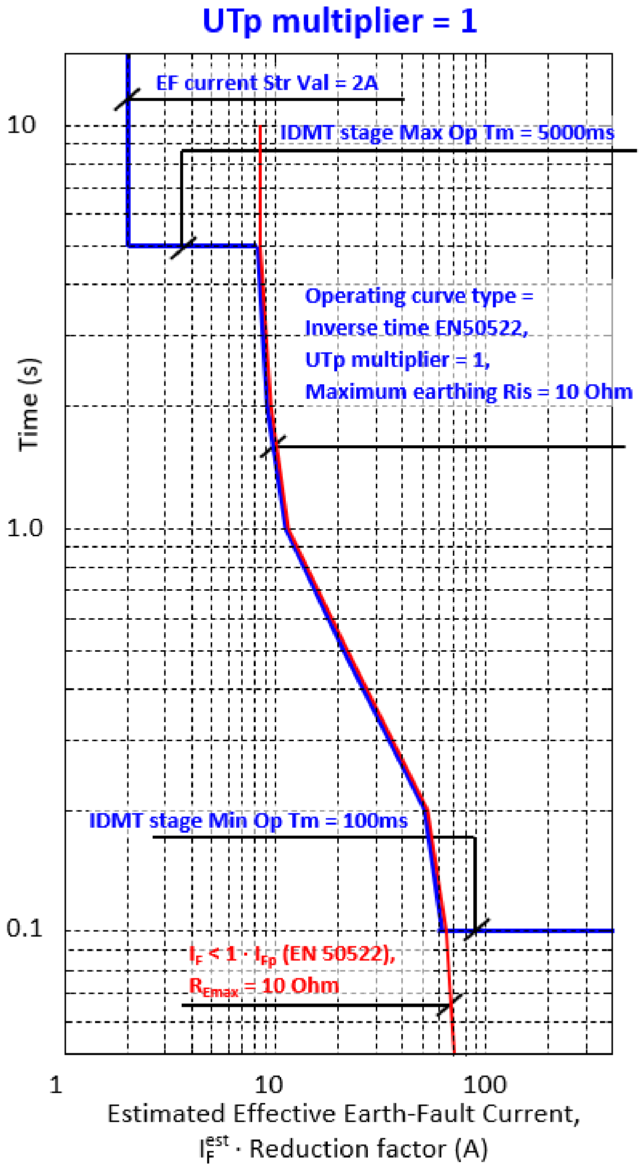


*Figure 343: Operation timer characteristic of IFPTOC function when Operation principle = "EF-current based" and Operating curve type = "Inverse time EN50522". Setting UTp multiplier is 1.0, Maximum earthing Ris = 10ohms, EF current Str Val = 0.02*In (2A), IDMT stage Min Op Tm = 100 ms and IDMT stage Max Op Tm = 5000 ms. Reduction factor = 1.0. Characteristics are according to standard EN50522.*

Example 2b. Inverse time operation of IFPTOC, when *Operation principle* = "EF-current based" and *Operating curve type* = "Inverse time EN50522" is illustrated in *Figure 344*. Start value for operation is set to be 0.04*In (4 A). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms. Setting *UTp multiplier* is 2.0 and setting *Maximum earthing Ris* is 10 ohms. Reduction factor = 1.0. For illustrating the operating speed requirement of protection, limits of earth potential rise durations defined in standard EN50522 scaled into corresponding earth-fault current requirements using the maximum earthing resistance R_{Emax} (setting *Maximum earthing Ris*) encountered in protected feeder are shown for reference.

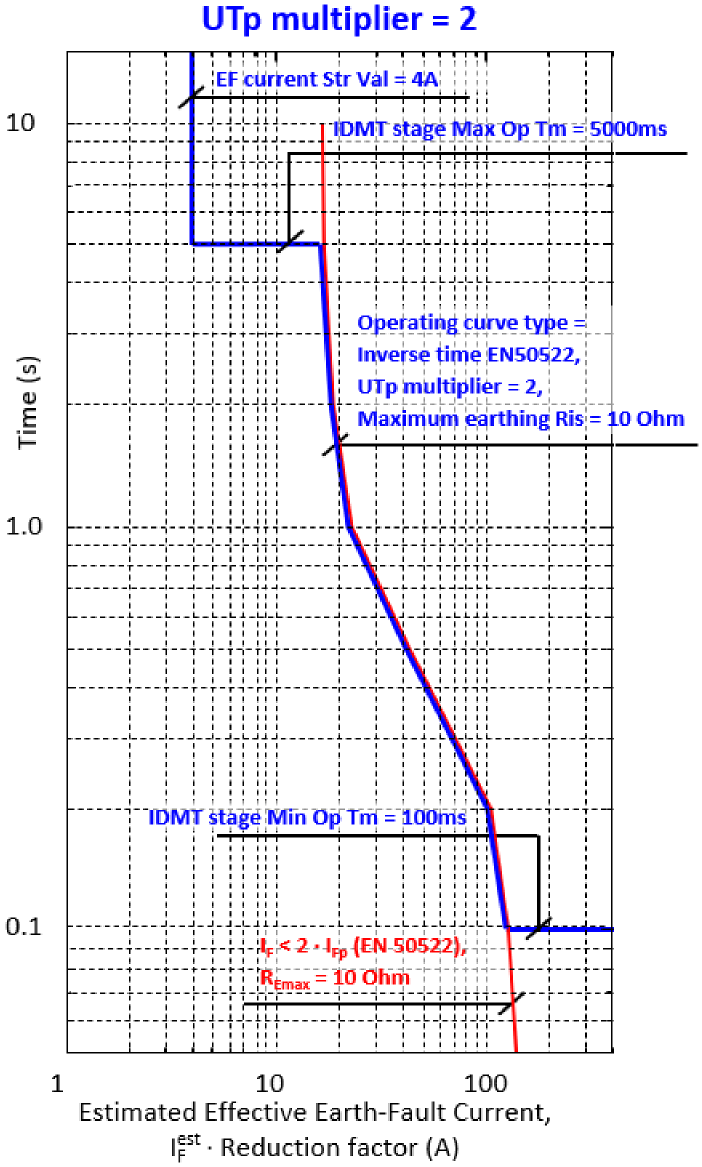


*Figure 344: Operation timer characteristic of IFPTOC function when Operation principle = "EF-current based" and Operating curve type = "Inverse time EN50522". Setting UTp multiplier is 2.0, Maximum earthing Ris = 10 ohms, EF current Str Val = 0.02*In (4 A), IDMT stage Min Op Tm = 100 ms and IDMT stage Max Op Tm = 5000 ms. Reduction factor = 1.0. Characteristics are according to standard EN50522.*

Example 2c. Inverse time operation of IFPTOC, when *Operation principle* = "EF-current based" and *Operating curve type* = "Inverse time EN50522" is illustrated in *Figure 345*. Start value for operation is set to be 0.06*In (6 A). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms. Setting *UTp multiplier* is 4.0 and setting *Maximum earthing Ris* is 10 ohms. Reduction factor = 1.0. For illustrating the operating speed requirement of protection, limits of earth potential rise durations defined in standard EN50522 scaled into corresponding earth-fault current requirements using the maximum earthing resistance R_{Emax} (setting *Maximum earthing Ris*) encountered in protected feeder are shown for reference.

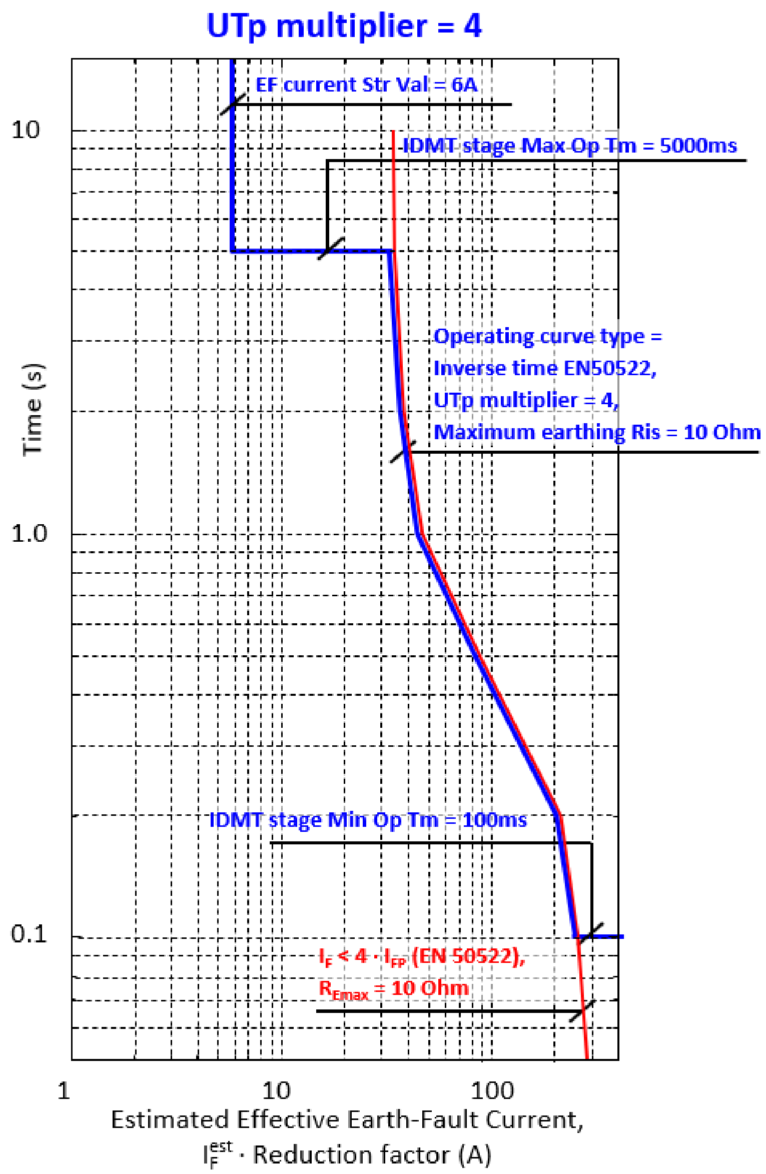


*Figure 345: Operation timer characteristic of IFPTOC function when Operation principle = “EF-current based” and Operating curve type = “Inverse time EN50522”. Setting UTp multiplier is 4.0, Maximum earthing Ris = 10 ohms, EF current Str Val = 0.06*In (6 A), IDMT stage Min Op Tm = 100 ms and IDMT stage Max Op Tm = 5000 ms. Reduction factor = 1.0. Characteristics are according to standard EN50522.*

When Operating curve type = “Inverse time IEEE80” is selected, then

- Operate time is inverse time according to standard IEEE80:

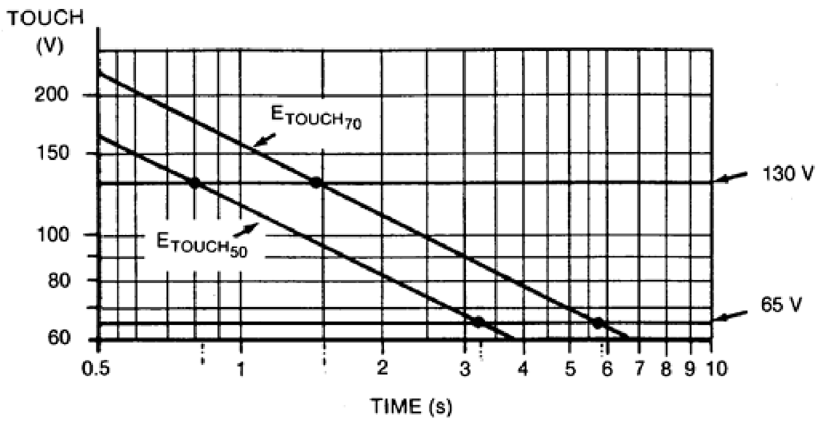


Figure 346: Permissible time-touch voltage characteristics given in standard IEEE80 (metal-to-metal contact)

- This operation mode can be also used when maximum allowed earth potential rise vs. operation speed follows a relationship such as 750 V/√*t*[*sec*].
- Time margin for practical circuit-breaker operate time can be applied with setting *CB delay Comp*. Default setting is 0 ms.
- START and ST_EF outputs are activated when estimated effective earth-fault current magnitude (considering the effect of settings *Reduction factor* and *Enable harmonics*) exceeds setting *EF current Str Val* and earth fault is detected, and earth-fault current estimate is validated. Note that *Ena RF Compensation* = “Enable” does not affect this start condition. It is important to set setting *EF current Str Val* according to required protection sensitivity.
- OPERATE and OP_EF-outputs are activated so that the operate time is according to the touch voltage requirements defined in standard IEEE80. i.e. operate time is inversely proportional to the estimated fault current.
- Reset timer is started if any of the above conditions for START is not anymore valid. START and ST_EF outputs stay activated until the reset timer expires (setting *Reset delay time*). After OPERATE output activation, START, ST_EF, OPERATE and OP_EF outputs are reset immediately i.e. reset delay time is no longer valid.
- During re-striking/intermittent earth faults, the very high current transient may result to very fast operation times. In case longer operation during re-striking/ intermittent earth faults is preferred and operation should be based preferably on counted number of transients, then setting *Reset delay time* should be set to low value, say 20-40 ms. Dedicated intermittent earth-fault protection functionality based on counted number of transients is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.
- Applicable settings are: *Reduction factor, EF current Str Val, CB delay Comp, IEEE multiplier, Maximum earthing Ris, IDMT stage Min Op Tm, IDMT stage Max Op Tm, Reset delay time*.

According to the standard IEEE80, the values of the permissible touch voltage U_{Tp} as a function of the fault duration t_f are defined as follows:

For body weight of 50kg:

$$U_{Tp} = (1000 + 1.5 \cdot C_s \cdot \rho_s) \cdot \frac{0.116}{\sqrt{t_s}}$$

(Equation 122)

For body weight of 70kg:

$$U_{Tp} = (1000 + 1.5 \cdot C_s \cdot \rho_s) \cdot \frac{0.157}{\sqrt{t_s}}$$

(Equation 123)

where

C_s is the surface layer derating factor

ρ_s is the surface material resistivity in Ω·m

ρ is the resistivity of the earth beneath the surface material in Ω·m

If no protective surface layer is used, then C_s =1 and $\rho_s = \rho$.

The equations of IEEE Std 80-2013 are in IFPTOC-function modelled with following simplified equation, with only one setting *IEEE multiplier*:

$$U_{TF}^{est} = IEEE\ multiplier \cdot \frac{1}{\sqrt{t_s}}$$

(Equation 124)

With setting *IEEE multiplier* the operate time as a function of estimated touch voltage magnitude can be adjusted. For body weight of 70kg, C_s =1, $\rho_s = \rho$ = 0 Ω·m, then *IEEE multiplier* equals 157.0.

In case *Operation principle* = “EF current based”, setting *Maximum earthing Ris* is used to scale the touch voltage and earth potential rise requirements defined in standard IEEE80 into corresponding earth-fault current requirements. When *Operating curve type* = “Inverse time IEEE80” is selected, then the protection operate time as a function of estimated effective earth-fault current I_F^{est} (taking into account the effect of settings *Reduction factor* and *Enable harmonics*) is according to equation below:

$$t = \left(\frac{IEEE\ multiplier}{Maximum\ earthing\ Ris * Reduction\ factor * I_F^{est}}\right)^2 - CB\ delay\ comp\ [s]$$

(Equation 125)

Example numerical values of the permissible touch voltage U_{Tp} converted into corresponding earth-fault current requirements as a function of the fault duration t_f according to standard IEEE80 are shown in table below.

Table 629: Numerical example of the values of the permissible touch voltages U_{Tp} as a function of the fault duration t_f according to standard IEEE80 converted into corresponding permissible earth-fault current values. The numerical values assume body weight of 70 kg, C_s =1, $\rho_s = \rho$ = 0 Ω·m, then IEEE multiplier equals 157. Conversion is made with parameter R_{Emax}, which is the setting *Maximum*

***earthing Ris* in primary ohms i.e. the maximum earthing resistance encountered in protected feeder.**

Fault duration t_f [sec.]	Permissible touch voltage, U_{Tp} converted into corresponding permissible fault current, I_{Fp} [A]
0.05	702 V/R_{Emax}
0.10	496 V/R_{Emax}
0.20	351 V/R_{Emax}
0.50	222 V/R_{Emax}
1.00	157 V/R_{Emax}
2.00	111 V/R_{Emax}
5.00	70 V/R_{Emax}
10.00	50 V/R_{Emax}

In some countries, safety during an earth fault is defined in terms of highest allowed earth potential rise (EPR) as a function of fault duration. As an example, in Finnish national Electrical Safety Regulations 89 define highest allowed earth potential rise as a function of fault duration as shown in table below.

Table 630: Highest allowed EPR values based on Electrical Safety

Group	Highest allowed EPR [V], when earth fault is automatically disconnected within time *t* [sec]
a	750V/√*t*
b	2000V/√*t*
c	3000V/√*t*
d	500V/√*t*
e1	750V/√*t*
e2	1000V/√*t*

The regulations of *Table 630* are implemented into IFPTOC. In case *Operation principle* = “EF current based”, setting *Maximum earthing Ris* is used to convert the highest allowed earth potential risevalues into corresponding earth-fault current values. Setting *IEEE multiplier* is set to equal the highest allowed voltage value, for example for group d, *IEEE multiplier* = 500. Conversion of the highest allowed earth potential rise value to the highest allowed earth-fault current magnitude with setting *Maximum earthing Ris* is shown in *Table 631*.

Setting *Maximum earthing Ris* in primary ohms is selected based on the maximum earthing resistance encountered in protected feeder.

Table 631: Conversion of the highest allowed earth potential rise value into corresponding earth-fault current values according to the Electrical Safety Regulations

89 with setting *Maximum earthing Ris* in primary ohms i.e. the maximum earthing resistance encountered in protected feeder.

Group	Highest allowed EPR values [V] converted into corresponding permissible fault current, I_{Fp} [A],when earth fault is automatically disconnected within time t [sec]
a	(750 V/ *Maximum earthing Ris*)/√t
b	(2000 V/ *Maximum earthing Ris*)/√t
c	(3000 V/ *Maximum earthing Ris*)/√t
d	(500 V/ *Maximum earthing Ris*)/√t
e1	(750 V/ *Maximum earthing Ris*)/√t
e2	(1000 V/ *Maximum earthing Ris*)/√t

It is important to note, that:

1. Minimum effective earth-fault current magnitude (considering the effect of *Reduction factor*), which must be exceeded for the function to start, is defined with setting *EF current Str Val*. It is important to set this value according to required protection sensitivity.
2. With *IDMT stage Min Op Tm* setting user can define minimum allowed operate time for IFPTOC i.e. this is the minimum allowed operate time of IFPTOC.
3. With *IDMT stage Max Op Tm* setting user can define maximum allowed operate time for IFPTOC i.e. this is the maximum allowed operate time of IFPTOC although IDMT timer would define slower operate time.

Parameter defining maximum earthing resistance, setting *Maximum earthing Ris* must be always set in case *Operation principle* = “EF current based” and *Operating curve type* = “Inverse time IEEE80” is selected. Setting *Maximum earthing Ris* is needed to scale the touch voltage and earth potential rise requirements defined in standard IEEE80 into corresponding earth-fault current requirements.

Setting *Reduction factor* considers the fact that only part of the earth-fault current (I_F) will flow back through “remote” earth and introduces earthing and touch voltages.

When *Operating curve type* = “Inverse time IEEE80” is selected, then setting *UTp multiplier* is not effective.

Consider next the following example with *Operating curve type* = “Inverse time IEEE80”:

Example 3. Inverse time operation of IFPTOC, when *Operation principle* = “EF-current based” and *Operating curve type* = “Inverse time IEEE80” is illustrated in *Figure 347*. Start value for operation is set to be 0.02*In (2 A). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms. Setting *IEEE multiplier* is 500 and setting *Maximum earthing Ris* is 10 ohms. *Reduction factor* = 1.0. For illustrating the operating speed requirement of protection, limits of earth potential rise durations defined in Finnish national Electrical Safety Regulations 89 scaled the into corresponding earth-fault current requirements using the maximum earthing resistance R_{Emax} (setting *Maximum earthing Ris*) encountered in protected feeder are shown for reference.

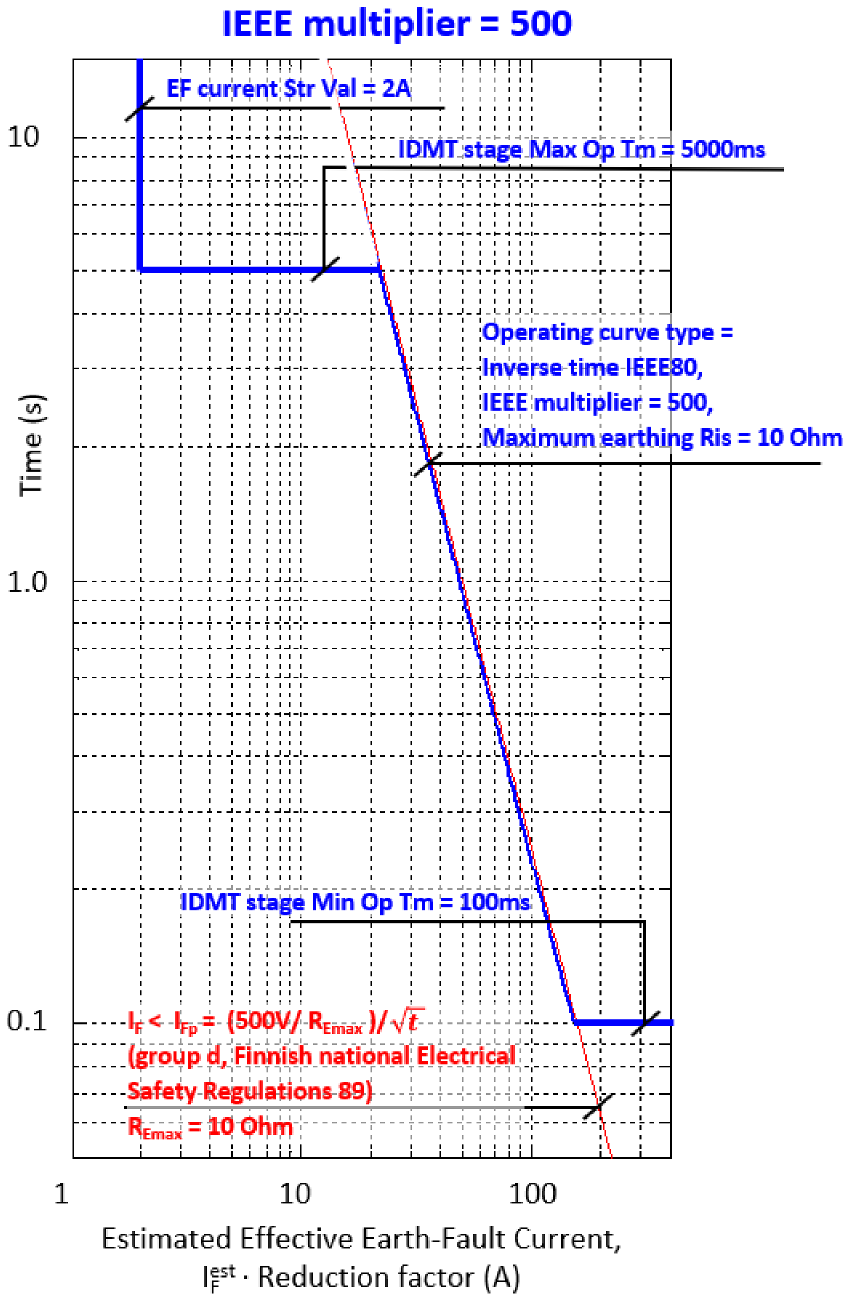


*Figure 347: Operation timer characteristic of IFPTOC-function when Operation principle = "EF-current based" and Operating curve type = "Inverse time IEEE80". Setting IEEE multiplier is 500,Maximum earthing Ris is 10 ohms, EF current Str Val = 0.02*In (2 A), IDMT stage Min Op Tm = 100 ms and IDMT stage Max Op Tm = 5000 ms. Reduction factor = 1.0. Characteristics are according to standard IEEE80.*

Principle based on touch voltage estimate

The operation of IFPTOC based on touch voltage estimate is described next. In case *Operation principle* = "Touch voltage based", then operation is based on the estimated touch voltage magnitude according to *Equation 119*. The harmonic content of touch voltage can be included into estimate with setting *Enable harmonics* = "Enable".

Operation time can be either definite time or inverse time, selected with setting *Operating curve type* = “Definite time”, “Inverse time EN50522” or “Inverse time IEEE80”.

When *Operating curve type* = “Definite time” is selected, then

- Operate time is according to definite time (DT) operation.
- START and ST_EF outputs are activated when estimated touch voltage (considering the effect of settings *Reduction factor* and *Enable harmonics*) exceeds setting *Touch Vol Str Val* and earth fault is detected and earth-fault current estimate is validated. Note that *Ena RF Compensation* = “Enable” does not affect this start condition. It is important to set setting *Touch Vol Str Val* according to required protection sensitivity.
- OPERATE and OP_EF outputs are activated after *Operation timer* has elapsed, defined with setting *DT stage Op time*.
- Reset timer is started if any of the above conditions for START is not anymore valid. START and ST_EF outputs stay activated until the reset timer expires (setting Reset delay time). After OPERATE output activation, START, ST_EF, OPERATE and OP_EF outputs are reset immediately i.e. reset delay time is no longer valid.
- During re-striking/intermittent earth faults, in case operation should be based preferably on counted number of transients, then setting *Reset delay time* should be set to low value, say 20-40 ms, thus definite operation is ineffective during re-striking/intermittent earth faults. Dedicated intermittent earth-fault protection functionality based on counted number of transients is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.
- Applicable settings are: *Reduction factor, Maximum earthing Ris, Touch Vol Str Val, DT stage Op time, Reset delay time*.
- Note that setting *CB Delay Comp* (circuit breaker delay compensation) is not applicable in definite time operation.

Consider next the following example:

Example 4. Setting *Touch Vol Str Val* = 40 V and *DT stage Op time* = 400 ms. IFPTOC starts when estimated touch voltage exceeds 40 V and operates after 400 ms, if start conditions are met. Maximum earthing resistance value encountered in the protected feeder is set to be 10 ohms (setting *Maximum earthing Ris*) and *Reduction factor* = 1. For illustrating possible operating speed requirements of protection, limits of touch and earth potential rise durations defined in standard EN50522 are shown for reference.

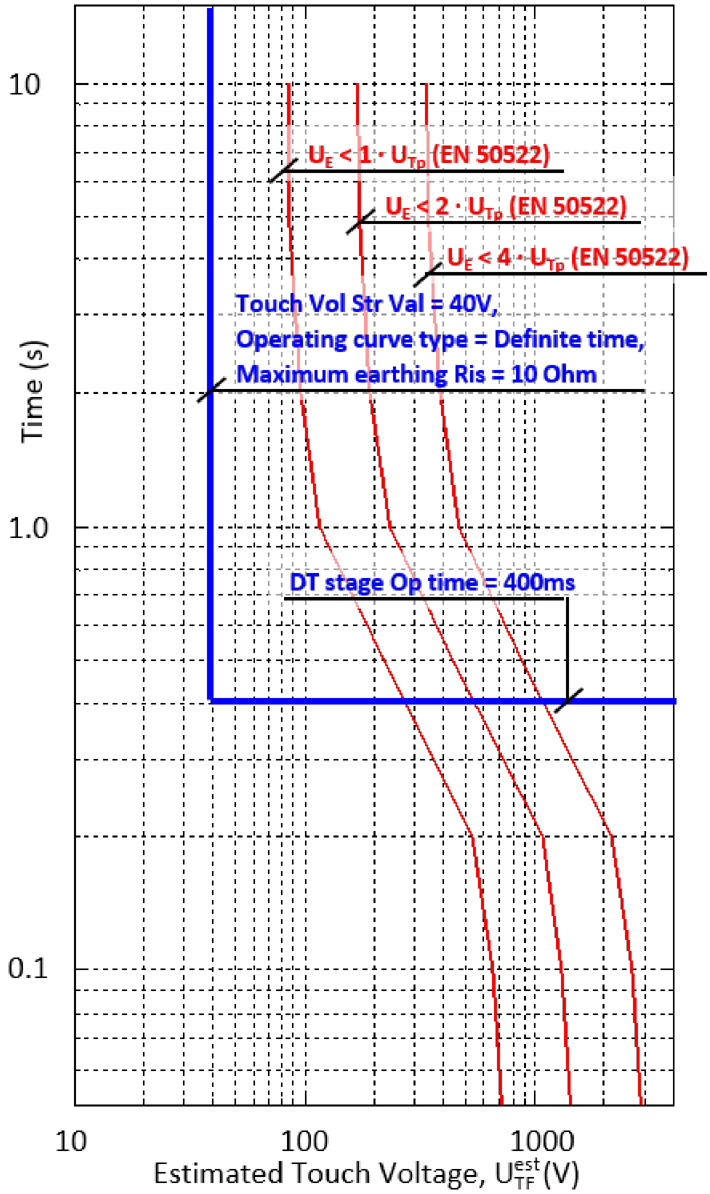


Figure 348: Example of definite time operation of IFPTOC, when Operation principle = "Touch voltage based", Operating curve type = "Definite time". Setting Touch Vol Str Val = 40 V and DT stage Op time = 400 ms. Maximum earthing Ris = 10 ohm

Parameter defining maximum earthing resistance, setting *Maximum earthing Ris* must be always set in case *Operation principle* = "Touch voltage based" and *Operating curve type* = "Definite time" is selected. Setting *Maximum earthing Ris* is needed to scale the estimated earth-fault current value into corresponding touch voltage or earth potential rise value.

When *Operating curve type* = "Inverse time EN50522" is selected, then

- Operate time is inverse time according to standard EN50522:

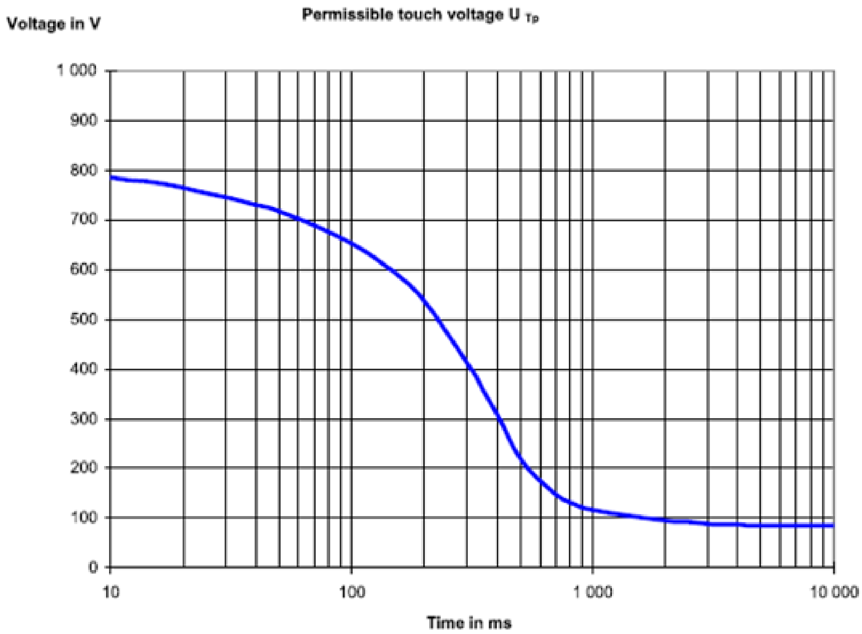


Figure 349: Permissible time-touch voltage characteristics given in standard EN 50522

- Time margin for practical circuit-breaker operate time can be applied with setting *CB delay Comp*. Default setting is 0 ms.
- START and ST_EF outputs are activated when estimated touch voltage (considering the effect of settings *Reduction factor* and *Enable harmonics*) exceeds setting *Touch Vol Str Val* and earth fault is detected and earth-fault current estimate is validated. Note that *Ena RF Compensation* = “Enable” does not affect this start condition.
- OPERATE and OP_EF outputs are activated according to time-touch voltage characteristics given in standard EN 50522 i.e. operate time is inversely proportional to the estimated touch voltage.
- Reset timer is started if any of the above conditions for START is not anymore valid. START and ST_EF outputs stay activated until the reset timer expires (setting Reset delay time). After OPERATE output activation, START, ST_EF, OPERATE and OP_EF outputs are reset immediately i.e. reset delay time is no longer valid.
- During re-striking/intermittent earth faults, the very high current transient may result to very fast operation times. In case longer operation during re-striking/ intermittent earth faults is preferred and operation should be based preferably on counted number of transients, then setting *Reset delay time* should be set to low value, say 20-40 ms. Dedicated intermittent earth-fault protection functionality based on counted number of transients is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.
- Applicable settings are: *Reduction factor, Maximum earthing Ris, Touch Vol Str Val, CB delay Comp, UTp multiplier, IDMT stage Min Op Tm, IDMT stage Max Op Tm, Reset delay time*.

It is important to note, that:

1. Settings *Reduction factor* and *Maximum earthing Ris* are used to scale the estimated effective earth-fault current value into corresponding touch voltage or earth-potential rise estimate.
2. Setting *UTp multiplier* enables operation based on permissible earth potential rise U_E, by scaling of the permissible time-touch voltage characteristics given in standard EN 50522 with Setting *UTp multiplier*, see table below.

Table 632: Permissible touch voltages U_{Tp} and earth potential rise U_E values as a function of the fault duration t_f according to standard EN50522 with U_{Tp} multiplier as a parameter

Fault duration t_f [sec.]	Permissible touch voltage, U_{Tp}, U_{Tp} multiplier = 1.0 [V]	Permissible earth potential rise, U_E, U_{Tp} multiplier = 2.0 [V]	Permissible earth potential rise, U_E, U_{Tp} multiplier = 4.0 [V]
0.05	716	1432	2864
0.10	654	1308	2616
0.20	537	1074	2148
0.50	220	440	880
1.00	117	234	468
2.00	96	192	384
5.00	86	172	344
10.00	85	170	340

3. Minimum touch voltage or earth potential rise magnitude (considering the effect of *Reduction factor*), which must be exceeded for the function to start, is defined with setting *Touch Vol Str Val*. It is important to set setting *Touch Vol Str Val* according to required protection sensitivity.
4. With *IDMT stage Min Op Tm* setting user can define minimum allowed operate time for IFPTOC i.e. this is the minimum allowed operate time of IFPTOC.
5. With *IDMT stage Max Op Tm* setting user can define maximum allowed operate time for IFPTOC i.e. this is the maximum allowed operate time of IFPTOC although IDMT timer would define slower operate time.

Parameter defining maximum earthing resistance, setting *Maximum earthing Ris* must be always set in case *Operation principle* = "Touch voltage based" and *Operating curve type* = "Inverse time EN50522" is selected. Setting *Maximum earthing Ris* is needed to scale the estimated effective earth-fault current value to corresponding touch voltage or earth potential rise value.

Setting *Reduction factor* considers the fact that only part of the earth-fault current (I_F) will flow back through "remote" earth and introduces earthing and touch voltages.

Minimum practical value for setting *Touch Vol Str Val* is 0.5% of CT primary current multiplied by setting *Maximum earthing Ris*. For example, in case CT primary current is 200 A, and *Maximum earthing Ris* = 10 ohm, then minimum practical value for setting *Touch Vol Str Val* is 0.5%*200 A*10 ohm = 10 V. For CT with 400 A primary current, then minimum practical value for setting *Touch Vol Str Val* is 0.5%*400 A*10 ohm = 20 V. The lower setting *Touch Vol Str Val* is used, the higher sensitivity in terms of fault resistance can be obtained. Sensitivity in terms of fault resistance depends also on the network parameters (nominal voltage, damping and detuning) as described by *Equation 126*.

$$R_F[ohm] \leq \frac{U_{PE} \cdot \left(\sqrt{I_d^4 + 2I_d^2 \cdot I_v^2 - (U_F/R_E)^2 \cdot I_v^2 + I_v^4} - I_d \cdot (U_F/R_E) \right)}{(I_d^2 + I_v^2) \cdot (U_F/R_E)}$$

(Equation 126)

where U_{PE} is the nominal phase-to-earth voltage [V], I_d is the total system damping [A], I_v is the detuning [A], U_F is setting *Touch Vol Str Val* in primary volts and R_E is setting *Maximum earthing Ris* in primary ohms.

When *Operating curve type* = "Inverse time EN50522" is selected, then the protection operate time as a function of estimated touch voltage U_{TF}^{est} (taking account the effect of *Reduction factor*) is according to *Equation 127*:

$$t = 0.29 \times e^{ln\left(-\frac{722.8 - \left(\frac{U_{TF}^{est}}{UTp\ multiplier} \right)}{85.3 - \left(\frac{U_{TF}^{est}}{UTp\ multiplier} \right)} \right) / 2.39} - CB\ delay\ comp\ [s]$$

(Equation 127)

In IFPTOC function, the preferred presentation of operation timer characteristics is by plotting the protection operate time as a function of permissible/estimated touch voltage as illustrated in *Figure 350*, *Figure 351* and *Figure 352*.

Consider next three examples with *Operating curve type* = "Inverse time EN50522":

Example 5a. Inverse time operation of IFPTOC, when *Operation principle* = "Touch voltage based", *Operating curve type* = "Inverse time EN50522" and setting *UTp multiplier* = 1.0 is illustrated in *Figure 350*. Start value for operation is set to be 20 V (setting *Touch Vol Str Val*). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms (settings *IDMT stage Min Op Tm, IDMT stage Max Op Tm*). Maximum earthing resistance value encountered in the protected feeder is set to be 10 ohms (setting *Maximum earthing Ris*) and Reduction factor = 1. For illustrating the operating speed requirement of protection, limits of touch voltage durations defined in standard EN50522 are shown for reference.

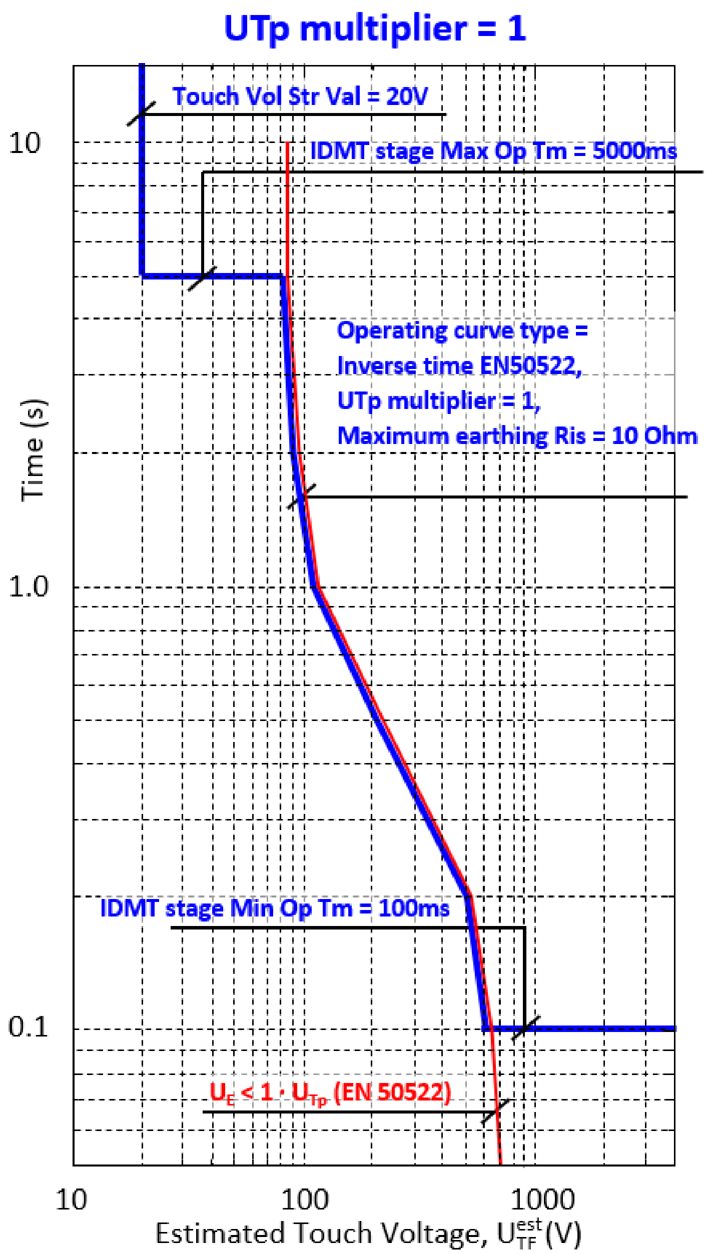


Figure 350: Operation timer characteristic of IFPTOC function when Operation principle = "Touch voltage based", Operating curve type = "Inverse time EN50522" and Operating curve type = 1.0. Characteristics are according to standard EN50522. Maximum earthing Ris = 10 ohm.

Example 5b. Inverse time operation of IFPTOC, when *Operation principle* = "Touch voltage based", *Operating curve type* = "Inverse time EN50522" and setting *UTp multiplier* = 2.0 is illustrated in *Figure 351*. Start value for operation is set to be 40 V (setting *Touch Vol Str Val*). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms (settings *IDMT stage Min Op Tm, IDMT stage Max Op Tm*). Maximum earthing resistance value encountered in the protected feeder is set to be 10 ohms (setting *Maximum earthing Ris*) and *Reduction factor* = 1. For illustrating the operating speed requirement of protection, limits of earth potential rise durations defined in standard EN50522 are shown for reference.

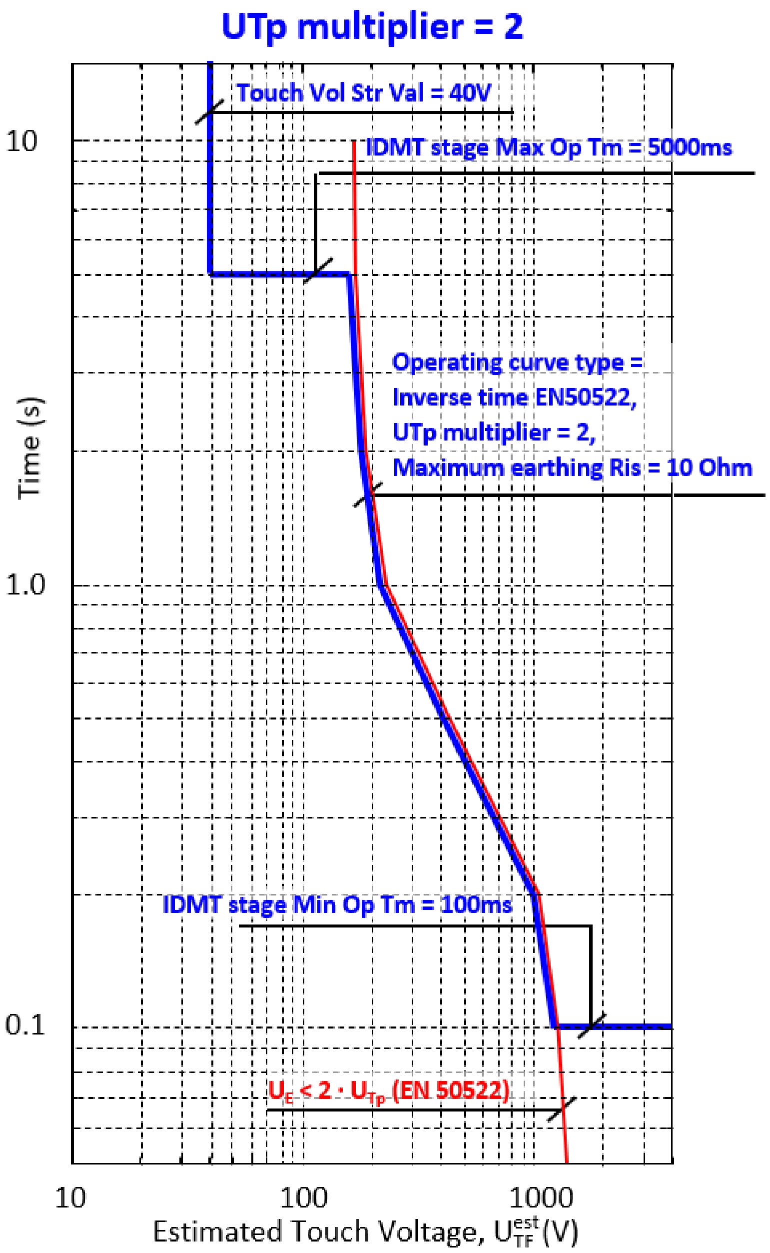


Figure 351: Operation timer characteristic of IFPTOC function when Operation principle = "Touch voltage based", Operating curve type = "Inverse time EN50522" and UTp multiplier = 2.0. Characteristics are according to standard EN50522. Maximum earthing Ris = 10 ohm.

Example 5c. Inverse time operation of IFPTOC, when *Operation principle* = "Touch voltage based", *Operating curve type* = "Inverse time EN50522" and setting *UTp multiplier* = 4.0 is illustrated in *Figure 352*. Start value for operation is set to be 60 V (setting *Touch Vol Str Val*). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms (settings *IDMT stage Min Op Tm, IDMT stage Max Op Tm*). Maximum earthing resistance value encountered in the protected feeder is set to be 10 ohms (setting *Maximum earthing Ris*) and *Reduction factor* = 1. For illustrating the operating speed requirement of protection, limits of earth potential rise durations defined in standard EN50522 are shown for reference.

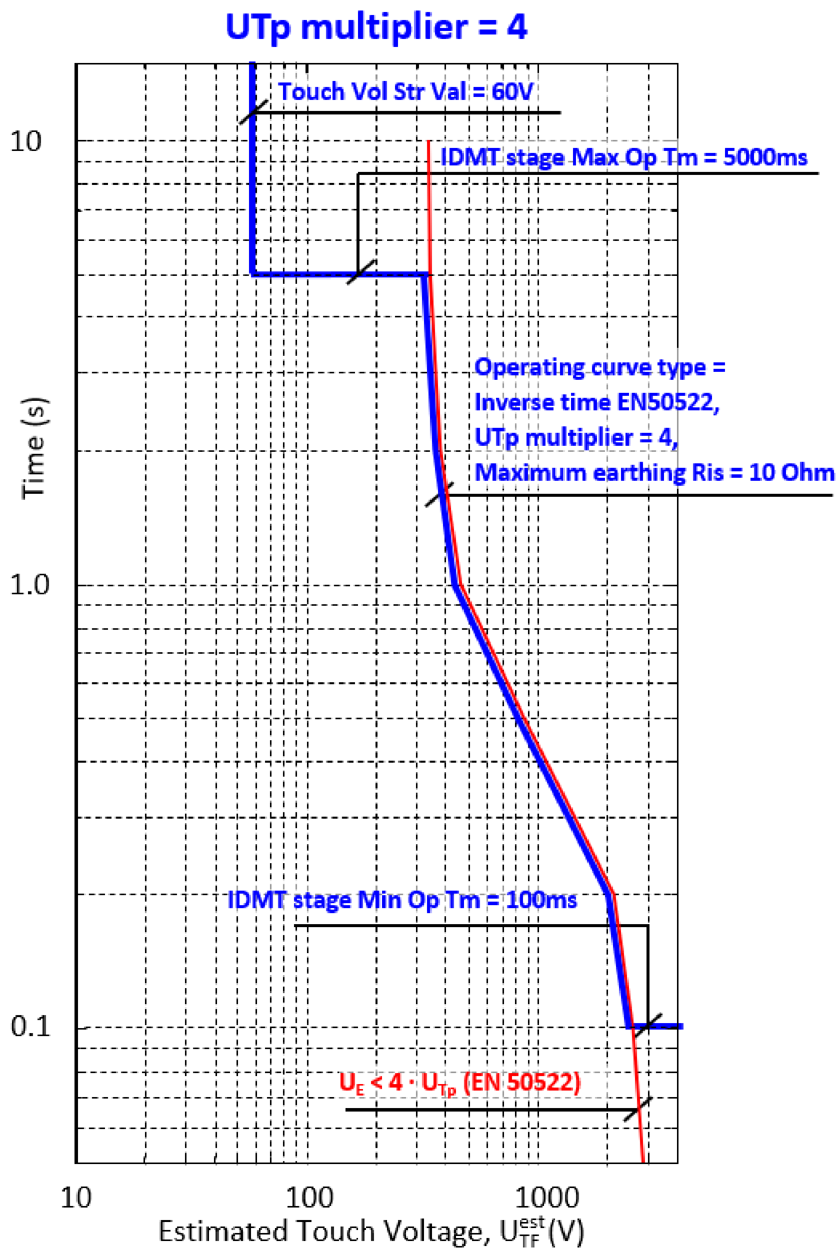


Figure 352: Operation timer characteristic of IFPTOC function when Operation principle = "Touch voltage based", Operating curve type = "Inverse time EN50522" and UTp multiplier = 4.0. Characteristics are according to standard EN50522. Maximum earthing Ris = 10 ohm.

When *Operating curve type* = "Inverse time IEEE80" is selected, then

- Operate time is inverse time according to standard IEEE80:

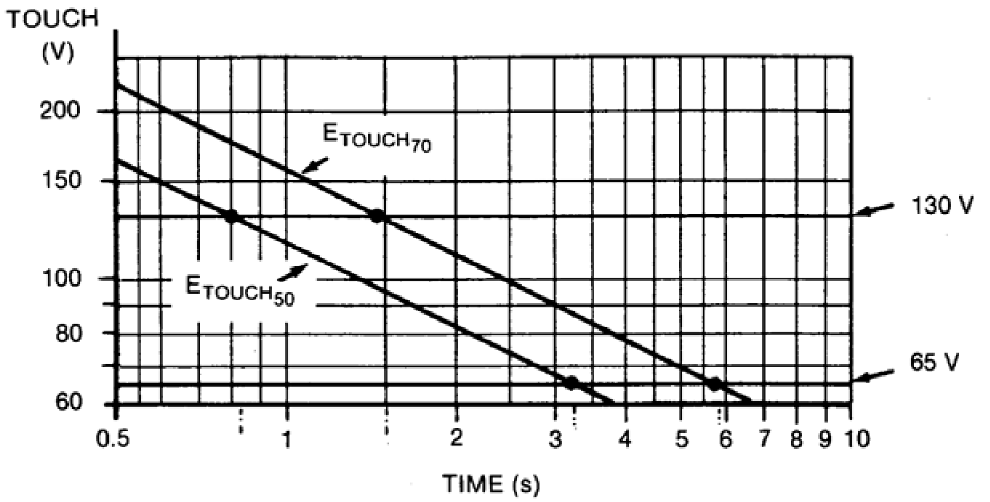


Figure 353: Permissible time-touch voltage characteristics given in standard IEEE80 (metal-to-metal contact).

- This operation mode can be also used when maximum allowed earthing voltage, i.e. earth potential rise, vs. operation speed follows a relationship such as 750V/ √*t*[*sec*].
- Time margin for practical circuit-breaker operate time can be applied with setting *CB delay Comp*. Default setting is 0 ms.
- START and ST_EF outputs are activated when estimated touch voltage (considering the effect of settings *Reduction factor* and *Enable harmonics*) exceeds setting *Touch Vol Str Val* and earth fault is detected and earth-fault current estimate is validated. Note that *Ena RF Compensation* = "Enable" does not affect this start condition.
- OPERATE and OP_EF outputs are activated according to time-touch voltage characteristics given in standard IEEE80 i.e. operate time is inversely proportional to the estimated touch voltage.
- Reset timer is started if any of the above conditions for START is not anymore valid. START and ST_EF outputs stay activated until the reset timer expires (setting *Reset delay time*). After OPERATE output activation, START, ST_EF, OPERATE and OP_EF outputs are reset immediately i.e. reset delay time is no longer valid.
- During re-striking/intermittent earth faults, the very high current transient may result to very fast operation times. In case longer operation during re-striking/ intermittent earth faults is preferred and operation should be based preferably on counted number of transients, then setting *Reset delay time* should be set to low value, say 20-40 ms. Dedicated intermittent earth-fault protection functionality based on counted number of transients is described in *Chapter 4.2.10.5.6 Intermittent earth-fault protection*.
- Applicable settings are: *Reduction factor, Maximum earthing Ris, Touch Vol Str Val, CB delay Comp, IEEE multiplier, IDMT stage Min Op Tm, IDMT stage Max Op Tm, Reset delay time*.

According to the standard IEEE80, the values of the permissible touch voltage U_{Tp} as a function of the fault duration t_f are defined as follows:

For body weight of 50 kg:

$$U_{Tp} = (1000 + 1.5 \cdot C_s \cdot \rho_s) \cdot \frac{0.116}{\sqrt{t_s}}$$

(Equation 128)

For body weight of 70 kg:

$$U_{Tp} = (1000 + 1.5 \cdot C_s \cdot \rho_s) \cdot \frac{0.157}{\sqrt{t_s}}$$

(Equation 129)

where

C_s is the surface layer derating factor

ρ_s is the surface material resistivity in Ω·m

ρ is the resistivity of the earth beneath the surface material in Ω·m

If no protective surface layer is used, then C_s =1 and $\rho_s = \rho$.

The equations of IEEE Std 80-2013 are in IFPTOC function modelled with following simplified equation, with only one parameter *IEEE multiplier*:

$$U_{TF}^{est} = IEEE\ multiplier \cdot \frac{1}{\sqrt{t_s}}$$

(Equation 130)

With setting *IEEE multiplier* operate time as a function of estimated touch voltage magnitude can be adjusted. For body weight of 70 kg, C_s =1, $\rho_s = \rho$ = 0 Ω·m, then *IEEE multiplier* equals 157.0.

In IFPTOC, the protection operate time t as a function of estimated touch voltage U_{TF}^{est} according to standard IEEE80 follows equation below:

$$t = \left(\frac{IEEE\ multiplier}{U_{TF}^{est}}\right)^2 - CB\ delay\ comp\ [s]$$

(Equation 131)

Example numerical values of the permissible touch voltage U_{Tp} as a function of the fault duration t_f according to standard IEEE80 are shown in *Table 633*. Values in *Table 633* assume body weight of 70 kg, C_s =1, $\rho_s = \rho$ = 0 Ω·m, then IEEE multiplier equals 157.0.

Table 633: Numerical example of the values of the permissible touch voltages U_{Tp} as a function of the fault duration t_f according to standard IEEE80 programmed

into IFPTOC. The numerical values assume body weight of 70 kg, C_s =1, ρ_s = ρ = 0 Ω·m, then *IEEE multiplier* equals 157.

Fault duration t_f [sec.]	Permissible touch voltage, U_{Tp} [V]
0.05	702
0.10	496
0.20	351
0.50	222
1.00	157
2.00	111
5.00	70
10.00	50

In some countries, safety during an earth fault is defined in terms of highest allowed earth potential rise (EPR) as a function of fault duration. As an example, in Finnish national Electrical Safety Regulations 89 define highest allowed earth potential rise (EPR) as a function of fault duration as shown in table below.

Table 634: Highest allowed EPR value based on Electrical Safety Regulations 89

Group	Highest allowed EPR [V], when earth-fault is automatically disconnected within time *t* [sec]
a	$750V/\sqrt{t}$
b	$2000V/\sqrt{t}$
c	$3000V/\sqrt{t}$
d	$500V/\sqrt{t}$
e1	$750V/\sqrt{t}$
e2	$1000V/\sqrt{t}$

The regulations of *Table 634* are implemented into IFPTOC. Setting *IEEE multiplier* is set to equal the highest allowed voltage value, for example for group d, *IEEE multiplier* = 500.

It is important to note, that:

1. Minimum effective touch-voltage magnitude (considering the effect of *Reduction factor*), which must be exceeded for the function to start, is defined with setting *Touch Vol Str Val*. It is important to set setting *Touch Vol Str Val* according to required protection sensitivity.
2. With *IDMT stage Min Op Tm* setting user can define minimum allowed operate time for IFPTOC i.e. this is the minimum allowed operate time of IFPTOC.
3. With *IDMT stage Max Op Tm* setting user can define maximum allowed operate time for IFPTOC i.e. this is the maximum allowed operate time of IFPTOC although IDMT timer would define slower operate time.

Parameter defining maximum earthing resistance, setting *Maximum earthing Ris* must be always set in case *Operation principle* = “Touch voltage based” and *Operating curve type* = “Inverse time IEEE80” is selected. Setting *Maximum earthing Ris* is needed to scale the estimated earth-fault current value into corresponding touch voltage or earth potential rise value.

Setting *Reduction factor* considers the fact that only part of the earth-fault current (I_F) will flow back through “remote” earth and introduces earth potential rise and touch voltages.

When *Operating curve type* = “Inverse time IEEE80” is selected, then setting *UTp multiplier* is not effective.

Consider next the following example with Operating curve type = “Inverse time IEEE80”:

Example 6. Inverse time operation of IFPTOC, when *Operation principle* = “Touch voltage based”, *Operating curve type* = “Inverse time IEEE80” and setting *IEEE multiplier* = 500 is illustrated in *Figure 354*. Start value for operation is set to be 20 V (setting *Touch Vol Str Val*). IFPTOC is set to have minimum operate time 100 ms and maximum operate time of 5000 ms (settings *IDMT stage Min Op Tm, IDMT stage Max Op Tm*). Maximum earthing resistance value encountered in the protected feeder is set to be 10 ohms (setting *Maximum earthing Ris*) and *Reduction factor* = 1. For illustrating the operating speed requirement of protection, limits of earth potential rise durations defined in Finnish national Electrical Safety Regulations 89 are shown for reference.

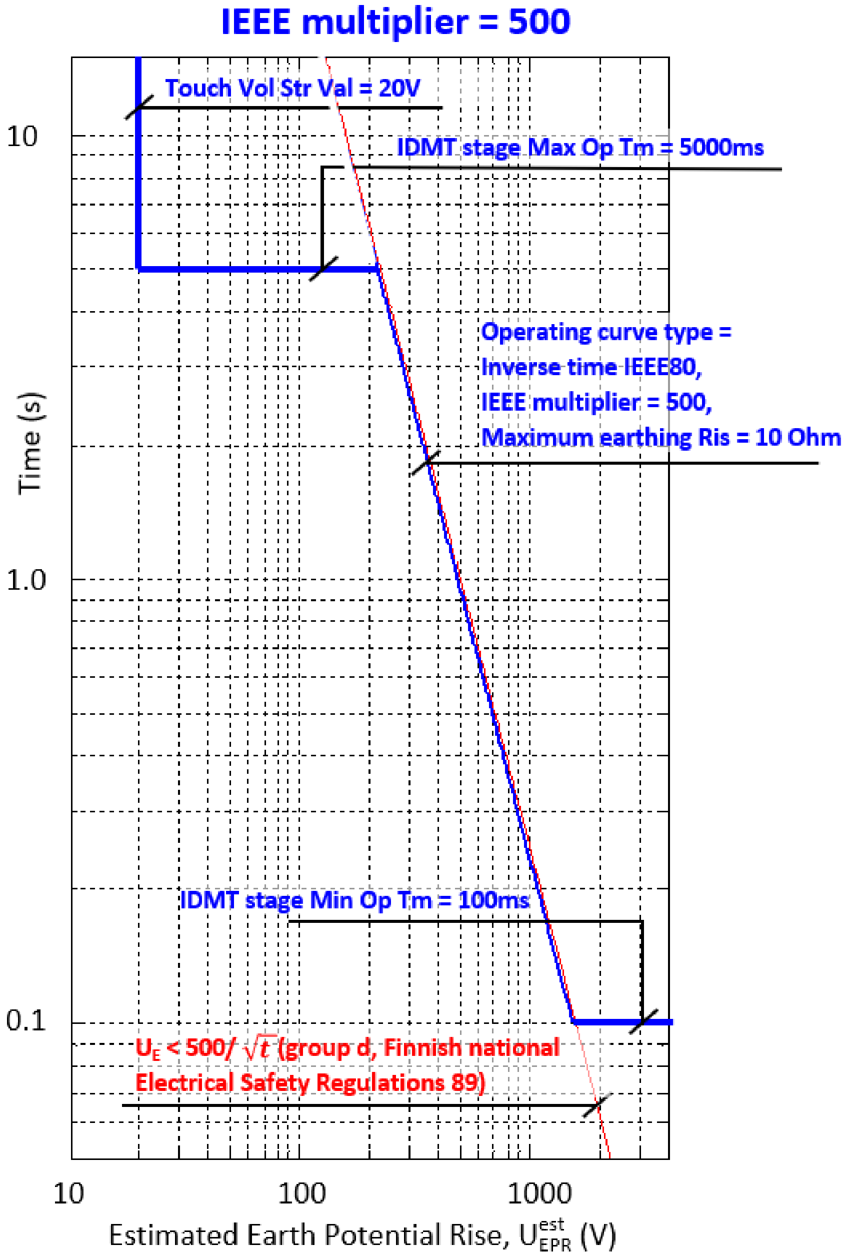


Figure 354: Operation timer characteristic of IFPTOC function when Operation principle = "Touch voltage based", Operating curve type = "Inverse time IEEE80" and IEEE multiplier = 500. Characteristics are according to standard IEEE80. Maximum earthing Ris = 10ohm.

Cross-country fault protection

In high impedance earthed networks, single phase earth fault introduces over-voltages in the healthy phases. Such over-voltages may initiate another single-phase earth fault in another phase and location in a galvanically connected network. Such fault condition is commonly known as cross-country fault, which is a two phase short-circuit through earth with high earth fault current. Cross-country fault must be therefore quickly disconnected in order to limit risk to health and damages to equipment.

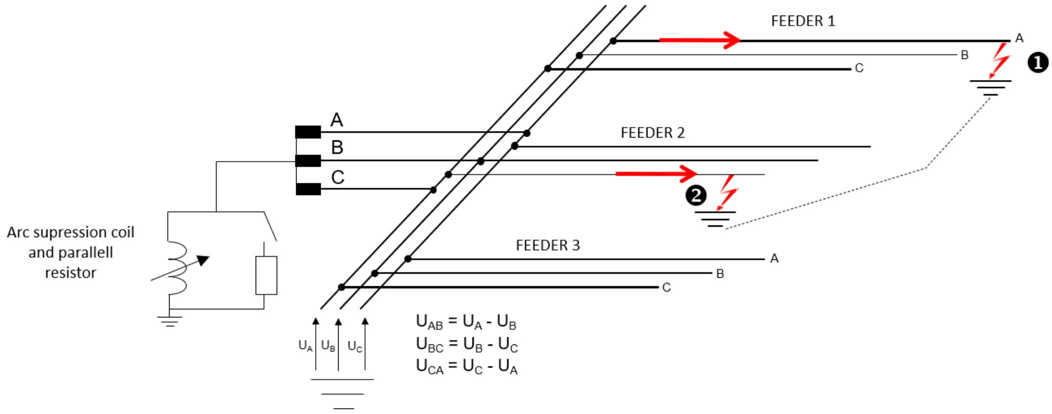


Figure 355: Simplified illustration of a cross-country fault between phases A and C, where two simultaneous single-phase earth faults occur in two different locations and two different phases in the network

IFPTOC has an in-build dedicated functionality for cross-county fault detection and tripping. Detection of cross-country fault is always enabled, but tripping may be enabled or disabled with setting *Enable XC Op mode* = "on" or "off". In case multiple instances of IFPTOC are applied in the protection configuration, only single instance of IFPTOC requires cross-country fault tripping functionality to be enabled; in other instances, cross-country fault tripping functionality may be disabled. As default *Enable XC Op mode* = "on" i.e. tripping is enabled during cross-country faults.

There are two independent criteria for cross-country fault detection: The 1st criterion requires that residual current exceeds a value which is higher than maximum single-phase earth-fault current of the network, and the 2nd criterion monitors voltage dip in any of the phase-to-phase voltages.

Residual over-current criterion

Monitoring of the magnitude of calculated residual current (I_o) and comparing it to setting *XC stage A Str Val* during a detected earth fault:

$$EF\_IND = TRUE, \quad AND$$
$$I_o\,(calculated) > XC\ stage\ A\ Str\ Val$$

(Equation 132)

Calculated I_o is used to avoid problems in case of possible CBCT saturation during high current cross-country fault.

It should be noted, that setting value *XC stage A Str Val* is given in unit [xIn], where In is phase current nominal value. Typical value for *XC stage A Str Val* in primary amperes is few hundreds of amperes. The setting *XC stage A Str Val* should not be higher than the estimated minimum cross-country fault current (I_{F_XCmin}), and on the other hand it must be checked against the uncompensated earth-fault current of the network (I_{eNet}) and setting of the low-set overcurrent stage (*3I>*):

$XC\ stage\ A\ Str\ Val < I_{F\_XCmin}$ AND
$XC\ stage\ A\ Str\ Val > \max(2 \cdot I_{eNet}, 3I>)$

(Equation 133)

where

I_{eNet} = Uncompensated earth-fault current of the network taking into account the decentralized compensation.

3I> = Setting of the low-set overcurrent stage of the protected feeder

The magnitude of the minimum expected cross-country fault current can be coarsely estimated based on the knowledge of the maximum earthing resistance values, *Maximum earthing Ris*, of all the feeders in the substation, and using the following equation:

$$I_{F\_XCmin} \approx \sqrt{\frac{3 \cdot U_{PE}{}^2 \cdot Y_{F1}{}^2 \cdot Y_{F2}{}^2}{Y_{F1}{}^2 + Y_{F2}{}^2 + 2 \cdot Y_{F1} \cdot Y_{F2} + 4 \cdot X_k{}^2 \cdot Y_{F1}{}^2 \cdot Y_{F2}{}^2 + 4 \cdot R_k{}^2 \cdot Y_{F1}{}^2 \cdot Y_{F2}{}^2 + 4 \cdot R_k \cdot (Y_{F1}{}^2 \cdot Y_{F2} + Y_{F2}{}^2 \cdot Y_{F1})}}$$

(Equation 134)

where

I_{F_XCmin} = Minimum expected cross-country fault current

U_{n_PE} = Nominal phase-to-earth voltage

Y_{F1} = 1 / *Maximum earthing Ris* = Admittance corresponding to the set maximum earthing resistance value of the protected feeder

Y_{F2} = 1 / max(*Maximum earthing Ris_i*) = Admittance corresponding to the maximum of the set earthing resistance values of other feeders in the substation

X_k = Sum of short-circuit reactances of the incoming HV-network and main transformer referred to MV-side

R_k = Sum of short-circuit resistances of the incoming HV-network and main transformer referred to MV-side

Example 1:

- U_{n_PE} = 11.547 kV
- *Maximum earthing Ris* = 15 ohm
- *Maximum earthing Ris_i* = 10 ohm
- X_k = 2.2 ohm
- R_k = 0.2 ohm
- *3I>* = 200 A
- I_{eNet} = 320 A

Using the above parameters I_{F_XCmin} equals 0.8 kA in order of magnitude, which is also higher than the uncompensated earth-fault current of the network and the setting of the low-set overcurrent stage of the protected feeder. So, setting *XC stage A Str Val* can be selected between I_{eNet} = 320 A and I_{F_XCmin} = 800 A.

Assuming phase CT-ratio 400/1 A, the setting *XC stage A Str Val* is selected to be 700 A (1.75*In).

Phase-to-phase under-voltage criterion

Monitoring of the magnitude of any phase-to-phase voltage (U_{AB}, U_{BC} or U_{CA}) and comparing it to setting *XC stage PP V Val* during a detected earth fault:

$$EF\_IND = TRUE, \quad AND$$

$$U_{ph-ph} < XC\ stage\ PP\ V\ Val$$

(Equation 135)

During a single-phase earth fault phase-to-phase voltages are not affected, but during a cross-country fault the phase-to-phase voltages are affected, refer to *Figure 356*. Default setting for *XC stage PP V Val* is 0.9xU_{n_PP}, where U_{n_PP} is the nominal phase-to-phase voltage.

In case all three phase-to-phase voltages (U_{AB}, U_{BC} and U_{CA}) are under setting for *XC stage PP V Val* , such condition is considered as permanent three phase under-voltage condition, not a cross-country fault.

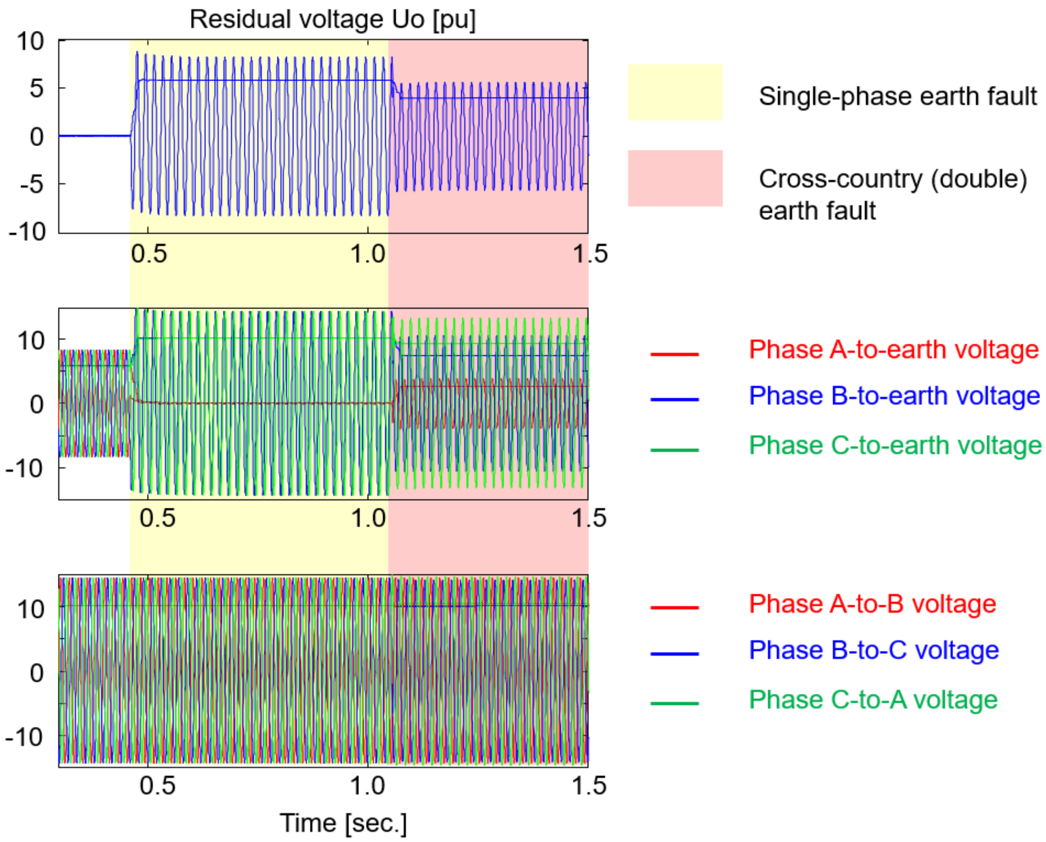


Figure 356: Illustration of behavior of residual, phase-to-earth and phase-to-phase voltages during an evolvement of single-phase earth fault into cross-country fault in a 10 kV compensated network

The magnitude of phase-to-phase voltage between faulted phases during a cross-country fault can be estimated using the following equation:

$$U_{PP\_XC} \approx \sqrt{\frac{3 \cdot (Y_{F1}^2 + Y_{F2}^2 + 2 \cdot Y_{F1} \cdot Y_{F2}) \cdot U_{PE}^2}{Y_{F1}^2 + Y_{F2}^2 + 2 \cdot Y_{F1} \cdot Y_{F2} + 4 \cdot X_k^2 \cdot Y_{F1}^2 \cdot Y_{F2}^2 + 4 \cdot R_k^2 \cdot Y_{F1}^2 \cdot Y_{F2}^2 + 4 \cdot R_k \cdot (Y_{F1}^2 \cdot Y_{F2} + Y_{F2}^2 \cdot Y_{F1})}}$$

(Equation 136)

where

U_{PP_XC} = Estimate of the highest phase-to-phase voltage during cross-country fault with minimum expected cross-country fault current according to *Equation 136*.

Example 2:

- U_{n_PP} = 20 kV
- *Maximum earthing Ris* = 15 ohm
- *Maximum earthing Ris_i* = 10 ohm
- X_k = 2.2 ohm
- R_k = 0.2 ohm

Using the above parameters U_{PP_XC} equals 19.3 kV in order of magnitude (19.3 kV/20 kV=~0.97xU_{n_PP}). However, taking additionally into account normal variations in supply voltage, the setting *XC stage PP V Val* can be selected 0.9xU_{n_PP} (18.0 kV). In this way unnecessary activations of phase-to-phase undervoltage condition can be prevented.

Figure 357 illustrates fault current magnitude according to *Equation 134* and phase-to-phase voltage magnitude according to *Equation 136*, during a cross-country fault as a function of fault resistance. Note that fault resistance is due to earthing resistances of the fault locations only, and its value equals the average of fault resistances R_{F1} and R_{F2} in both fault locations. U_{n_PP} = 20 kV, X_k = 2.2 ohm, R_k = 0.2 ohm.

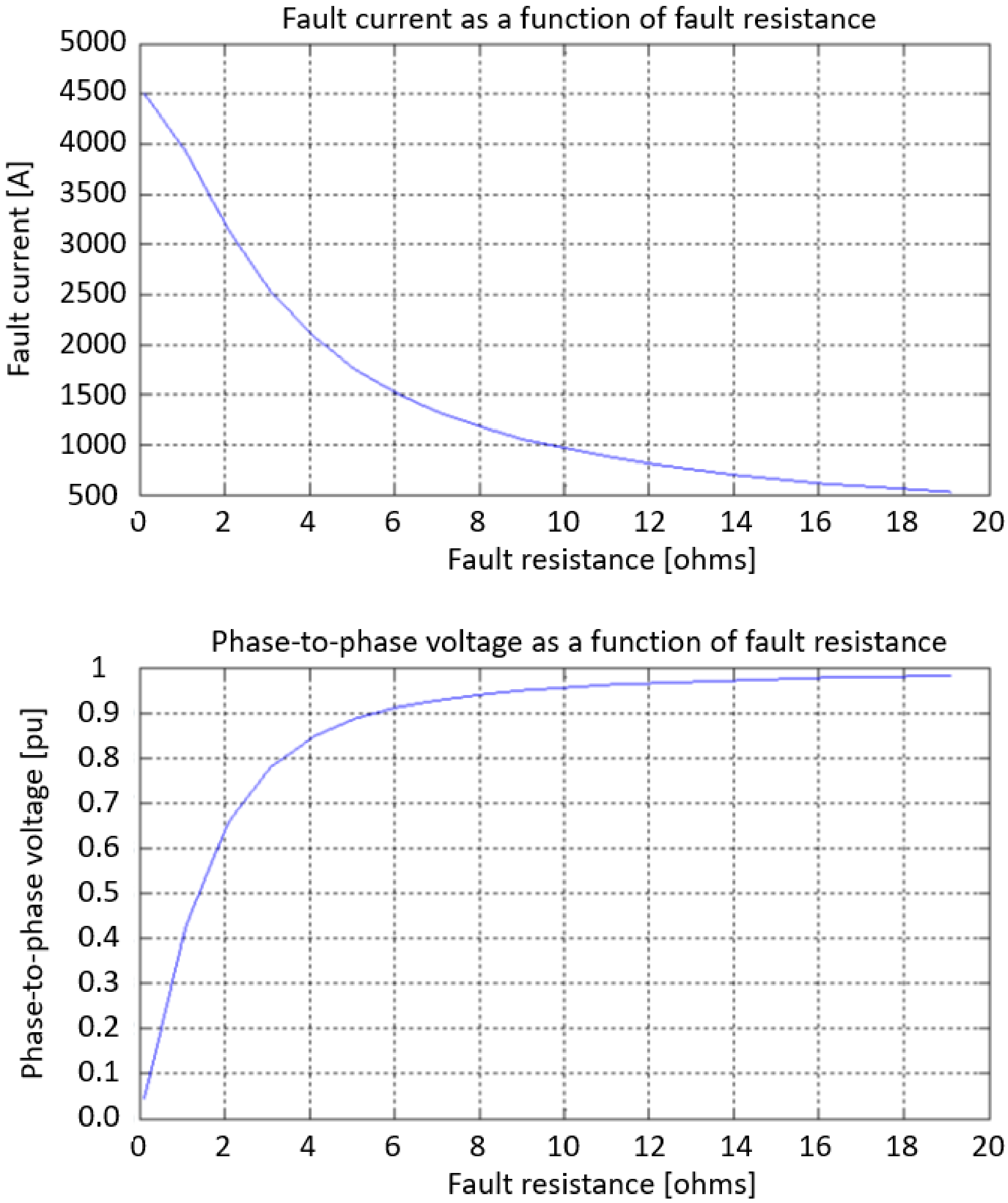


Figure 357: Illustration of fault current magnitude and phase-to-phase voltage magnitude during a cross-country fault as a function of fault resistance. Note that fault resistance equals the average of fault resistances R_{F1} and R_{F2}. U_{n_PP} = 20 kV, X_k = 2.2 ohm, R_k = 0.2 ohm.

Setting value *XC stage PP V Val* is given in per unit format with system nominal phase-to-phase value as reference.

Fulfilment of either *Equation 132* or *Equation 135* declares cross-county fault detection condition in the network. The cross-country fault is indicated by activating the `XC_FLT` output.

During detected cross-country fault, the “EF current based” or “Touch voltage based” operation of IFPTOC is blocked.

In case tripping of cross-country fault is enabled (setting *Enable XC Op mode* = “on”), then operation of IFPTOC requires that simultaneously both the magnitude of calculated residual current (I_o) and estimated earth-fault current (I_F^{est}) exceeds setting *XC stage A Str Val* during a detected earth fault:

$$EF\_IND = TRUE,\ \ AND$$
$$I_o\ (calculated) > XC\ stage\ A\ Str\ Val,\ \ AND$$
$$I_F^{est} > XC\ stage\ A\ Str\ Val$$

(Equation 137)

Operate time for cross-country fault operation is given with setting *XC stage Op time*. Typical operate time is 60-100 ms.

The cross-country stage earth fault module always evaluates the true fault current magnitude (considering the effect of setting *Enable harmonics*) i.e. it is not affected by settings *Ena RF Compensation* and *Reduction factor*.

The cross-country fault indication is given in Recorded data as *XC fault detection* or in Output data as XC_FLT.

When start and operate conditions of cross-country earth fault module are fulfilled, this is indicated by activation of START and OPERATE outputs and ST_XC and OP_XC outputs.

In case tripping of cross-country fault is enabled, operate time is given with setting *XC stage Op time*. Reset time is defined with setting *Reset delay time*. Note that setting *CB Delay comp* (circuit breaker delay compensation) is not applicable in definite time operation, but it must be taken into account in setting *XC stage Op time*.

Applicable settings for cross-country earth fault module are: *Enable XC Op mode, XC stage A Str Val, XC stage PP V Val, XC stage Op time and Reset delay time*.

Intermittent earth-fault protection

Operation time requirement of earth-fault protection in safety standards assumes continuous flow of fault current. In case of resonant earthed network, earth faults are often re-striking i.e. fault arc is not continuous, but intermittent. During re-striking/intermittent earth faults, the very high but narrow current transient may result to very fast operation times, if operation time is based on IDMT-operation i.e. *Operation curve type* = Inverse time EN50522 or Inverse time IEEE80. Requirement for operation with IDMT-timer is that timer is not reset between successive current transients i.e. *Reset delay time* should be set long enough. However, in case operation during re-striking/intermittent earth faults is preferably based on number of counted transients, then setting *Reset delay time* should be set to low value, say 20-40 ms, and dedicated intermittent earth-fault protection functionality must be enabled.

Intermittent earth-fault module is enabled with setting *Ena Intermit EF mode* = “on”. Module is enabled by default. In case multiple instances of IFPTOC are applied in the protection configuration, and operation during re-striking/intermittent earth faults is preferably based on number of counted transients, only single instance of IFPTOC requires Intermittent earth-fault module functionality to be enabled; in other instances, Intermittent earth-fault module functionality may be disabled.

The IFPTOC has inbuild directional transient detector module for detecting earth-fault transients. Transient detector module is used to count the number of transients during an earth fault to discriminate intermittent earth fault from continuous earth fault.

Transient detector module counts the number of transients during an earth fault both in faulty and healthy feeders. Detection of transients is indicated with PEAK_IND output.

Internal start of intermittent earth-fault module is obtained when the presence of earth fault is indicated (EF_IND), it's validity is confirmed (VALID_EF) and at least one transient is detected in the protected feeder. Whenever a fault transient is detected, this is indicated with the PEAK_IND output.

When the number of detected transients reaches the *Intr EF counter Lim* setting, INTR_EF output is activated. Activation of INTR_EF output indicates detection of a restriking or intermittent earth fault in the protected feeder.

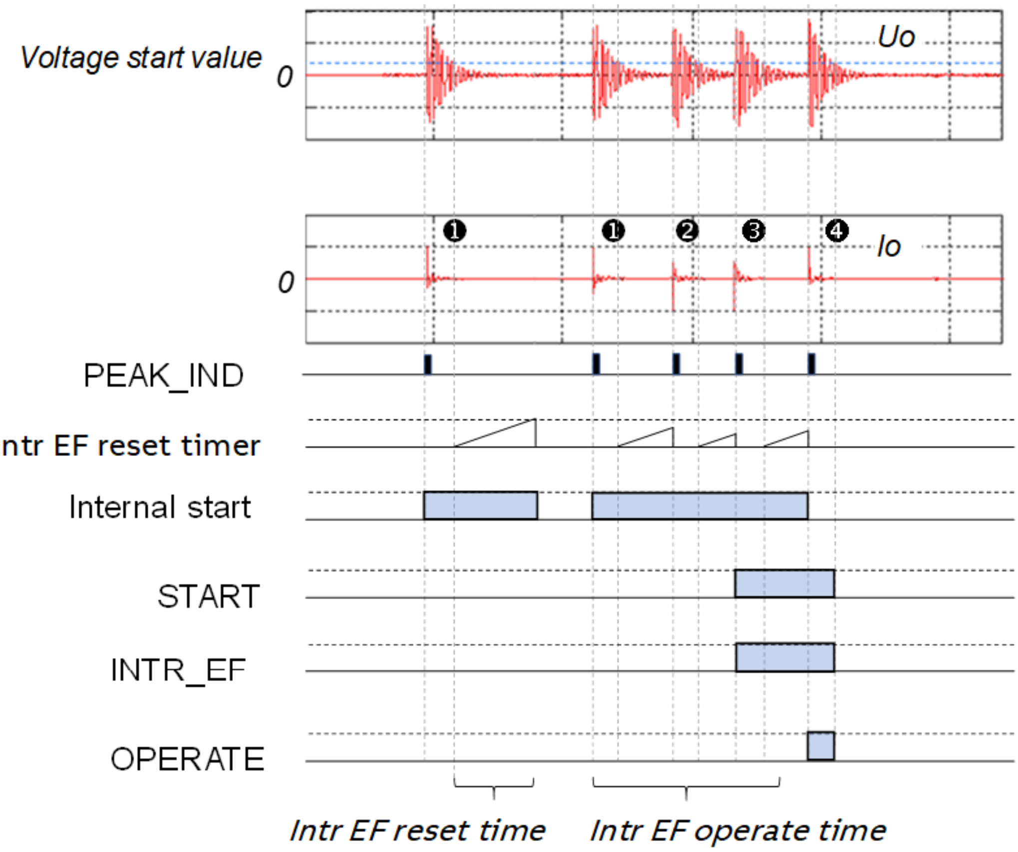


Figure 358: Illustration of operation of intermittent earth-fault module. Setting Intr EF counter Lim = 3

When a required number of intermittent earth-fault transients set with the *Intr EF counter Lim* setting are detected without the function being reset (depends on the drop-off time set with the setting *Intr EF reset time*) and the presence of single-phase earth fault in the protected feeder is confirmed (activation of EF_IND and VALID_EF outputs), the START and ST_INTR_EF outputs are activated. The OPERATE and OP_INTR_EF outputs are activated when operate delay time *Intr EF operate time* has elapsed (from fault beginning), required number of transients exceeds setting *Intr EF counter Lim* (so actually for operation there must be *Intr*

EF counter Lim +1 detected transients). OPERATE output activation occurs always at time of detected transient. OPERATE output signal has fixed length of 100 ms, but OP_INTR_EF signal is activated for only one cycle time i.e. 2. 5m.

Several factors affect the magnitude and frequency of fault transients, such as the fault inception angle on the voltage wave, fault location, fault resistance and the parameters of the feeders and the supplying transformers. If the fault is permanent (non-transient), the initial fault transient in current and voltage can be measured, whereas the intermittent fault creates repetitive transients. The practical sensitivity of transient detection is limited to approximately a few hundreds of ohms of fault resistance. Therefore, the application of transient detection is limited to low-ohmic earth faults.

Setting *Intr EF counter Lim* minimum value is 3 in order to provide secure indication of intermittent/re-striking earth fault. This is due to the fact that sometimes the fault ignition transient is characterized by highly distorted waveform, which may result into multiple transients to be detected at time of fault ignition. By increasing the value of *Intr EF counter Lim* setting, one increases the security of correct fault type identification.

Information about detected intermittent earth fault is also available in *Recorded data* as *Intermittent EF Det* or in Output data as INTR_EF.

During re-striking/intermittent earth faults, the very high current transient may result to very fast operation times in case operation principle is based on earth fault current or touch voltage estimate. In case longer and more deterministic operation during re-striking/intermittent earth faults is preferred, the operation can be based on counted number of transients instead of IDMT operation. In transient counter-based operation the setting *Reset delay time* should be set to low value, say 20-40 ms. For the Intermittent earth-fault module reset delay time is defined with setting *Intr EF reset time*. During intermittent earth faults, typically longer reset time is needed to prevent unwanted function reset between the current spikes. Recommended setting value for *Intr EF reset time* is between 300-500 ms.

Actual operation time of intermittent earth-fault module cannot pre-determined exactly as the timing of successive transients is not constant.

At time OPERATE output is activated from intermittent earth-fault protection, also output OP_INTR_EF is activated OPERATE output signal has fixed length of 100 ms, but OP_INTR_EF signal is activated for only one cycle time i.e. 2.5 m. If OP_INTR_EF is to be used in e.g. protection logics, it should be prolonged with TOF-function in protection configuration.

Applicable settings for Intermittent earth-fault module are: *Ena Intermit EF mode, Intr EF counter Lim, Intr EF operate time and Intr EF reset time.*

Note that setting *CB Delay Comp* (circuit breaker delay compensation) is not applicable in definite time operation, but it must be taken into account in setting *Intr EF operate time*.

Switch onto fault protection

During switch onto fault condition i.e. when breaker is closed into existing fault, earth-fault current estimate may be disturbed by the inrush currents of energized transformers. Therefore, IFPTOC includes a dedicated switch onto fault (SOTF) logic module. SOTF-functionality provides dedicated fault detection and tripping in case feeder breaker is closed into earth fault.

Switch onto fault protection module is enabled with setting *Enable SOTF mode* = "on". Module is enabled by default.

In case multiple instances of IFPTOC are applied in the protection configuration, ALL instances of IFPTOC requires SOTF module functionality to be enabled to provide selective operation during an SOTF condition.

SOTF condition is declared, if an earth fault is detected (`EF_IND = TRUE`) within set *SOTF Cond duration* milliseconds from breaker close command (input `CB_CL_CMD` is activated).

Indication of detected SOTF condition is declared by activation of `ST_SOTF` and `START` outputs.

Operate time during switch onto fault condition is given with setting SOTF operate time. `OPERATE` and `OP_SOTF` outputs are activated after operation timer has elapsed.

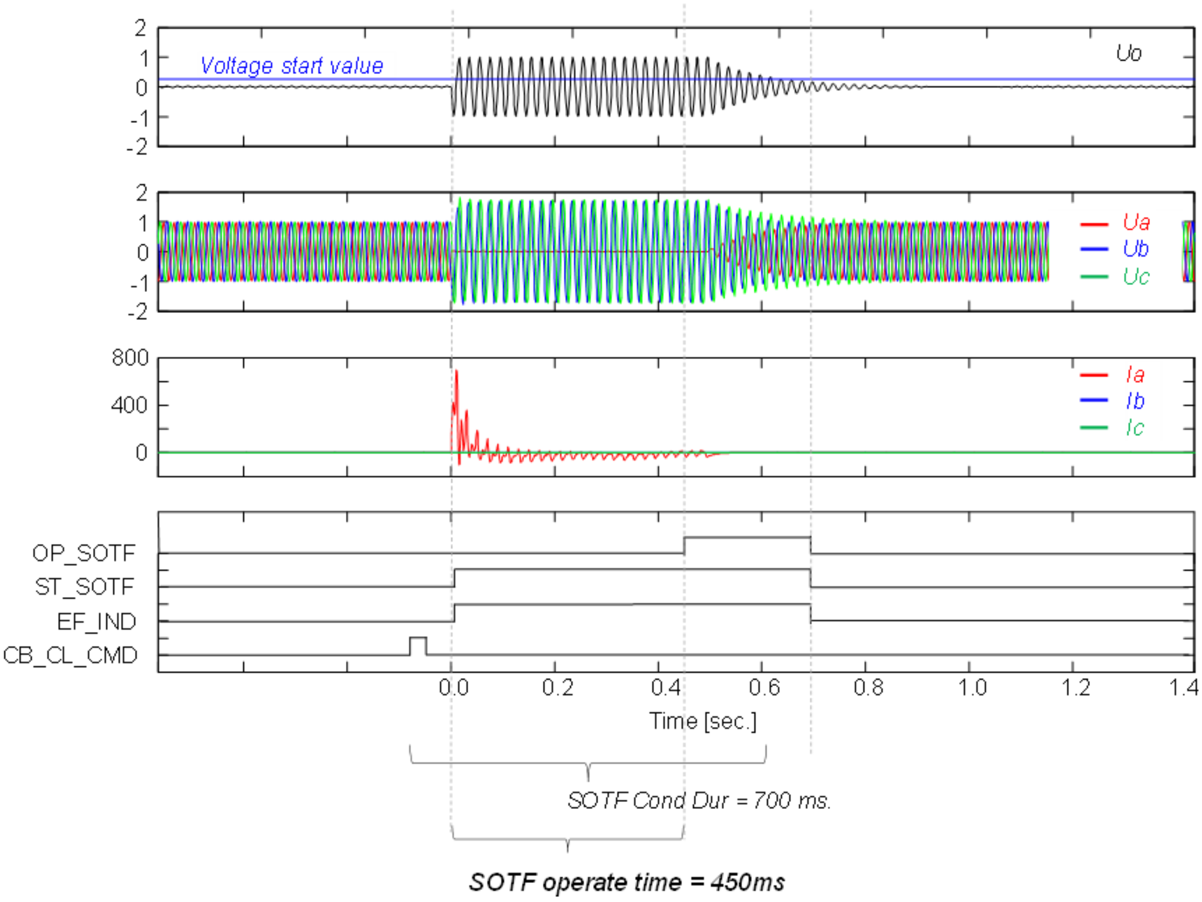


Figure 359: Illustration of switch onto fault condition and operation of SOTF logic in IFPTOC

Switch-onto-fault (SOTF) logic module enabling requires connection of breaker close command into input CB_CL_CMD. Switch-onto-fault (SOTF) logic module can be disabled by not connecting the breaker close command signal to IFPTOC.

In case SOTF condition is detected, then all other functionality of IFPTOC function is blocked.

Setting *SOTF Cond duration* must be set higher than *SOTF operate time* + *SOTF reset time*. SOTF functionality is reset after *SOTF Cond duration* expires or at least when earth-fault detection signal deactivates (EF_IND).

SOTF logic is not activated in case earth fault is detected (EF_IND = TRUE) before breaker close command (input CB_CL_CMD is activated).

For the SOTF module typically longer reset time is needed to prevent unwanted function reset between the current spikes during intermittent earth fault, setting SOTF reset time. Recommended setting value is between 300-500 ms.

Applicable settings for the SOTF-module are: *Enable SOTF mode, SOTF Cond duration, SOTF operate time and SOTF reset time*.

Note that setting *CB Delay comp* (circuit breaker delay compensation) is not applicable in definite time operation, but it must be taken into account in setting *SOTF operate time*.

Faulted phase identification

The faulted phase selection module provides information about the faulted phase (A, B or C) during a single-phase earth fault.

The faulted phase is identified by monitoring the “phase-wise” fault current estimators as follows:

$$I^1_{EF\_A} = abs(\Delta I^1_A - (\Delta I^1_B + \Delta I^1_C)/2)$$

(Equation 138)

$$I^1_{EF\_B} = abs(\Delta I^1_B - (\Delta I^1_C + \Delta I^1_A)/2)$$

(Equation 139)

$$I^1_{EF\_C} = abs(\Delta I^1_C - (\Delta I^1_A + \Delta I^1_B)/2)$$

(Equation 140)

Maximum value indicates the faulted phase. Actual implementation utilizes Cumulative Phasor Summing (CPS) together with admittance calculation.

Faulted phase is available in Recorded data as *Faulted phase*. In Monitored data faulted phase is given in FAULT_PHASE.

Faulted phase information is not given in case of cross-country fault (XC_FLT = TRUE).

Fault resistance estimation

Protection function IFPTOC includes fault resistance (R_F) magnitude estimation based on information on the faulted phase, the faulted phase voltage and estimated earth fault current magnitude (fundamental frequency). Fault resistance magnitude can be estimated with equation:

$$R_F = \frac{U_{ph\_faulted}}{I_F^{est1}}$$

(Equation 141)

Where

$U_{ph\_faulted}$ = Faulted phase voltage magnitude, fundamental frequency [V]

I_F^{est1} = Estimated earth-fault current magnitude, fundamental frequency [A]

Actual implementation utilizes Cumulative Phasor Summing (CPS).

Magnitude of estimated fault resistance in primary ohms is available in Recorded data: *Fault resistance*. In monitored data this information is given: RF.

Fault resistance estimation is not done in case of cross-country fault (XC_FLT = TRUE).

In case of intermittent earth fault, fault resistance estimation is not accurate.

Trip logic

Protection function IFPTOC supports both tripping and alarming earth-fault handling defined with setting *Operation mode* = "Alarming EF" or "Tripping EF". With *Operation mode* = "Alarming EF", OPERATE and corresponding OP_EF/OP_XC/OP_SOTF/OP_INTR outputs are not activated. *Operation mode* = "Alarming EF" is applicable in networks, where due to low touch voltages tripping of earth-fault is not required (requires existence of Global Earthing System, GES). Monitoring of prevailing earth-fault current and/or touch voltage magnitude can be done via Monitored data.

When start conditions of touch voltage protection, earth-fault current protection, cross-country fault protection, intermittent earth-fault protection or switch onto fault protection are fulfilled, this is indicated by activation of START and corresponding ST_EF/ST_XC/ST_SOTF/ST_INTR outputs. When operate conditions are fulfilled and setting *Operation mode* = "Tripping EF", this is indicated by activation of OPERATE and corresponding OP_EF/OP_XC/OP_SOTF/OP_INTR outputs.

The timer calculates the start duration value, which indicates the percentage elapse of operate timer, 100% means that operate time is completely elapsed and OPERATE output is activated. The value is available in the Recorded data as *Start duration* and in Monitored data as START_DUR.

Estimate for time left to operate is available in in Monitored data as TIME_TO_OPER in real time based on fault current or touch voltage magnitude. In the Recorded data estimate for time left to operate is available as *Time left to operate* with assumption that fault current or touch voltage at the triggering moment (recorded data is triggered with TRIGG_REC input rising edge) will remain the same until the OPERATE and corresponding OP_EF/OP_XC/OP_SOTF/OP_INTR outputs would become activated. Furthermore, if OPERATE and corresponding OP_EF/OP_XC/OP_SOTF/OP_INTR outputs have been activated, the actual operate time of protection is available in the Recorded data as *Operate time* and in Monitored data as OPERATE_TIME.

Information about started and operated timers are available in Recorded data: *Started timers, Operated timers*. This data is binary coded number as illustrated in *Table 635*.

Table 635: Binary to decimal conversion of the *Started timers* and *Operated timers* in Recorded data

Timer notation	Timer1	Timer2	Timer3	Timer4
Timer description	Touch voltage/fault current estimation module	Cross-country earth-fault module	Switch onto fault (SOTF) module	Intermittent earth fault module
Binary (0 or 1) 0=not started/not operated, 1=started/operated	0 or 1	0 or 1	0 or 1	0 or 1

Started/Operated timers (integer): Timer1·2^0+ Timer2·2^1+ Timer3·2^2+ Timer4·2^3

Numerical example. If both Touch voltage/fault current estimation module timer (+1) and intermittent timer (+8) have been started but only Touch voltage estimation module timer have operated, then: *Started timers* 1+8 = 9 and *Operated timers* = 1.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal in protection configuration. The influence of the BLOCK input signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timer” mode, the operation timer is frozen to the prevailing value, but the operate outputs are not deactivated when blocking is activated. In the “Block all” mode, the whole function is blocked, and the timers and pre-fault phasor buffers are reset. In the “Block OPERATE output” mode, only the operate outputs are blocked.

Recorded data

The required information for later fault analysis is recorded when the recording function of IFPTOC function is triggered by activating TRIGG_REC input or writing to the corresponding DO “LD0.IF1RFRC1.RcdTrg.Oper.ctlVal”.

Activation of `OPERATE` output results to automatic triggering of fault recording.

The recording function of IFPTOC includes recorded data 1 data objects as shown in *Table 636*.

Table 636: Recorded data 1 data objects of the IFPTOC function

Parameter name	Parameter description	Recorded Data DO
Triggering time	Triggering time	(Timestamp) IF1RFRCx.TchV.t.
Residual voltage	Residual voltage magnitude [xUn]	(MX) IF1RFRCx.VRes.mag.f
Residual current	Residual current magnitude [xIn]	(MX) IF1RFRCx.ARes.mag.f
Touch voltage	Touch voltage magnitude [V]	(MX) IF1RFRCx.TchV.mag.f
Touch voltage rms	Touch voltage magnitude incl harmonics [V]	(MX) IF1RFRCxTchVRms.mag.f
Fault current	Fault current magnitude (incl. reduction) [A]	(MX)) IF1RFRCx.FltA.res.cVal.mag.f
Fault current rms	Fault current magnitude incl harmonics (and reduction) [A]	(MX) IF1RFRCx.FltARms.mag.f
Start duration	Start duration [%]	(MX) IF1RFRCx.StrDur.mag.f
Faulted phase	Faulted phase	(ST) IF1RFRCx.FltLoop.stVal
Fault resistance	Fault point resistance [in primary ohm]	(MX) IF1RFRCx.FltPtRis.mag.f
Transient Ris Comp	Transient resistive component [A]	(MX) IF1RFRCx.AResReal.mag.f
Transient React Comp	Transient reactive component [A]	(MX) IF1RFRCx.AResImag.mag.f
Non qualified Harmon	Non qualified harmonics	(ST) IF1RFRCx.NonQualH.stVal
EF indication	Non-directional earth fault detection	(ST) IF1RFRCx.EFDet.stVal
Valid EF detection	Valid EF detection in protected feeder	(ST) IF1RFRCx.EFDetVald.stVal
XC fault detection	Cross-country fault detection	(ST) IF1RFRCx.XcnDet.stVal
Time left to operate	Time left to operate [sec.]	(MX) IF1RFRCx.TmOpEst.mag.f
Intermittent EF Det	Restriking (intermittent) earth fault detection	(ST) IF1RFRCx.ItmEFInd.stVal
Started timers	Started timers	(ST) IF1RFRCx.ActStrSt.stVal
Operated timers	Operated timers	(ST) IF1RFRCx.ActOpSt.stVal
Operate time	Actual operate time [sec]	(MX) IF1RFRCx.StrOpTm.mag.f

A total of two sets of recorded data are saved in data banks *Recorded data 1* and *Recorded data 2*. Data bank *Recorded data 1* holds the most recent recorded data and the older data is moved into the data bank *Recorded data 2* when triggering occurs. When all two banks have data and a new triggering occurs, the latest data is placed into bank *Recorded data 1* and the data in bank *Recorded data 2* is overwritten by the data from bank *Recorded data 1*.

It is possible to reset corresponding recorded data by either:

- activating LHMI parameter Clear/Clear/IFPTOCx reset = 1 (“Clear”) or
- writing directly by MMS LD0.IFPTRCx.RcdRs.Oper.ctlVal = 1 (“Clear”)”

4.2.10.6 Signals

IFPTOC Input signals

Table 637: IFPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
EXT_RELEASE	BOOLEAN	0=False	External GFC start signal, alternative for internal GFC module.
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
CB_CL_CMD	BOOLEAN	0=False	Defines breaker close command. This signal is used in the switch on to fault (SOTF) logic.
TRIGG_REC	BOOLEAN	0=False	External recorded data triggering. There are two recorded data banks available.

IFPTOC Output signals

Table 638: IFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ST_EF	BOOLEAN	Start signal according to estimated fault current or touch voltage according to the standards
ST_XC	BOOLEAN	Start signal according to cross-country stage earth-fault module
ST_SOTF	BOOLEAN	Start signal according to SOTF-module
ST_INTR_EF	BOOLEAN	Start signal according to intermittent earth-fault module
OP_EF	BOOLEAN	Operate signal according to estimated fault current or

Table continues on the next page

Name	Type	Description
		touch voltage according to the standards
OP_XC	BOOLEAN	Operate signal according to cross-country stage earth-fault module
OP_SOTF	BOOLEAN	Operate signal according to SOTF-module
OP_INTR_EF	BOOLEAN	Operate signal according to intermittent earth-fault module
PEAK_IND	BOOLEAN	Current transient detection indication (both in the faulty and healthy feeder)
INTR_EF	BOOLEAN	Intermittent earth fault indication in the faulty feeder
EF_IND	BOOLEAN	Non-directional indication of earth-fault in the network
VALID_EF	BOOLEAN	Validity of earth-fault current estimate is confirmed
XC_FLT	BOOLEAN	Indication of cross-country fault in the network

4.2.10.7 IFPTOC Settings

Table 639: IFPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.01...1.00	xUn	0.01	0.20	Start value for neutral point voltage Uo. Note that Un means phase to earth nominal voltage.
EF current Str Val	0.005...1.000	xIn	0.001	0.010	Earth-fault current threshold for DT stage or IDMT stage. Note that In means phase nominal current.
Touch Vol Str Val	10.0...2900.0	V	0.1	80.0	Touch voltage start threshold for DT stage or IDMT stage in primary volts
Operating curve type	15=Definite time 18=Inverse time EN50522 19=Inverse time IEEE80			18=Inverse time EN50522	Selection of time delay curve type in touch voltage/fault current estimation module
Ena RF compensation	0=Disable 1=Enable			0=Disable	Enable compensation of fault resistance in the estimated earth-fault current

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
DT stage Op time	100...60000	ms	10	500	Operate delay time for Touch voltage/fault current estimation module, DT timer
IDMT stage Min Op Tm	50...6000	ms	10	100	Minimum operate delay for touch voltage/fault current estimation module IDMT timer according to standard EN50522/ IEEE80
IDMT stage Max Op Tm	500...7200000	ms	10	10000	Maximum operate delay for touch voltage/fault current estimation module IDMT timer according to standard EN50522/ IEEE80
UTp multiplier	0.10...5.00		0.01	1.00	UTp multiplier for IDMT curve according to standard EN50522
Reduction factor	0.10...1.00		0.01	1.00	Reduction factor in the touch voltage/fault current estimation module according to standard EN50522/ IEEE80
Maximum earthing Ris	0.5...1000.0	ohm	0.1	10.0	Maximum earthing resistance encountered in the protected feeder in primary ohms according to standard EN50522/IEEE80
IEEE multiplier	50.0...5000.0		0.1	157.0	Multiplier according to standard IEEE80
XC stage A Str Val	0.10...5.00	xIn	0.01	1.00	Current threshold for cross-country fault module. Note that In means phase nominal current
XC stage PP V Val	0.01...1.00	xUn	0.01	0.90	Phase-to-phase voltage threshold for cross-country fault detection module. Note that Un means phase to phase nominal voltage.
XC stage Op time	60...60000	ms	10	200	Operate delay time for cross-country fault detection stage
Intr EF operate time	100...10000	ms	10	1000	Operate delay time during intermittent earth fault

Table 640: IFPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
EF validity Op mode	1=Resistive 2=Resistive, Reactive			2=Resistive, Reactive	EF validity operation mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=No validity				
EF validity Min Curr	0.005...0.200	*In	0.001	0.010	Minimum current for EF validity evaluation. Note that In means residual nominal current.
Ena cyclic reset	0=Disable 1=Enable			1=Enable	Enable adaptation of fault direction determination to a fault direction change during the fault
Intr EF reset time	40...60000	ms	10	500	Reset delay time used in intermittent earth fault module

Table 641: IFPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation principle	1=EF current based 2=Touch voltage based			2=Touch voltage based	Operation principle
Enable harmonics	0=Disable 1=Enable			0=Disable	Enable harmonics for fault current calculation
Operation mode	1=Alarming EF 2=Tripping EF			2=Tripping EF	Operation criteria
Enable XC Op mode	1=on 5=off			1=on	Enable cross-country fault tripping functionality
Reset delay time	0...6000	ms	10	20	Reset delay time
Ena Intermit EF mode	1=on 5=off			1=on	Enable intermittent earth fault module
Enable SOTF mode	1=on 5=off			1=on	Enable Switch-On-To-Fault logic module
SOTF Cond duration	100...16000	ms	10	2000	Switch-On-To-Fault module duration
SOTF operate time	40...6000	ms	10	60	Switch-On-To-Fault module operate delay time

Table 642: IFPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
SOTF reset time	100...10000	ms	10	500	Reset delay time for Switch-OnTo-Fault (SOTF) module
Revert time	200...10000	ms	10	300	Revert time for delta-calculation
Max Dur delta Calc	300...10000	ms	10	2000	Maximum duration for delta calculation
Intr EF counter Lim	3...20		1	3	Peak counter limit for discrimination of intermittent earth fault from

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					continuous earth fault.
CB delay Comp	0...200	ms	1	0	Delay compensation for circuit-breaker operate time

4.2.10.8 IFPTOC Monitored data

Table 643: IFPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
FLT_CURRENT	FLOAT32	0.00...6000.00	A	Magnitude of estimated earth-fault current [primary amperes] (fundamental freq.)
FLT_CURR_RMS	FLOAT32	0.00...6000.00	A	Magnitude of estimated earth-fault current [primary amperes], rms (incl. harmonics)
TCH_VOLTAGE	FLOAT32	0.00...440000.00	V	Magnitude of estimated touch voltage (fundamental freq.) [primary volts]
TCH_VOLT_RMS	FLOAT32	0.00...440000.00	V	Magnitude of estimated touch voltage [primary volts], rms (incl. harmonics)
RF	FLOAT32	0.0...20000.0	ohm	Fault point resistance in primary ohms
FAULT_PHASE	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault -2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Faulted phase
TR_RIS_COMP	FLOAT32	-6000.0...6000.0	A	Magnitude of transient real part of residual current, in primary amperes (fundamental freq.)
TR_REACT_COMP	FLOAT32	-6000.0...6000.0	A	Magnitude of transient imaginary part of residual current, in primary amperes (fundamental freq.)
NON_Q_HARMON	INT32	0...127		Non qualified harmonics in binary coded format
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
OPERATE_TIME	FLOAT32	0.000...7200.000	s	Actual operate time
TIME_TO_OPER	FLOAT32	0.000...7200.000	s	Time left to operate

4.2.10.9 Technical data

Table 644: IFPTOC Technical data

Characteristics	Value
Operation accuracy	Depending on the frequency of the measured current f_n ±2 Hz
	Earth-fault current and touch voltage: ±1% of the set value or ±0.005 × I_n for I_F^{est} Accuracy of U_{EPR}^{est} follows I_F^{est} accuracy. Residual voltage: ±1.5% of the set value or ±0.002 × U_n Residual current: ±1.5% of the set value or ±0.002 × I_n (at currents ≤10 x I_n, when Uo is nominal) ±5.0% of the set value (at currents > 10 x I_n)
Start time [1]	Typically 30 ms
Reset time	<30 ms
Reset ratio	Typically 0.96
Retardation time	<50 ms
Operate time accuracy	±1.0% of the set value or ±20 ms (DT) ±3% of the theoretical value or ±40 ms (IDMT)

4.3 Differential protection

4.3.1 Line differential protection with in-zone power transformer LNPLDF (ANSI 87L)

4.3.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Line differential protection with in-zone power transformer	LNPLDF	3Id/I>	87L

[1] Measured with static signal output (SSO)

4.3.1.2 Function block

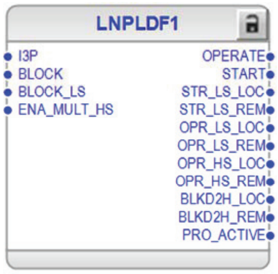


Figure 360: Function block

4.3.1.3 Functionality

The line differential protection with in-zone power transformer LNPLDF is used as feeder differential protection for the distribution network lines and cables. LNPLDF includes low, stabilized and high, non-stabilized stages. The line differential protection can also be used when there is an in-zone transformer in the protected feeder section.

The stabilized low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. Second harmonic restraint insures that the low stage does not operate due to energizing of a tapped or in-zone transformer. The high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The operating time characteristic for the low stage can be selected to be either definite time (DT) or inverse definite time (IDMT). The direct inter-trip ensures both ends are always operated, even without local criteria.

4.3.1.4 Analog channel configuration

LNPLDF has one analog group input which must be properly configured.

Table 645: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The function can also be set into test mode by setting the *Operation* setting to “test/blocked”.

The operation of the line differential protection and related measurements, stabilized and instantaneous stages can be described using a module diagram.

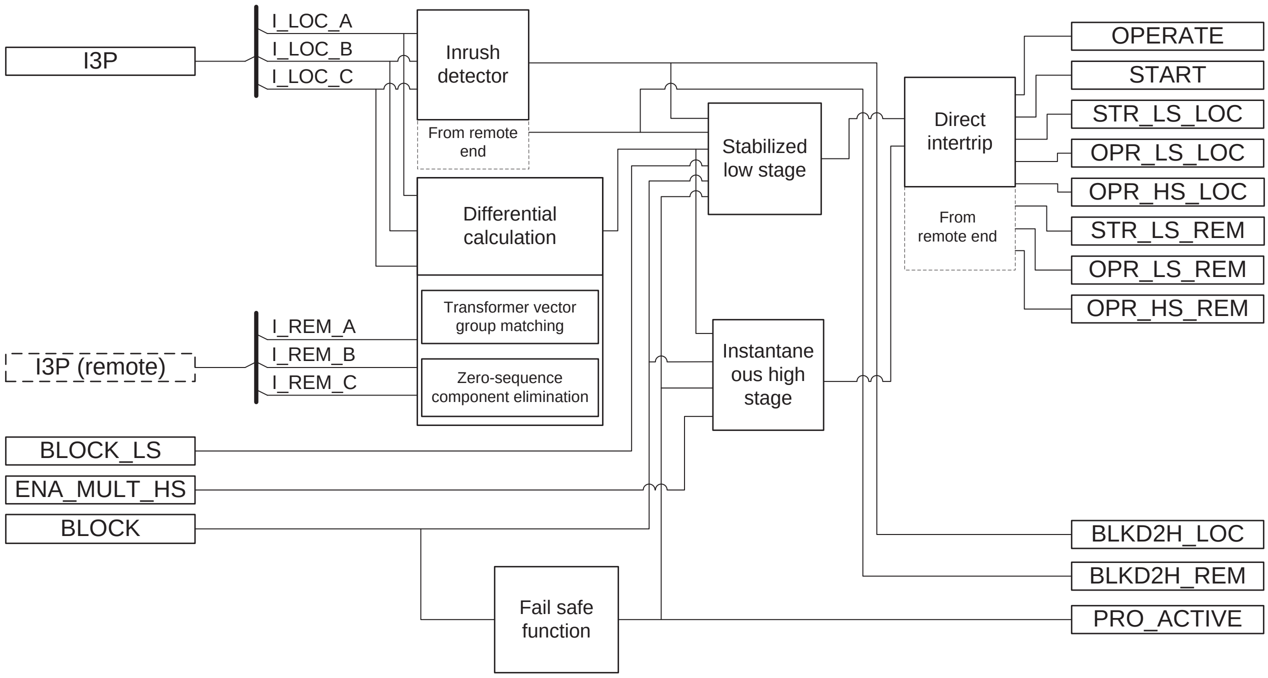


Figure 361: Functional module diagram. I_LOC_x stands for current of the local end and I_REM_x for phase currents of the remote ends.

Stabilized low stage

In the stabilized low stage, the higher the load current is, the higher the differential current required for tripping is. This happens on normal operation or during external faults. When an internal fault occurs, the currents on both sides of the protected object flow towards the fault and cause the stabilizing current to be considerably lower. This makes the operation more sensitive during internal faults. The low stage includes a timer delay functionality.

The characteristic of the low stage taking the apparent differential current into account is influenced by various factors:

- Small tapped loads within the protection zone
- Current transformer errors
- Current transformer saturation
- Small asymmetry of the communication channel go and return paths
- Small steady state line charging current
- In-zone transformer no load current
- Impact of tap changer positions

The timer is activated according to the calculated differential, stabilizing current and the set differential characteristic.

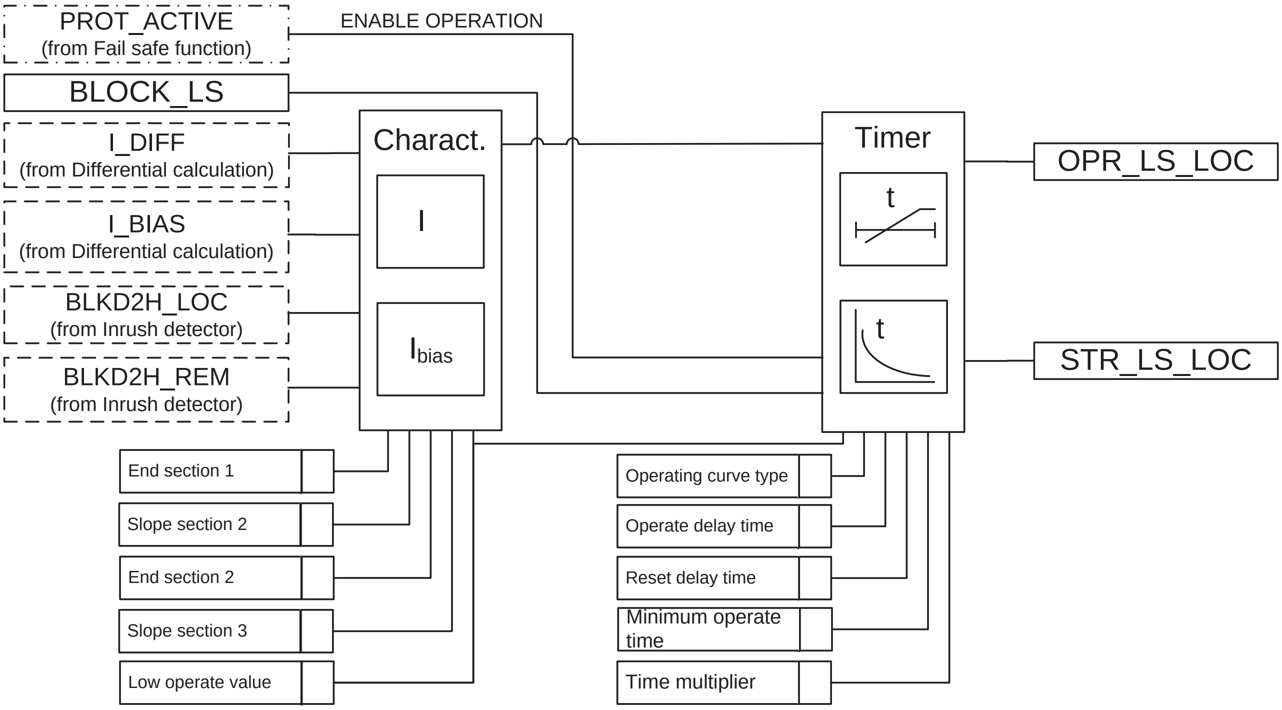


Figure 362: Operation logic of the stabilized low stage

The stabilization affects the operation of the function.

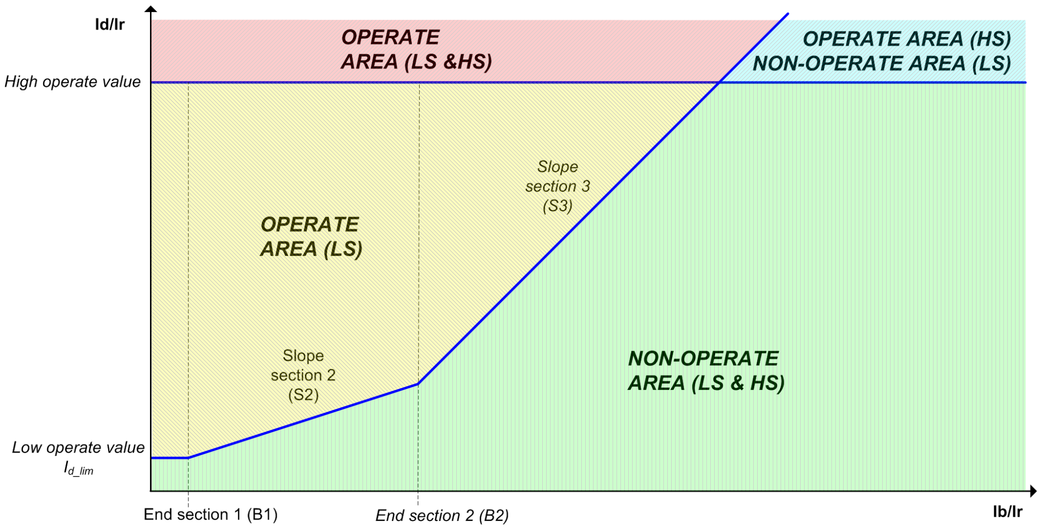


Figure 363: Operating characteristics of the protection. (LS) stands for the low stage and (HS) for the high stage.

The slope of the operating characteristic curve of the differential function varies in the different sections of the range:

- Section 1 where 0.0 < I_b/I_r < *End section 1*. The differential current required for tripping is constant. The value of the differential current is the same as the basic setting (*Low operate value*) selected for the function. The basic setting allows the appearance of the no-load current of the line, the load current of the tapped load and minor inaccuracies of the current transformers. It can also be used to influence the overall level of the operating characteristic.
- Section 2 where *End section 1* < I_b/I_r < *End Section 2*. This is called the influence area of the starting ratio. In this section, the variations in the starting ratio affect the slope of the characteristic, meaning the required change for tripping in the differential current in comparison with the change in the load current. CT errors should be considered in the starting ratio.
- Section 3 where *End section 2* < I_b/I_r. By setting the slope in this section, attention can be paid to prevent unnecessary operation of the protection when there is an external fault, and the differential current is mainly produced by saturated current transformers.

The operation of the differential protection is based on the fundamental frequency components. The operation is accurate and stable and the DC component and the harmonics of the current do not cause unwanted operations.

Inrush detector

The transformer inrush currents cause high degrees of second harmonic to the measured phase currents. The inrush detector detects inrush situations in transformers. The second harmonic based local blocking is selected into use with the *Restraint mode* parameter. The blocking for the low stage on the local end is issued when the second harmonic blocking is selected and the inrush is detected.

The inrush detector calculates the ratio of the second harmonic current `I_2H_LOC_A` and the fundamental frequency current `I_1H_LOC_A`. If the line differential protection is used in normal mode (*Winding selection* is “Not in use”), the calculated value is compared with the parameter value of the *Start value 2.H* setting. If the calculated value exceeds the set value and the fundamental frequency current `I_1H_LOC_A` is more than seven percent of the nominal current, the output signal `BLK2H_A` is activated. The inrush detector handles the other phases the same way.

If the line differential protection is used in the in-zone transformer mode (*Winding selection* is “Winding 1” or “Winding 2”), the weighted average is calculated for the 2^{nd} harmonic ratios in different phases and the weighted ratio is then compared with the value of the *Start value 2.H* setting. If the calculated weighted ratio value exceeds the set value and the fundamental frequency current `I_1H_LOC_A` is more than seven percent of the nominal current, output signal `BLK2H_A` is activated.

The locally detected transformer inrush is also transferred to the remote end as a binary indication signal independently of the local *Restraint mode* setting parameter value. When the internal blocking of the stabilized low stage is activated, the `RSTD2H_LOC` and `RSTD2H_REM` outputs will also be activated at the same time depending on whether the inrush has been detected on local or remote end or on both ends.

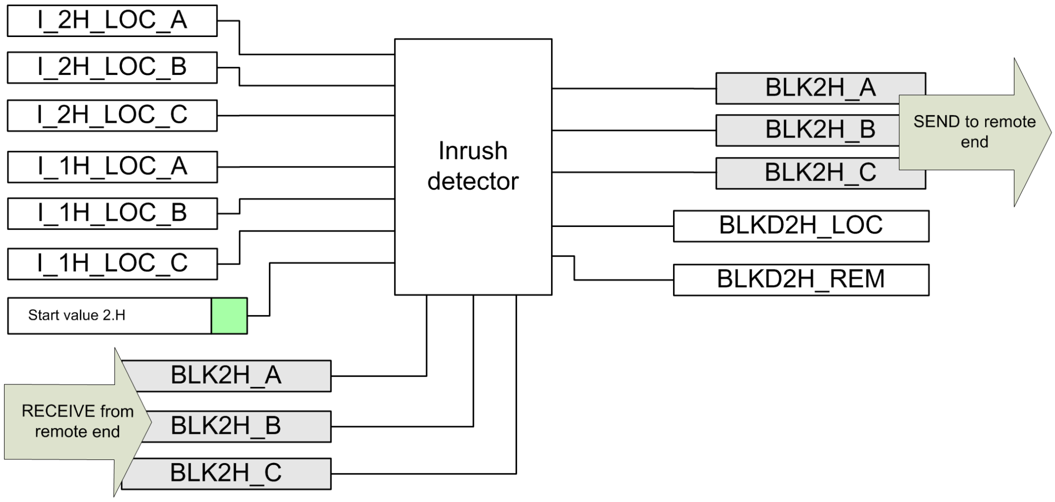


Figure 364: Inrush current detection logic

Differential calculation

The operating principle is to calculate on both ends differential current from currents entering and leaving the protection zone by utilizing the digital communication channels for data exchange. The differential currents are almost zero on normal operation. The differential protection is phase segregated and the differential currents are calculated separately on both ends.

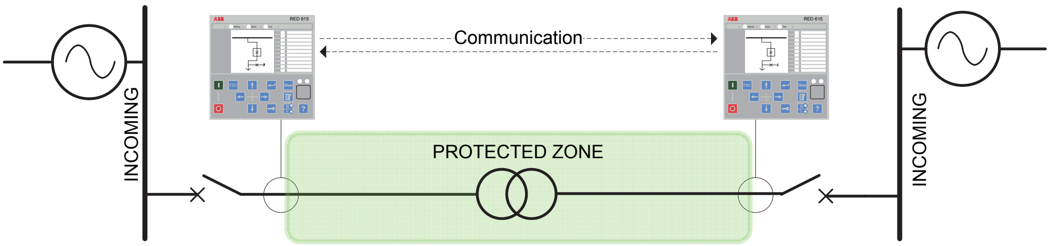


Figure 365: Basic protection principle

The differential current IΔ (I_d) of the protection relay is obtained on both ends with the formula:

$$I_d = \left|\bar{I}_{LOC} + \bar{I}_{REM}\right|$$

(Equation 142)

The stabilizing current I_{bias} (I_b) of the protection relay is obtained on both ends with the formula:

$$I_b = \frac{\left|\bar{I}_{LOC} - \bar{I}_{REM}\right|}{2}$$

(Equation 143)

Depending on the location of the star points of the current transformers, the polarity of the local end remote currents may be different causing malfunction of the calculation algorithms. The CT transformation ratio may be different and this needs to be compensated to provide a correct differential current calculation result on both ends.

The operation characteristics related settings are given in units as percentage of the current transformer secondary nominal current on each line end protection relay. For the actual primary setting, the corresponding CT ratio on each line end has to be considered. An example of how the *CT ratio correction* parameter values should be selected on both line ends in the example case to compensate the difference in the nominal levels can be presented.

Another example for differential application without in-zone transformer where line rated current is 400 A. The ratio of CTs are 800/1 and 400/1.

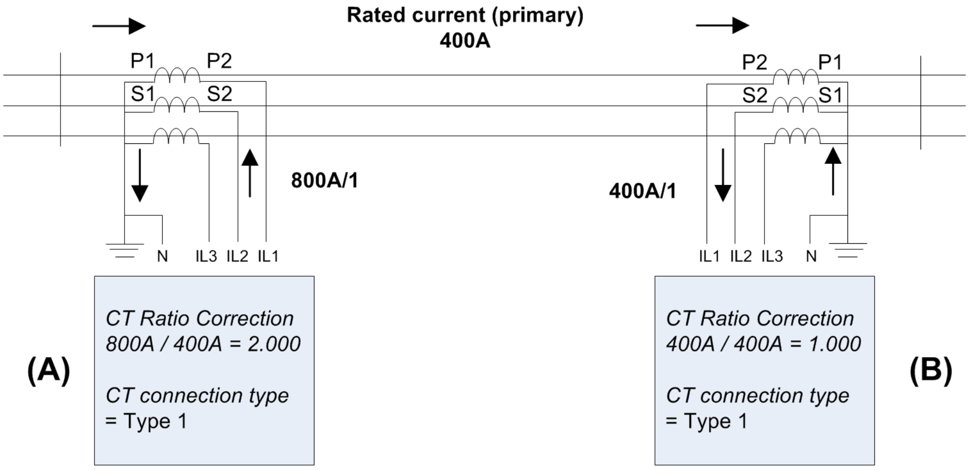


Figure 366: Example of CT ratio correction setting calculation in line differential application

The settings for *CT ratio Corrections* for protection relay A and protection relay (B) are:

CT ratio Correction (A) = 800 A / 400 A = 2.000

CT ratio Correction (B) = 400 A / 400 A = 1.000

The CT secondary current often differs from the rated current at the rated load of the power transformer. The CT transforming ratio can be corrected on both sides of the power transformer with the *CT ratio Correction* setting.

First, the rated load of the power transformer is calculated on both sides when the apparent power and phase-to-phase voltage are known.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(Equation 144)

I_{nT}	Rated load of the power transformer
S_n	Rated power of the power transformer
U_n	Rated phase-to-phase voltage

Next, the settings for the CT ratio correction can be calculated with the formula:

$$CT\ ratio\ correction = \frac{I_n}{I_{nT}}$$

(Equation 145)

I_n Nominal primary current of the CT

After the CT ratio correction, the measured currents and corresponding setting values of LNPLDF are expressed in multiples of the rated power transformer current Ir (×Ir) or percentage value of Ir (%Ir).

An example shows how the CT ratio correction settings are calculated; when the rated power of the transformer is 5 MVA, the ratio of CTs on the 20 kV side is 200/1 and that on the 10.5 kV side is 300/1.

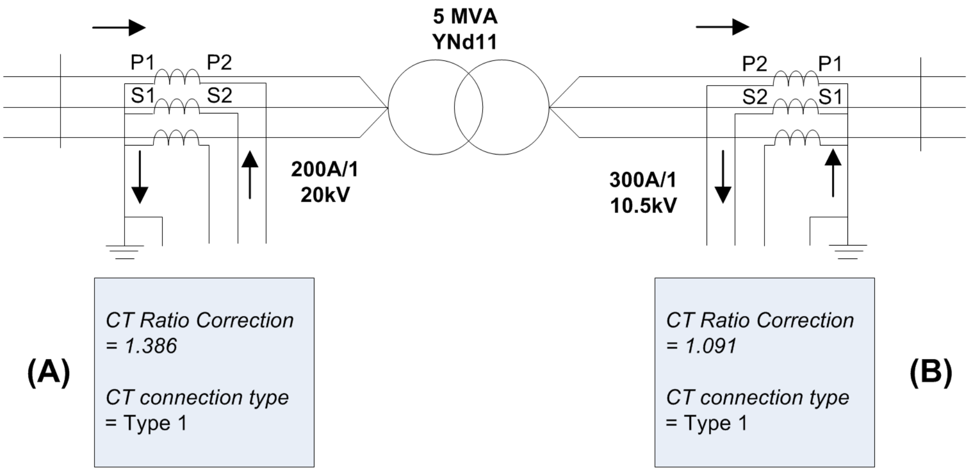


Figure 367: Example of CT ratio correction setting calculation with in-zone transformer

The rated load of the transformer is:

HV side (A): I_{nT_A}= 5 MVA / (1.732 × 20 kV) = 144.3 A

LV side (A): I_{nT_B}= 5 MVA / (1.732 × 10.5 kV) = 274.9 A

So the settings for *CT ratio corrections* at HV (A) and LV (B) side are:

CT ratio correction (A) = 200 A / 144.3 A = 1.386

CT ratio correction (B) = 300 A / 274.9 A = 1.091

CT connections

The connections of the primary current transformers are designated as “Type 1” and “Type 2”.

- If the positive directions of the winding 1 and winding 2 protection relay currents are opposite, the *CT connection type* setting parameter is “Type 1”. The connection examples of “Type 1” are as shown in the *Figure 368* and *Figure 369*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is “Type 2”. The connection examples of “Type 2” are as shown in the *Figure 370* and *Figure 371*.
- The default value of the *CT connection type* setting is “Type 1”.

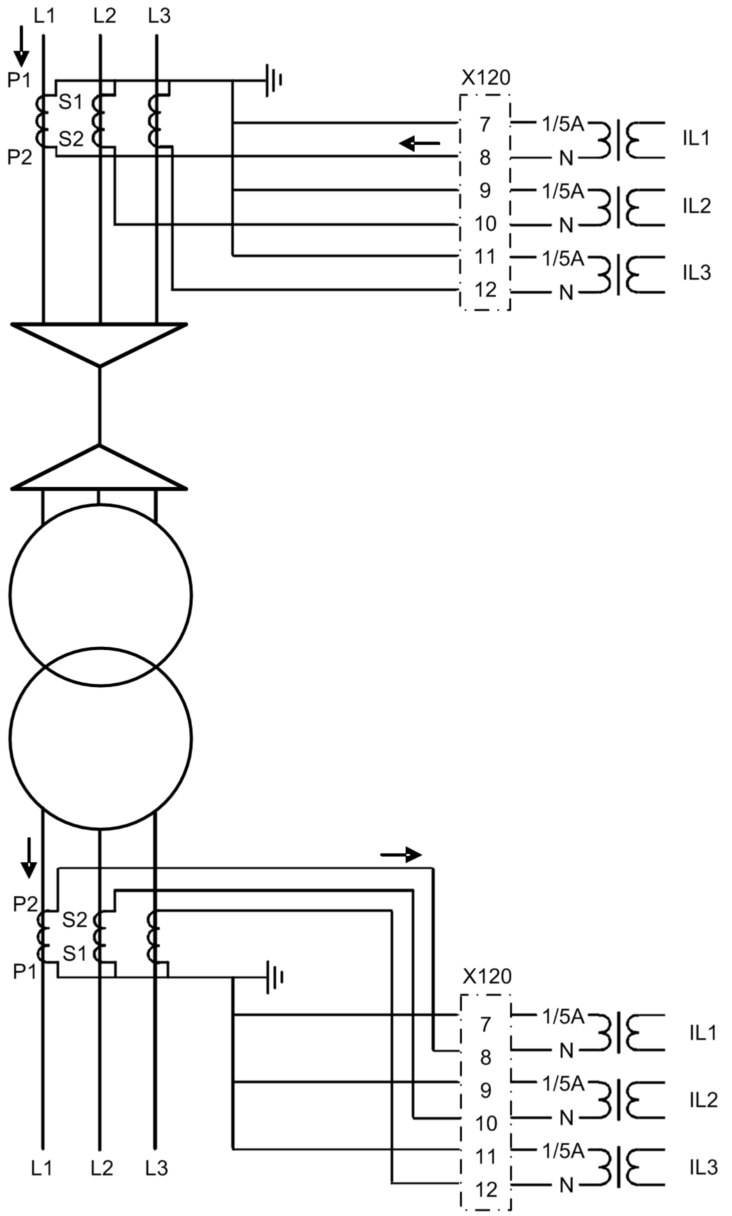


Figure 368: Connection example of current transformers of Type 1

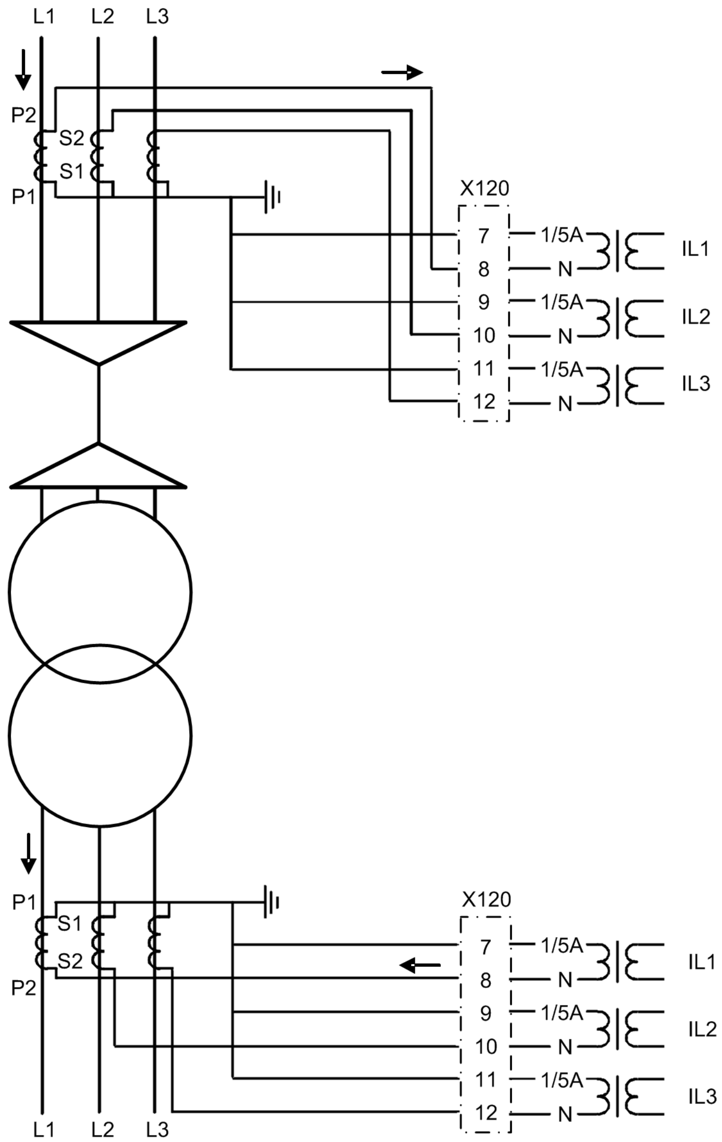


Figure 369: Connection example of current transformers of Type 1

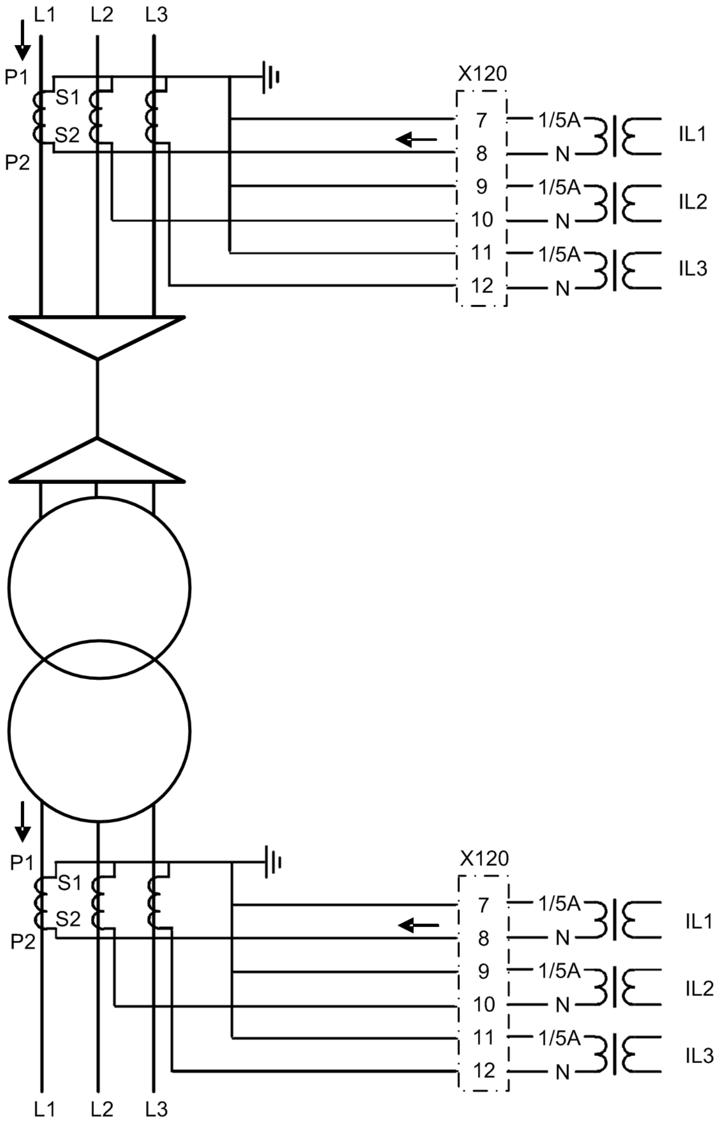


Figure 370: Connection example of current transformers of Type 2

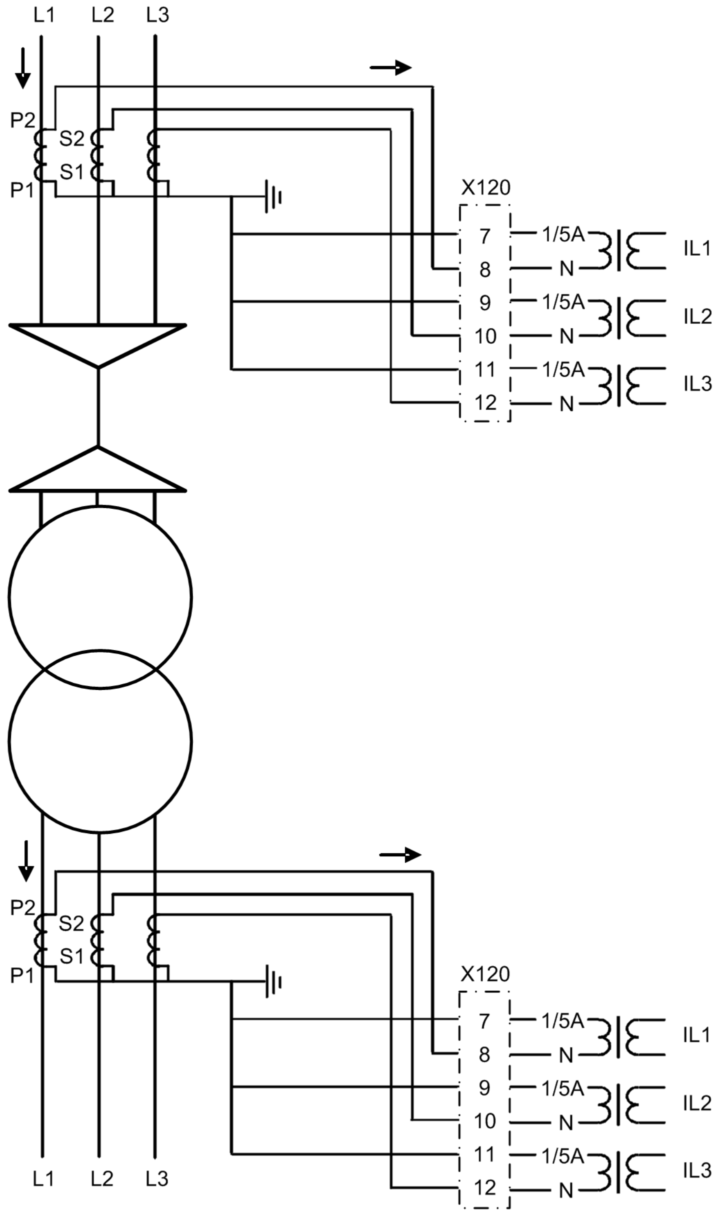


Figure 371: Connection example of current transformers of Type 2

Transformer vector group matching

Before differential and bias currents can be calculated, the phase difference of the currents must be vector group matched based on the transformer connection type. The vector group of the power transformer is numerically matched on the high voltage and low voltage sides by means of the *Winding selection*, *Winding 1 type*, *Winding 2 type* and *Clock number* settings. Thus no interposing CTs are needed if there is only a power transformer inside the protected zone. The matching is based on phase shifting and a numerical delta connection in the protection relay. If the neutral of a star-connected power transformer is earthed, any earth-fault in the network is perceived by the protection relay as a differential current. The elimination of the zero-sequence component can be selected for that winding by setting the Zro A elimination parameter.

Winding selection setting defines the protection relay location respect to the transformer. If the protection relay is situated at the HV side of the transformer, then protection relay location setting is set to “Winding 1” and respectively to “Winding 2” if protection relay is situated at the LV side. If the differential protection relays are used to protect a line without in-zone transformer, then the setting is set to “Not in use”. In this case vector group matching is ignored.

The matching of the phase difference is based on the phase shifting and the numerical delta connection inside the protection relay. The *Winding 1 type* parameter determines the connection on winding 1 (“Y”, “YN”, “D”, “Z”, “ZN”). The vector group matching can be implemented either on both, winding 1 and winding 2, or only on winding 1 or winding 2, at intervals of 30° with the *Clock number* setting. Similarly, the *Winding 2 type* parameter determines the connections of the phase windings on the low voltage side (“y”, “yn”, “d”, “z”, “zn”).

When the vector group matching is Yy0 and the *CT connection type* is according to “Type 2”, the phase angle of the phase currents connected to the protection relay does not change. When the vector group matching is Yy6, the phase currents are on one side turned 180° in the protection relay.

Example 1, vector group matching of an YNd11-connected power transformer on winding 1, *CT connection type* according to type 1. The *Winding 1 type* setting is “YN”, *Winding 2 type* is “d” and *Clock number* is “Clk Num 11”. This is compensated internally by giving winding 1 internal compensation value +30° and winding 2 internal compensation value 0°:

$$\bar{I}_{L1mHV} = \frac{\bar{I}_{L1} - \bar{I}_{L2}}{\sqrt{3}}$$

(Equation 146)

$$\bar{I}_{L2mHV} = \frac{\bar{I}_{L2} - \bar{I}_{L3}}{\sqrt{3}}$$

(Equation 147)

$$\bar{I}_{L3mHV} = \frac{\bar{I}_{L3} - \bar{I}_{L1}}{\sqrt{3}}$$

(Equation 148)

Example 2, if vector group is Yd11 and *CT connection type* is according to type 1, the compensation is a little different. The *Winding 1 type* setting is “Y”, *Winding 2 type* is “d” and *Clock number* is “Clk Num 11”. This is compensated internally by giving winding 1 internal compensation value 0° and winding 2 internal compensation value -30°:

$$\bar{I}_{L1mLV} = \frac{\bar{I}_{L1} - \bar{I}_{L3}}{\sqrt{3}}$$

(Equation 149)

$$\bar{I}_{L2mLV} = \frac{\bar{I}_{L2} - \bar{I}_{L1}}{\sqrt{3}}$$

(Equation 150)

$$\bar{I}_{L3mLV} = \frac{\bar{I}_{L3} - \bar{I}_{L2}}{\sqrt{3}}$$

(Equation 151)

The “Y” side currents stay untouched, while the “d” side currents are compensated to match the currents actually flowing in the windings.

In this example there is no neutral current on either side of the transformer (assuming there are no earthing transformers installed). In the previous example, the matching is done differently to have the winding 1 neutral current compensated at the same time.

Table 646: LNPLDF vector group matching

Vector group of the transformer	Winding 1 type	Winding 2 type	Phase shift	Zero sequence current elimination
Yy0	Y	y	0	Not needed
YNy0	YN	y	0	HV side
YNyn0	YN	yn	0	HV & LV side
Yyn0	Y	yn	0	LV side
Yy2	Y	y	2	Not needed
YNy2	YN	y	2	(Automatic)
YNyn2	YN	yn	2	(Automatic)
Yyn2	Y	yn	2	(Automatic)
Yy4	Y	y	4	Not needed
YNy4	YN	y	4	(Automatic)
YNyn4	YN	yn	4	(Automatic)
Yyn4	Y	yn	4	(Automatic)
Yy6	Y	y	6	Not needed
YNy6	YN	y	6	HV side
YNyn6	YN	yn	6	HV & LV side
Yyn6	Y	yn	6	LV side
Yy8	Y	y	8	Not needed
YNy8	YN	y	8	(Automatic)
YNyn8	YN	yn	8	(Automatic)
Yyn8	Y	yn	8	(Automatic)
Yy10	Y	y	10	Not needed

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Phase shift	Zero sequence current elimination
YNy10	YN	y	10	(Automatic)
YNyn10	YN	yn	10	(Automatic)
Yyn10	Y	yn	10	(Automatic)
Yd1	Y	d	1	Not needed
YNd1	YN	d	1	(Automatic)
Yd5	Y	d	5	Not needed
YNd5	YN	d	5	(Automatic)
Yd7	Y	d	7	Not needed
YNd7	YN	d	7	(Automatic)
Yd11	Y	d	11	Not needed
YNd11	YN	d	11	(Automatic
Dd0	D	d	0	Not needed
Dd2	D	d	2	Not needed
Dd4	D	d	4	Not needed
Dd6	D	d	6	Not needed
Dd8	D	d	8	Not needed
Dd10	D	d	10	Not needed
Dy1	D	y	1	Not needed
Dyn1	D	yn	1	(Automatic)
Dy5	D	y	5	Not needed
Dyn5	D	yn	5	(Automatic)
Dy7	D	y	7	Not needed
Dyn7	D	yn	7	(Automatic)
Dy11	D	y	11	Not needed
Dyn11	D	yn	11	(Automatic)
Yz1	Y	z	1	Not needed
YNz1	YN	z	1	(Automatic)
YNzn1	YN	zn	1	LV side
Yzn1	Y	zn	1	(Automatic)
Yz5	Y	z	5	Not needed
YNz5	YN	z	5	(Automatic)
YNzn5	YN	zn	5	LV side
Yzn5	Y	zn	5	(Automatic)
Yz7	Y	z	7	Not needed
YNz7	YN	z	7	(Automatic)
YNzn7	YN	zn	7	LV side
Yzn7	Y	zn	7	(Automatic)

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Phase shift	Zero sequence current elimination
Yz11	Y	z	11	Not needed
YNz11	YN	z	11	(Automatic)
YNzn11	YN	zn	11	LV side
Yzn11	Y	zn	11	(Automatic)
Zy1	Z	y	1	Not needed
Zyn1	Z	yn	1	(Automatic)
ZNyn1	ZN	yn	1	HV side
ZNy1	ZN	y	1	(Automatic)
Zy5	Z	y	5	Not needed
Zyn5	Z	yn	5	(Automatic)
ZNyn5	ZN	yn	5	HV side
ZNy5	ZN	y	5	(Automatic)
Zy7	Z	y	7	Not needed
Zyn7	Z	yn	7	(Automatic)
ZNyn7	ZN	yn	7	HV side
ZNy7	ZN	y	7	(Automatic)
Zy11	Z	y	11	Not needed
Zyn11	Z	yn	11	(Automatic)
ZNyn11	ZN	yn	11	HV side
ZNy11	ZN	y	11	(Automatic)
Dz0	D	z	0	Not needed
Dzn0	D	zn	0	LV side
Dz2	D	z	2	Not needed
Dzn2	D	zn	2	(Automatic)
Dz4	D	z	4	Not needed
Dzn4	D	zn	4	(Automatic)
Dz6	D	z	6	Not needed
Dzn6	D	zn	6	LV side
Dz8	D	z	8	Not needed
Dzn8	D	zn	8	(Automatic)
Dz10	D	z	10	Not needed
Dzn10	D	zn	10	(Automatic)
Zd0	Z	d	0	Not needed
ZNd0	ZN	d	0	HV side
Zd2	Z	d	2	Not needed
ZNd2	ZN	d	2	(Automatic)
Zd4	Z	d	4	Not needed

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Phase shift	Zero sequence current elimination
ZNd4	ZN	d	4	(Automatic)
Zd6	Z	d	6	Not needed
ZNd6	ZN	d	6	HV side
Zd8	Z	d	8	Not needed
ZNd8	ZN	d	8	(Automatic)
Zd10	Z	d	10	Not needed
ZNd10	ZN	d	10	(Automatic)
Zz0	Z	z	0	Not needed
ZNz0	ZN	z	0	HV side
ZNzn0	ZN	zn	0	HV & LV side
Zzn0	Z	zn	0	LV side
Zz2	Z	z	2	Not needed
ZNz2	ZN	z	2	(Automatic)
ZNzn2	ZN	zn	2	(Automatic)
Zzn2	Z	zn	2	(Automatic)
Zz4	Z	z	4	Not needed
ZNz4	ZN	z	4	(Automatic)
ZNzn4	ZN	zn	4	(Automatic)
Zzn4	Z	zn	4	(Automatic)
Zz6	Z	z	6	Not needed
ZNz6	ZN	z	6	HV side
ZNzn6	ZN	zn	6	HV & LV side
Zzn6	Z	zn	6	LV side
Zz8	Z	z	8	Not needed
ZNz8	ZN	z	8	(Automatic)
ZNzn8	ZN	zn	8	(Automatic)
Zzn8	Z	zn	8	(Automatic)
Zz10	Z	z	10	Not needed
ZNz10	ZN	z	10	(Automatic)
ZNzn10	ZN	zn	10	(Automatic)
Zzn10	Z	zn	10	(Automatic)

Zero-sequence component elimination

If *Clock number* is “Clk Num 2“, “Clk Num 4”, “Clk Num 8” or “Clk Num 10”, the vector group matching is always done on both, winding 1 and winding 2. The combination results in the correct compensation. In this case the zero-sequence component is always removed from both sides automatically. The *Zro A elimination* parameter cannot change this.

If *Clock number* is “Clk Num 1”, “Clk Num 5”, “Clk Num 7” or “Clk Num 11”, the vector group matching is done on one side only. A possible zero-sequence component of the phase currents at earth faults occurring outside the protection area is automatically eliminated in the numerically implemented delta connection before the differential current and the biasing current are calculated. This is why the vector group matching is almost always made on the star connected side of the “Ynd” and “Dyn” connected transformers.

If *Clock number* is “Clk Num 0” or “Clk Num 6”, the zero-sequence component of the phase currents is not eliminated automatically on either side. Therefore, the zero-sequence component on the star connected side that is earthed at its star point has to be eliminated by using the Zro A elimination parameter.

The same parameter has to be used to eliminate the zero-sequence component if there is, for example, an earthing transformer on the delta-connected side of the “Ynd” power transformer in the area to be protected. In this case, the vector group matching is normally made on the side of the star connection. On the side of the delta connection, the elimination of the zero-sequence component has to be eliminated by using the Zro A elimination parameter.

By using the Zro A elimination parameter, the zero-sequence component of the local phase currents is calculated and reduced for each phase current:

$$\bar{I}_{LOC\_A} = \bar{I}_{LOC\_A} - \frac{1}{3} \times \left(\bar{I}_{LOC\_A} + \bar{I}_{LOC\_B} + \bar{I}_{LOC\_C} \right)$$

(Equation 152)

$$\bar{I}_{LOC\_B} = \bar{I}_{LOC\_B} - \frac{1}{3} \times \left(\bar{I}_{LOC\_A} + \bar{I}_{LOC\_B} + \bar{I}_{LOC\_C} \right)$$

(Equation 153)

$$\bar{I}_{LOC\_C} = \bar{I}_{LOC\_C} - \frac{1}{3} \times \left(\bar{I}_{LOC\_A} + \bar{I}_{LOC\_B} + \bar{I}_{LOC\_C} \right)$$

Fail safe function

To prevent malfunction during communication interference, the operation of LNPLDF is blocked when the protection communication supervision detects severe interference in the communication channel. The timer reset stage is activated in case the stabilized stage is started during a communication interruption. The protection communication supervison is connected internally from PCSITPC to LNPLDF (dotted OK line).

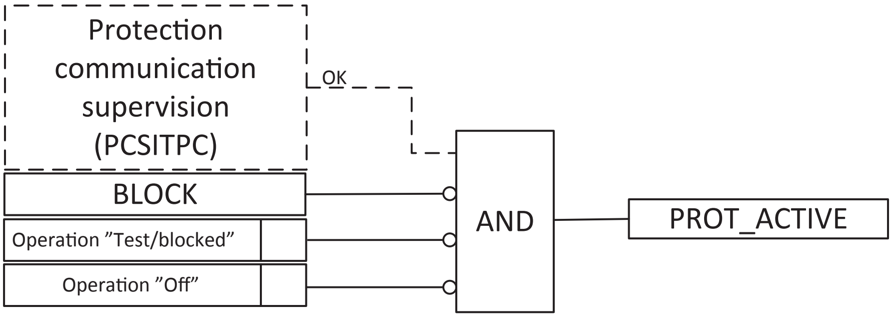


Figure 372: Operation logic of the fail safe function

The function can also be set into “test/blocked” state with the *Operation* setting. This can also be utilized during the commissioning.

The BLOCK input is provided for blocking the function with the logic. When the function is blocked, the monitored data and measured values are still available but the binary outputs are blocked. When the function is blocked, the direct inter-trip is also blocked.

The PRO_ACTIVE output is always active when the protection function is capable of operating. PRO_ACTIVE can be used as a blocking signal for backup protection functions.

Timer

Once activated, the timer activates the STR_LS_LOC output. Depending on the value of the set *Operating curve type*, the timer characteristics are according to DT or IDMT. When the operation timer has reached the value set with the *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPR_LS_LOC output is activated. When the operation mode is according to IDMT, *Low operate value* is used as reference value (Start value) in the IDMT equations presented in the Standard inverse-time characteristics section.

A timer reset state is activated when a drop-off situation happens. The reset is done according to the DT characteristics.

For a detailed description of the timer characteristics, see the *Chapter 11 General function block features* section in this manual.

Instantaneous high stage

In addition to the stabilized low stage, LNPLDF has an instantaneous high stage. The stabilizing is not done with the instantaneous high stage. The instantaneous high stage operates immediately when the differential current amplitude is higher than the set value of the *High operate value* setting. If the ENA_MULT_HS input is active, the *High operate value* setting is internally multiplied by the *High Op value Mult* setting.

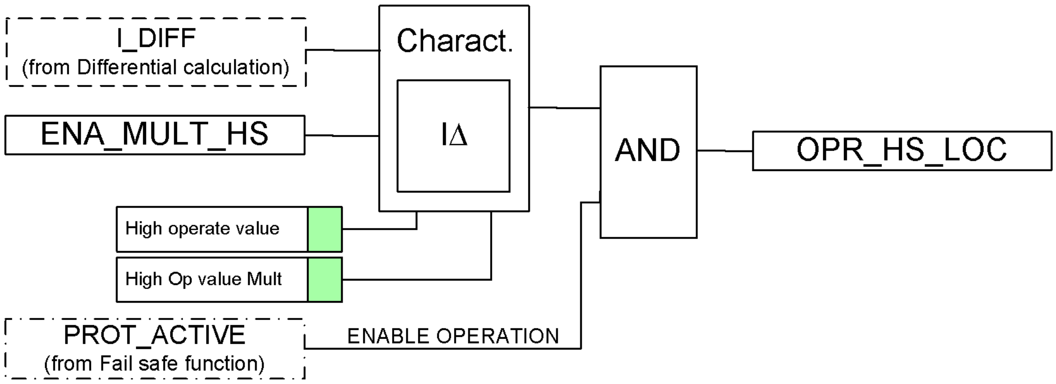


Figure 373: Operation logic of instantaneous high stage

Direct inter-trip

Direct inter-trip is used to ensure the simultaneous opening of the circuit breakers at both ends of the protected line when a fault is detected. Both start and operate signals are sent to the remote end via communication. The direct-intertripping of the line differential protection is included into LNPLDF. The `OPERATE` output combines the operate signals from both stages, local and remote, so that it can be used for the direct inter-trip signal locally.

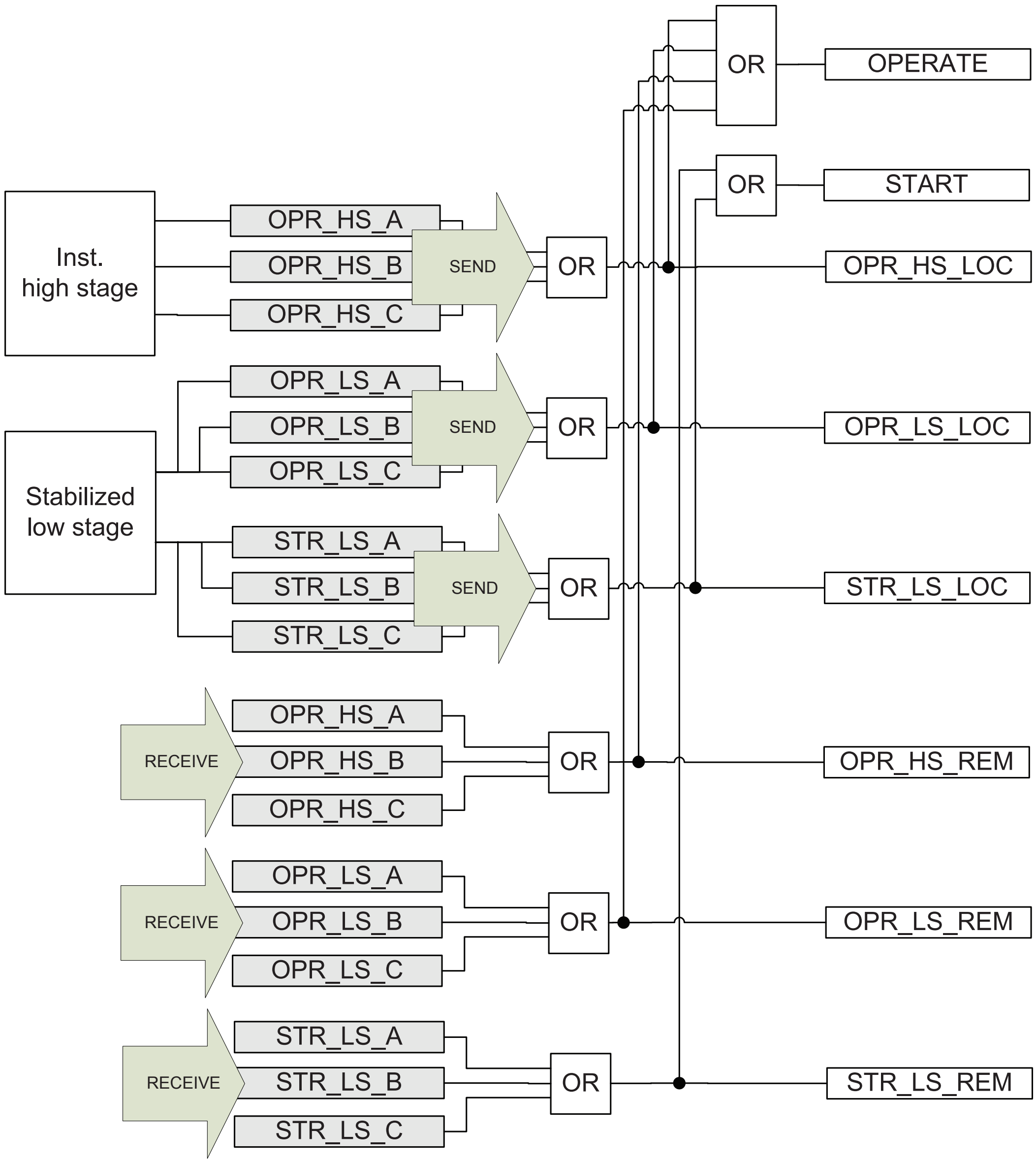


Figure 374: Operation logic of the direct intertrip function

The start and operate signals are provided separately for the low and high stages, and in the local and remote.

Blocking functionality

There are two independent inputs that can be used for blocking the function: BLOCK and BLOCK_LS. The difference between these inputs is that BLOCK_LS (when TRUE) blocks only the stabilized low stage leaving the instantaneous high stage operative. BLOCK (when TRUE) blocks both stages and also the PRO_ACTIVE output is updated according to the BLOCK input status, as described in the Fail safe function chapter.

The BLOCK and BLOCK_LS input statuses affect only the behavior of the local protection instance. When a line differential protection stage (stabilized low or instantaneous high) is blocked, also the received remote signals related to the corresponding stage are ignored (received direct inter-trip signals from the remote end). The binary signal transfer functionality should therefore be used for transferring the possible additional blocking information between the local and remote terminals whenever the blocking logic behavior needs to be the same on both line ends.

Test mode

The line differential function in one protection relay can be set to test mode, that is, the *Operation* setting is set to “test/blocked”. This blocks the line differential protection outputs in the protection relay and sets the remote protection relay to a remote test mode, such that the injected currents are echoed back with the shifted phase. It is also possible that both protection relays are simultaneously in the test mode. When the line differential protection function is in the test mode:

- The remote end protection relay echoes locally injected current samples back with the shifted phase. The current samples that are sent to the remote protection relay are scaled with the CT ratio correction setting.
- The operation of both stages (stabilized low or instantaneous high) are blocked, and also the direct inter-trip functionality is blocked (both receive and send) in the protection relay where the test mode is active.
- The remote end line differential protection function that is in the normal mode (On) is not affected by the local end being in the test mode. This means that the remote end function is operative but, at the same time, it ignores the received current samples from the other end protection relay which is in the test mode.
- The PRO_ACTIVE output is false only in the protection relay that is currently in the test mode.

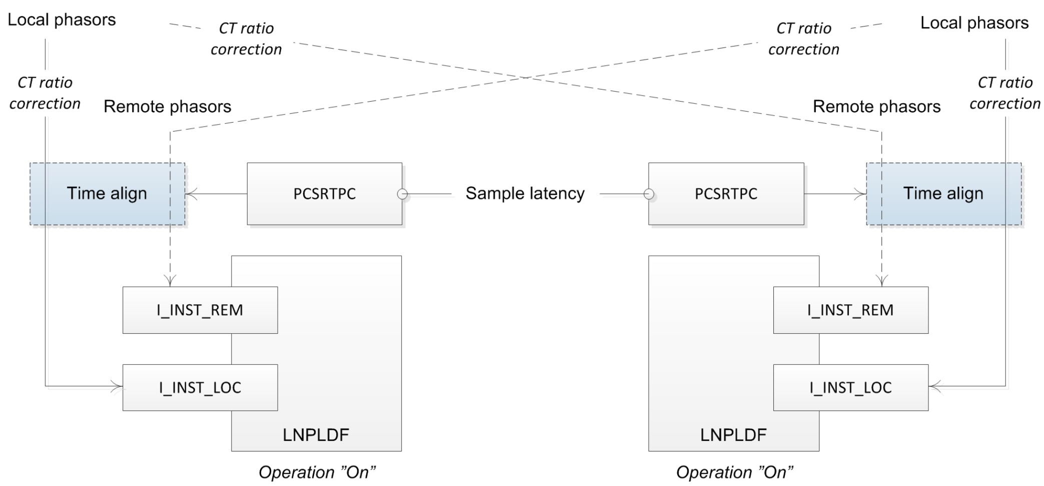


Figure 375: Operation during the normal operation of the line differential protection

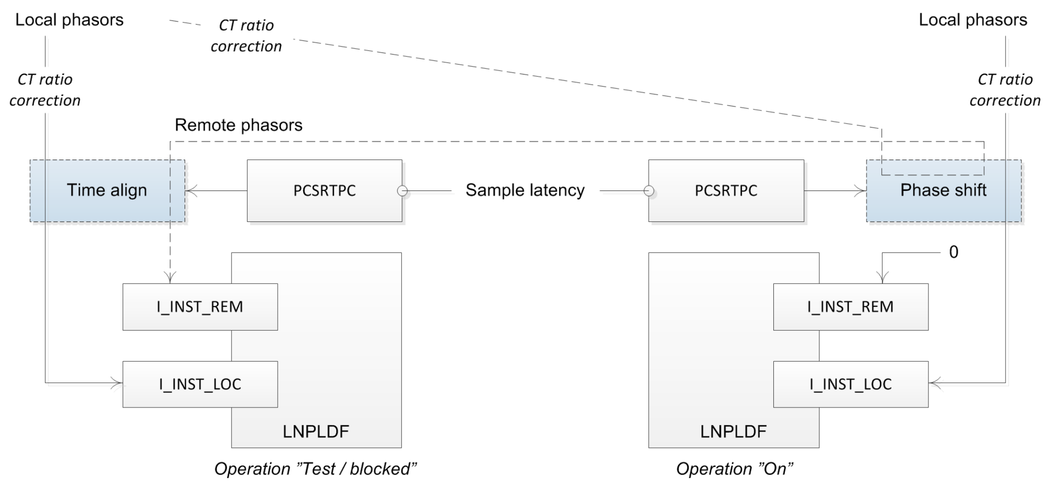


Figure 376: Operation during test operation of the line differential protection

4.3.1.6 Commissioning

The commissioning of the line differential protection scheme would be difficult without any support features in the functionality because of the relatively long distance between the protection relays. This has been taken into consideration in the design of the line differential protection. The communication channel can be used for echoing the locally fed current phasors from the remote end. By using this mode, it is possible to verify that differential calculation is done correctly in each phase. Also, the protection communication operation is taken into account with the differential current calculation when this test mode is used.

Required material for testing the protection relay

- Calculated settings
- Terminal diagram
- Circuit diagrams
- Technical and application manuals of the protection relay
- Single of three-phase secondary current source
- Single of three-phase primary current source
- Timer with start and stop interfaces
- Auxiliary voltage source for the protection relays
- PC with related software, a Web browser for WHMI

The setting and configuration of the protection relay must be completed before testing.

The terminal diagram, available in the technical manual, is a general diagram of the protection relay.

The same diagram is not always applicable to each specific delivery, especially for the configuration of all the binary inputs and outputs. Therefore, before testing, check that the available terminal diagram corresponds to the protection relay.

The circuit diagrams of the application are recommended to be available. These are required for checking the terminal block numbers of the current, trip, alarm and possibly other auxiliary circuits.

The technical and application manuals contain application and functionality summaries, function blocks, logic diagrams, input and output signals, setting parameters and technical data sorted per function.

The minimum requirement for a secondary current injection test device is the ability to work as a one phase current source.

The protection relay should be prepared for the test before testing a particular function. The logic diagram of the tested protection function must be considered while performing the test. All included functions in the protection relay are tested according to the corresponding test instructions in this chapter. The functions can be tested in any order according to user preferences. Therefore, the test instructions are presented in alphabetical order. Only the functions that are in use (*Operation* is set to "On") should be tested.

The response from the test can be viewed in different ways.

- Binary output signals
- Monitored data values in the LHMI (logical signals)
- A PC with a Web browser for WHMI use (logical signals and phasors)

All used setting groups should be tested.

Checking the external optical and electrical connections

The user must check the installation to verify that the protection relay is connected to the other required parts of the protection system. The protection relay and all the connected circuits are to be de-energized during the check-up.

Checking of CT circuits

Check that the wiring is in strict accordance with the supplied connection diagram.

The CTs must be connected in accordance with the terminal diagram provided with the protection relay, both with regards to phases and polarity. The following tests are recommended for every primary CT or CT core connected to the protection relay.

- Primary injection test to verify the current ratio of the CT, the correct wiring up to the protection relay and correct phase sequence connection (that is L1, L2, L3.)
- Polarity check to prove that the predicted direction of the secondary current flow is correct for a given direction of the primary current flow. This is an essential test for the proper operation of the directional function, protection or measurement in the protection relay.
- CT secondary loop resistance measurement to confirm that the current transformer secondary loop DC resistance is within specification and that there are no high resistance joints in the CT winding or wiring.
- CT excitation test to ensure that the correct core in the CT is connected to the protection relay. Normally only a few points along the excitation curve are checked to ensure that there are no wiring errors in the system, for example, due to a mistake in connecting the CT's measurement core to the protection relay.
- CT excitation test to ensure that the CT is of the correct accuracy rating and that there are no short circuited turns in the CT windings. Manufacturer's design curves should be available for the CT to compare the actual results.

- Earthing check of the individual CT secondary circuits to verify that each three-phase set of main CTs is properly connected to the station earth and only at one electrical point.
- Insulation resistance check.
- Phase identification of CT shall be made.

CT and VT connectors are pre-coded, and the CT and VT connector markings are different. For more information, see the installation manual.

De-energize the CT primary side and disconnect the CT secondary circuits from the protection relay while carrying out the CT core excitation curve plotting.

If the CT secondary circuit is opened or its earth connection is missing or removed without the CT primary being de-energized first, dangerous voltages may be produced. This can be lethal and cause damage to the insulation. The re-energizing of the CT primary should be prohibited as long as the CT secondary is open or unearthed.

Checking of the power supply

Check that the auxiliary supply voltage remains within the permissible input voltage range under all operating conditions. Check that the polarity is correct before powering the protection relay.

Checking binary I/O circuits

Always check the binary input circuits from the equipment to the protection relay interface to make sure that all signals are connected correctly. If there is no need to test a particular input, the corresponding wiring can be disconnected from the terminal of the protection relay during testing. Check all the connected signals so that both input voltage level and polarity are in accordance with the protection relay specifications. However, attention must be paid to the electrical safety instructions.

Always check the binary output circuits from the protection relay to the equipment interface to make sure that all signals are connected correctly. If a particular output needs to be tested, the corresponding wiring can be disconnected from the terminal of the protection relay during testing. Check all the connected signals so that both load and polarity are in accordance with the protection relay specifications. However, attention must be paid to the electrical safety instructions.

Checking of optical connections

Check that the Tx and Rx optical connections are correct.

A relay equipped with optical connections requires a minimum depth of 180 mm (7.0866 in) for plastic fiber cables and 275 mm (10.8268 in) for glass fiber cables. Check the allowed minimum bending radius from the optical cable manufacturer.

Applying of required settings for the protection relay

Download all calculated settings and measurement transformer parameters in the protection relay.

Connecting of test equipment to the protection relay

Before testing, connect the test equipment according to the protection relay specific connection diagram.

Pay attention to the correct connection of the input and output current terminals. Check that the input and output logical signals in the logic diagram for the function under test are connected to the corresponding binary inputs and outputs of the protection relay. Select the correct auxiliary voltage source according to the power supply module of the protection relay. Select the correct auxiliary voltage source according to the power supply module of the protection relay.

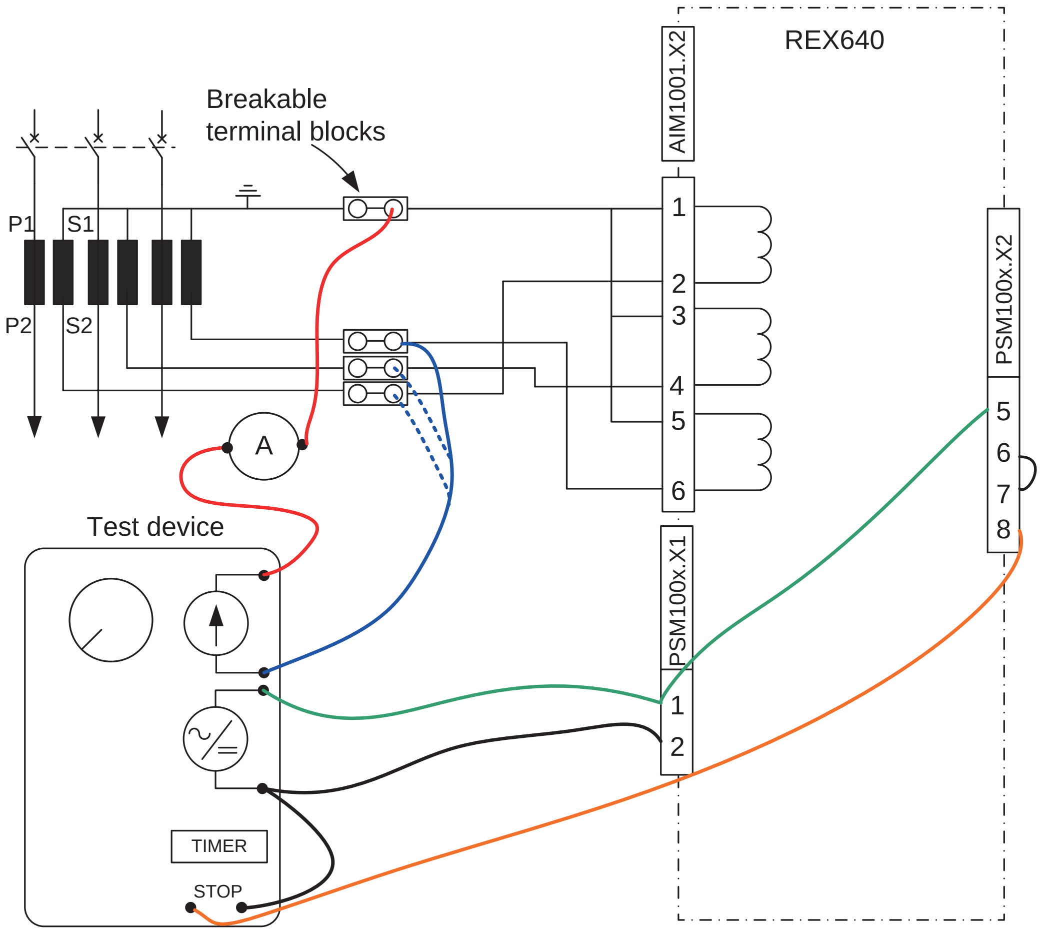


Figure 377: Example of connections to test the line differential protection relay

Secondary current injection

There are two alternative modes to check the operation of a line differential protection relay. These are not exclusive methods for each other and can be used for various test on the protection relay.

Normal mode

In normal mode, that is, the mode when the function is on normal operation, the local end protection relay sends phasors to the remote end protection relay and receives phasors measured by the remote end protection relay. This mode can be used in testing the operating level and time of the low and high stages of the local end protection relay. This is due to a test situation when the remote end does not measure any current and therefore, all the current fed to the local end current circuit is seen as differential current at both ends.

Testing of the line differential protection is done with both protection relays separated geographically from each other. It is important to note that local actions in one protection relay cause operation also in the remotely located protection relay. When testing the line differential function, actions have to be done in both protection relays.

Before the test, the trip signal to the circuit breaker shall be blocked, for example by breaking the trip circuit by opening the terminal block or by using some other suitable method.

When injecting current to one phase in the local end protection relay, the current is seen as a differential current at both ends. If a current $I_{injected}$ is injected, L1 in phase L1, the differential and stabilizing currents for phase L1 are:

$$ID\_A = I_{injected}$$

(Equation 154)

$$IB\_A = \frac{I_{injected}}{2}$$

(Equation 155)

The operation is equal for phases L2 and L3.

Verifying the settings

1. Block the unwanted trip signals from the protection relay units involved.
2. Inject a current in phase L1 and increase the current until the function operates for phase L1.

   The injected operate current corresponds to the set *Low operate value*. The monitored values for ID_A should be equal to the injected current.

3. Repeat point 2 by current injection in phases L2 and L3.
4. Measure the operating time by injecting the single-phase current in phase L1.

   The injected current should be four times the operating current. The time measurement is stopped by the trip output from the protection relay unit.

5. Disconnect the test equipment and reconnect the current transformers and all other circuits including the trip circuit.

Phasor echoing method

The line differential function in one protection relay can be set to special test mode, that is, the *Operation* setting is set to “test/blocked”. When this mode is in use, the remote end protection relay echoes locally injected current phasors back with the shifted phase and settable amplitude. Therefore, the local end line differential function is also automatically blocked and the remote end line differential function discards the phasors it receives from the protection relay in the test mode.

When the test mode is active, the *CT connection type* is still used by the line differential protection function as in the normal operation mode. The setting can be used for shifting the phase (0 or 180 degrees).

Parameter Settings - LNPLDF1

Edit | Refresh Values | Setting Group 1*

PARAMETER NAME	RELAY VALUE	UNIT	MIN.	MAX.	STEP
Operation	test/blocked				
Winding selection	Not in use				
CT ratio correction	1.000		0.2	5	0.001
CT connection type	Type 2				
Restraint mode	None				
Reset delay time	0	ms	0	60000	1
Setting Group 1					
Low operate value	10	%Ir	10	200	1
High operate value	200	%Ir	200	4000	1
High Op value Mult	1.0		0.5	1	0.1
End section 1	100	%Ir	0	200	1
Slope section 2	50	%	10	50	1
End section 2	200	%Ir	200	2000	1
Slope section 3	150	%	10	200	1
Operating curve type	IEC Def. Time				
Operate delay time	45	ms	45	200000	1

Figure 378: An example of a test mode situation where three-phase currents are injected to the local end protection relay

4.3.1.7 Application

LNPLDF is designed for the differential protection of overhead line and cable feeders in a distribution network. LNPLDF provides absolute selectivity and fast operating times as unit protection also in short lines where distance protection cannot be applied.

LNPLDF provides selective protection for radial, looped and meshed network topologies and can be used in isolated neutral networks, resistance earthed networks, compensated (impedance earthed) networks and solidly earthed networks. In a typical network configuration where the line differential protection scheme is applied, the protected zone, that is, the line or cable, is fed from two directions.

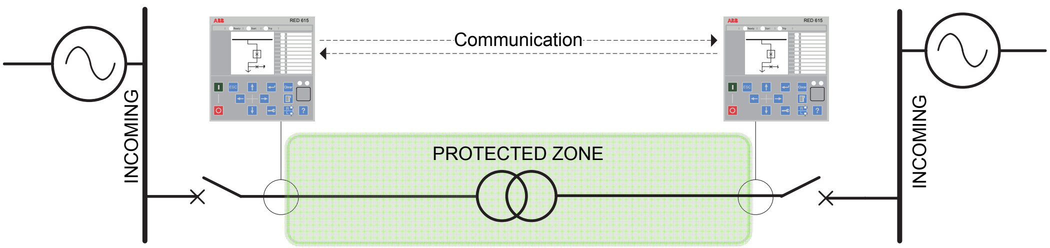


Figure 379: Line protection with phase segregated line differential with in-zone transformer

LNPLDF can be utilized for various types of network configurations or topologies. Case A shows the protection of a ring-type distribution network. The network is also used in the closed ring mode. LNPLDF is used as the main protection for different sections of the feeder. In case B, the interconnection of two substations is done with parallel lines and each line is protected with the line differential protection. In case C, the connection line to mid scale power generation (typical size around 10...50 MVA) is protected with the line differential function. The protection includes the transformer from the protection field. In case D, the connection between two substations and a small distribution transformer is located at the tapped load. The usage of LNPLDF is not limited to these applications.

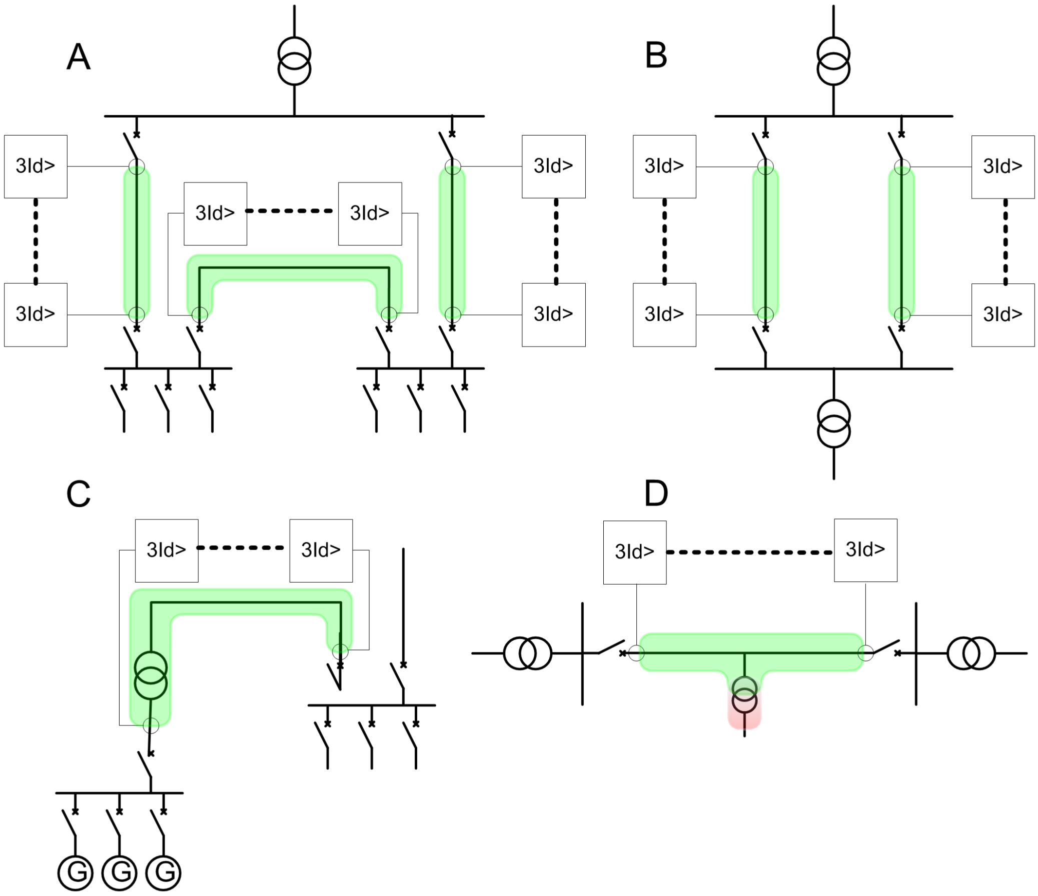


Figure 380: Line differential applications

Communication supervision

A typical line differential protection application includes LNPLDF as the main protection. Backup over current functions is needed if a protection communication failure occurs. When the communication supervision function detects a failure in the communication between the protective units, the safe operation of the line is still guaranteed by blocking the line differential protection and unblocking the over current functions.

When a communication failure is detected, the protection communication supervision function issues block for the LNPLDF line differential protection and unblock for the instantaneous and high stages (instance 2) of the over current protection. These are used to give backup protection for the remote end feeder protection relay. In situations where the selectivity is weaker than usually, the protection should still be available for the system.

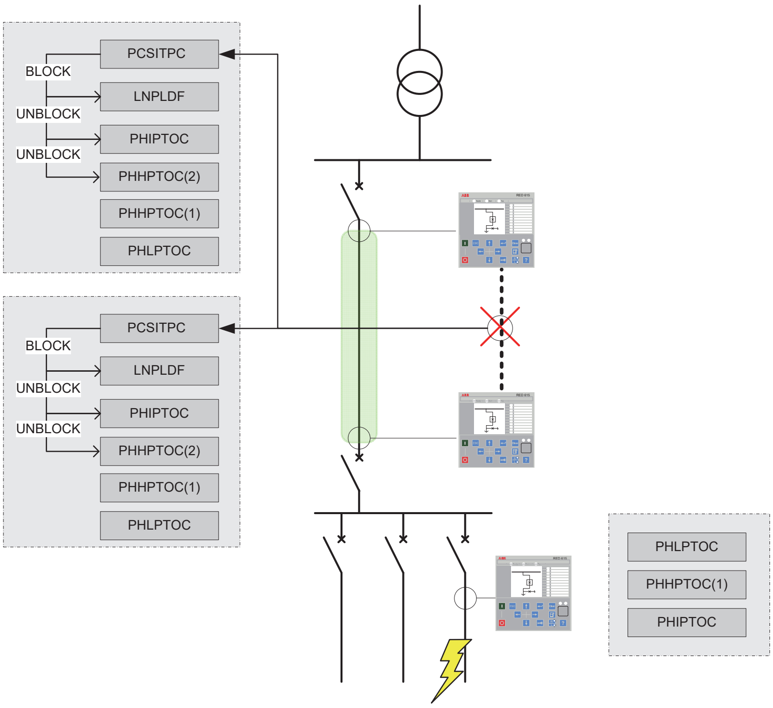


Figure 381: Protection communication supervision detects failures on communication

In-zone transformer

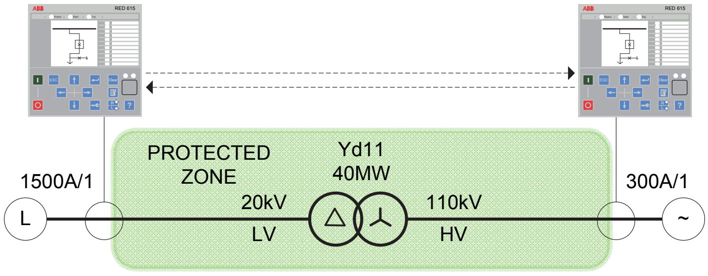


Figure 382: In-zone transformer example about CT ratio correction calculation

The CT ratio correction calculation starts with the rated load current calculation for HV and LV sides. The rated load current is defined as the rated power of the transformer divided by the square root of three times the nominal phase-to-phase voltage at the HV or LV side.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(Equation 156)

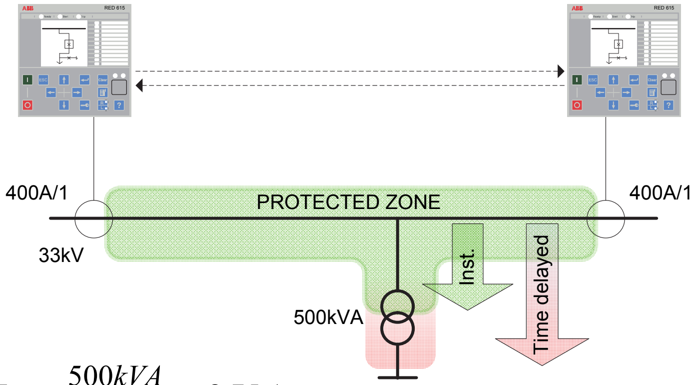
The rated load current of the transformer on the HV side is 209.9 A (40 MW / (√3 × 110 kV)) and the rated load current of the transformer on the LV side is 1154.7 A (40 MW / (√3 × 20 kV)). This means that the CT ratio corrections for the HV and LV sides are:

CT ratio correction (HV) = 1.429 (300 A / 209.9 A)

CT ratio correction (LV) = 1.299 (1500 A / 1154.7 A)

Small power transformers in a tap

With a relatively small power transformer in a line tap, the line differential protection can be applied without the need of current measurement from the tap. In such cases, the line differential function is time delayed for low differential currents below the high set limit and LNPLDF coordinates with the downstream protection relays in the relevant tap. For differential currents above the set limit, the operation is instantaneous. As a consequence, when the load current of the tap is negligible, the low resistive line faults are cleared instantaneously at the same time as maximum sensitivity for the high resistive faults are maintained but with a time delayed operation. The maximum sensitivity for high resistive faults is maintained at the same time, but with a time delayed operation.

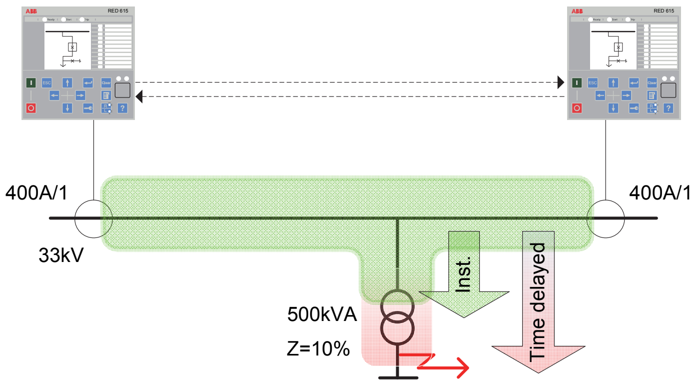


$$I_L = \frac{500kVA}{\sqrt{3} \cdot 33kV} \cong 8.75A$$

$$\mathrm{I}_{\Delta} > \left[\frac{8.75A}{400\ A}\right] * 1\mathrm{A} = 0.02A = 2\%$$

Figure 383: Influence of the tapped transformer load current to the stabilized low stage setting

The stabilized stage provides both DT and IDMT characteristics that are used for time selective protection against faults which are not covered by the instantaneous stage. The impedance of the line is typically an order of magnitude lower than the transformer impedance providing significantly higher fault currents when the fault is located on the line.



$$I_F = \frac{1.1 \cdot 500kVA}{\sqrt{3} \cdot 33kV \cdot 0.10} \cong 96.23A$$

$$\mathrm{I}_{\Delta} < \left[\frac{96.23A}{400\ A}\right] * 1\mathrm{A} = 0.24A = 24\%$$

Figure 384: Influence of the short circuit current at LV side of the tapped transformer to the differential current

Detection of the inrush current during transformer start-up

When the line is energized, the transformer magnetization inrush current is seen as differential current by the line differential protection and may cause malfunction of the protection if not taken into account. The inrush situation may only be detected on one end but the differential current is always seen on both ends. The inrush current includes high order harmonic components which can be detected and used as the blocking criteria for the stabilized stage. The inrush detection information is changed between two ends so that fast and safe blocking of the stabilized stage can be issued on both ends.

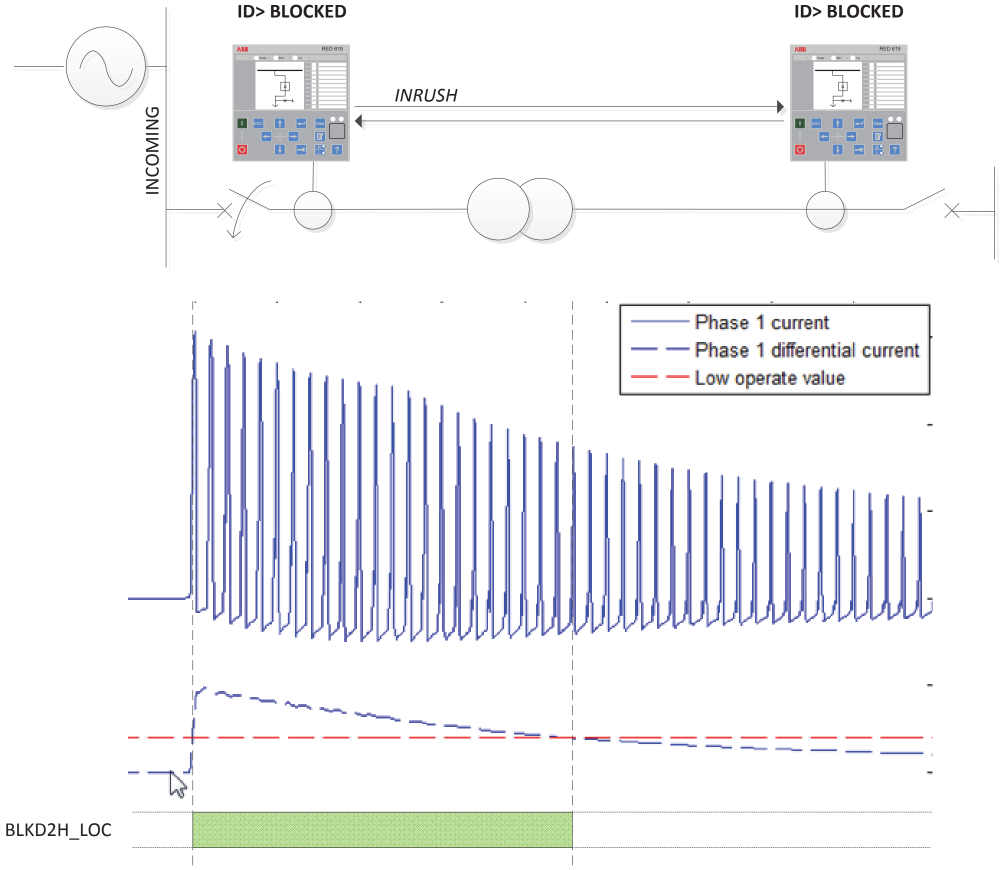


Figure 385: Blocking of line differential functions during detected transformer start-up current

If the protection stage is allowed to start during the inrush situation, the time delay can be selected so that the stabilized stage does not operate in the inrush situation.

4.3.1.8 Signals

LNPLDF Input signals

Table 647: LNPLDF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Signal for blocking the function

Table continues on the next page

Name	Type	Default	Description
BLOCK_LS	BOOLEAN	0=False	Signal for blocking the stab. stage
ENA_MULT_HS	BOOLEAN	0=False	Enables the high stage multiplier

LNPLDF Output signals

Table 648: LNPLDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate, local or remote, stabilized or instantaneous stage
START	BOOLEAN	Start, local or remote
STR_LS_LOC	BOOLEAN	Start stabilized stage local
STR_LS_REM	BOOLEAN	Start stabilized stage remote
OPR_LS_LOC	BOOLEAN	Operate stabilized stage local
OPR_LS_REM	BOOLEAN	Operate stabilized stage re-mote
OPR_HS_LOC	BOOLEAN	Operate instantaneous stage local
OPR_HS_REM	BOOLEAN	Operate instantaneous stage remote
BLKD2H_LOC	BOOLEAN	Restraint due 2nd harmonics detected local
BLKD2H_REM	BOOLEAN	Restraint due 2nd harmonics detected remote
PRO_ACTIVE	BOOLEAN	Status of the protection, true when function is operative

4.3.1.9 LNPLDF Settings

Table 649: LNPLDF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Low operate value	10...200	%Ir	1	10	Basic setting for the stabilized stage start
High operate value	200...4000	%Ir	1	2000	Instantaneous stage operate value
Start value 2.H	10...50	%	1	20	The ratio of the 2. harmonic com-ponent to funda-mental component required for block-ing
High Op value Mult	0.5...1.0		0.1	1.0	Multiplier for scal-ing the high stage operate value

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IDMT curves
End section 1	0...200	%Ir	1	100	Turn-point between the first and the second line of the operating characteristics
Slope section 2	10...50	%	1	50	Slope of the second line of the operating characteristics
End section 2	200...2000	%Ir	1	500	Turn-point between the second and the third line of the operating characteristics
Slope section 3	10...200	%	1	150	Slope of the third line of the operating characteristics
Operating curve type	1=ANSI Ext. inv. 3=ANSI Norm. inv. 5=ANSI Def. Time 9=IEC Norm. inv. 10=IEC Very inv. 12=IEC Ext. inv. 15=IEC Def. Time			15=IEC Def. Time	Selection of time delay curve for stabilized stage
Operate delay time	45...200000	ms	1	45	Operate delay time for stabilized stage

Table 650: LNPLDF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 4=test/blocked 5=off			1=on	Operation mode of the function
Winding selection	1=Not in use 2=Winding 1 3=Winding 2			1=Not in use	IED location respect to transformer, HV (Winding 1) side or LV (Winding 2) side
Winding 1 type	1=Y 2=YN 3=D 4=Z 5=ZN			1=Y	Connection of the HV side windings
Winding 2 type	1=y 2=yn 3=d 4=z 5=zn			1=y	Connection of the LV side windings
Clock number	0=Clk Num 0 1=Clk Num 1 2=Clk Num 2 4=Clk Num 4 5=Clk Num 5 6=Clk Num 6 7=Clk Num 7			0=Clk Num 0	Setting the phase shift between HV and LV with clock number for connection group compensation (e.g. Dyn11 -> 11)

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=Clk Num 8 10=Clk Num 10 11=Clk Num 11				
CT ratio correction	0.200...5.000		0.001	1.000	Local phase current transformer ratio correction
CT connection type	1=Type 1 2=Type 2			1=Type 1	CT connection type. Determined by the directions of the connected current transformers.
Zro A elimination	1=Not eliminated 2=Winding 1 3=Winding 2 4=Winding 1 and 2			1=Not eliminated	Elimination of the zero-sequence current
Restraint mode	1=None 2=Harmonic2			1=None	Selects what restraint modes are in use

Table 651: LNPLDF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	0	Reset delay time for stabilized stage
Minimum operate time	45...60000	ms	1	45	Minimum operate time for stabilized stage IDMT curves

4.3.1.10 LNPLDF Monitored data

Table 652: LNPLDF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
I_AMPL_LOC_A	FLOAT32	0.00...40.00	xIr	Local phase A amplitude after correction
I_AMPL_LOC_B	FLOAT32	0.00...40.00	xIr	Local phase B amplitude after correction
I_AMPL_LOC_C	FLOAT32	0.00...40.00	xIr	Local phase C amplitude after correction
I_AMPL_REM_A	FLOAT32	0.00...40.00	xIr	Remote phase A amplitude after correction
I_AMPL_REM_B	FLOAT32	0.00...40.00	xIr	Remote phase B amplitude after correction
I_AMPL_REM_C	FLOAT32	0.00...40.00	xIr	Remote phase C amplitude after correction
ID_A	FLOAT32	0.00...80.00	xIr	Differential current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Stabilization current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Stabilization current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Stabilization current phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_ANGL_DIFF_A	FLOAT32	-180.00...180.00	deg	Current phase angle differential between local and remote, phase A
I_ANGL_DIFF_B	FLOAT32	-180.00...180.00	deg	Current phase angle differential between local and remote, phase B
I_ANGL_DIFF_C	FLOAT32	-180.00...180.00	deg	Current phase angle differential between local and remote, phase C
LNPLDF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
IL1-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL1
IL2-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL2
IL3-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL3
IL1-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL1
IL2-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL2
IL3-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL3

4.3.1.11 Technical data

Table 653: LNPLDF Technical data

Characteristics	Value		
Operation accuracy [1]	Depending on the frequency of the measured current: f_n ±2 Hz		
	Low stage	±2.5% of the set value	
	High stage	±2.5% of the set value	
High stage, operate time [2, 3]	Minimum	Typical	Maximum
	20 ms	23 ms	27 ms
Reset time	Typically 40 ms		
Reset ratio	Typically 0.96		
Retardation time	<40 ms		

Table continues on the next page

1 With the symmetrical communication channel (as when using dedicated fiber optic).
2 Without additional delay in the communication channel (as when using dedicated fiber optic).
3 Measured with static power output. When differential current = 2 × *High operate value* and f_n = 50 Hz with galvanic pilot wire link + 5 ms.

Characteristics	Value
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in inverse time mode	±5.0% of the set value or ±20 ms [4]
Suppression of harmonics	RMS: No suppression DFT: -50 dB at f = n × fn, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression

4.3.2 Stabilized and instantaneous differential protection for two-winding transformers TR2PTDF (ANSI 87T)

4.3.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized and instantaneous differential protection for two-winding transformers	TR2PTDF	3dI>T	87T

4.3.2.2 Function block

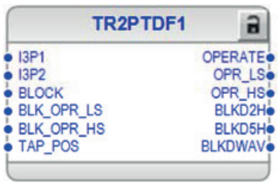


Figure 386: Function block

4.3.2.3 Functionality

The stabilized and instantaneous differential protection for two-winding transformers function TR2PTDF is designed to protect two-winding transformers and generator-transformer blocks. TR2PTDF includes low biased and high instantaneous stages.

The biased low stage provides a fast clearance of faults while remaining stable with high currents passing through the protected zone increasing errors on current measuring. The second harmonic restraint, together with the waveform based algorithms, ensures that the low stage does not operate due to the transformer inrush currents. The fifth harmonic restraint ensures that the low stage does not operate on apparent differential current caused by a harmless transformer over-excitation.

[4] *Low operate value* multiples in the range of 1.5...20

The instantaneous high stage provides a very fast clearance of severe faults with a high differential current regardless of their harmonics.

The setting characteristic can be set more sensitive with the aid of tap changer position compensation. The correction of transformation ratio due to the changes in tap position is done automatically based on the tap changer status information.

4.3.2.4 Analog channel configuration

TR2PTDF has two analog group inputs which must be properly configured.

Table 654: Analog inputs

Input	Description
I3P1	Three-phase currents
I3P2	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of TR2PTDF can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

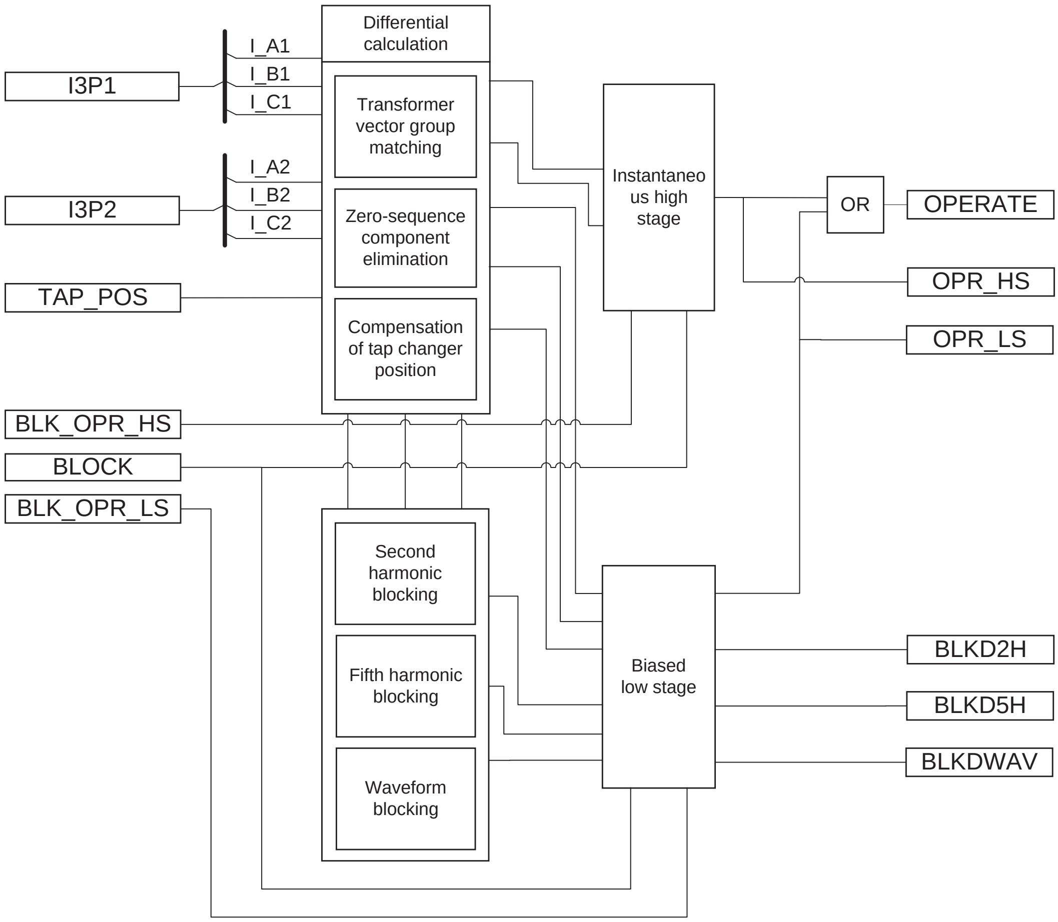


Figure 387: Functional module diagram

Differential calculation

TR2PTDF operates phase-wise on a difference of incoming and outgoing currents. The positive direction of the currents is towards the protected object.

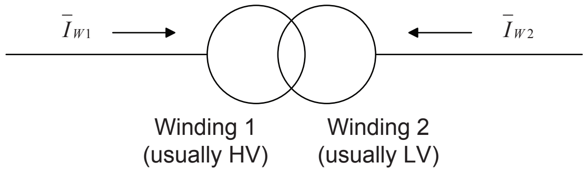


Figure 388: Positive direction of the currents

$$I_d = \left| \bar{I}_{W1} + \bar{I}_{W2} \right|$$

(Equation 157)

In a normal situation, no fault occurs in the area protected by TR2PTDF. Then the currents $\bar{I}_{W1}$ and $\bar{I}_{W2}$ are equal and the differential current I_d is zero. In practice, however, the differential current deviates from zero in normal situations. In the power transformer protection, the differential current is caused by CT inaccuracies, variations in tap changer position (if not compensated), transformer no-load current and instantaneous transformer inrush currents. An increase in the load current causes the differential current, caused by the CT inaccuracies and the tap changer position, to grow at the same percentage rate.

In a biased differential protection relay in normal operation or during external faults, the higher the load current is the higher is the differential current required for tripping. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

$$I_b = \frac{\left|\bar{I}_{W1} - \bar{I}_{W2}\right|}{2}$$

(Equation 158)

If the biasing current is small compared to the differential current or if the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has most certainly occurred in the area protected by the differential protection relay. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

Transformer vector group matching

The phase difference of the winding 1 and winding 2 currents that is caused by the vector group of the power transformer is numerically compensated. The matching of the phase difference is based on the phase shifting and the numerical delta connection inside the protection relay. The *Winding 1 type* parameter determines the connection on winding 1 (”Y”, ”YN”, ”D”, ”Z”, ”ZN”). The *Winding 2 type* parameter determines the connections of the phase windings on the low voltage side (“y”, ”yn”, ”d”, ”z”, ”zn”).

The vector group matching can be implemented either on both, winding 1 and winding 2, or only on winding 1 or winding 2, at intervals of 30° with the *Clock number* setting.

When the vector group matching is Yy0 and the *CT connection type* is according to "Type 2", the phase angle of the phase currents connected to the protection relay does not change. When the vector group matching is Yy6, the phase currents are turned 180° in the protection relay.

Example 1

Vector group matching of a Ynd11-connected power transformer on winding 1, *CT connection type* according to type 1. The *Winding 1 type* setting is ”YN”, *Winding 2 type* is “d” and *Clock number* is “Clk Num 11”. This is compensated internally by giving winding 1 internal compensation value +30° and winding 2 internal compensation value 0°:

$$\bar{I}_{L1mHV} = \frac{\bar{I}_{L1} - \bar{I}_{L2}}{\sqrt{3}}$$
$$\bar{I}_{L2mHV} = \frac{\bar{I}_{L2} - \bar{I}_{L3}}{\sqrt{3}}$$
$$\bar{I}_{L3mHV} = \frac{\bar{I}_{L3} - \bar{I}_{L1}}{\sqrt{3}}$$

(Equation 159)

Example 2

But if vector group is Yd11 and *CT connection type* is according to type 1, the compensation is a little different. The *Winding 1 type* setting is ”Y”, *Winding 2 type* is “d” and *Clock number* is “Clk Num 11”. This is compensated internally by giving winding 1 internal compensation value 0° and winding 2 internal compensation value -30°;

$$\bar{I}_{L1mLV} = \frac{\bar{I}_{L1} - \bar{I}_{L3}}{\sqrt{3}}$$
$$\bar{I}_{L2mLV} = \frac{\bar{I}_{L2} - \bar{I}_{L1}}{\sqrt{3}}$$
$$\bar{I}_{L3mLV} = \frac{\bar{I}_{L3} - \bar{I}_{L2}}{\sqrt{3}}$$

(Equation 160)

The "Y" side currents stay untouched, while the "d" side currents are compensated to match the currents actually flowing in the windings.

In this example there is no neutral current on either side of the transformer (assuming there are no earthing transformers installed). In the previous example, however, the matching is done differently to have the winding 1 neutral current compensated at the same time.

Zero-sequence component elimination

If *Clock number* is "Clk Num 2", "Clk Num 4", "Clk Num 8" or "Clk Num 10", the vector group matching is always done on both, winding 1 and winding 2. The combination results in the correct compensation. In this case the zero-sequence component is always removed from both sides automatically. The *Zro A elimination* parameter cannot change this.

If *Clock number* is "Clk Num 1", "Clk Num 5", "Clk Num 7" or "Clk Num 11", the vector group matching is done on one side only. A possible zero-sequence component of the phase currents at earth faults occurring outside the protection area is eliminated in the numerically implemented delta connection before the differential current and the biasing current are calculated. This is why the vector group matching is almost always made on the star connected side of the "Ynd" and "Dyn" connected transformers.

If *Clock number* is "Clk Num 0" or "Clk Num 6", the zero-sequence component of the phase currents is not eliminated automatically on either side. Therefore, the zero-sequence component on the star connected side that is earthed at its star point has to be eliminated by using the *Zro A elimination* parameter.

The same parameter has to be used to eliminate the zero-sequence component if there is, for example, an earthing transformer on the delta-connected side of the "Ynd" power transformer in the area to be protected. In this case, the vector group matching is normally made on the side of the star connection. On the side of the delta connection, the elimination of the zero-sequence component has to be separately selected.

By using the *Zro A elimination* parameter, the zero-sequence component of the phase currents is calculated and reduced for each phase current:

$$\bar{I}_{L1m} = \bar{I}_{L1} - \frac{1}{3} x\left(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3}\right)$$
$$\bar{I}_{L2m} = \bar{I}_{L2} - \frac{1}{3} x\left(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3}\right)$$
$$\bar{I}_{L3m} = \bar{I}_{L3} - \frac{1}{3} x\left(\bar{I}_{L1} + \bar{I}_{L2} + \bar{I}_{L3}\right)$$

(Equation 161)

In many cases with the earthed neutral of a "wye" winding, it is possible to make the compensation so that a zero-sequence component of the phase currents is automatically eliminated. For example, in a case of a "Ynd" transformer, the compensation is made on the winding 1 side to automatically eliminate the zero-sequence component of the phase currents on that side (and the "d" side does not have them). In those cases, explicit elimination is not needed.

Compensation of tap changer position

The position of the tap changer used for voltage control can be compensated and the position information is provided for the protection function through the tap position indication function TPOSYLTC.

Typically, the tap changer is located within the high voltage winding, that is, winding 1, of the power transformer. The *Tapped winding* parameter specifies whether the tap changer is connected to the high voltage side winding or the low voltage side winding. This parameter is also used to enable and disable the automatic adaptation to the tap changer position. The possible values are "Not in use", "Winding 1" or "Winding 2".

The *Tap nominal* parameter tells the number of the tap, which results in the nominal voltage (and current). When the current tap position deviates from this value, the input current values on the side where the tap changer resides are scaled to match the currents on the other side.

A correct scaling is determined by the number of steps and the direction of the deviation from the nominal tap and the percentage change in voltage resulting from a deviation of one tap step. The percentage value is set using the *Step of tap* parameter.

The operating range of the tap changer is defined by the *Min winding tap* and *Max winding tap* parameters. The *Min winding tap* parameter tells the tap position number resulting in the minimum effective number of winding turns on the side of the transformer where the tap changer is connected. Correspondingly, the *Max* *winding tap* parameter tells the tap position number resulting in the maximum effective number of winding turns.

The *Min winding tap* and *Max winding tap* parameters help the tap position compensation algorithm know in which direction the compensation is being made. This ensures also that if the current tap position information is corrupted for some reason, the automatic tap changer position adaptation does not try to adapt to any unrealistic position values.

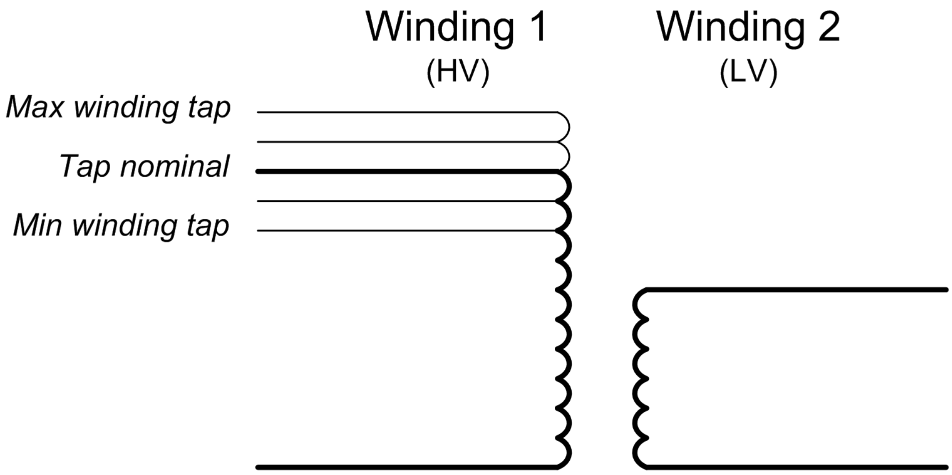


Figure 389: Simplified presentation of the high voltage and medium voltage windings with demonstration of the Max winding tap, Min winding tap and Tap nominal parameters

The position value is available through the Monitored data view on LHMI or through other communication tools in the tap position indication function. When the quality of the `TAP_POS` value is not good, the position information in `TAP_POS` is not used but the last value with the good quality information is used instead. In addition, the minimum sensitivity of the biased stage, set by the *Low operate value* setting, is automatically desensitized with the total range of the tap position correction. The new acting low operate value is

$$Desensitized\ Low\ operate\ value\ = Low operate\ value + ABS(Max Winding\ tap - Min\ winding\ tap) \times Step\ of\ tap$$

(Equation 162)

Second harmonic blocking

The transformer magnetizing inrush currents occur when energizing the transformer after a period of de-energization. The inrush current can be many times the rated current and the halving time can be up to several seconds. To the differential protection, the inrush current represents a differential current, which would cause the differential protection to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

Blocking the operation of the TR2PTDF biased low stage at a magnetizing inrush current is based on the ratio of the amplitudes of the second harmonic digitally filtered from the differential current and the fundamental frequency (Id2f /Id1f).

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of another transformer running in parallel with the protected transformer already connected to the network.

The ratio of the second harmonic to a fundamental component can vary considerably between the phases. Especially when the delta compensation is done for a Ynd1 connected transformer and the two phases of the inrush currents are otherwise equal but opposite in phase angle, the subtraction of the phases in a delta compensation results in a very small second harmonic component.

Some measures have to be taken in order to avoid the false tripping of a phase having too low a ratio of the second harmonic to the fundamental component. One way could be to always block all the phases when the second harmonic blocking conditions are fulfilled in at least one phase. The other way is to calculate the weighted ratios of the second harmonic to the fundamental component for each phase using the original ratios of the phases. The latter option is used here. The second harmonic ratios I_2H_RAT_x are given in Monitored data.

The ratio to be used for second harmonic blocking is, therefore, calculated as a weighted average on the basis of the ratios calculated from the differential currents of the three phases. The ratio of the concerned phase is of most weight compared to the ratios of the other two phases. In this protection relay, if the weighting factors are four, one and one, four is the factor of the phase concerned. The operation of the biased stage on the concerned phase is blocked if the weighted ratio of that phase is above the set blocking limit *Start value 2.H* and if blocking is enabled through the *Restraint mode* parameter.

Using separate blocking for the individual phases and weighted averages calculated for the separate phases provides a blocking scheme that is stable at the connection inrush currents.

If the peak value of the differential current is very high, that is I_r>12×In, the limit for the second harmonic blocking is desensitized (in the phase in question) by increasing it proportionally to the peak value of the differential current.

The connection of the power transformer against a fault inside the protected area does not delay the operation of the tripping, because in such a situation the blocking based on the second harmonic of the differential current is prevented by a separate algorithm based on a different waveform and a different rate of change of the normal inrush current and the inrush current containing the fault current. The algorithm does not eliminate the blocking at inrush currents, unless there is a fault in the protected area.

The feature can also be enabled and disabled with the *Harmonic deblock 2.H* parameter.

Fifth harmonic blocking

The inhibition of TR2PTDF operation in the situations of overexcitation is based on the ratio of the fifth harmonic and the fundamental component of the differential current (Id5f/Id1f) . The ratio is calculated separately for each phase without weighting . If the ratio exceeds the setting value of *Start value 5.H* and if blocking is enabled through the *Restraint mode* parameter, the operation of the biased stage of TR2PTDF in the concerned phase is blocked. The fifth harmonic ratios I_5H_RAT_x are given in Monitored data.

At dangerous levels of overvoltage, which can cause damage to the transformer, the blocking can be automatically eliminated. If the ratio of the fifth harmonic and the fundamental component of the differential current exceeds the *Stop value*

5.H parameter, the blocking removal is enabled. The enabling and disabling of deblocking feature is also done through the *Harmonic deblock 5.H* parameter.

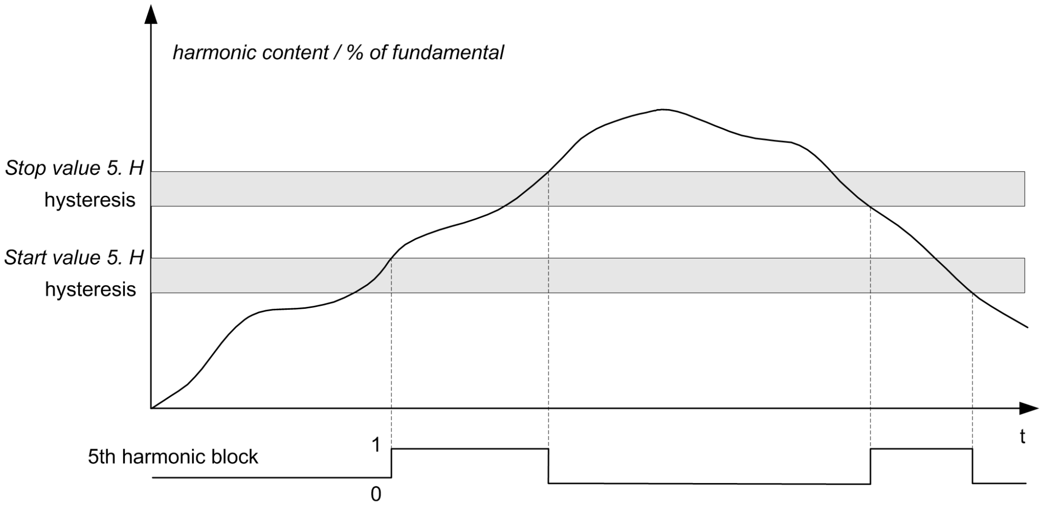


Figure 390: The limits and operation of the fifth harmonic blocking when both blocking and deblocking features are enabled using the Harmonic deblock 5.H control parameter.

The fifth harmonic blocking has a hysteresis to avoid rapid fluctuation between "TRUE" and "FALSE". The blocking also has a counter, which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Also the fifth harmonic deblocking has a hysteresis and a counter which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Waveform blocking

The biased low stage can always be blocked with waveform blocking. The stage can not be disabled with the *Restraint mode* parameter. This algorithm has two parts. The first part is intended for external faults while the second is intended for inrush situations. The algorithm has criteria for a low current period during inrush where also the differential current (not derivative) is checked.

Biased low stage

The current differential protection needs to be biased because the possible appearance of a differential current can be due to something else than an actual fault in the transformer (or generator).

In the case of transformer protection, a false differential current can be caused by:

- CT errors
- Varying tap changer positions (if not automatically compensated)
- Transformer no-load current
- Transformer inrush currents
- Transformer overexcitation in overvoltage
- Underfrequency situations
- CT saturation at high currents passing through the transformer

The differential current caused by CT errors or tap changer positions increases at the same percent ratio as the load current.

In the protection of generators, the false differential current can be caused by various factors.

- CT errors
- CT saturation at high currents passing through the generator

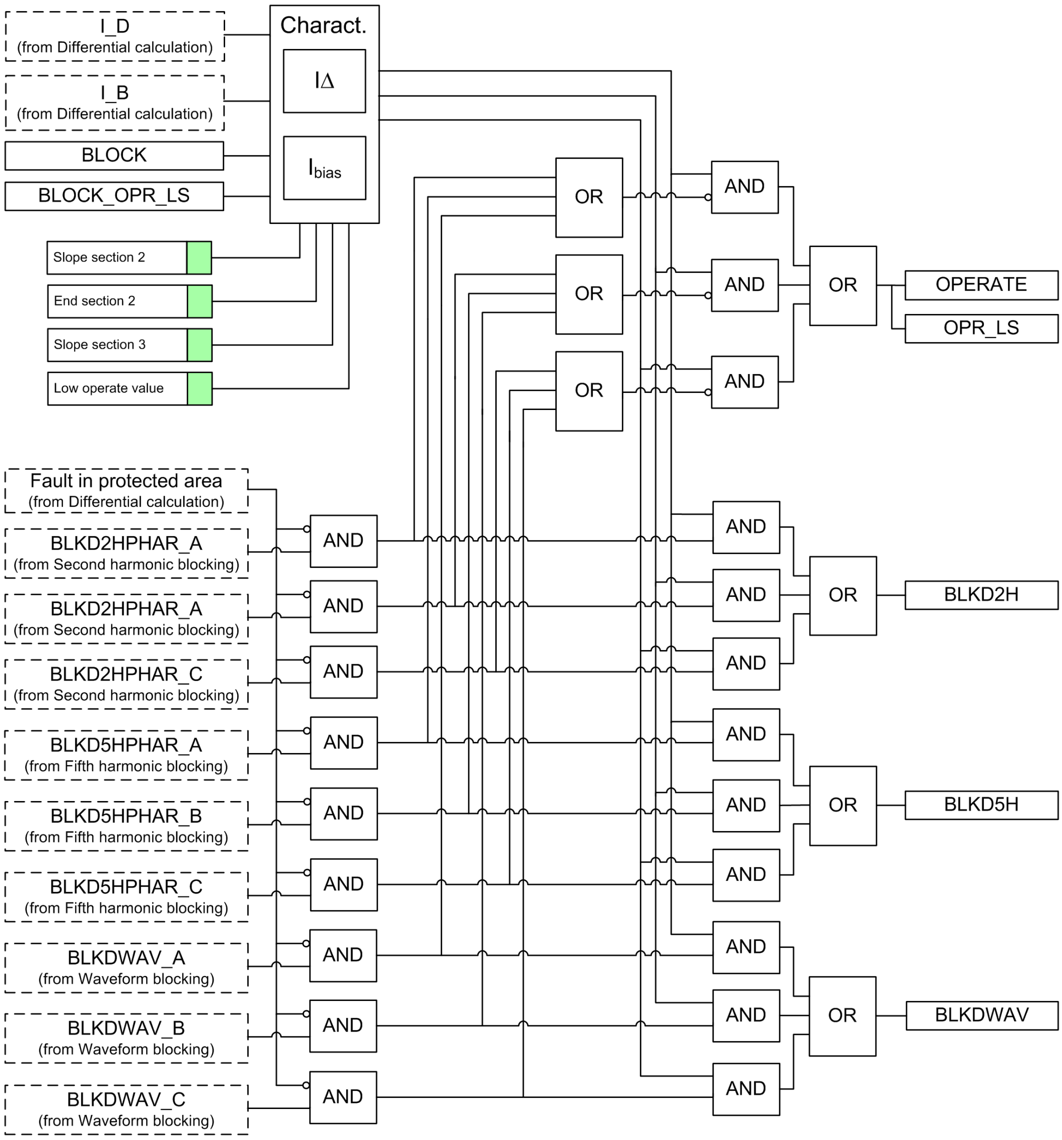


Figure 391: Operation logic of the biased low stage

The high currents passing through a protected object can be caused by the short circuits outside the protected area, the high currents fed by the transformer in motor start-up or the transformer inrush situations. Therefore, the operation of the differential protection is biased in respect to the load current. In biased differential protection, the higher the differential current required for the protection to operate, the higher the load current.

The operating characteristic of the biased low stage is determined by *Low operate value*, *Slope section 2* and the setting of the second turning point of the operating characteristic curve, *End section 2* (the first turning point is fixed). The settings are the same for all the phases. When the differential current exceeds the operating value determined by the operating characteristic, the differential function awakes. If the differential current stays above the operating value continuously for a suitable period, which is 1.1 times the fundamental cycle, the OPR_LS output is activated. The OPERATE output is always activated when the OPR_LS output is activated .

The stage can be blocked internally by the second or fifth harmonic restraint, or by special algorithms detecting inrush and current transformer saturation at external faults. When the operation of the biased low stage is blocked by the second harmonic blocking functionality, the BLKD2H output is activated.

When operation of the biased low stage is blocked by the fifth harmonic blocking functionality, the BLKD5H output is activated. Correspondingly, when the operation of the biased low stage is blocked by the waveform blocking functionality, the BLKDWAV output is activated according to the phase information.

When required, the operate outputs of the biased low stage can be blocked by the BLK_OPR_LS or BLOCK external control signals.

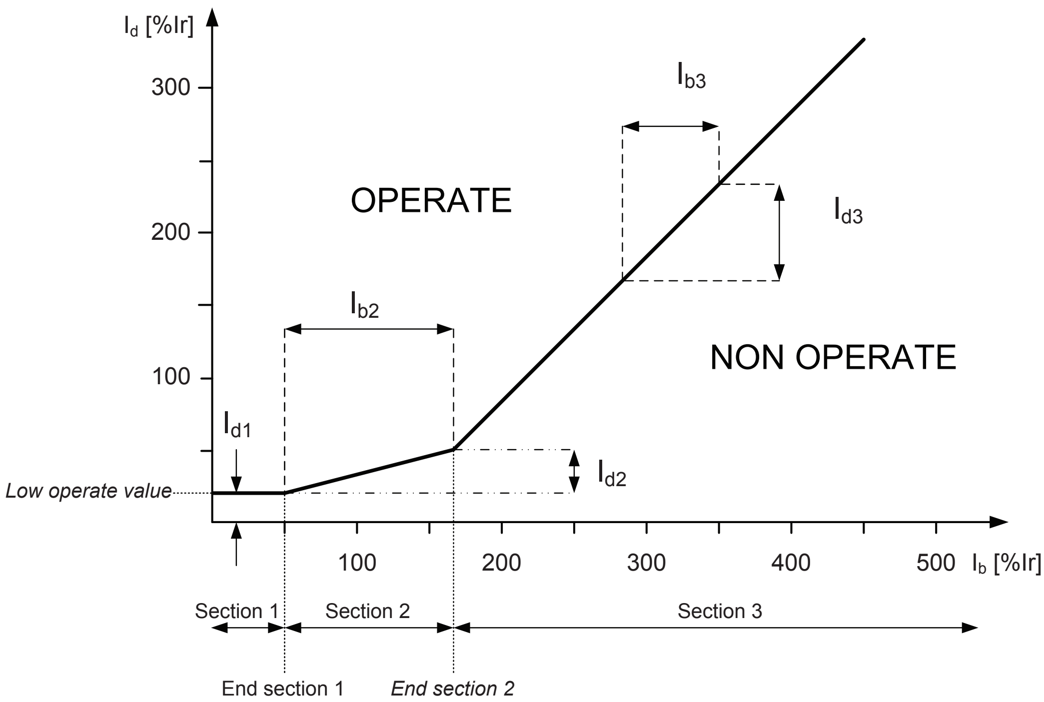


Figure 392: Operation characteristic for biased operation of TR2PTDF

The *Low operate value* of the biased stage of the differential function is determined according to the operation characteristic:

Low operate value = Id1

Slope section 2 and *Slope section 3* are determined correspondingly:

$$Slope\ \ section 2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

(Equation 163)

$$Slope\ section3 = \frac{I_{d3}}{I_{b3}} \cdot 100\%$$

(Equation 164)

The second turning point *End section 2* can be set in the range of 100 percent to 500 percent.

The slope of the differential function's operating characteristic curve varies in the different sections of the range.

- In section 1, where 0 percent Ir < Ib < End section 1, End section 1 being fixed to 50 percent Ir, the differential current required for tripping is constant. The value of the differential current is the same as the *Low operate value* selected for the function. *Low operate value* basically allows the no-load current of the power transformer and small inaccuracies of the current transformers, but it can also be used to influence the overall level of the operating characteristic. At the rated current, the no-load losses of the power transformer are about 0.2 percent. If the supply voltage of the power transformer suddenly increases due to operational disturbances, the magnetizing current of the transformer increases as well. In general the magnetic flux density of the transformer is rather high at rated voltage and a rise in voltage by a few percent causes the magnetizing current to increase by tens of percent. This should be considered in *Low operate value*
- In section 2, where End section 1 < Ib/In < *End section 2*, is called the influence area of *Slope section 2*. In this section, variations in the starting ratio affect the slope of the characteristic, that is, how big a change in the differential current is required for tripping in comparison with the change in the load current. The starting ratio should consider CT errors and variations in the transformer tap changer position (if not compensated). Too high a starting ratio should be avoided, because the sensitivity of the protection for detecting inter-turn faults depends basically on the starting ratio.
- In section 3, where Ib/In > *End section 2*, the slope of the characteristic can be set by *Slope section 3* that defines the increase in the differential current to the corresponding increase in the biasing current.

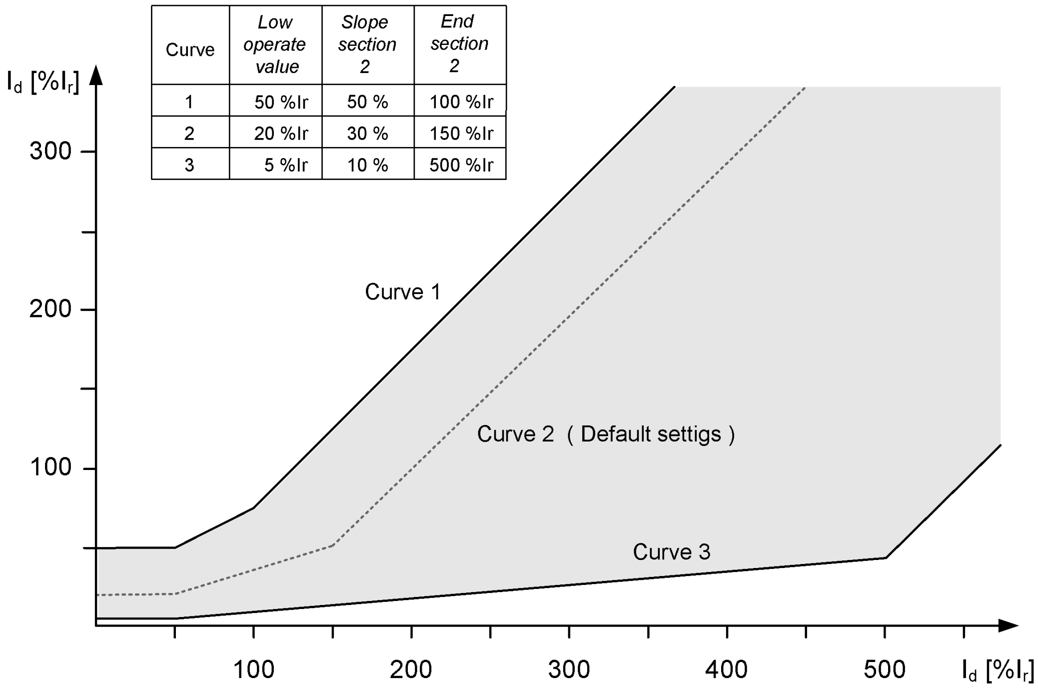


Figure 393: Setting range for biased low stage

If the biasing current is small compared to the differential current of the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has most likely occurred in the area protected by TR2PTDF. Then the internal blocking signals of the biased stage are inhibited.

Instantaneous high stage

The instantaneous high stage operation can be enabled and disabled with the *Enable high set* setting. The corresponding parameter values are "TRUE" and "FALSE."

The operation of the instantaneous high stage is not biased. The instantaneous stage operates and the output `OPR_HS` is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous value of the differential current exceeds 2.5 times the value of *High operate value*. The factor 2.5 (=1.8 × √2) is due to the maximum asymmetric short circuit current.

If the biasing current is small compared to the differential current or the phase angle between the winding 1 and winding 2 phase currents is close to zero (in a normal situation, the phase difference is 180 degrees), a fault has occurred in the area protected by TR2PTDF. Then the operation value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

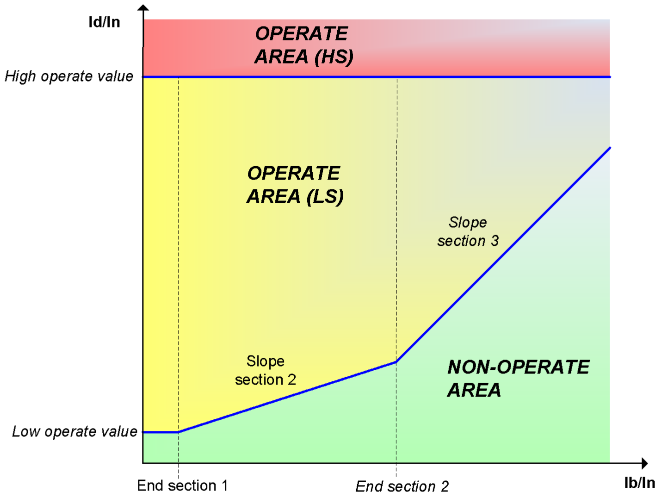


Figure 394: Operating characteristics of the protection. (LS) stands for the biased low stage and (HS) for the instantaneous high stage

The OPERATE output is activated always when the OPR_HS output activates .

The internal blocking signals of the differential function do not prevent the operate signal of the instantaneous differential current stage. When required, the operate outputs of the instantaneous high stage can be blocked by the BLK_OPR_HS and BLOCK external control signals.

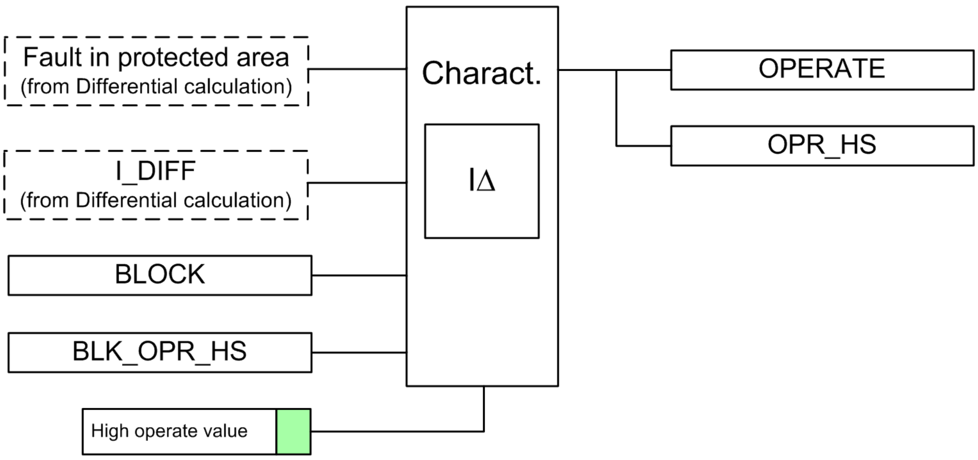


Figure 395: Operation logic of instantaneous high stage

Reset of the blocking signals (de-block)

All three blocking signals, that is, waveform and second and fifth harmonic, have a counter, which holds the blocking on for a certain time after the blocking conditions have ceased to be fulfilled. The deblocking takes place when those counters have elapsed. This is a normal case of deblocking.

The blocking signals can be reset immediately if a very high differential current is measured or if the phase difference of the compared currents (the angle between the compared currents) is close to zero after the automatic vector group matching has been made (in a normal situation, the phase difference is 180 degrees). This does not, however, reset the counters holding the blockings, so the blocking signals may return when these conditions are not valid anymore.

External blocking functionality

TR2PTDF has three inputs for blocking.

- When the BLOCK input is active ("TRUE"), the operation of the function is blocked but measurement output signals are still updated.
- When the BLK_OPR_LS input is active ("TRUE"), TR2PTDF operates normally except that the OPR_LS output is not active or activated in any circumstance. Additionally, the OPERATE output can be activated only by the instantaneous high stage (if not blocked as well).
- When the BLK_OPR_HS input is active ("TRUE"), TR2PTDF operates normally except that the OPR_HS output is not active or activated in any circumstance. Additionally, the OPERATE output can be activated only by the biased low stage (if not blocked as well).

4.3.2.6 Application

TR2PTDF is a unit protection function serving as the main protection for transformers in case of winding failure. The protective zone of a differential protection includes the transformer, the bus-work or the cables between the current transformer and the power transformer. When bushing current transformers are used for the differential protection relay, the protective zone does not include the bus work or cables between the circuit breaker and the power transformer.

In some substations, there is a current differential protection for the busbar. The busbar protection includes bus work or cables between the circuit breaker and the power transformer. Internal electrical faults are very serious and cause immediate damage. Short circuits and earth faults in windings and terminals are normally detected by the differential protection. If enough turns are short-circuited, the interturn faults, which are flashovers between the conductors within the same physical winding, are also detected. The interturn faults are the most difficult transformer-winding faults to detect with electrical protections. A small interturn fault including a few turns results in an undetectable amount of current until the fault develops into an earth fault. Therefore, it is important that the differential protection has a high level of sensitivity and that it is possible to use a sensitive setting without causing unwanted operations for external faults.

It is important that the faulty transformer is disconnected as fast as possible. As TR2PTDF is a unit protection function, it can be designed for fast tripping, thus providing a selective disconnection of the faulty transformer. TR2PTDF should never operate to faults outside the protective zone.

TR2PTDF compares the current flowing into the transformer to the current leaving the transformer. A correct analysis of fault conditions by TR2PTDF must consider the changes to voltages, currents and phase angles. The traditional transformer differential protection functions required auxiliary transformers for the correction of the phase shift and turns ratio. The numerical microprocessor based differential algorithm implemented in TR2PTDF compensates for both the turns ratio and the phase shift internally in the software.

The differential current should theoretically be zero during normal load or external faults if the turns ratio and the phase shift are correctly compensated. However, there are several different phenomena other than internal faults that cause unwanted and false differential currents. The main reasons for unwanted differential currents are:

- Mismatch due to varying tap changer positions
- Different characteristics, loads and operating conditions of the current transformers
- Zero sequence currents that only flow on one side of the power transformer
- Normal magnetizing currents
- Magnetizing inrush currents
- Overexcitation magnetizing currents.

TR2PTDF is designed mainly for the protection of two-winding transformers. TR2PTDF can also be utilized for the protection of generator-transformer blocks as well as short cables and overhead lines. If the distance between the measuring points is relatively long in line protection, interposing CTs can be required to reduce the burden of the CTs.

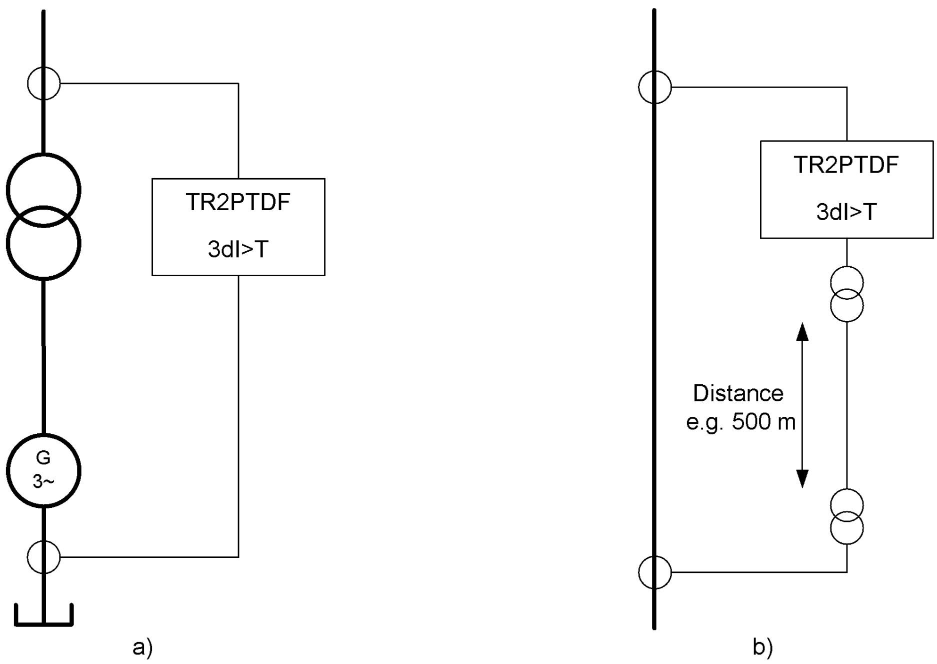


Figure 396: Differential protection of a generator-transformer block and short cable/line

TR2PTDF can also be used in three-winding transformer applications or two-winding transformer applications with two output feeders.

On the double-feeder side of the power transformer, the current of the two CTs per phase must be summed by connecting the two CTs of each phase in parallel. Generally this requires the interposing CTs to handle the vector group and/or ratio mismatch between the two windings/feeders.

The accuracy limit factor for the interposing CT must fulfill the same requirements as the main CTs. Please note that the interposing CT imposes an additional burden to the main CTs.

The most important rule in these applications is that at least 75 percent of the short-circuit power has to be fed on the side of the power transformer with only one connection to the protection relay.

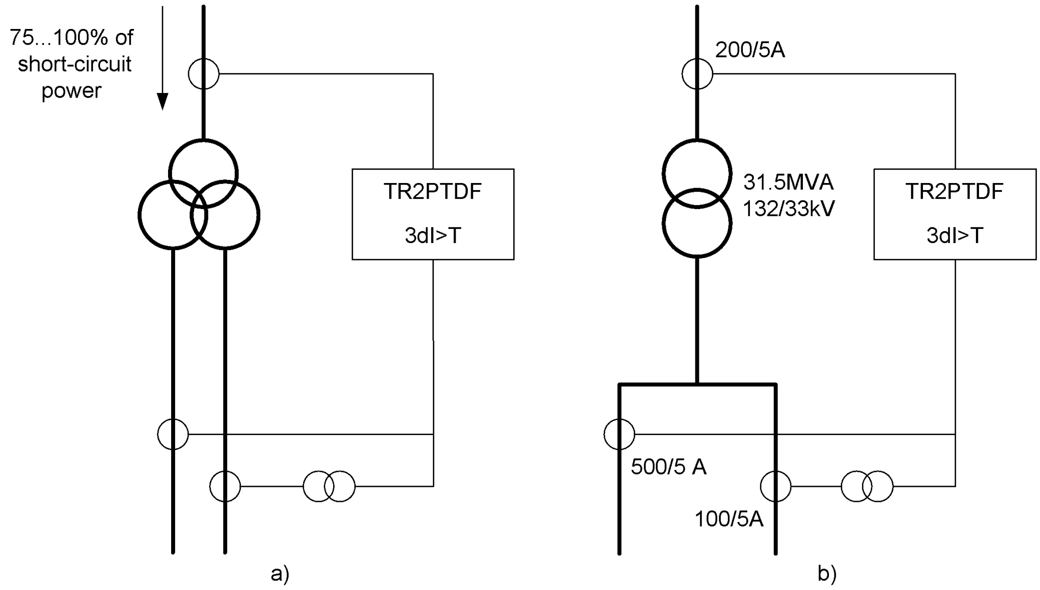


Figure 397: Differential protection of a three-winding transformer and a transformer with two output feeders

TR2PTDF can also be used for the protection of the power transformer feeding the frequency converter. An interposing CT is required for matching the three-winding transformer currents to a two-winding protection relay.

The fundamental frequency component is numerically filtered with a Fourier filter, DFT. The filter suppresses frequencies other than the set fundamental frequency, and therefore the protection relay is not adapted for measuring the output of the frequency converter, that is, TR2PTDF is not suited for protecting of a power transformer or motor fed by a frequency converter

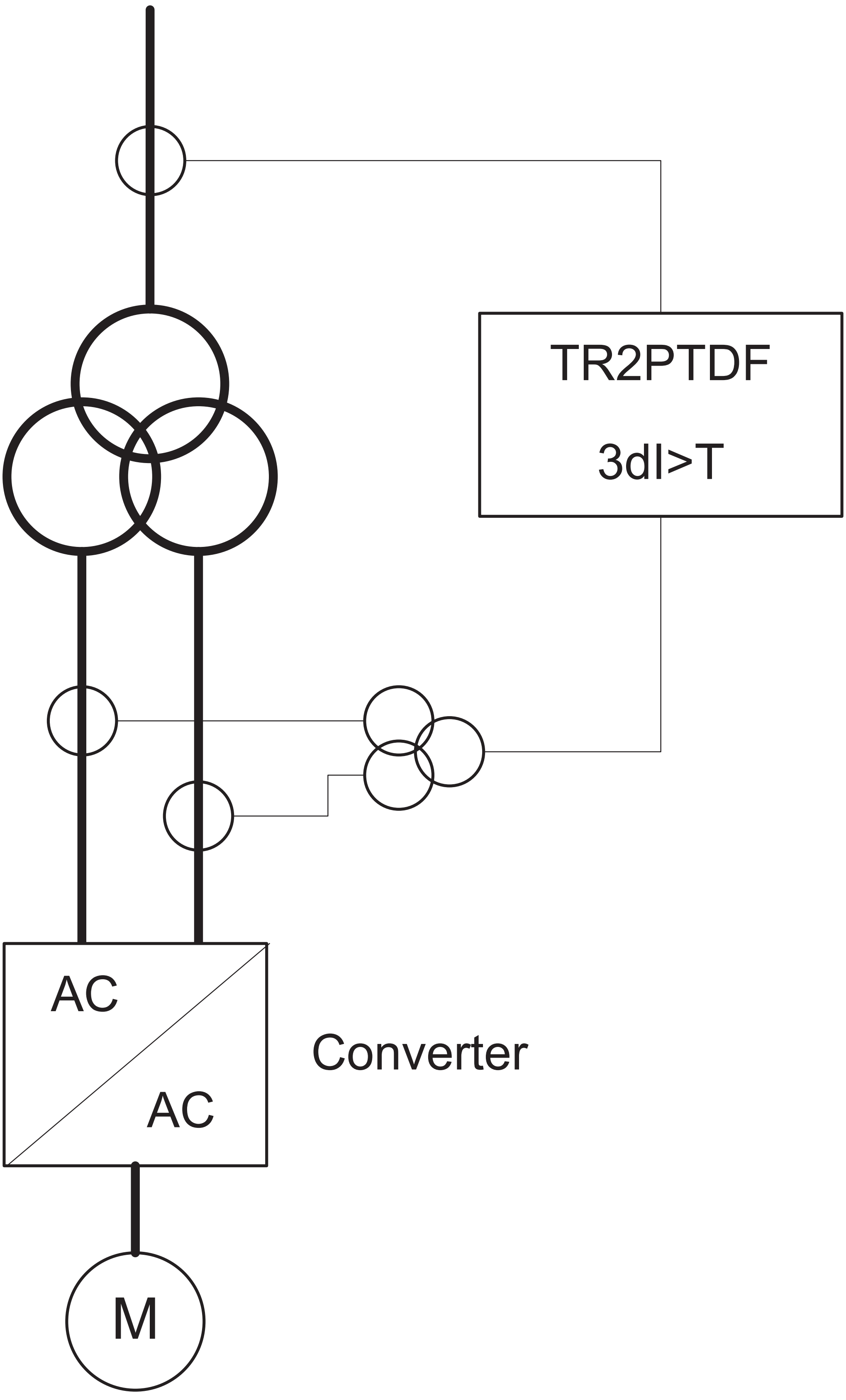


Figure 398: Protection of the power transformer feeding the frequency converter

Transforming ratio correction of CTs

The CT secondary currents often differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on both sides of the power transformer with the *CT ratio Cor Wnd 1* and *CT ration Cor Wnd 2* settings.

First, the rated load of the power transformer must be calculated on both sides when the apparent power and phase-to-phase voltage are known.

$$I_{nT} = \frac{S_n}{\sqrt{3} \times U_n}$$

(Equation 165)

I_{nT}	rated load of the power transformer
S_n	rated power of the power transformer
U_n	rated phase-to-phase voltage

Next, the settings for the CT ratio correction can be calculated.

$$CT\ ratio\ correction = \frac{I_{1n}}{I_{nT}}$$

(Equation 166)

I_{1n}	nominal primary current of the CT

After the CT ratio correction, the measured currents and corresponding setting values of TR2PTDF are expressed in multiples of the rated power transformer current I_r (xI_r) or percentage value of I_r ($\%I_r$).

The rated input current (1A or 5A) of the relay does not have to be same for the HV and the LV side. For example, the rated secondary current of 5 A can be used on the HV side, while 1A is used on the LV side or vice versa.

Example

The rated power of the transformer is 25 MVA, the ratio of the CTs on the 110 kV side is 300/1 and that on the 21 kV side is 1000/1

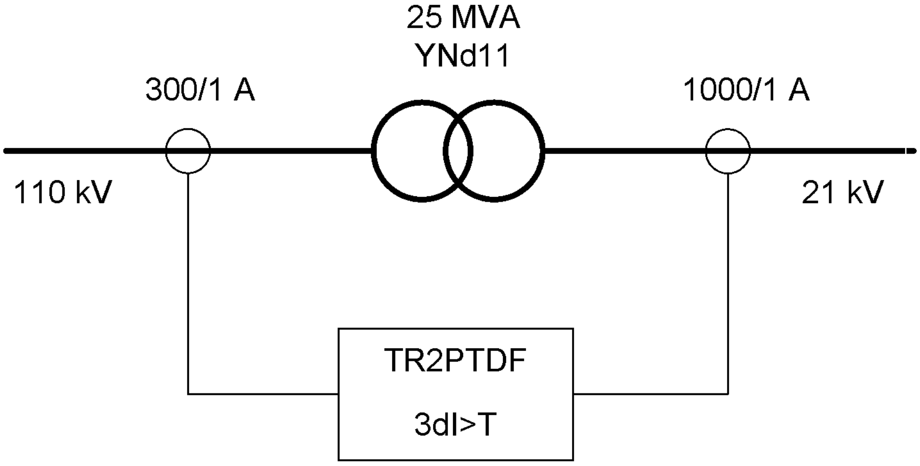


Figure 399: Example of two-winding power transformer differential protection

The rated load of the transformer is calculated:

HV side: I_{nT_Wnd1} = 25 MVA / (1.732 x 110 kV) = 131.2 A

LV side: I_{nT_Wnd2} = 25 MVA / (1.732 x 21 kV) = 687.3 A

Settings:

CT ratio Cor Wnd 1= 300 A / 131.2 A = “2.29”

CT ratio Cor Wnd 2= 1000 A / 687.3 A = “1.45”

Vector group matching and elimination of the zero-sequence component

The vector group of the power transformer is numerically matched on the high voltage and low voltage sides by means of the *Winding 1 type*, *Winding 2 type* and *Clock number* settings. Thus no interposing CTs are needed if there is only a power transformer inside the protected zone. The matching is based on phase shifting and a numerical delta connection in the protection relay. If the neutral of a star-connected power transformer is earthed, any earth fault in the network is perceived by the protection relay as a differential current. The elimination of the zero-sequence component can be selected for that winding by setting the *Zro A elimination* parameter.

Table 655: TR2PTDF settings corresponding to the power transformer vector groups and zero-sequence elimination

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Yy0	Y	y	Clk Num 0	Not needed
YNy0	YN	y	Clk Num 0	HV side
YNyn0	YN	yn	Clk Num 0	HV & LV side
Yyn0	Y	yn	Clk Num 0	LV side
Yy2	Y	y	Clk Num 2	Not needed
YNy2	YN	y	Clk Num 2	Not needed

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
YNyn2	YN	yn	Clk Num 2	Not needed
Yyn2	Y	yn	Clk Num 2	Not needed
Yy4	Y	y	Clk Num 4	Not needed
YNy4	YN	y	Clk Num 4	Not needed
YNyn4	YN	yn	Clk Num 4	Not needed
Yyn4	Y	yn	Clk Num 4	Not needed
Yy6	Y	y	Clk Num 6	Not needed
YNy6	YN	y	Clk Num 6	HV side
YNyn6	YN	yn	Clk Num 6	HV & LV side
Yyn6	Y	yn	Clk Num 6	LV side
Yy8	Y	y	Clk Num 8	Not needed
YNy8	YN	y	Clk Num 8	Not needed
YNyn8	YN	yn	Clk Num 8	Not needed
Yyn8	Y	yn	Clk Num 8	Not needed
Yy10	Y	y	Clk Num 10	Not needed
YNy10	YN	y	Clk Num 10	Not needed
YNyn10	YN	yn	Clk Num 10	Not needed
Yyn10	Y	yn	Clk Num 10	Not needed
Yd1	Y	d	Clk Num 1	Not needed
YNd1	YN	d	Clk Num 1	Not needed
Yd5	Y	d	Clk Num 5	Not needed
YNd5	YN	d	Clk Num 5	Not needed
Yd7	Y	d	Clk Num 7	Not needed
YNd7	YN	d	Clk Num 7	Not needed
Yd11	Y	d	Clk Num 11	Not needed
YNd11	YN	d	Clk Num 11	Not needed
Dd0	D	d	Clk Num 0	Not needed
Dd2	D	d	Clk Num 2	Not needed
Dd4	D	d	Clk Num 4	Not needed
Dd6	D	d	Clk Num 6	Not needed
Dd8	D	d	Clk Num 8	Not needed
Dd10	D	d	Clk Num 10	Not needed
Dy1	D	y	Clk Num 1	Not needed
Dyn1	D	yn	Clk Num 1	Not needed
Dy5	D	y	Clk Num 5	Not needed
Dyn5	D	yn	Clk Num 5	Not needed
Dy7	D	y	Clk Num 7	Not needed

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Dyn7	D	yn	Clk Num 7	Not needed
Dy11	D	y	Clk Num 11	Not needed
Dyn11	D	yn	Clk Num 11	Not needed
Yz1	Y	z	Clk Num 1	Not needed
YNz1	YN	z	Clk Num 1	Not needed
YNzn1	YN	zn	Clk Num 1	LV side
Yzn1	Y	zn	Clk Num 1	Not needed
Yz5	Y	z	Clk Num 5	Not needed
YNz5	YN	z	Clk Num 5	Not needed
YNzn5	YN	zn	Clk Num 5	LV side
Yzn5	Y	zn	Clk Num 5	Not needed
Yz7	Y	z	Clk Num 7	Not needed
YNz7	YN	z	Clk Num 7	Not needed
YNzn7	YN	zn	Clk Num 7	LV side
Yzn7	Y	zn	Clk Num 7	Not needed
Yz11	Y	z	Clk Num 11	Not needed
YNz11	YN	z	Clk Num 11	Not needed
YNzn11	YN	zn	Clk Num 11	LV side
Yzn11	Y	zn	Clk Num 11	Not needed
Zy1	Z	y	Clk Num 1	Not needed
Zyn1	Z	yn	Clk Num 1	Not needed
ZNyn1	ZN	yn	Clk Num 1	HV side
ZNy1	ZN	y	Clk Num 1	Not needed
Zy5	Z	y	Clk Num 5	Not needed
Zyn5	Z	yn	Clk Num 5	Not needed
ZNyn5	ZN	yn	Clk Num 5	HV side
ZNy5	ZN	y	Clk Num 5	Not needed
Zy7	Z	y	Clk Num 7	Not needed
Zyn7	Z	yn	Clk Num 7	Not needed
ZNyn7	ZN	yn	Clk Num 7	HV side
ZNy7	ZN	y	Clk Num 7	Not needed
Zy11	Z	y	Clk Num 11	Not needed
Zyn11	Z	yn	Clk Num 11	Not needed
ZNyn11	ZN	yn	Clk Num 11	HV side
ZNy11	ZN	y	Clk Num 11	Not needed
Dz0	D	z	Clk Num 0	Not needed
Dzn0	D	zn	Clk Num 0	LV side

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Dz2	D	z	Clk Num 2	Not needed
Dzn2	D	zn	Clk Num 2	Not needed
Dz4	D	z	Clk Num 4	Not needed
Dzn4	D	zn	Clk Num 4	Not needed
Dz6	D	z	Clk Num 6	Not needed
Dzn6	D	zn	Clk Num 6	LV side
Dz8	D	z	Clk Num 8	Not needed
Dzn8	D	zn	Clk Num 8	Not needed
Dz10	D	z	Clk Num 10	Not needed
Dzn10	D	zn	Clk Num 10	Not needed
Zd0	Z	d	Clk Num 0	Not needed
ZNd0	ZN	d	Clk Num 0	HV side
Zd2	Z	d	Clk Num 2	Not needed
ZNd2	ZN	d	Clk Num 2	Not needed
Zd4	Z	d	Clk Num 4	Not needed
ZNd4	ZN	d	Clk Num 4	Not needed
Zd6	Z	d	Clk Num 6	Not needed
ZNd6	ZN	d	Clk Num 6	HV side
Zd8	Z	d	Clk Num 8	Not needed
ZNd8	ZN	d	Clk Num 8	Not needed
Zd10	Z	d	Clk Num 10	Not needed
ZNd10	ZN	d	Clk Num 10	Not needed
Zz0	Z	z	Clk Num 0	Not needed
ZNz0	ZN	z	Clk Num 0	HV side
ZNzn0	ZN	zn	Clk Num 0	HV & LV side
Zzn0	Z	zn	Clk Num 0	LV side
Zz2	Z	z	Clk Num 2	Not needed
ZNz2	ZN	z	Clk Num 2	Not needed
ZNzn2	ZN	zn	Clk Num 2	Not needed
Zzn2	Z	zn	Clk Num 2	Not needed
Zz4	Z	z	Clk Num 4	Not needed
ZNz4	ZN	z	Clk Num 4	Not needed
ZNzn4	ZN	zn	Clk Num 4	Not needed
Zzn4	Z	zn	Clk Num 4	Not needed
Zz6	Z	z	Clk Num 6	Not needed
ZNz6	ZN	z	Clk Num 6	HV side
ZNzn6	ZN	zn	Clk Num 6	HV & LV side

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Zzn6	Z	zn	Clk Num 6	LV side
Zz8	Z	z	Clk Num 8	Not needed
ZNz8	ZN	z	Clk Num 8	Not needed
ZNzn8	ZN	zn	Clk Num 8	Not needed
Zzn8	Z	zn	Clk Num 8	Not needed
Zz10	Z	z	Clk Num 10	Not needed
ZNz10	ZN	z	Clk Num 10	Not needed
ZNzn10	ZN	zn	Clk Num 10	Not needed
Zzn10	Z	zn	Clk Num 10	Not needed
Yy0	Y	y	Clk Num 0	Not needed
YNy0	YN	y	Clk Num 0	HV side
YNyn0	YN	yn	Clk Num 0	HV & LV side
Yyn0	Y	yn	Clk Num 0	LV side
Yy2	Y	y	Clk Num 2	Not needed
YNy2	YN	y	Clk Num 2	Not needed
YNyn2	YN	yn	Clk Num 2	Not needed
Yyn2	Y	yn	Clk Num 2	Not needed
Yy4	Y	y	Clk Num 4	Not needed
YNy4	YN	y	Clk Num 4	Not needed
YNyn4	YN	yn	Clk Num 4	Not needed
Yyn4	Y	yn	Clk Num 4	Not needed
Yy6	Y	y	Clk Num 6	Not needed
YNy6	YN	y	Clk Num 6	HV side
YNyn6	YN	yn	Clk Num 6	HV & LV side
Yyn6	Y	yn	Clk Num 6	LV side
Yy8	Y	y	Clk Num 8	Not needed
YNy8	YN	y	Clk Num 8	Not needed
YNyn8	YN	yn	Clk Num 8	Not needed
Yyn8	Y	yn	Clk Num 8	Not needed
Yy10	Y	y	Clk Num 10	Not needed
YNy10	YN	y	Clk Num 10	Not needed
YNyn10	YN	yn	Clk Num 10	Not needed
Yyn10	Y	yn	Clk Num 10	Not needed
Yd1	Y	d	Clk Num 1	Not needed
YNd1	YN	d	Clk Num 1	Not needed
Yd5	Y	d	Clk Num 5	Not needed
YNd5	YN	d	Clk Num 5	Not needed

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
Yd7	Y	d	Clk Num 7	Not needed
YNd7	YN	d	Clk Num 7	Not needed
Yd11	Y	d	Clk Num 11	Not needed
YNd11	YN	d	Clk Num 11	Not needed
Dd0	D	d	Clk Num 0	Not needed
Dd2	D	d	Clk Num 2	Not needed
Dd4	D	d	Clk Num 4	Not needed
Dd6	D	d	Clk Num 6	Not needed
Dd8	D	d	Clk Num 8	Not needed
Dd10	D	d	Clk Num 10	Not needed
Dy1	D	y	Clk Num 1	Not needed
Dyn1	D	yn	Clk Num 1	Not needed
Dy5	D	y	Clk Num 5	Not needed
Dyn5	D	yn	Clk Num 5	Not needed
Dy7	D	y	Clk Num 7	Not needed
Dyn7	D	yn	Clk Num 7	Not needed
Dy11	D	y	Clk Num 11	Not needed
Dyn11	D	yn	Clk Num 11	Not needed
Yz1	Y	z	Clk Num 1	Not needed
YNz1	YN	z	Clk Num 1	Not needed
YNzn1	YN	zn	Clk Num 1	LV side
Yzn1	Y	zn	Clk Num 1	Not needed
Yz5	Y	z	Clk Num 5	Not needed
YNz5	YN	z	Clk Num 5	Not needed
YNzn5	YN	zn	Clk Num 5	LV side
Yzn5	Y	zn	Clk Num 5	Not needed
Yz7	Y	z	Clk Num 7	Not needed
YNz7	YN	z	Clk Num 7	Not needed
YNzn7	YN	zn	Clk Num 7	LV side
Yzn7	Y	zn	Clk Num 7	Not needed
Yz11	Y	z	Clk Num 11	Not needed
YNz11	YN	z	Clk Num 11	Not needed
YNzn11	YN	zn	Clk Num 11	LV side
Yzn11	Y	zn	Clk Num 11	Not needed
Zy1	Z	y	Clk Num 1	Not needed
Zyn1	Z	yn	Clk Num 1	Not needed
ZNyn1	ZN	yn	Clk Num 1	HV side

Table continues on the next page

Vector group of the transformer	Winding 1 type	Winding 2 type	Clock number	Zro A Elimination
ZNy1	ZN	y	Clk Num 1	Not needed
Zy5	Z	y	Clk Num 5	Not needed
Zyn5	Z	yn	Clk Num 5	Not needed
ZNyn5	ZN	yn	Clk Num 5	HV side
ZNy5	ZN	y	Clk Num 5	Not needed
Zy7	Z	y	Clk Num 7	Not needed
Zyn7	Z	yn	Clk Num 7	Not needed
ZNyn7	ZN	yn	Clk Num 7	HV side
ZNy7	ZN	y	Clk Num 7	Not needed
Yy0	Y	y	Clk Num 0	Not needed

Commissioning

The correct settings, which are *CT connection type*, *Winding 1 type*, *Winding 2 type* and *Clock number*, for the connection group compensation can be verified by monitoring the angle values I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2, I_ANGL_C2_A2, I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 while injecting the current into the transformer. These angle values are calculated from the compensated currents. See signal description from Monitored data table.

When a station service transformer is available, it can be used to provide current to the high voltage side windings while the low voltage side windings are short-circuited. This way the current can flow in both the high voltage and low voltage windings. The commissioning signals can be provided by other means as well. The minimum current to allow for phase current and angle monitoring is 0.015 I_r.

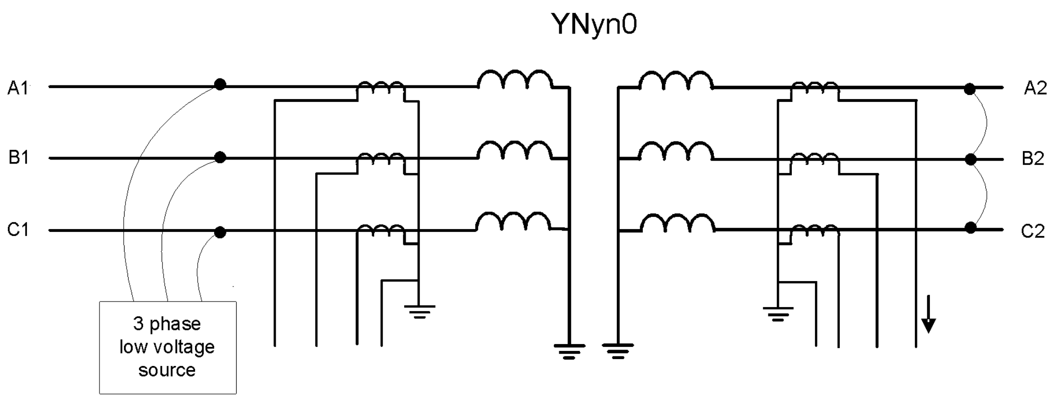


Figure 400: Low voltage test arrangement. The three-phase low voltage source can be the station service transformer.

The *Tapped winding* control setting parameter has to be set to “Not in use” to make sure that the monitored current values are not scaled by the automatic adaptation to the tap changer position. When only the angle values are required, the setting of *Tapped winding* is not needed since angle values are not affected by the tap changer position adaptation.

When injecting the currents in the high voltage winding, the angle values I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2 have to show +120 deg. Otherwise the phase order can be wrong or the polarity of a current transformer differs from the polarities of the other current transformers on the same side.

If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 show -120 deg, the phase order is wrong on the high voltage side. If the angle values I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2 show -120 deg, the phase order is wrong on the low voltage side. If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 do not show the same value of +120, the polarity of one current transformer can be wrong. For instance, if the polarity of the current transformer measuring IL2 is wrong, I_ANGL_A1_B1 shows -60 deg, I_ANGL_B1_C1 shows -60 deg and I_ANGL_C1_A1 shows +120 deg.

When the phase order and the angle values are correct, the angle values I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 usually show ±180 deg. There can be several reasons if the angle values are not ±180 deg. If the values are 0 deg, the value given for *CT connection type* is probably wrong. If the angle values are something else, the value for *Clock number* can be wrong. Another reason is that the combination of *Winding 1 type* and *Winding 2 type* does not match *Clock number*. This means that the resulting connection group is not supported.

Example

If *Winding 1 type* is set to "Y", *Winding 2 type* is set to "y" and *Clock number* is set to "Clk num 1", the resulting connection group "Yy1" is not a supported combination. Similarly if *Winding 1 type* is set to "Y", *Winding 2 type* is set to "d" and *Clock number* is set to "Clk num 0", the resulting connection group "Yd0" is not a supported combination. All the non-supported combinations of *Winding 1 type*, *Winding 2 type* and *Clock number* settings result in the default connection group compensation that is "Yy0".

4.3.2.7 CT connections and transformation ratio correction

The connections of the primary current transformers are designated as "Type 1" and "Type 2".

- If the positive directions of the winding 1 and winding 2 protection relay currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in *Figure 401* and *Figure 402*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in *Figure 403* and *Figure 404*.
- The default value of the *CT connection type* setting is "Type 1".

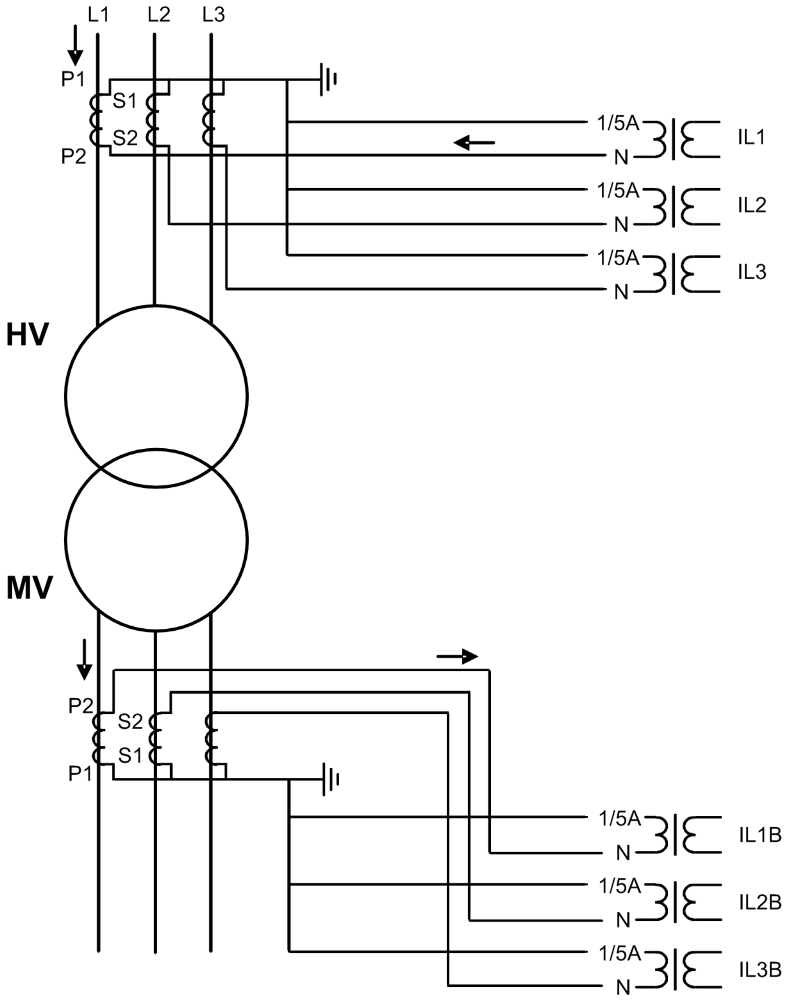


Figure 401: Connection example of current transformers of Type 1

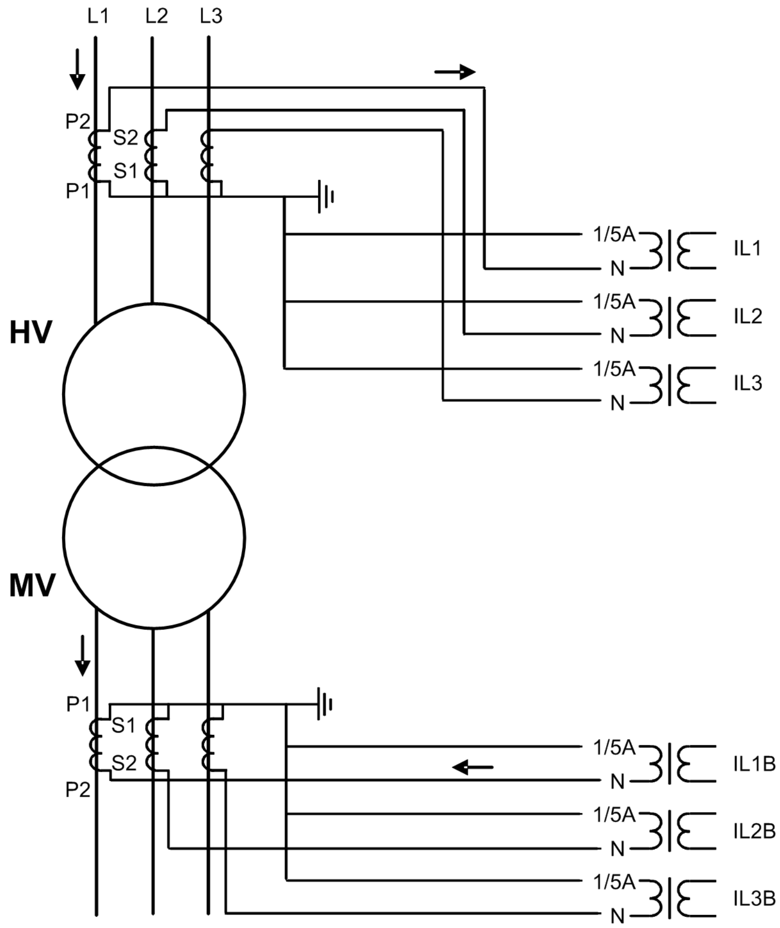


Figure 402: Alternative connection example of current transformers of Type 1

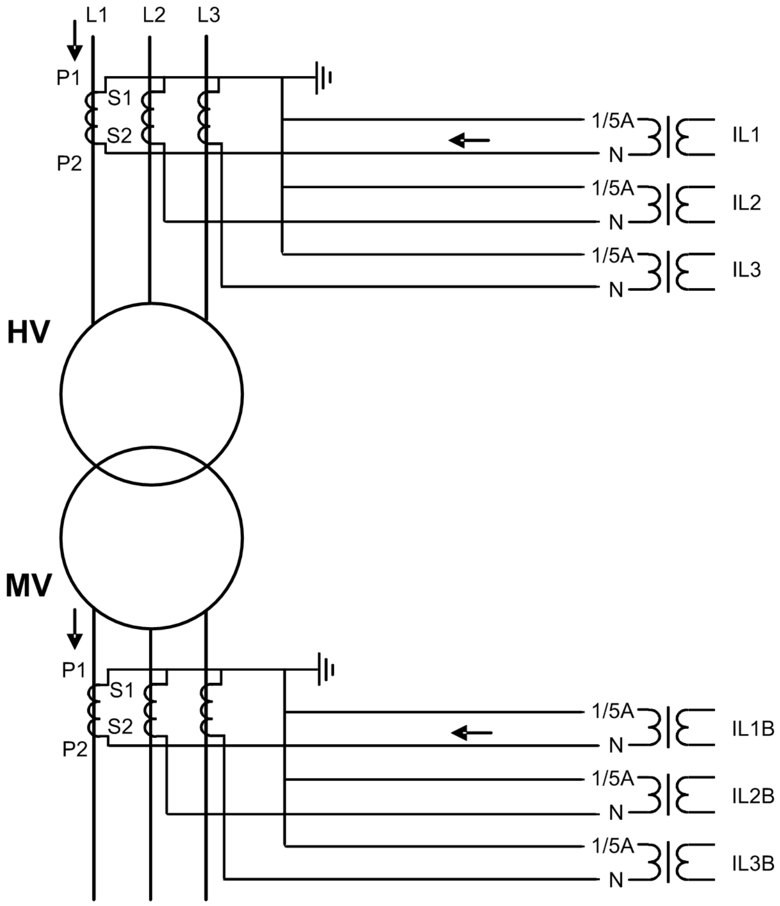


Figure 403: Connection of current transformers of Type 2 and example of the currents during an external fault

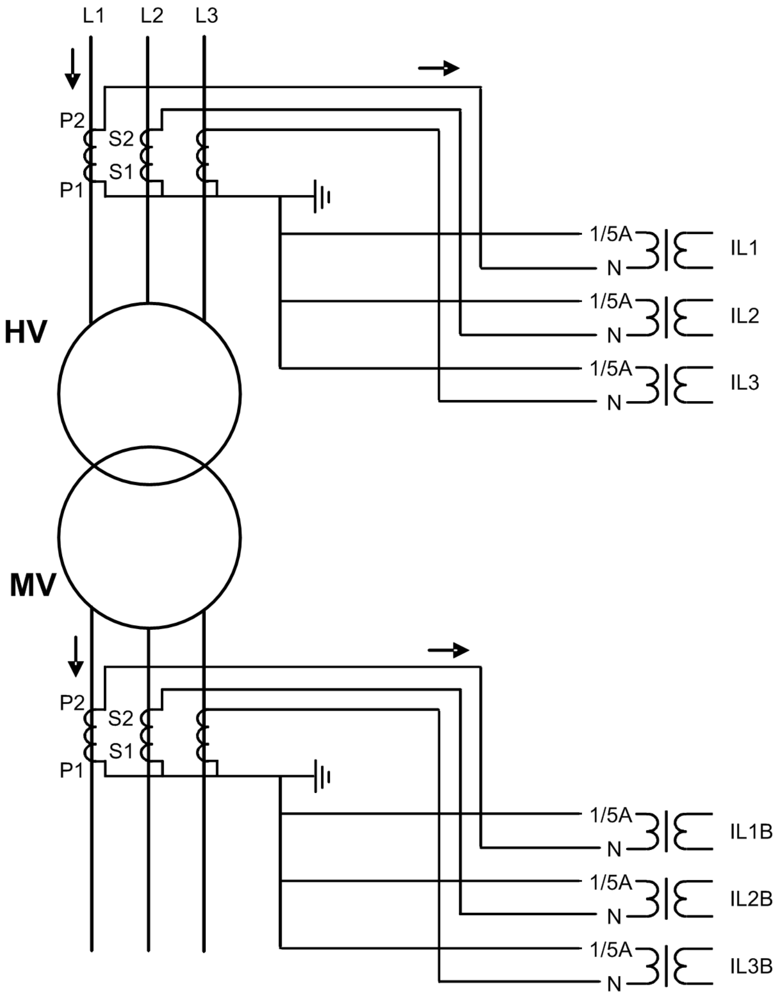


Figure 404: Alternative connection example of current transformers of Type 2

The CT secondary currents often differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on both sides of the power transformer with the *CT ratio Cor Wnd 1* and *CT ratio Cor Wnd 2* settings.

4.3.2.8 Signals

TR2PTDF Input signals

Table 656: TR2PTDF Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
BLOCK	BOOLEAN	0=False	Block

Table continues on the next page

Name	Type	Default	Description
BLK_OPR_LS	BOOLEAN	0=False	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks operate outputs from instantaneous stage

TR2PTDF Output signals

Table 657: TR2PTDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate combined
OPR_LS	BOOLEAN	Operate from low set
OPR_HS	BOOLEAN	Operate from high set
BLKD2H	BOOLEAN	2nd harmonic restraint block status
BLKD5H	BOOLEAN	5th harmonic restraint block status
BLKDWAV	BOOLEAN	Waveform blocking status

4.3.2.9 TR2PTDF Settings

Table 658: TR2PTDF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
High operate value	500...3000	%Ir	10	1000	Instantaneous stage setting
Low operate value	5...50	%Ir	1	20	Basic setting for biased operation
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 2	100...500	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics
Restraint mode	5=Waveform 6=2.h + waveform 8=5.h + waveform 9=2.h + 5.h + wav			9=2.h + 5.h + wav	Restraint mode
Start value 2.H	7...20	%	1	15	2. harmonic blocking ratio
Start value 5.H	10...50	%	1	35	5. harmonic blocking ratio

Table 659: TR2PTDF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Enable high set	0=False 1=True			1=True	Enable high set stage
Slope section 3	10...100	%	1	100	Slope of the third line of the operating characteristics
Harmonic deblock 2.	0=False 1=True			1=True	2. harmonic deblocking in case of switch on to fault
Stop value 5.H	10...50	%	1	35	5. harmonic deblocking ratio
Harmonic deblock 5.	0=False 1=True			0=False	5. harmonic deblocking in case of severe overvoltage

Table 660: TR2PTDF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off/On
CT connection type	1=Type 1 2=Type 2			1=Type 1	CT connection type. Determined by the directions of the connected current transformers
Winding 1 type	1=Y 2=YN 3=D 4=Z 5=ZN			1=Y	Connection of the HV side windings
Winding 2 type	1=y 2=yn 3=d 4=z 5=zn			1=y	Connection of the LV side windings
Clock number	0=Clk Num 0 1=Clk Num 1 2=Clk Num 2 4=Clk Num 4 5=Clk Num 5 6=Clk Num 6 7=Clk Num 7 8=Clk Num 8 10=Clk Num 10 11=Clk Num 11			0=Clk Num 0	Setting the phase shift between HV and LV with clock number for connection group compensation (e.g. Dyn11 -> 11)
Zro A elimination	1=Not eliminated 2=Winding 1 3=Winding 2 4=Winding 1 and 2			1=Not eliminated	Elimination of the zero-sequence current
CT ratio Cor Wnd 1	0.40...4.00		0.01	1.00	CT ratio correction, winding 1
CT ratio Cor Wnd 2	0.40...4.00		0.01	1.00	CT ratio correction, winding 2

Table 661: TR2PTDF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min winding tap	-36...36		1	17	The tap position number resulting the minimum number of effective winding turns on the side of the transformer where the tap changer is.
Max winding tap	-36...36		1	0	The tap position number resulting the maximum number of effective winding turns on the side of the transformer where the tap changer is.
Tap nominal	-36...36		1	8	The nominal position of the tap changer resulting the default transformation ratio of the transformer (as if there was no tap changer)
Tapped winding	1=Not in use 2=Winding 1 3=Winding 2			1=Not in use	The winding where the tap changer is connected to
Step of tap	0.60...9.00	%	0.01	1.50	The percentage change in voltage corresponding one step of the tap changer

4.3.2.10 TR2PTDF Monitored data

Table 662: TR2PTDF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Operate phase A
OPR_B	BOOLEAN	0=False 1=True		Operate phase B
OPR_C	BOOLEAN	0=False 1=True		Operate phase C
BLKD2H_A	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase A status
BLKD2H_B	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase B status
BLKD2H_C	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase C status
BLKD5H_A	BOOLEAN	0=False 1=True		5th harmonic restraint block phase A status
BLKD5H_B	BOOLEAN	0=False 1=True		5th harmonic restraint block phase B status

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
BLKD5H_C	BOOLEAN	0=False 1=True		5th harmonic restraint block phase C status
BLKDWAV_A	BOOLEAN	0=False 1=True		Waveform blocking phase A status
BLKDWAV_B	BOOLEAN	0=False 1=True		Waveform blocking phase B status
BLKDWAV_C	BOOLEAN	0=False 1=True		Waveform blocking phase C status
BLKD2HPHAR	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, combined
BLKD2HPHAR_A	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase A
BLKD2HPHAR_B	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase B
BLKD2HPHAR_C	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase C
BLKD5HPHAR	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, combined
BLKD5HPHAR_A	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase A
BLKD5HPHAR_B	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase B
BLKD5HPHAR_C	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase C
I_AMPL_A1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase A
I_AMPL_B1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase B
I_AMPL_C1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase C
I_AMPL_A2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase A
I_AMPL_B2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase B
I_AMPL_C2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential Current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential Current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential Current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Biasing current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Biasing current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Biasing current phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_2H_RAT_A	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase A
I_2H_RAT_B	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase B
I_2H_RAT_C	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 1
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 1
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 1
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 2
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 2
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 2
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase C
I_5H_RAT_A	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase A
I_5H_RAT_B	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase B
I_5H_RAT_C	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase C
TR2PTDF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
IL1-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL1
IL2-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL2
IL3-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL3
IL1-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL1
IL2-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL2
IL3-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL3

4.3.2.11 Technical data

Table 663: TR2PTDF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±3.0% of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	Low stage	31 ms	35 ms	40 ms
	High stage	15 ms	17 ms	20 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, …		

4.3.3 Stabilized and instantaneous differential protection for two- or three-winding transformers TR3PTDF (ANSI 87T3)

4.3.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized and instantaneous differential protection for two- or three-winding transformers	TR3PTDF	3dI>3W	87T3

4.3.3.2 Function block

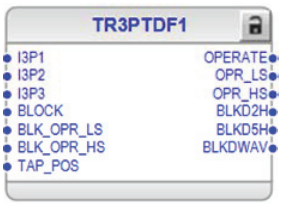


Figure 405: Function block

4.3.3.3 Functionality

The stabilized and instantaneous differential protection for two- or three-winding transformers function TR3PTDF provides up to three three-phase current sets or restraints designed for the protection of two-winding or three-winding transformers and generator-transformer blocks. It is possible to have two three-

[1] Current before fault = 0.0 × I_n, f_n = 50 Hz. Injected differential current = 2.0 × set operation value
[2] Measured with static power output f_n = 50 Hz.

phase current sets either on the winding 1 or winding 2 side in case of two-winding transformer protection. The function includes a biased low stage and an instantaneous high stage.

The biased low stage provides fast fault clearing while remaining stable with the high currents passing through the protected zone, which increase the errors in current measuring. The second harmonic restraint, together with waveform-based algorithms, ensures that the low stage does not operate due to the transformer inrush currents. The fifth harmonic restraint ensures that the low stage does not operate on apparent differential current caused by a harmless transformer overexcitation.

The instantaneous high stage provides very fast clearing of severe faults with a high differential current regardless of their harmonics.

The setting characteristic can be set more sensitive with tap changer position compensation. The correction of the transformation ratio due to changes in tap position is done automatically based on the tap changer status information provided to the function through input.

4.3.3.4 Analog channel configuration

TR3PTDF has three analog group inputs which must be properly configured.

Table 664: Analog inputs

Input	Description
I3P1	Three-phase currents
I3P2	Three-phase currents
I3P3 [1]	Three-phase currents Necessary when *Current group 3 type* is other than "Not in use"

See the preprocessing function blocks in this document for the possible signal sources. The `GRPOFF` signal is available in the function block called Protection.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of TR3PTDF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

[1] Can be connected to `GRPOFF` if *Current group 3 type* is set to "Not in use"

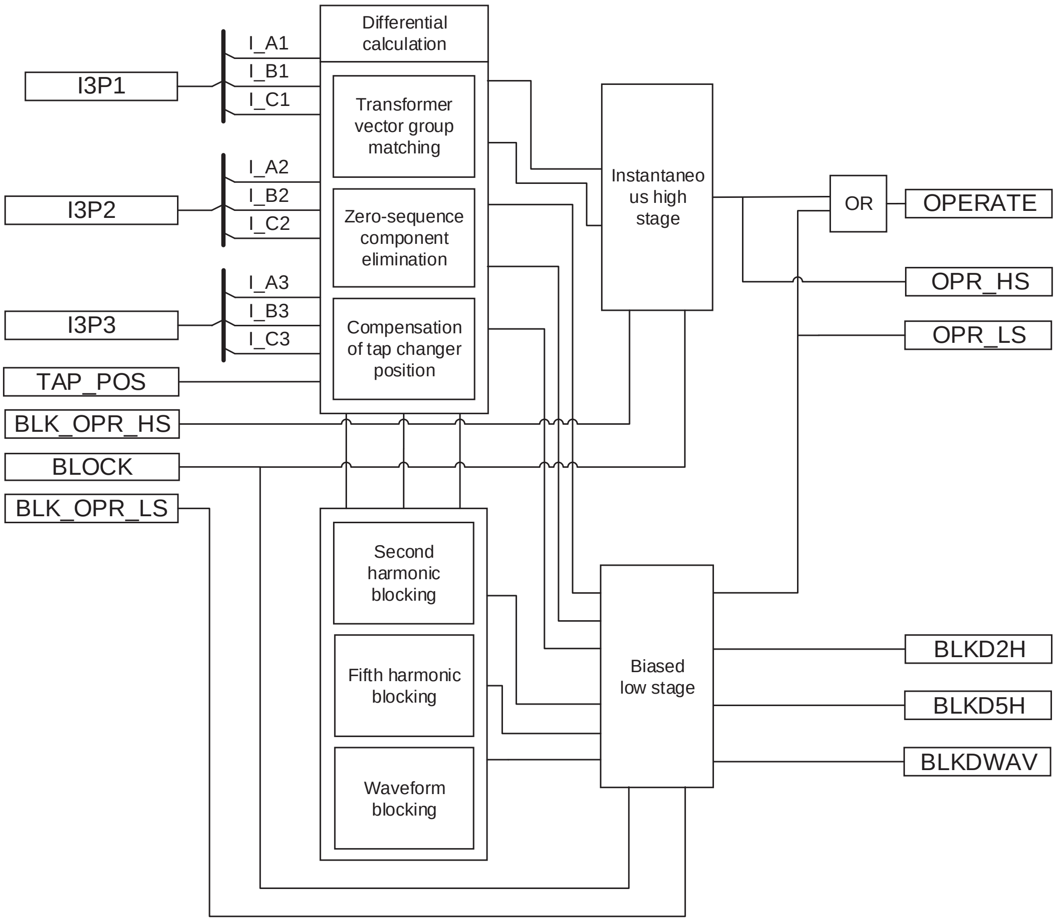


Figure 406: Functional module diagram

Differential calculation

TR3PTDF operates phasewise on the difference of incoming and outgoing currents. The positive direction of the currents is towards the protected object.

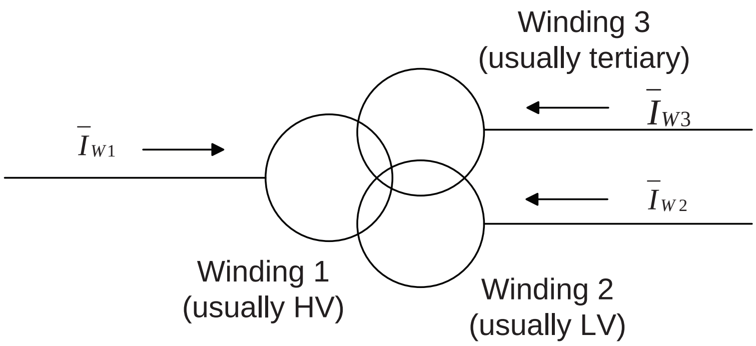


Figure 407: Single-line diagram of the positive direction of the currents in a threewinding transformer

The normalized amplitude of the differential current per phase Id is obtained using the equation:

$$I_d = \left| \bar{I}_{W1} + \bar{I}_{W2} + \bar{I}_{W3} \right|$$

(Equation 167)

In a normal situation, no fault occurs in the area protected by TR3PTDF. Then the currents I_{W1}, I_{W2} and I_{W3} cancel each other and the differential current I_d is zero. In practice, however, the differential current deviates from zero in normal situations. In the power transformer protection, the differential current is caused by CT inaccuracies, variations in tap changer position (if not compensated), transformer no-load current and instantaneous transformer inrush currents. An increase in the load current makes the differential current, caused by the CT inaccuracies and the tap changer position, grow at the same percentage rate.

In a biased differential protection relay in normal operation or during external faults, the higher the load current is, the higher the differential current required for tripping. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the bias current to be considerably smaller, which makes the operation more sensitive during internal faults.

$$I_b = \frac{\left| \bar{I}_X - \bar{I}_Y - \bar{I}_Z \right|}{2}$$

(Equation 168)

I_X	One of the normalized currents I_{W1}, I_{W2} and I_{W3} determined by the angle differences between the currents and their amplitudes
I_Y and I_Z	Remaining two currents

I_X is selected based on one of the criteria below.

- The angle between I_X and I_Y and also between I_X and I_Z is over 120 degrees while the amplitude of I_X is not less than

  $0.9 \cdot MAX(| I_X|, | I_Y|, | I_Z|)$
- The one with the highest amplitude ($I_X = MAX(| I_X|, | I_Y|, | I_Z|)$)

In case of a two-winding transformer having additional restraint (additional three-phase current set) either on the winding 1 or winding 2 side, currents are connected to the third winding current inputs. This ensures that if the currents of the opposite direction are measured in the restraints (through current), meaning the current is passing through the protected zone, this current affects the bias current of the differential protection.

If the bias current is small compared to the differential current or if the phase angle between the currents of two windings with the highest phase current (in case of three-winding transformer) or the phase angle between the compared phase currents (in case of two-winding transformer) is close to zero, a fault has most certainly occurred in the area protected by the differential protection relay. The operating value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

Transformer vector group matching

The phase differences of the winding 1 and winding 2 currents (winding 1 and winding 3 in case of a three-winding transformer) that are caused by the vector groups of the power transformer are numerically compensated in the function.

Phase difference matching is based on the ABB-patented generalized transform method. Settings *Phase shift Wnd 1-2* and *Phase shift Wnd 1-3* determine the current phase angle difference between windings 1 and 2 and between 1 and 3, respectively.

Normally, the transformer vector group designation includes the winding configurations and the phase angle difference between given with a clock number. For example, YNd1 has clock number 1. Settings *Phase shift Wnd 1-2* and *Phase shift Wnd 1-3* are calculated as clock number · 30 deg.

Table 665: Examples of Phase shift Wnd 1-2 (and Phase shift Wnd 1-3) settings for some common vector groups

Vector group between windings 1 and 2 (or windings 1 and 3)	Phase angle
YNd1, Yd1, Dyn1, Dy1	30°
YNd5, Yd5, Dyn5, Dy5	150°
YNd7, Yd7, Dyn7, Dy7	210°
YNd11, Yd11, Dyn11, Dy11	330°

The vector group matching can be set in the resolution of 0.1 degrees, which allows for cycloconverter applications with a phase angle difference of, for example, 7.5 degrees between windings.

The *Phase Ref winding* setting is used to define which of the windings is the reference. The phase reference can be selected from *Phase Ref winding* as "Winding 1", "Winding 2" or "Winding 3". The currents in the winding selected as the phase reference are not modified (except the removal of the zero-sequence current if set active) when the currents in other windings are matched with the reference winding (if the set phase shift between the windings is not zero).

The *Phase Ref winding* setting does not affect settings *Phase shift Wnd 1-2* and *Phase shift Wnd 1-3*.

Zero-sequence component elimination

If a wye-connected power transformer neutral is earthed, or if there is a separate earthing transformer inside the differential protection zone, any out-of-zone earth fault in the network is seen as differential current unless the zero-sequence component is correctly eliminated.

The zero-sequence elimination is done with the *Zro A elimination* setting. The recommended rules for this setting are:

- For power transformer wye-connected windings with earthed neutral point, *Zro A elimination* must be activated.
- For power transformer wye-connected windings with isolated neutral, and for delta-connected windings, *Zro A elimination* is not activated unless there is a separate earthing transformer inside the protected zone (that is, between the power transformer winding and CTs).
- It does no harm to activate *Zro A elimination* even if it is not needed.

Compensation of tap changer position

The position of the tap changer used for voltage control can be compensated according to the actual tap changer position. The position information is provided to the protection function through the tap changer position indication function TPOSYLTC.

Typically, the tap changer is located within the HV winding, that is, winding 1 of the power transformer. The *Tapped winding* setting parameter specifies whether the tap changer is connected to winding 1, winding 2 or winding 3. The *Tapped winding* setting parameter is also used to enable or disable the automatic adaptation to the tap changer position. The possible values are "Not in use", "Winding 1", "Winding 2", "Winding 3".

There can be only one tap changer in the transformer, that is, the function can take into account and compensate only for one tap changer.

The *Tap nominal* setting parameter provides the number of the tap which results in the nominal voltage and current. When the current tap position deviates from this value, the input current values where the tap changer resides are scaled to match the currents on the other side.

A correct scaling is determined by the number of steps, the direction of the deviation from the nominal tap and the percentage change in the voltage resulting from a deviation of one tap step. The percentage value is set via the *Step of tap* setting.

The operating range of the tap changer is defined by the *Min winding tap* and *Max winding tap* settings. The *Min winding tap* setting gives the tap position number resulting from the minimum effective number of winding turns on the side of the transformer where the tap changer is connected. Correspondingly, the *Max winding tap* setting gives the tap position number resulting from the maximum effective number of winding turns.

The *Min winding tap* and *Max winding tap* settings help the tap position compensation algorithm find the direction of the compensation. This also ensures that if the current tap position information is corrupted, the automatic tap changer position adaptation does not try to adapt to any unrealistic position values.

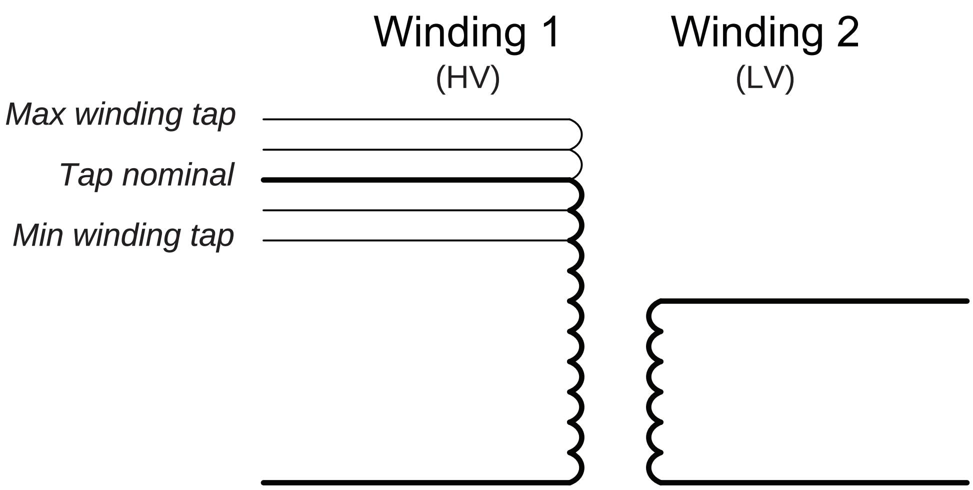


Figure 408: Simplified presentation of the HV and LV windings of a two-winding transformer with demonstration of the settings Max winding tap, Min winding tap and Tap nominal

The position value is available in the Monitored data view on LHMI or through other communication tools in TPOSYLTC. When the quality of the `TAP_POS` input value is not good, the position information in the `TAP_POS` input is not used, and the last value with the good quality information is used instead. In addition, the minimum sensitivity of the biased stage, set by the *Low operate value* setting, is automatically desensitized with the total range of the tap position correction. The new acting low operate value can be calculated.

$$Desensitized\ Low\ operate\ value = Low\ operate\ value + ABS(Max\ winding\ tap - Min\ winding\ tap) \cdot Step\ of\ tap$$

(Equation 169)

Second harmonic blocking

Transformer-magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current may be many times the rated current, and the half-life can be up to several seconds. To the differential protection relay, the inrush current represents a differential current that causes the protection relay to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

The blocking of the biased low stage of the protection relay at magnetizing inrush current is based on the ratio of the amplitudes of the second harmonic to the fundamental frequency component of the differential current (Id2f / Id1f).

The blocking also prevents an unwanted operation at recovery and a sympathetic magnetizing inrush. At recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of another transformer running in parallel with the protected transformer already connected to the network.

The ratio of the second harmonic to the fundamental component can vary considerably between the phases. Especially when the delta compensation is done for a Ynd1-connected transformer and the two phases of the inrush currents are otherwise equal but opposite in phase angle, their subtraction in a delta compensation results in a very small second harmonic component.

Because of the small second harmonic component, some action must be taken to avoid false tripping of the phase having a too low ratio of the second harmonic to the fundamental component. One way could be to block all phases when the second harmonic blocking conditions are fulfilled at least in one phase. The other way is to calculate weighted ratios of the second harmonic to the fundamental for each phase using the original ratios of the phases. The latter option is used here.

The ratio used for the second harmonic blocking is calculated as a weighted average on the basis of the ratios calculated from the differential currents of the three phases. The ratio of the phase has the most weight compared to the ratios of the other two phases (the weighting factors are 4, 1 and 1, where 4 is the factor of the phase). The operation of the biased stage on the phase is blocked if the weighted ratio of that phase is above the set *Start value 2.H* blocking limit and if the blocking is enabled through the *Restraint mode* setting.

Using separate blocking for the individual phases and weighted averages calculated for the separate phases provides a stable blocking scheme at connection inrush currents.

The switching of the power transformer onto fault inside the protected area does not delay the operation of the tripping, because in such a situation the blocking based on the second harmonic of the differential current is prevented by a separate algorithm based on the different waveform and the different rate of change of the normal inrush current and the inrush current containing the fault current. The algorithm does not eliminate the blocking at inrush currents unless there is a fault in the protected area.

The feature can be enabled and disabled through the *Harmonic deblock 2.* setting.

Fifth harmonic blocking

The inhibition of the protection relay operation in situations of overexcitation is based on the ratio of the fifth harmonic to the fundamental component of the differential current (Id5f / Id1f). The ratio is calculated separately for each phase without weighting factors. If the ratio exceeds the set value of *Start value 5.H* and blocking is enabled through the *Restraint mode* setting, the operation of the biased stage of the protection relay in the phase is blocked.

At dangerous levels of overvoltage which may cause damage to the transformer, the blocking can be automatically eliminated. The blocking is removed if the ratio of the fifth harmonic to the fundamental component of the differential current exceeds the set value of the *Stop value 5.H* setting, and the blocking removal is enabled. The deblocking feature can be enabled or disabled with the *Harmonic deblock 5.* setting.

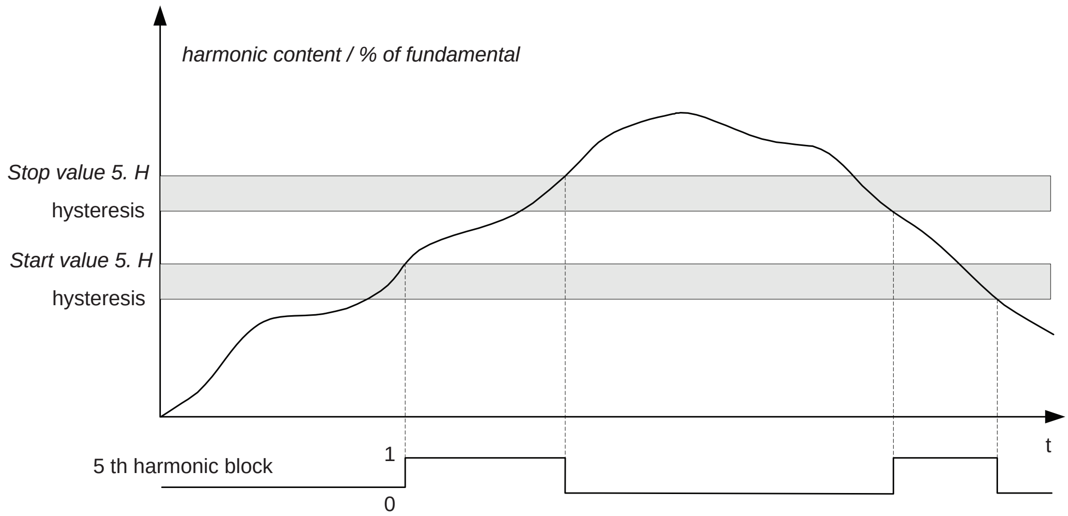


Figure 409: The fifth harmonic blocking limits and the operation when both blocking and deblocking features are enabled through the Harmonic deblock 5. setting

Fifth harmonic blocking has a hysteresis to avoid rapid fluctuation between TRUE and FALSE. The required consecutive fulfillments of the condition can be counted using the blocking counter. When the condition is not fulfilled, the counter is decreased (if >0).

Also fifth harmonic deblocking (based on the higher limit, *Stop value 5.H*, if enabled with *Harmonic deblock 5.*) has a hysteresis and a counter which counts the required consecutive fulfillments of the condition. When the condition is not fulfilled, the counter is decreased (if >0).

Waveform blocking

The biased low stage can always be blocked with waveform blocking; it cannot be disabled with *Restraint mode*. This algorithm has two parts. The first part is intended for external faults while the second is intended for inrush situations. The algorithm has criteria for the low-current periods of differential current during the inrush and external fault.

Blocking reset

All three blocking signals, that is, waveform and the second and fifth harmonic, have a counter or time limit which holds the blocking on for a certain time after the blocking conditions have ceased to be fulfilled. The deblocking takes place when the counters or time have elapsed. This is a normal case of deblocking.

The blocking signals can be reset immediately if a very high differential current is measured or if the phase difference (angle) between the compared currents is close to zero (in normal situations, the phase difference is 180 degrees).

Biased low stage

Biasing of the current differential protection is needed since a possible appearance of a differential current can also be due to something else than an actual fault in the transformer (or generator).

In the case of transformer protection, there can be several reasons for the false differential current.

- CT errors
- Varying tap changer positions (if not automatically compensated)
- Transformer no-load current
- Transformer inrush currents
- Transformer overexcitation during overvoltage situations
- Transformer overexcitation during underfrequency situations
- CT saturation at high currents passing through the transformer

The differential current caused by CT errors and tap changer position increases at the same percentage ratio as the load current.

In the protection of generators, the false differential current can be caused by several reasons.

- CT errors
- CT saturation at high currents flowing through the generator

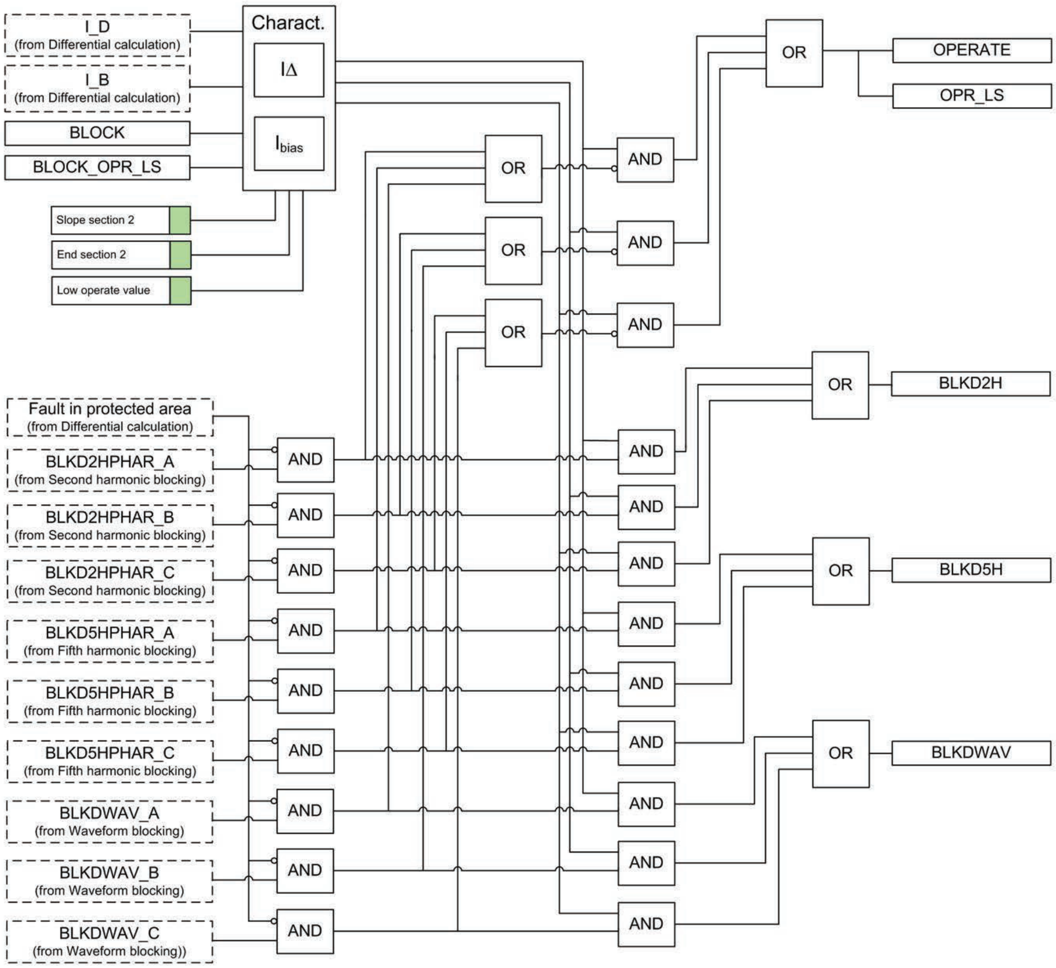


Figure 410: Operation logic of the biased low stage

The high currents passing through a protected object can be caused by the short circuits outside the protected area, the high currents fed by the transformer in a motor startup or transformer inrush situations. Therefore, the operation of the differential protection is biased with respect to the load current. In biased differential protection, the higher the differential current required for the protection to trip, the higher the load current.

The operation characteristic of the biased low stage is determined by *Low operate value*, *Slope section 2* and the second turning point setting of the operating characteristic curve, *End section 2* (the first turning point and the slope of the last part of the characteristic are fixed). The settings are the same for each phase. When the differential current exceeds the operating value determined by the operating characteristic, the differential function is activated. If the differential current stays above the operating value continuously for a suitable period, the `OPR_LS` output is activated. The activation of the `OPR_LS` output activates the OPERATE output.

The stage can be blocked internally by the second or the fifth harmonic restraint, or by special algorithms detecting the inrush and current transformer saturation at external faults. When the operation of the biased low stage is blocked by the second harmonic blocking functionality, the `BLKD2H` output is activated.

The `BLKD5H` output is activated when the biased low stage is blocked by the fifth harmonic blocking functionality. Correspondingly, when the operation of the biased low stage is blocked by the waveform blocking functionality, the BLKDWAV output is activated according to the phase information.

When required, the operating outputs of the biased low stage can be blocked by the external control signals BLK_OPR_LS and BLOCK.

The operation of the protection relay is affected by biasing as shown in *Figure 411*.

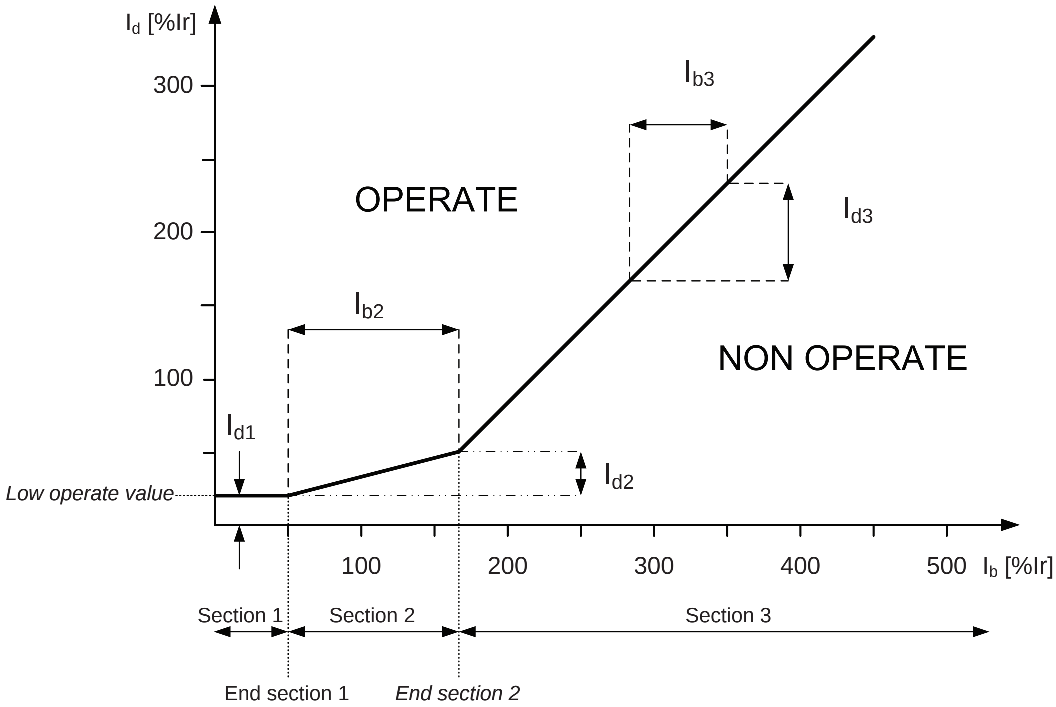


Figure 411: Operation characteristic for biased operation of TR3PTDF

The *Low operate value* setting of the biased stage of the differential function is determined according to the operating characteristics curve:

$$Low\ operate\ value = Id1$$

(Equation 170)

The *Slope section 2* setting is determined correspondingly:

$$Slope\ section\ 2 = \frac{Id2}{Ib2} \cdot 100\,\%$$

(Equation 171)

The second turning point *End section 2* can be set in the range 100...500 %.

The slope of the operating characteristic curve of the differential function varies in three different sections of the range.

Table 666: Different sections of the range and their operation

Sections	Operation
Section 1	In section 1, where 0 percent Ir < Ib < End section 1, with End section 1 being fixed to 50 percent of Ir, the differential current required for tripping is constant. The value of the differential current is the same as the *Low operate value* selected for the function. The *Low operate value* setting allows for the no-load current of the power transformer and small inaccuracies of the current transformers, but it can also be used to influence the overall level of the operation characteristic. At the rated current, the no-load losses of the power transformer are about 0.2 percent. If the supply voltage of the power transformer suddenly increases due to operational disturbances, the magnetizing current of the transformer increases as well. In general, the magnetic flux density of the transformer is rather high at the rated voltage and the rise in voltage by a few percent causes the magnetizing current to increase by tens percent. This should be considered in *Low operate value*.
Section 2	Section 2, where End section 1 < Ib < *End section 2*, is called the influence area of *Slope section 2*. In this section, the variations in the starting ratio affect the slope of the characteristic, that is, how big a change in the differential current is required for tripping compared to the change in the load current. The starting ratio should consider CT errors and variations in the transformer tap changer position (if not compensated). Too high a starting ratio should be avoided, because the sensitivity of the protection for detecting inter-turn faults depends on the starting ratio.
Section 3	In section 3, where Ib > *End section 2*, the slope of the characteristic is constant. The slope is 100 percent, which means that the increase in the differential current is equal to the corresponding increase in the biasing current.

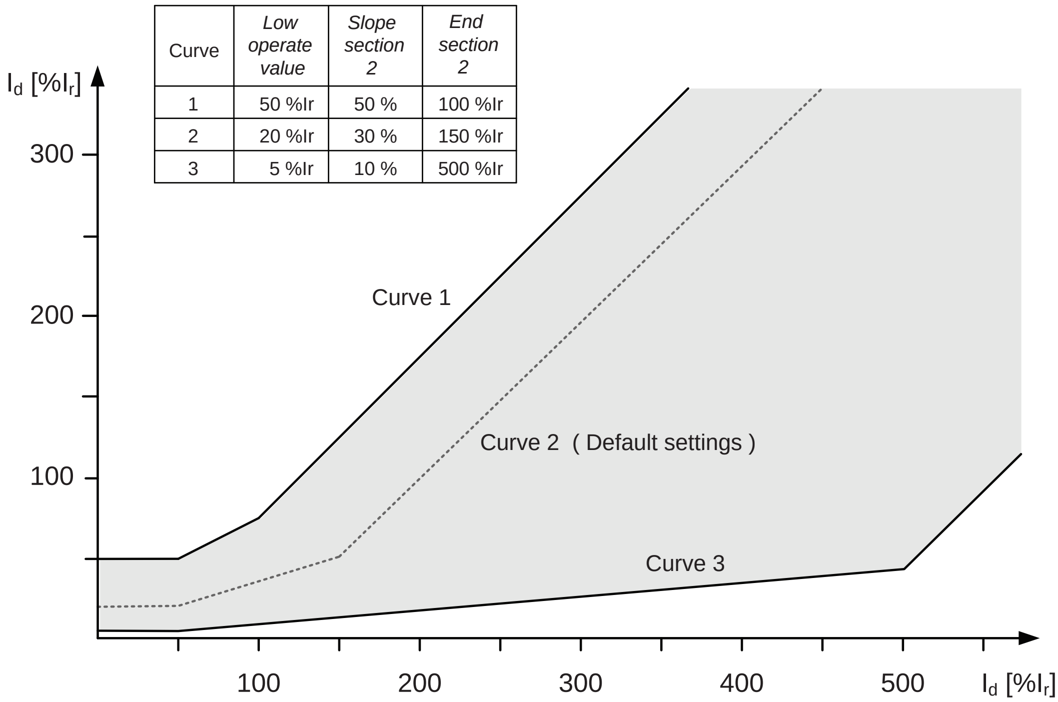


Figure 412: Setting range for biased low stage

If the biasing current is small compared to the differential current or if the phase angle between the currents of two windings with the highest phase current is close to zero (normally, the phase difference is 180 degrees) or the phase angle between the compared phase currents (in case of two-winding transformer) is close to zero, a fault has most certainly occurred in the area protected by the differential protection relay. The internal blocking signals of the biased stage are inhibited.

The operation of the differential protection is based on the fundamental frequency components. The operation is accurate and stable: the DC component and harmonics of the current do not cause unwanted operations.

Instantaneous high stage

Instantaneous high stage can be enabled or disabled with the *Enable high set* setting. The corresponding parameter values are "True" and "False".

The operation of Instantaneous high stage is not biased. The instantaneous stage operates and the `OPR_HS` output is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set operation value *High operate value* or when the instantaneous value of the differential current exceeds 2.5 · *High operate value*. The value 2.5 (=1.8 · √2) is due to the maximum asymmetric short circuit current.

If the biasing current is small compared to the differential current, or if the phase angle between the currents of the two windings with the highest phase current is close to zero (normally, the phase difference is 180 degrees) or the phase angle between the compared phase currents (in case of a two-winding transformer) is close to zero, a fault has occurred in the area protected by the differential protection. The operating value set for the instantaneous stage is automatically halved and the internal blocking signals of the biased stage are inhibited.

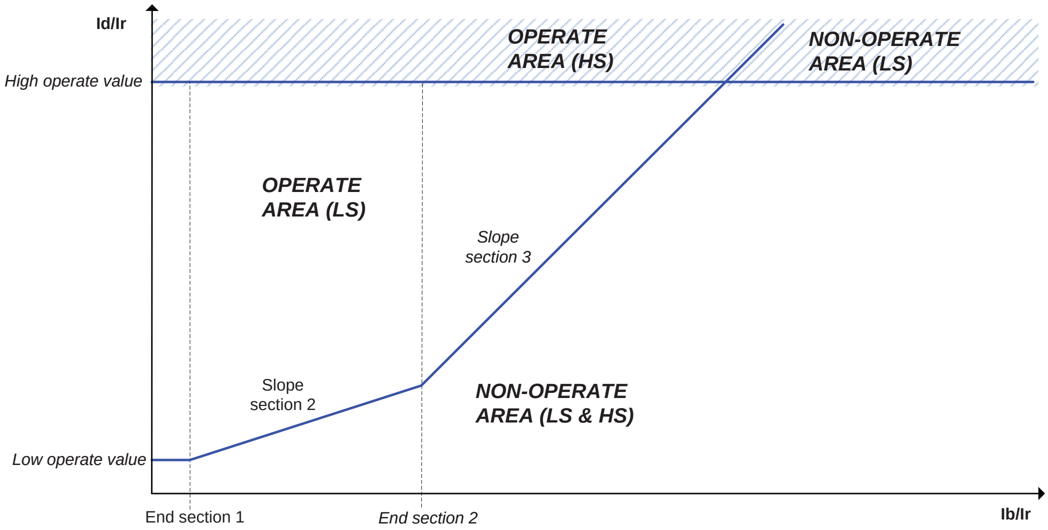


Figure 413: Operating characteristics of the protection. LS stands for the biased low stage and HS for the instantaneous high stage

The OPERATE output is always activated with the OPR_HS output. The internal blocking signals of the differential function do not prevent the trip signal of the instantaneous differential current stage from being activated. When required, the operating outputs of Instantaneous high stage can be blocked by the external control signals BLK_OPR_HS or BLOCK.

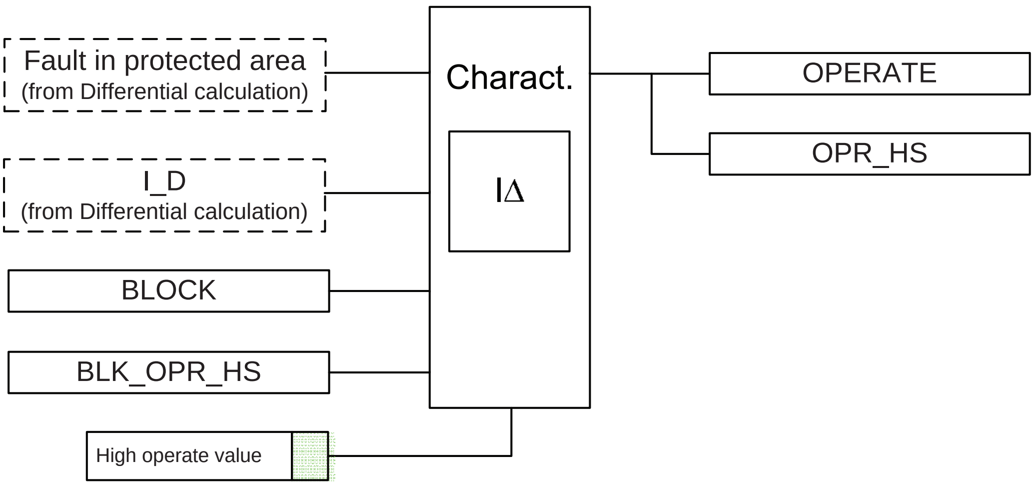


Figure 414: Operation logic of Instantaneous high stage

External blocking functionality

TR3PTDF has three inputs for blocking.

Blocking inputs	Description
BLOCK	When active (TRUE), the operation of the function is blocked; only measurement value outputs are updated.
BLK_OPR_LS	When active (TRUE), TR3PTDF acts normally except that the OPR_LS output is not active or activated in any circumstances. Additionally, the OPERATE output can be activated only by the instantaneous high stage (if not blocked).
BLK_OPR_HS	When active (TRUE), TR3PTDF acts normally except that the OPR_HS output is not active or activated in any circumstances. Additionally, the OPERATE output can be activated only by the biased low stage (if not blocked).

4.3.3.6 Current transformer connections and transformation ratio correction

The combinations of the connections of the primary current transformers are designated as "Type 1" and "Type 2". The type needs to be selected separately for the combination of CT connections on the winding 1 and 2 sides as well as for the combination of CT connections on the winding 1 and 3 sides in case of three-winding transformer.

- If the positive directions of the winding 1 and winding 2 relay currents are opposite, the setting parameter *CT connection 1-2* is "Type 1", as shown in *Figure 415*.
- If the positive directions of the winding 1 and winding 2 relay currents are equal, the setting parameter *CT connection 1-2* is "Type 2", as shown in *Figure 416*.
- 'The default value of the *CT connection 1-2* settings is "Type 1".
- The same applies for the *CT connection 1-3* settings.

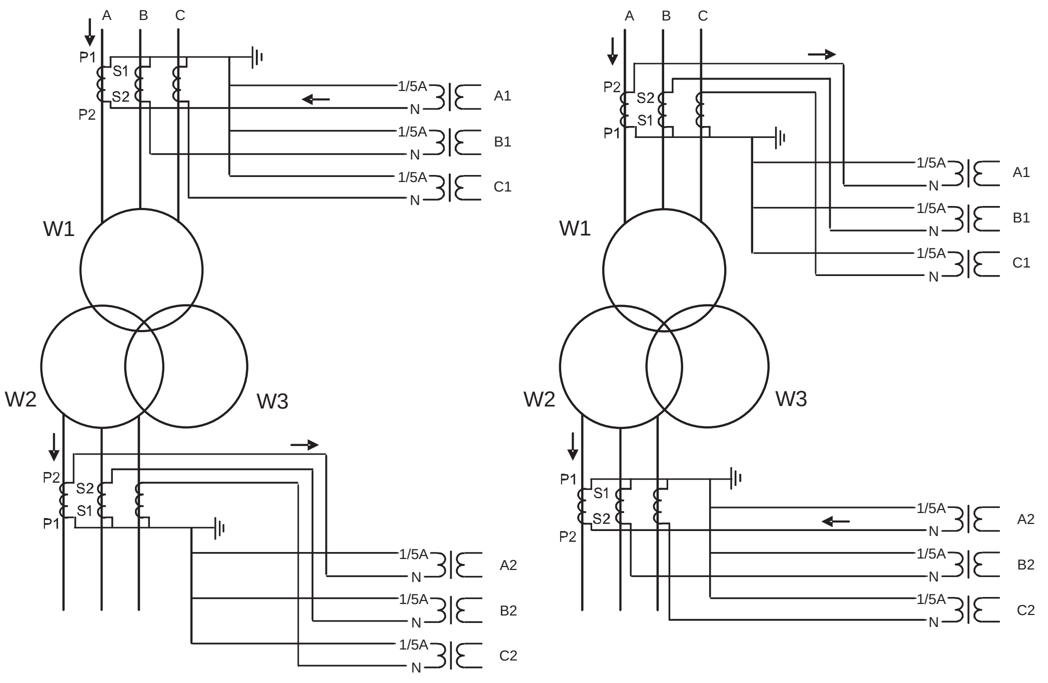


Figure 415: Connection of current transformers of Type 1 and example of currents during an external fault

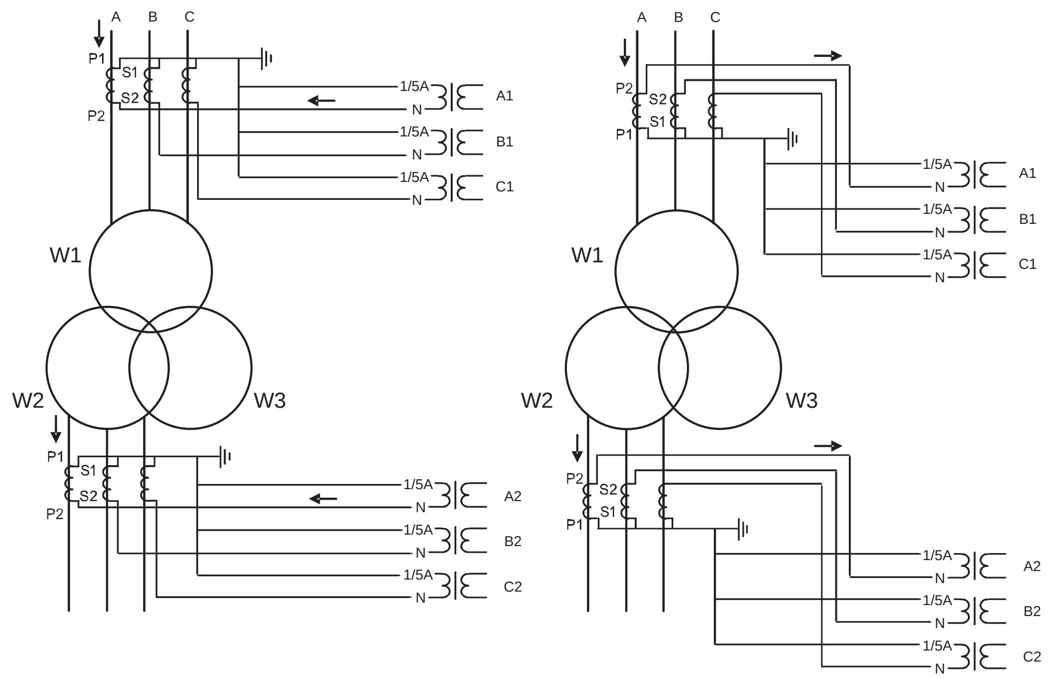


Figure 416: Connection of current transformers of Type 2 and example of currents during an external fault

Similar connections are done for a three-winding transformer.

If the rated primary current of the current transformers is not equal to the rated current of the power transformer on a side of the transformer, setting parameters *CT ratio Cor Wnd 1*, *CT ratio Cor Wnd 2* and *CT ratio Cor 3* must be used to correct the transformation ratios. *CT ratio Cor Wnd 1* and *CT ratio Cor Wnd 2* are used to correct the ratios on winding 1 and 2 while the use of *CT ratio Cor 3* depends on the setting *Current group 3 type*. If *Current group 3 type* is "Winding 3", the *CT ratio Cor 3* setting is used to correct the ratios on winding 3. If *Current group 3* type is "Wnd 2 restraint", the ratio correction is made to the ratios of the second restraint on winding 2. If *Current group 3 type* is "Wnd 1 restraint", the ratio correction is made to the ratios of the second restraint on winding 1.

4.3.3.7 Application

TR3PTDF is a unit protection. It acts as the main protection of transformers in case of winding failure. The protective zone of a differential protection includes the transformer itself and the bus work or cables between the current transformer and the power transformer. When bushing current transformers are used for the differential protection relay, the protective zone does not include the bus work or cables between the circuit breaker and the power transformer.

In some substations, there is a current differential protection for the busbar. Such a busbar protection includes the bus work or cables between the circuit breaker and the power transformer. The internal electrical faults are serious and cause immediate damage. The short circuits and earth faults in the windings and terminals are normally detected by the differential protection. Inter-turn faults, which are flashovers between conductors within the same physical winding, can also be detected if a large enough number of turns are short-circuited. Inter-turn faults are the most difficult transformer winding faults to detect with electrical protections. A small inter-turn fault including just a few turns results in an undetectable amount of current until it develops into an earth fault. Therefore the differential protection must have a high level of sensitivity and it must be possible to use a sensitive setting without causing unwanted operations for external faults.

The faulty transformer must be disconnected as fast as possible. As the differential protection is a unit protection, it can be designed for fast tripping, thus providing a selective disconnection of the faulty transformer. The differential protection should not operate because of faults outside the protective zone.

A transformer differential protection compares the current flowing into the transformer to the current leaving the transformer. A correct analysis of fault conditions by the differential protection must consider changes to voltages, currents and phase angles. The traditional transformer differential protection functions required auxiliary transformers for the correction of the phase shift and ratio. The numerical microprocessor-based differential algorithm implemented in TR3PTDF compensates for both the turns ratio and the phase shift internally in the software.

The differential current should theoretically be zero during a normal load or external faults if the turns ratio and phase shift are correctly compensated. However, there are several different phenomena other than internal faults that cause unwanted and false differential currents. There can be several main reasons for unwanted differential currents.

- Mismatch due to varying tap changer positions.
- Different characteristics, loads and operating conditions of the CTs.
- Zero-sequence currents that flow only on one side of the power transformer.
- Normal magnetizing currents.
- Magnetizing inrush currents.
- Overexcitation of magnetizing currents.

TR3PTDF is designed mainly for protection of two-winding or three-winding transformers. TR3PTDF can also be used for the protection of generator-transformer blocks as well as short cables and overhead lines. If the distance between the measuring points is relatively long in line protection, interposing CTs might be needed to reduce the burden of the CTs. For the interposing CT, the accuracy limit factor must fulfill the same requirements as for the main CTs. The interposing CT imposes an additional burden to the main CTs.

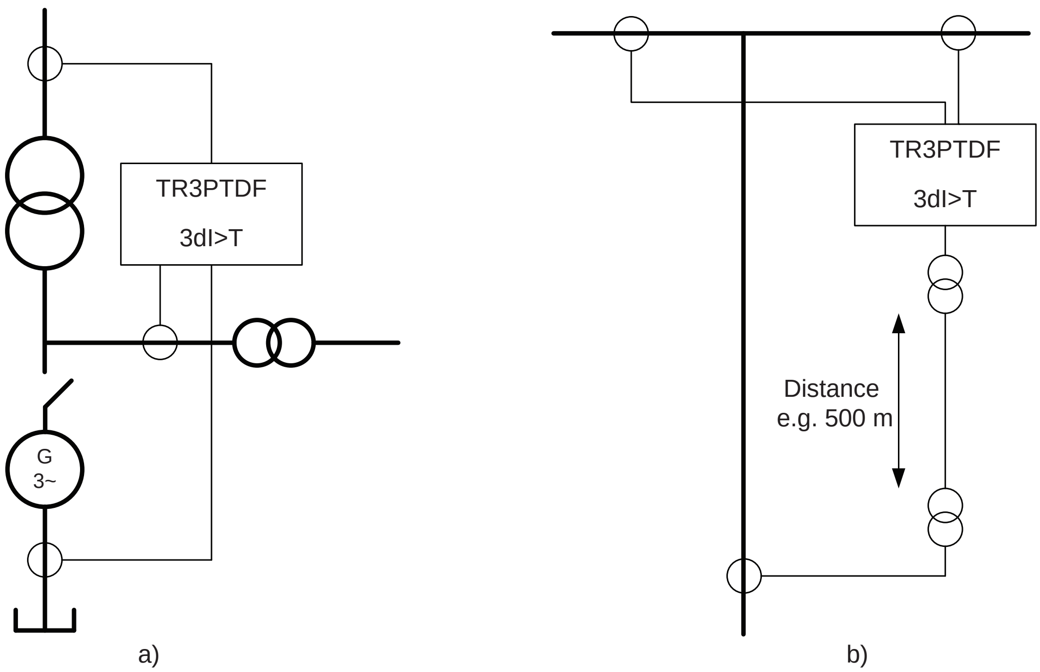


Figure 417: Differential protection of a generator-transformer block and short cable or line

TR3PTDF can be used in three-winding transformer applications or two-winding transformer applications with two output feeders.

On the double-feeder side of the two-winding power transformer, the currents from the other feeder are connected to the third three-phase current set of the protection relay (*Current group 3 type* to be set as "Wnd 2 restraint").

If the double-feeder side is on the input side of the transformer, *Current group 3 type* must be set as "Wnd 1 restraint".

In three-winding transformer applications, currents from winding 3 are always connected to the third three-phase current input set of the protection relay (*Current group 3 type* to be set as "Winding 3").

In the normal two-winding transformer application with one set of three-phase currents on both sides of the transformer, the *Current group 3 type* setting must be set as "Not in use".

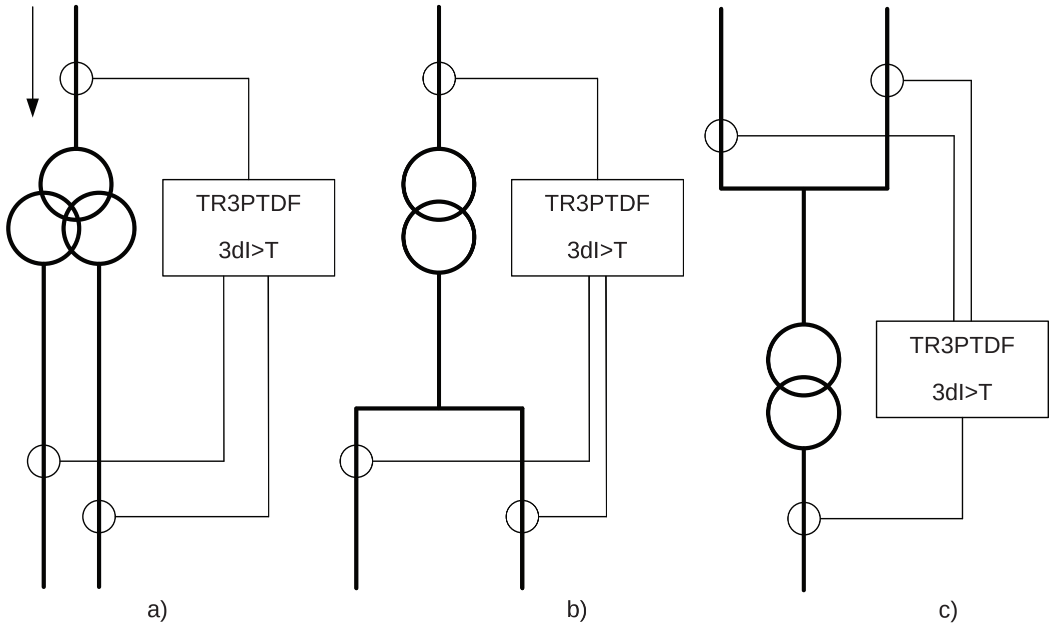


Figure 418: Differential protection of a three-winding transformer, transformer with two output feeders and transformer with two input feeders

Transforming ratio correction of CTs

The CT secondary currents often differ from the rated current at the rated load of the power transformer. The CT transforming ratios can be corrected on all sides of the power transformer with the CT ratio correction settings.

$$I_{nT} = \frac{S_n}{\sqrt{3} \cdot U_n}$$

(Equation 172)

I_{nT}	Rated load of the power transformer
S_n	Rated power of the power transformer
U_n	Rated phase-to-phase voltage

Three-winding transformer with one set of currents on each side of the transformer

100 MVA YNyn0d1 power transformer 154 kV/14.4 kV/4.37 kV. The corresponding rated currents are 375 A, 3007 A and 3303 A. At the HV side, the CT is 400 A, and on the MV sides both are 4000 A.

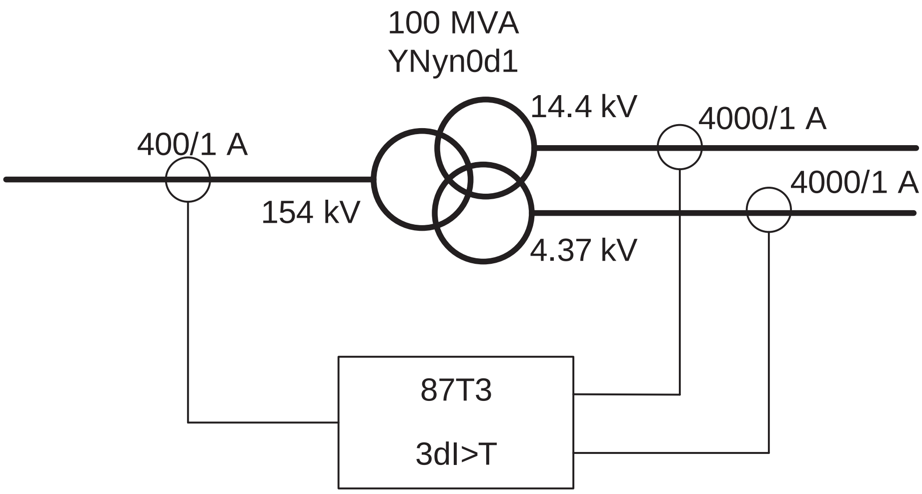


Figure 419: Example of three-winding power transformer differential protection

154 kV side: CT ratio correction factor = 400 A / 375 A = 1.07

The rated current 375 A corresponds to a 100 MVA power but on the MV sides 1.732 · 14.4 kV · 3007 A = 75 MVA and 1.732 · 4.37 kV · 3303 A = 25 MVA. Thus, the MV side rated currents cannot be used for calculations.

14.4kV side: CT ratio correction factor = 4000 A / (375 A · 154 kV / 14.4 kV) = 1.00

4.37kV side: CT ratio correction factor = 4000 A / (375 A · 154 kV / 4.37 kV) = 0.30

Assume for example a 50 MVA load on the 14.4 kV side and zero on the 4.37 kV side.

- 154 kV side current = 50 MVA / (1.732 · 154 kV) = 187.45 A

  TR3PTDF sees this as 185.45 A / 400 A · 1.07 = 0.50 xIr
- 14.4 kV side current = 50 MVA / (1.732 · 14.4 kV) = 2004.7 A

  TR3PDF seez this as 2004.7 A / 4000 A · 1.00 = 0.50 xIr

Assume for example a 20 MVA load on the 4.37 kV side and zero on the 14.4 kV side.

- 154kV side current = 20 MVA / (1.732 · 154 kV) = 75.0 A

  TR3PTDF sees this as 75 A / 400 A · 1.07 = 0.20 xIr
- 4.37kV side current = 20 MVA / (1.732 · 4.37 kV) = 2642.3 A

  TR3PTDF sees this as 2642.3 A / 4000 A · 0.30 = 0.20 xIr

Vector group matching and elimination of the zero-sequence component

The vector group of the power transformer is numerically matched on the windings on different sides of the transformer by the *Phase shift Wnd 1-2* and *Phase shift Wnd 1-3* settings. Thus no interposing CTs are needed if there is only a power transformer inside the protected zone. The matching is based on phase shifting and a numerical delta connection in the function.

If the neutral of a star-connected power transformer is earthed, any earth fault in the network is perceived by the protection as differential current. The elimination of the zero-sequence component can be selected to be on or off for that winding by the *Zro A elimination* setting. By default, the elimination is done for every winding.

Commissioning

The settings for the connection group compensation (*CT connection 1-2*, *Phase shift Wnd 1-2* and, in case of a three-winding transformer, also *CT connection 1-3* and *Phase shift Wnd 1-3* settings) can be verified by monitoring the angle values (I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2, I_ANGL_C2_A2, I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 and in case of three-winding transformer also I_ANGL_A3_B3, I_ANGL_B3_C3, I_ANGL_C3_A3, I_ANGL_A1_A3, I_ANGL_B1_B3 and I_ANGL_C1_C3) when injecting the current into the transformer. These angle values are calculated from the compensated currents.

When a station service transformer is available, it can be used to provide current into the winding 1 side, for example, HV windings, while the winding 2 side, for example, LV windings are short-circuited, as shown in Figure 420 (in case of a three-winding transformer, the tertiary winding side is short-circuited). This way the current can flow both in high-voltage and low-voltage windings (and in winding 3 in case of three-winding transformer). The commissioning signals can also be provided through other means. The currents need to be at least 0.015 pu to allow the phase current and angle monitoring.

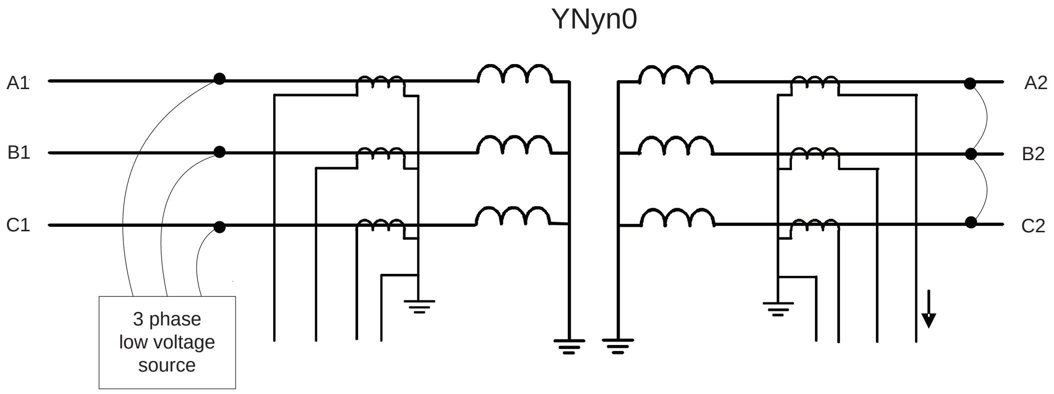


Figure 420: Low-voltage test arrangement. The three-phase low-voltage source can be the station service transformer, for example

The control setting *Tapped winding* should be set to value "Not in use" to ensure that the monitored current values are not scaled by the automatic adaptation to the tap changer position. When only the angle values are taken, this is not needed since the angle values are not affected by the tap changer position.

When injecting the currents into the HV winding, the angle values I_ANGL_A1_B1, I_ANGL_B1_C1, I_ANGL_C1_A1, I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2, and in case of three winding transformer, I_ANGL_A3_B3, I_ANGL_B3_C3 and I_ANGL_C3_A3, should be +120.

Otherwise, the phase order may be wrong or the polarity of one current transformer differs from the polarities of the other current transformers on the same side. If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 show -120°, the phase order is wrong on winding 1, for example, the high-voltage side. If the angle values I_ANGL_A2_B2, I_ANGL_B2_C2 and I_ANGL_C2_A2 show -120°, the phase order is wrong on winding 2, for example, the low-voltage side. If the angle values

I_ANGL_A3_B3, I_ANGL_B3_C3 and I_ANGL_C3_A3 show -120°, the phase order is wrong on winding 3, for example, the tertiary side. If the angle values I_ANGL_A1_B1, I_ANGL_B1_C1 and I_ANGL_C1_A1 do not show the same value (+120°), the polarity of one current transformer may be wrong. For example, if the polarity of the current transformer measuring IL2 is wrong, I_ANGL_A1_B1 shows -60°, I_ANGL_B1_C1 shows -60° and I_ANGL_C1_A1 shows +120°.

When the phase order and the angle values are correct, the angle values I_ANGL_A1_A2, I_ANGL_B1_B2 and I_ANGL_C1_C2 should show ±180° and in case of a three-winding transformer, also the angle values I_ANGL_A1_A3, I_ANGL_B1_B3 and I_ANGL_C1_C3 should show ±180°. There can be several reasons if this is not the case. If the angle values are 0, most probably the value given for *CT connection 1-2* (or *CT connection 1-3*) is wrong. If the angle values are something else, the value for *Phase shift Wnd 1-2* or *Phase shift Wnd 1-3* may be wrong.

Table 667: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match the actual CT connections on windings 1, 2 and 3

Angle output name	Angle value	Possible reason if not OK
I_ANGL_A1_B1	120	OK
I_ANGL_B1_C1	120	OK
I_ANGL_C1_A1	120	OK
I_ANGL_A2_B2	120	OK
I_ANGL_B2_C2	120	OK
I_ANGL_C2_A2	120	OK
I_ANGL_A3_B3	120	OK
I_ANGL_B3_C3	120	OK
I_ANGL_C3_A3	120	OK
I_ANGL_A1_A2	±180	OK
I_ANGL_B1_B2	±180	OK
I_ANGL_C1_C2	±180	OK
I_ANGL_A1_A3	±180	OK
I_ANGL_B1_B3	±180	OK
I_ANGL_C1_C3	±180	OK

Table 668: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match the actual CT connections on windings 1, 2 and 3 but the phase order is wrong on winding 1

Angle output name	Angle value	Possible reason if not OK
I_ANGL_A1_B1	–120	Wrong phase order
I_ANGL_B1_C1	–120	Wrong phase order
I_ANGL_C1_A1	–120	Wrong phase order
I_ANGL_A2_B2	+120	OK
I_ANGL_B2_C2	+120	OK
I_ANGL_C2_A2	+120	OK
I_ANGL_A3_B3	+120	OK
I_ANGL_B3_C3	+120	OK
I_ANGL_C3_A3	+120	OK
I_ANGL_A1_A2	+60	Winding 1 phase B connected as phase A
I_ANGL_B1_B2	–60	Winding 1 phase A connected as phase B
I_ANGL_C1_C2	±180	OK
I_ANGL_A1_A3	+60	Winding 1 phase B connected as phase A
I_ANGL_B1_B3	–60	Winding 1 phase A connected as phase B
I_ANGL_C1_C3	±180	OK

Table 669: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match the actual CT connections on windings 1, 2 and 3 but the phase order is wrong on winding 2

Angle output name	Angle value	Possible reason if not OK
I_ANGL_A1_B1	+120	OK
I_ANGL_B1_C1	+120	OK
I_ANGL_C1_A1	+120	OK
I_ANGL_A2_B2	–120	Wrong phase order
I_ANGL_B2_C2	–120	Wrong phase order
I_ANGL_C2_A2	–120	Wrong phase order
I_ANGL_A3_B3	+120	OK
I_ANGL_B3_C3	+120	OK
I_ANGL_C3_A3	+120	OK
I_ANGL_A1_A2	–60	Winding 2 phase B connected as phase A
I_ANGL_B1_B2	+60	Winding 2 phase A connected as phase B

Table continues on the next page

Angle output name	Angle value	Possible reason if not OK
I_ANGL_C1_C2	±180	OK
I_ANGL_A1_A3	±180	OK
I_ANGL_B1_B3	±180	OK
I_ANGL_C1_C3	±180	OK

Table 670: Angle outputs when settings CT connection 1-2 and CT connection 1-3 match the actual CT connections on windings 1, 2 and 3 but the phase B polarity is wrong compared to other phases on winding 2

Angle output name	Angle value	Possible reason if not OK
I_ANGL_A1_B1	+120	OK
I_ANGL_B1_C1	+120	OK
I_ANGL_C1_A1	+120	OK
I_ANGL_A2_B2	–60	Wrong polarity phase B
I_ANGL_B2_C2	–60	Wrong polarity phase B
I_ANGL_C2_A2	+120	OK
I_ANGL_A3_B3	+120	OK
I_ANGL_B3_C3	+120	OK
I_ANGL_C3_A3	+120	OK
I_ANGL_A1_A2	±180	OK
I_ANGL_B1_B2	0	Winding 2, wrong polarity phase B
I_ANGL_C1_C2	±180	OK
I_ANGL_A1_A3	±180	OK
I_ANGL_B1_B3	±180	OK
I_ANGL_C1_C3	±180	OK

4.3.3.8 Recommendations for current transformers

The more important the object to be protected, the more attention should be paid to the CTs. Normally, it is not possible to dimension the CTs so that they repeat currents with high DC components without saturating when the residual flux of the current transformer is high. TR3PTDF operates reliably even though the CTs are partially saturated. The purpose of the following current transformer recommendations is to secure the stability of the relay at high through-currents and the quick and sensitive operation of the relay at faults occurring in the protected area where the fault currents can be high.

The accuracy class recommended for CTs to be used with TR3PTDF is 5P, where the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is 5 percent.

The approximate value of the accuracy limit factor F_a corresponding to the actual CT burden can be calculated on the basis of the rated accuracy limit factor F_n (ALF) at the rated burden, the rated burden S_n, the internal burden S_{in} and the actual burden S_a of the CT.

$$F_a = F_n \cdot \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 173)

Example 1

In the example, the rated burden S_n of the CTs 5P20 is 10 VA, the secondary rated current 5A, the internal resistance R_{in} = 0.07 Ω and the accuracy limit factor F_n(ALF) corresponding to the rated burden is 20 (5P20). The internal burden of the current transformer is S_{in} = (5 A)^2 · 0.07 Ω = 1.75 VA. The input impedance of the relay at a rated current of 5 A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is S_a =(5 A)2 · (0.113 + 0.020) Ω = 3.33 VA. Thus the accuracy limit factor F_a corresponding to the actual burden is 46.

The CT burden can grow considerably at the rated current of 5 A. At the rated current of 1 A, the actual burden of the current transformer decreases, while the repeatability simultaneously improves.

At faults occurring in the protected area, the fault currents can be very high compared to the rated currents of the CTs. Due to the instantaneous stage of the differential function block, it is enough that during the first cycle, the CTs can repeat the current required for instantaneous tripping.

The CTs should be able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault, to secure that the operating times of the protection relay comply with the times stated in *Chapter 4.3.3.12 Technical data* .

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection fulfill the requirement of the equation.

$$Fa > K_r \ I_{kmax} \cdot (T_{dc} \cdot \omega \cdot (1 - e^{-\frac{Tm}{Tdc}}) + 1)$$

(Equation 174)

I_{kmax}	Maximum through-going fault current (in pu) at which the protection is not allowed to operate
T_{dc}	Primary DC time constant related to I_{kmax}
ω	Angular frequency, that is, 2 · π · 50 Hz
T_m	Time to saturate, that is, the duration of the saturation-free transformation
K_r	Remanence factor, 1/(1-r)

The parameter *r* gives the maximum remanence flux density in the CT core. The value of the parameter *r* depends on the magnetic material used and on the construction of the CT. For example, the value *r* = "0.4" means that the remanence flux density may be 40 percent of the saturation flux density. The manufacturer of the CT should be contacted when an accurate value for the parameter *r* is needed. The value *r* = "0.4" is recommended to be used when an accurate value is not available.

The minimum time to saturate (T_m) in TR3PTDF is 10 ms.

Two typical cases considered for the determination of the sufficient accuracy limit factor (F_a) are a fault occurring at the substation bus and re-energizing against a fault occurring further down in the network.

A fault occurring at the substation bus

The protection must be stable when a fault occurs during a normal operating situation. Re-energizing the transformer against a bus fault leads to very high fault currents and thermal stress. Therefore, re-energizing is not preferred in this case.

With this assumption, the remanence can be neglected.

The maximum through-going fault current I_{kmax} is typically 10 pu for a substation's main transformer. At a short circuit fault close to the supply transformer, the DC time constant (T_{dc}) of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

$$F_a > K_r \cdot I_{kmax} \cdot (T_{dc} \cdot \omega \cdot (1 - e^{-\frac{Tm}{Tdc}}) + 1) \approx 40$$

(Equation 175)

I_{kmax}	10 (pu)
T_{dc}	100 (ms)
ω	100π (Hz)
T_m	10 (ms)
K_r	1

Re-energizing against a fault occurring further down in the network

The protection must be stable during the re-energization against a fault on the line. In this case, the existence of remanence is very probable. In this example, it is 40 percent.

The fault current is now smaller and since the ratio of the resistance to the reactance is greater in this location, having a full DC offset is not possible. Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, here 50 ms.

Assuming a maximum fault current is 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

$$F_a > K_r \cdot I_{kmax} \cdot 0.9 \cdot (T_{dc} \cdot \omega \cdot (1 - e^{-\frac{Tm}{Tdc}}) + 1) \approx 40$$

(Equation 176)

I_{kmax}	0.7 · 10 = 7 (pu)
T_{dc}	50 (ms)
ω	100π (Hz)
T_m	10 (ms)
K_r	1/(1-0.4) = 1.6667

If the actual burden of the current transformer (S_a) in *Equation 173* cannot be reduced enough to provide a sufficient value for F_a, there are two alternatives.

- A current transformer with a higher rated burden S_n can be chosen (which also means a higher rated accuracy limit F_n) or
- A current transformer with a higher nominal primary current $I1_n$ (but the same rated burden) can be chosen.

Example 2

Assuming that the actions according to the current transformer with a higher nominal primary current $I1_n$ (but the same rated burden) are taken to improve the actual accuracy limit factor (F_a):

I_{rTR} = 1000 A	Rated secondary current of the transformer
I_{rCT} = 1500 A	Rated primary current of the CT on the transformer secondary side
F_n = 30	Rated accuracy limit factor of the CT
$F_a = (I_{rCT} / I_{rTR}) \cdot F_n$	Actual accuracy limit factor due to oversizing the CT

$F_a = (1500/1000) \cdot 30 = 45$

In differential protection it is important that the accuracy limit factors (F_a) at both sides of the phase CTs correspond with each other, that is, the burdens of the CTs on both sides should be as equal as possible. If high inrush or start currents with high DC components flow through the protected object when it is connected to the network, special attention should be paid to the performance and the burdens of the CTs and to the settings of the function block.

4.3.3.9 Signals

TR3PTDF Input signals

Table 671: TR3PTDF Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
I3P3	SIGNAL	-	Three-phase currents 3
BLOCK	BOOLEAN	0=False	Block
BLK_OPR_LS	BOOLEAN	0=False	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks operate outputs from instantaneous stage

TR3PTDF Output signals

Table 672: TR3PTDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate combined
OPR_LS	BOOLEAN	Operate from low set
OPR_HS	BOOLEAN	Operate from high set
BLKD2H	BOOLEAN	2nd harmonic restraint block status
BLKD5H	BOOLEAN	5th harmonic restraint block status
BLKDWAV	BOOLEAN	Waveform blocking status

4.3.3.10 TR3PTDF Settings

Table 673: TR3PTDF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
High operate value	500...3000	%Ir	10	1000	Instantaneous stage setting
Enable high set	0=False 1=True			1=True	Enable high set stage
Low operate value	5...50	%Ir	1	20	Basic setting for biased operation
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 2	100...500	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics
Restraint mode	5=Waveform 6=2.h + waveform 8=5.h + waveform 9=2.h + 5.h + wav			9=2.h + 5.h + wav	Restraint mode
Start value 2.H	7...20	%	1	15	2. harmonic blocking ratio
Start value 5.H	10...50	%	1	35	5. harmonic blocking ratio
Stop value 5.H	10...50	%	1	35	5. harmonic deblocking ratio
Harmonic deblock 2.	0=False 1=True			1=True	2. harmonic deblocking in case of switch on to fault
Harmonic deblock 5.	0=False 1=True			0=False	5. harmonic deblocking in case of severe overvoltage

Table 674: TR3PTDF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Slope section 3	10...100	%	1	100	Slope of the third line of the operating characteristics

Table 675: TR3PTDF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off/On
Current group 3 type	1=Not in use 2=Winding 3 3=Wnd 1 restraint 4=Wnd 2 restraint			2=Winding 3	Type of the third set/group of current inputs
CT connection 1-2	1=Type 1 2=Type 2			1=Type 1	CT connection type consideration between current groups 1 and 2
CT connection 1-3	1=Type 1 2=Type 2			1=Type 1	CT connection type consideration between current groups 1 and 3
Phase Ref winding	2=Winding 1 3=Winding 2 4=Winding 3			2=Winding 1	Reference winding for vector group matching
Zro A elimination	1=Not eliminated 2=Winding 1 3=Winding 2 4=Winding 1 and 2 5=Winding 3 6=Winding 1 and 3 7=Winding 2 and 3 8=Winding 1, 2, 3			1=Not eliminated	Elimination of the zero-sequence current
Phase shift Wnd 1-2	0.0...359.9	deg	0.1	0.0	Setting the phase shift between winding 1 and 2 in degrees
Phase shift Wnd 1-3	0.0...359.9	deg	0.1	0.0	Setting the phase shift between winding 1 and 3 in degrees
Min winding tap	-36...36		1	17	The tap position number resulting the minimum number of effective winding turns on the side of the transformer where the tap changer is.
Max winding tap	-36...36		1	0	The tap position number resulting the maximum number of effective winding turns on the side of the transformer where the tap changer is.
Tap nominal	-36...36		1	8	The nominal position of the tap changer resulting the default transformation ratio of the transformer (as if there was no tap changer)
Tapped winding	1=Not in use 2=Winding 1			1=Not in use	The winding where the tap changer is connected to

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Winding 2 4=Winding 3				
Step of tap	0.60...9.00	%	0.01	1.50	The percentage change in voltage corresponding one step of the tap changer
CT ratio Cor Wnd 1	0.20...5.00		0.01	1.00	CT ratio correction, winding 1
CT ratio Cor Wnd 2	0.20...5.00		0.01	1.00	CT ratio correction, winding 2
CT ratio Cor 3	0.20...5.00		0.01	1.00	CT ratio correction, current group 3

4.3.3.11 TR3PTDF Monitored data

Table 676: TR3PTDF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Operate phase A
OPR_B	BOOLEAN	0=False 1=True		Operate phase B
OPR_C	BOOLEAN	0=False 1=True		Operate phase C
BLKD2H_A	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase A status
BLKD2H_B	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase B status
BLKD2H_C	BOOLEAN	0=False 1=True		2nd harmonic restraint block phase C status
BLKD5H_A	BOOLEAN	0=False 1=True		5th harmonic restraint block phase A status
BLKD5H_B	BOOLEAN	0=False 1=True		5th harmonic restraint block phase B status
BLKD5H_C	BOOLEAN	0=False 1=True		5th harmonic restraint block phase C status
BLKDWAV_A	BOOLEAN	0=False 1=True		Waveform blocking phase A status
BLKDWAV_B	BOOLEAN	0=False 1=True		Waveform blocking phase B status
BLKDWAV_C	BOOLEAN	0=False 1=True		Waveform blocking phase C status
BLKD2HPHAR	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, combined

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
BLKD2HPHAR_A	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase A
BLKD2HPHAR_B	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase B
BLKD2HPHAR_C	BOOLEAN	0=False 1=True		2nd harmonic restraint blocking for PHAR LN, phase C
BLKD5HPHAR	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, combined
BLKD5HPHAR_A	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase A
BLKD5HPHAR_B	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase B
BLKD5HPHAR_C	BOOLEAN	0=False 1=True		5th harmonic restraint blocking for PHAR LN, phase C
I_AMPL_A1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase A
I_AMPL_B1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase B
I_AMPL_C1	FLOAT32	0.00...40.00	xIr	Connection group compensated primary current phase C
I_AMPL_A2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase A
I_AMPL_B2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase B
I_AMPL_C2	FLOAT32	0.00...40.00	xIr	Connection group compensated secondary current phase C
I_AMPL_A3	FLOAT32	0.00...40.00	xIr	Connection group compensated tertiary current phase A
I_AMPL_B3	FLOAT32	0.00...40.00	xIr	Connection group compensated tertiary current phase B
I_AMPL_C3	FLOAT32	0.00...40.00	xIr	Connection group compensated tertiary current phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential Current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential Current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential Current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Restraint current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Restraint current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Restraint current phase C
I_2H_RAT_A	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase A

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_2H_RAT_B	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase B
I_2H_RAT_C	FLOAT32	0.00...1.00		Differential current second harmonic ratio, phase C
I_5H_RAT_A	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase A
I_5H_RAT_B	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase B
I_5H_RAT_C	FLOAT32	0.00...1.00		Differential current fifth harmonic ratio, phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 1
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 1
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 1
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 2
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 2
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 2
I_ANGL_A3_B3	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, winding 3
I_ANGL_B3_C3	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, winding 3
I_ANGL_C3_A3	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, winding 3
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 2, phase C
I_ANGL_A1_A3	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 3, phase A
I_ANGL_B1_B3	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 3, phase B
I_ANGL_C1_C3	FLOAT32	-180.00...180.00	deg	Current phase angle diff between winding 1 and 3, phase C
TR3PTDF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
IL1-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL1
IL2-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL2
IL3-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL3

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
IL1-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL1
IL2-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL2
IL3-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL3

4.3.3.12 Technical data

Table 677: TR3PTDF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±3.0% of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	Low stage	30 ms	35 ms	40 ms
	High stage	17 ms	18 ms	20 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, …		

4.3.4 Numerically stabilized low-impedance restricted earth-fault protection LREFPNDF (ANSI 87NLI)

4.3.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Numerically stabilized low-impedance restricted earth-fault protection	LREFPNDF	dIoLo>	87NLI

4.3.4.2 Function block

Figure 421: Function block

[1] Current before fault = 0.0 × I_n, f_n = 50 Hz. Injected differential current = 2.0 × set operation value.
[2] Measured with static power output (SPO)

4.3.4.3 Functionality

The numerical stabilized low-impedance restricted earth-fault protection function LREFPNDF for a two-winding transformer is based on the numerically stabilized differential current principle. No external stabilizing resistor or non-linear resistor are required.

The fundamental components of the currents are used for calculating the residual current of the phase currents, the neutral current, differential currents and stabilizing currents. The operating characteristics are according to the definite time.

LREFPNDF contains a blocking functionality. The neutral current second harmonic is used for blocking during the transformer inrush situation. It is also possible to block function outputs, timers or the function itself.

4.3.4.4 Analog channel configuration

LREFPDIF has two analog group inputs which must be properly configured.

Table 678: Analog inputs

Input	Description
I3P	Three-phase currents
IRES	Residual current (measured)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 679: Special conditions

Condition	Description
IRES measured	The function requires that the current measured from the neutral side is connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LREFPNDF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

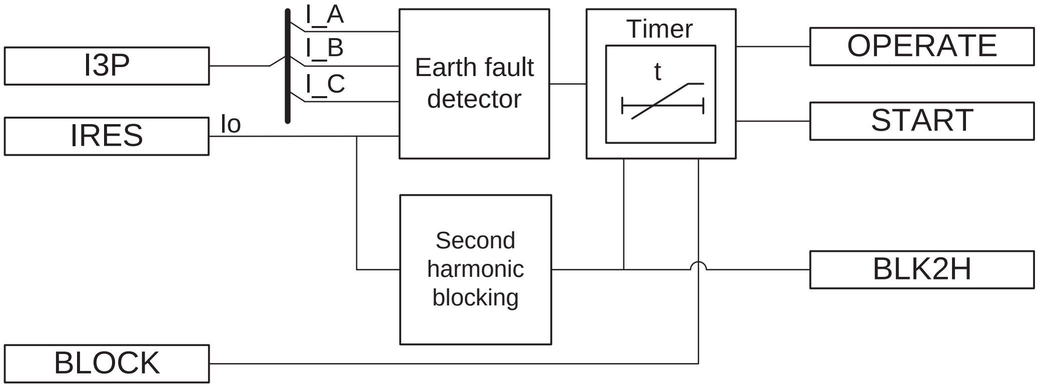


Figure 422: Functional module diagram

Earth-fault detector

The operation is based on comparing the amplitude and the phase difference between the sum of the fundamental frequency component of the phase currents (ΣI, residual current) and the fundamental frequency component of the neutral current (Io) flowing in the conductor between the transformer or generator's neutral point and earth. The differential current is calculated as the absolute value of the difference between the residual current, that is, the sum of the fundamental frequency components of the phase currents I_A, I_B and I_C, and the neutral current. The directional differential current ID_COSPHI is the product of the differential current and cosφ. The value is available in the monitored data view.

$$ID\_COSPHI = \left(\left| \overline{\Sigma I} - \overline{Io} \right| \right) \times \cos\varphi$$

(Equation 177)

$\overline{\Sigma I}$	Residual current
φ	Phase difference between the residual and neutral currents
$\overline{Io}$	Neutral current

An earth fault occurring in the protected area, that is, between the phase CTs and the neutral connection CT, causes a differential current. The directions, that is, the phase difference of the residual current and the neutral current, are considered in the operation criteria to maintain selectivity. A correct value for *CT connection type* is determined by the connection polarities of the current transformer.

The current transformer ratio mismatch between the phase current transformer and neutral current transformer (residual current in the analog input settings) is taken into account by the function with the properly set analog input setting values.

During an earth fault in the protected area, the currents ΣI and Io are directed towards the protected area. The factor cosφ is 1 when the phase difference of the residual current and the neutral current is 180 degrees, that is, when the currents are in opposite direction at the earth faults within the protected area. Similarly, ID_COSPHI is specified to be 0 when the phase difference between the residual current and the neutral current is less than 90 degrees in situations where there is no earth fault in the protected area. Thus tripping is possible only when the phase difference between the residual current and the neutral current is above 90 degrees.

The stabilizing current IB used by the stabilizing current principle is calculated as an average of the phase currents in the windings to be protected. The value is available in the monitored data view.

$$IB = \frac{\left|\overline{I\_A}\right| + \left|\overline{I\_B}\right| + \left|\overline{I\_C}\right|}{3}$$

(Equation 178)

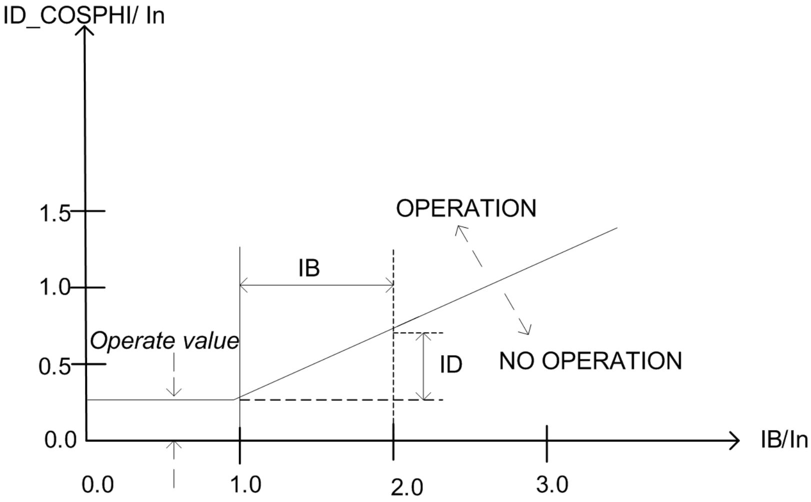


Figure 423: Operating characteristics of the stabilized earth-fault protection function

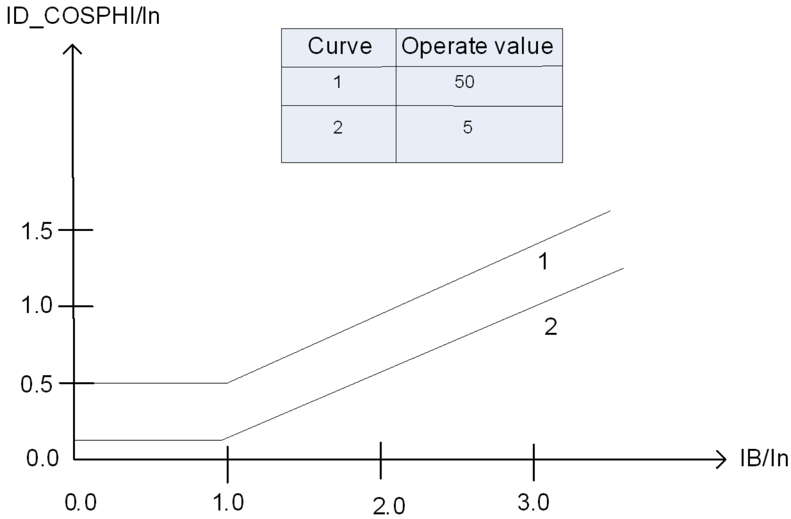


Figure 424: Setting range of the operating characteristics for the stabilized differential current principle of the earth-fault protection function

The *Operate value* setting is used for defining the characteristics of the function. The differential current value required for tripping is constant at the stabilizing current values 0.0 < IB/In < 1.0, where In is the nominal current, and the In in this context refers to the nominal of the phase current inputs. When the stabilizing current is higher than 1.0, the slope of the operation characteristic (ID/IB) is constant at 50 percent. Different operating characteristics are possible based on the *Operate value* setting.

For the protection of the trip, the measured neutral current has to be above 4 percent. When the condition has been fulfilled, the measured neutral current must stay above 2 percent, otherwise reset time is started.

To calculate the directional differential current ID_COSPHI, the fundamental frequency amplitude of both the residual and neutral currents has to be above 4 percent of In. If neither or only one condition is fulfilled at a time, the cosφ term is forced to 1. After the conditions are fulfilled, both currents must stay above 2 percent of In to allow the continuous calculation of the cosφ term.

Second harmonic blocking

This module compares the ratio of the current second harmonic (I_0_2H) and fundamental component of I_0 to the set value *Start value 2.H*. If the ratio (I_0_2H / I_0) value exceeds the set value, the BLK2H output is activated.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer connected to the network.

The second harmonic blocking is disabled when *Restraint mode* is set to "None" and enabled when set to "Harmonic2".

Timer

Once activated, the Timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the reset timer resets and the START output is deactivated.

The Timer calculates the start duration value START_DUR which indicates the percentage ratio of the start situation and the set operate time. The value is available through the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated. The activation of the output of the second harmonic blocking signal BLK2H deactivates the OPERATE output.

4.3.4.6 Application

An earth-fault protection using an overcurrent element does not adequately protect the transformer winding in general and the star-connected winding in particular.

The restricted earth-fault protection is mainly used as a unit protection for the transformer windings. LREFPNDF is a sensitive protection applied to protect the star-connected winding of a transformer. This protection system remains stable for all the faults outside the protected zone.

LREFPNDF provides higher sensitivity for the detection of earth faults than the overall transformer differential protection. This is a high-speed unit protection scheme applied to the star-connected winding of the transformer. LREFPNDF is normally applied when the transformer is earthed solidly or through low-impedance resistor (NER). LREFPNDF can be also applied on the delta side of the transformer if an earthing transformer (zig-zag transformer) is used there. In LREFPNDF, the difference of the fundamental component of all three phase currents and the neutral current is provided to the differential element to detect the earth fault in the transformer winding based on the numerical stabilized differential current principle.

Connection of current transformers

The connections of the primary current transformers are designated as "Type 1" and "Type 2".

- If the positive directions of the winding 1 and winding 2 protection relay currents are opposite, the *CT connection type* setting parameter is "Type 1". The connection examples of "Type 1" are as shown in figures *Figure 425* and *Figure 426*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in figures *Figure 427* and *Figure 428*.
- The default value of the *CT connection type* setting is "Type 1".

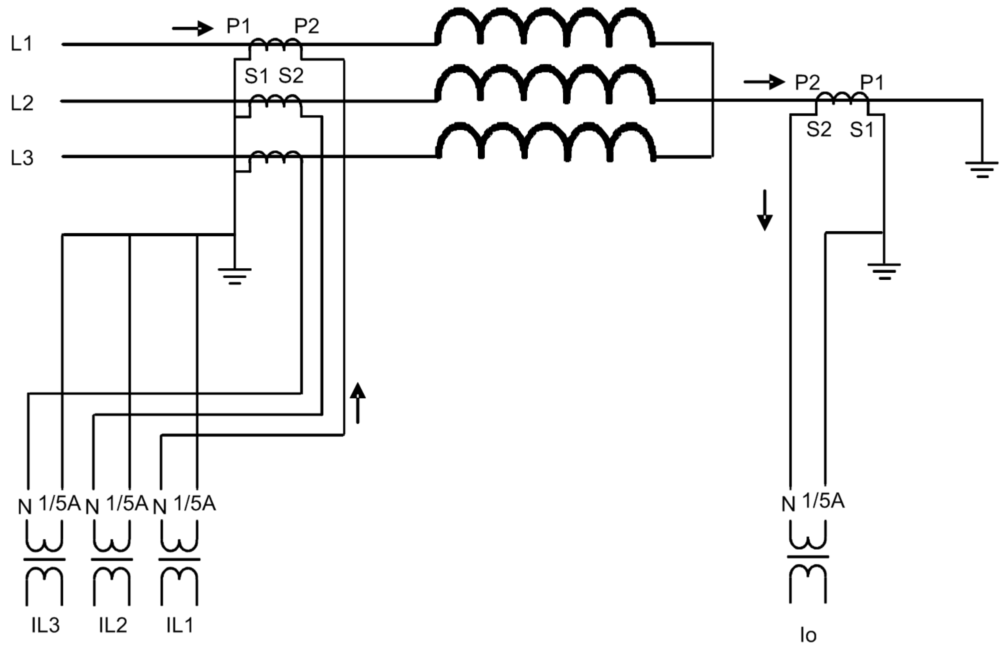


Figure 425: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation.

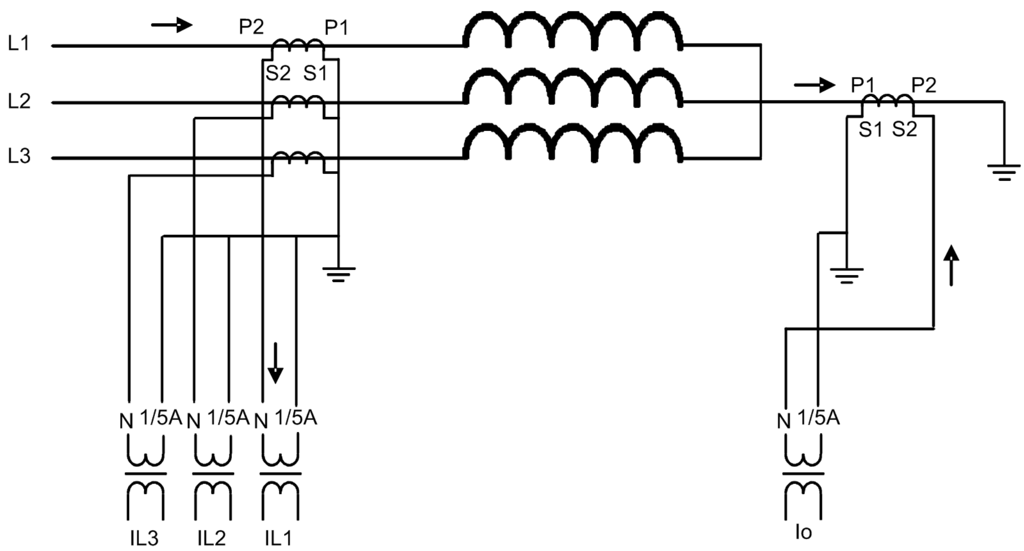


Figure 426: Connection of the current transformers of Type 1. The connected phase currents and the neutral current have opposite directions at an external earth-fault situation.

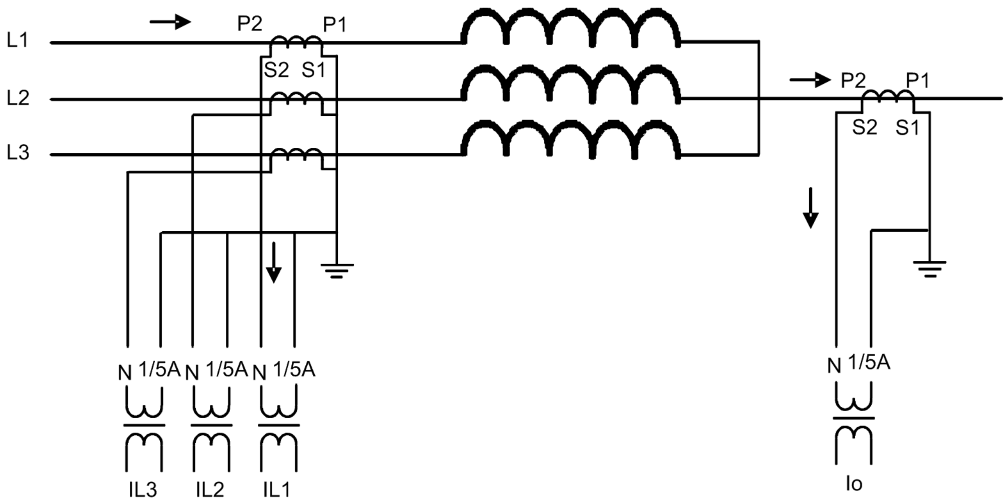


Figure 427: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation.

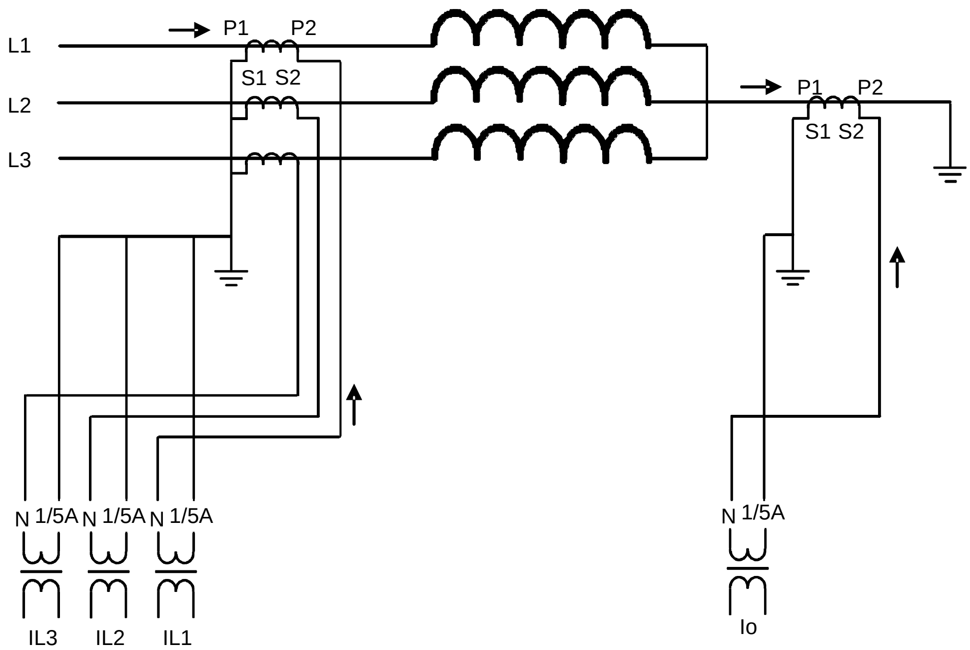


Figure 428: Connection of the current transformers of Type 2. The phase currents and the neutral current have equal directions at an external earth-fault situation.

Internal and external faults

LREFPNDF does not respond to any faults outside the protected zone. An external fault is detected by checking the phase angle difference of the neutral current and the sum of the phase currents. When the difference is less than 90 degrees, the operation is internally restrained or blocked. Hence the protection is not sensitive to an external fault. *Figure 429* and *Figure 430* are valid for CT connection type 1.

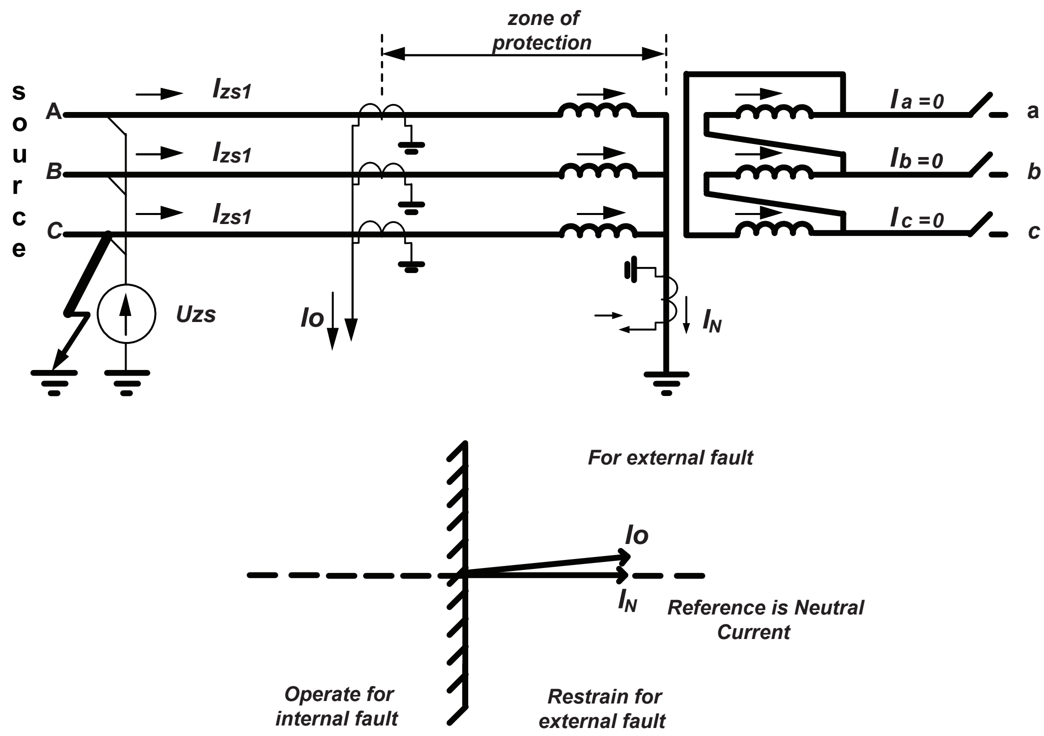


Figure 429: Current flow in all the CTs for an external fault

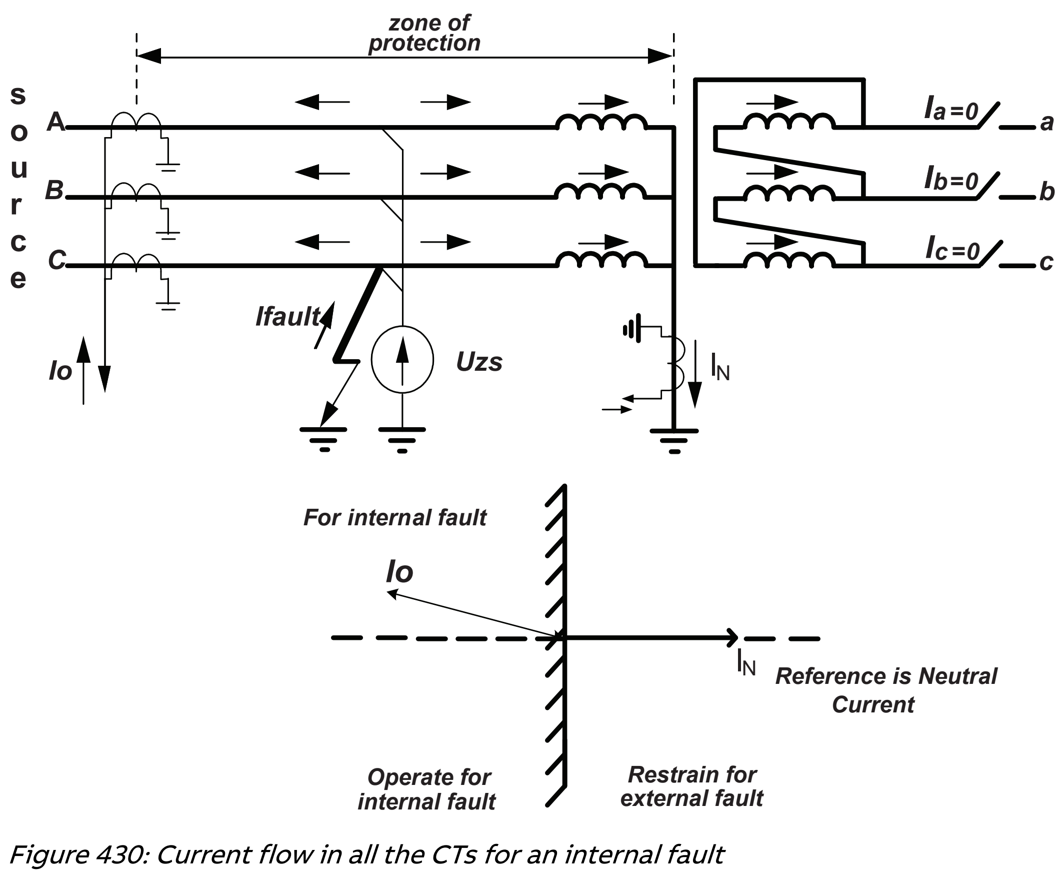


Figure 430: Current flow in all the CTs for an internal fault

LREFPNDF does not respond to phase-to-phase faults either, as in this case the fault current flows between the two line CTs and so the neutral CT does not experience this fault current.

Blocking based on the second harmonic of the neutral current

The transformer magnetizing inrush currents occur when the transformer is energized after a period of de-energization. The inrush current can be many times the rated current, and the halving time can be up to several seconds. For the differential protection relay, the inrush current represents the differential current, which causes the protection relay to operate almost always when the transformer is connected to the network. Typically, the inrush current contains a large amount of second harmonics.

The blocking also prevents unwanted operation at the recovery and sympathetic magnetizing inrushes. At the recovery inrush, the magnetizing current of the transformer to be protected increases momentarily when the voltage returns to normal after the clearance of a fault outside the protected area. The sympathetic inrush is caused by the energization of a transformer running in parallel with the protected transformer already connected to the network.

Blocking the starting of the restricted earth-fault protection at the magnetizing inrush is based on the ratio of the second harmonic and the fundamental frequency amplitudes of the neutral current Io_2H / Io. Typically, the second harmonic content of the neutral current at the magnetizing inrush is higher than that of the phase currents.

4.3.4.7 Signals

LREFPNDF Input signals

Table 680: LREFPNDF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

LREFPNDF Output signals

Table 681: LREFPNDF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLKD2H	BOOLEAN	2nd harmonic block

4.3.4.8 LREFPNDF Settings

Table 682: LREFPNDF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	5.0...50.0	%In	1.0	5.0	Operate value

Table 683: LREFPNDF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	40...300000	ms	1	40	Minimum operate time
Restraint mode	1=None 2=Harmonic2			1=None	Restraint mode
Start value 2.H	10...50	%	1	50	The ratio of the 2. harmonic to fundamental component required for blocking

Table 684: LREFPNDF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
CT connection type	1=Type 1 2=Type 2			2=Type 2	CT connection type

Table 685: LREFPNDF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.3.4.9 LREFPNDF Monitored data

Table 686: LREFPNDF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
RES2H	BOOLEAN	0=False 1=True		2nd harmonic restraint
ID_COSPHI	FLOAT32	0.00...80.00	xIn	Directional differential current Id cosphi
IB	FLOAT32	0.00...80.00	xIn	Bias current
LREFPNDF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.4.10 Technical data

Table 687: LREFPNDF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±2.5% of the set value or ±0.002 x I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Operate value*	37 ms	41 ms	45 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, …		

4.3.5 High-impedance based restricted earth-fault protection HREFPDIF (ANSI 87NHI)

4.3.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance based restricted earth-fault protection	HREFPDIF	dIoHi>	87NHI

4.3.5.2 Function block

Figure 431: Function block

4.3.5.3 Functionality

The high-impedance based restricted earth-fault protection function HREFPDIF is used for the restricted earth-fault protection of generators and power transformers.

The function starts when the differential neutral current exceeds the set limit. HREFPDIF operates with the DT characteristic.

[1] Current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.3.5.4 Analog channel configuration

HREFPDIF has one analog group input which must be properly configured.

Table 688: Analog inputs

Input	Description
IRES	Residual current (measured)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of HREFPDIF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

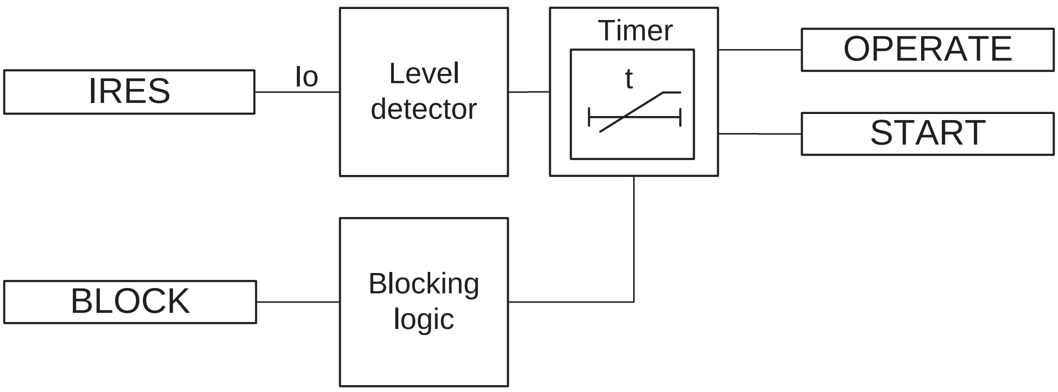


Figure 432: Functional module diagram

Level detector

The level detector compares the differential neutral current IDo to the set value of the *Operate value* setting. If the differential neutral current exceeds the *Operate value* setting, the level detector sends an enable signal to the timer module to start the definite timer.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration/System/ Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

4.3.5.6 Application

In solidly earthed systems, the restricted earth-fault protection is always deployed as a complement to the normal transformer differential protection. The advantage of the restricted earth-fault protection is its high sensitivity. Sensitivities of close to 1.0 percent can be achieved, whereas normal differential protection relays have their minimum sensitivity in the range of 5 to 10 percent. The level for HREFPDIF is dependent on the current transformers' magnetizing currents. The restricted earth-fault protection is also very fast due to the simple measuring principle as it is a unit type of protection.

The differences in measuring principle limit the biased differential protection relay's possibility to detect the earth faults. Such faults are then only detected by the restricted earth-fault function.

The restricted earth-fault protection relay is connected across each directly or to low-ohmic earthed transformer winding. If the same CTs are connected to other protection relays,, separate cores are to be used.

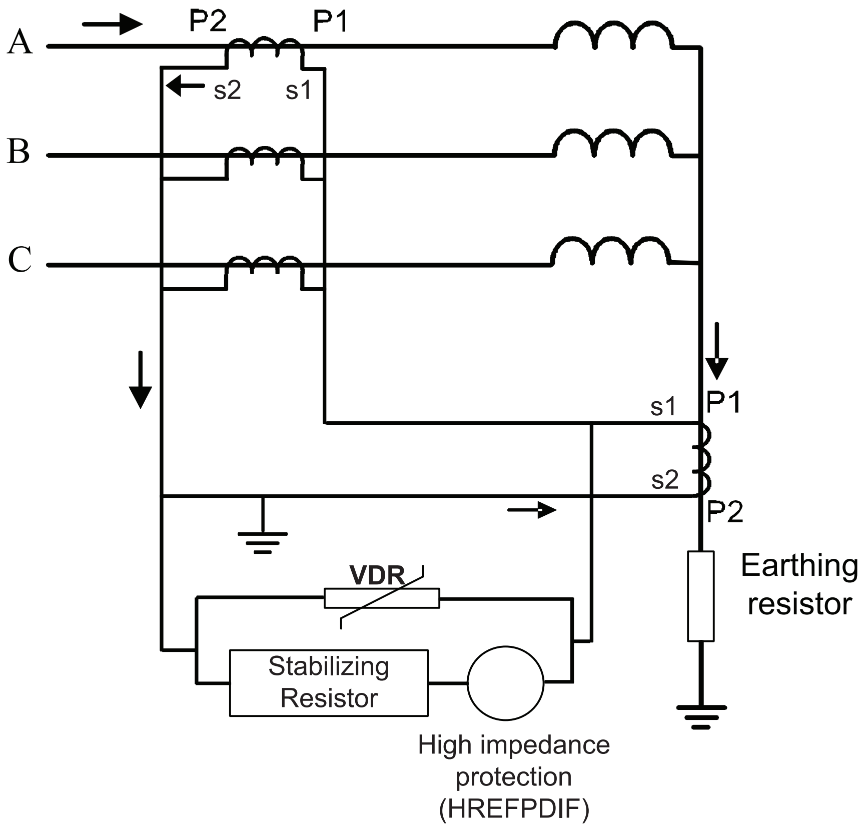


Figure 433: Connection scheme for the restricted earth-fault protection according to the high-impedance principle

High-impedance principle

High-impedance principle is stable for all types of faults outside the zone of protection. The stabilization is obtained by a stabilizing resistor in the differential circuit. This method requires that all the CTs used have a similar magnetizing characteristic, same ratio and relatively high knee point voltage. CTs on each sides are connected in parallel along with a relay-measuring branch as shown in *Figure 434*. The measuring branch is a series connection of stabilizing resistor and protection relay.

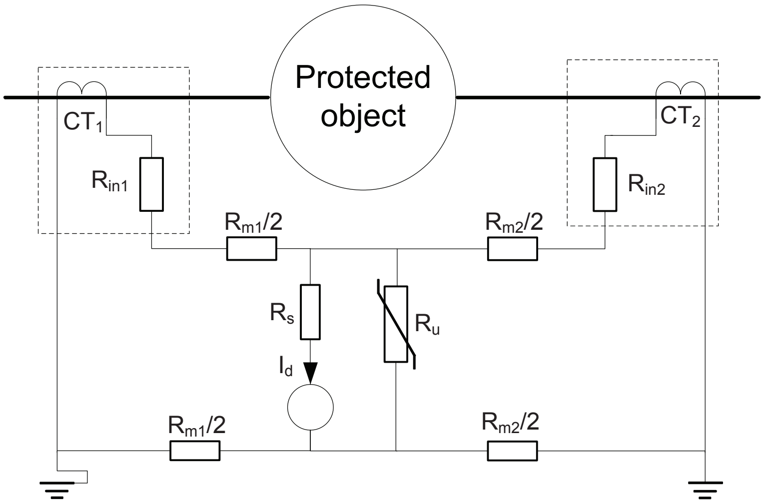


Figure 434: High-impedance principle

The stability of the protection is based on the use of the stabilizing resistor (Rs) and the fact that the impedance of the CT secondary quickly decreases as the CT saturates. The magnetization reactance of a fully saturated CT goes to zero and the impedance is formed only by the resistance of the winding (R_{in}) and lead resistance (R_m).

The CT saturation causes a differential current which now has two paths to flow: through the saturated CT because of the near-zero magnetizing reactance and through the measuring branch. The stabilizing resistor is selected as such that the current in the measuring branch is below the relay operating current during out-of-zone faults. As a result, the operation is stable during the saturation and can still be sensitive at the non-saturated parts of the current waveform as shown in *Figure 435*.

In case of an internal fault, the fault current cannot circulate through the CTs but it flows through the measuring branch and the protection operates. Partial CT saturation can occur in case of an internal fault, but the non-saturated part of the current waveform causes the protection to operate.

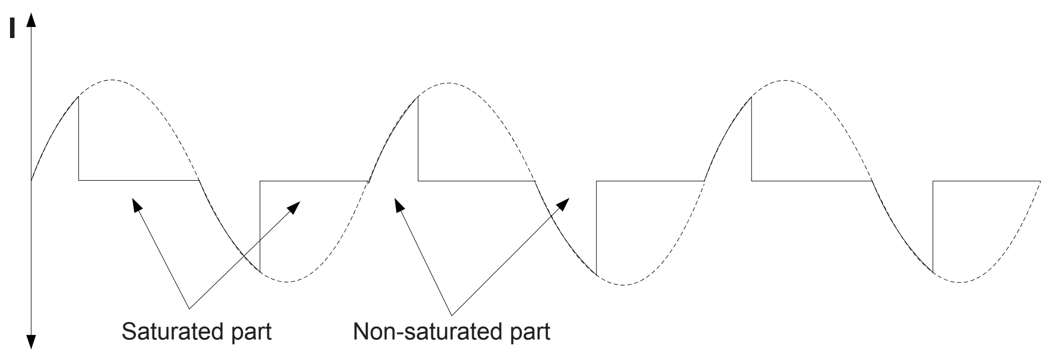


Figure 435: Secondary waveform of a saturated CT

At internal fault, the secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and IED. To limit this voltage, a voltage-dependent resistor VDR is used as shown in *Figure 434*.

The whole scheme, that is, the stabilizing resistor, voltage-dependent resistor and wiring, must be adequately maintained (operation- and insulation-tested regularly) to be able to withstand the high-voltage pulses which appear during an internal fault throughout the lifetime of the equipment. Otherwise, during a fault within the zone of protection, any flashover in the CT secondary circuits or in any other part of the scheme may prevent a correct operation of the high-impedance differential function.

4.3.5.7 The measuring configuration

The external measuring configuration is composed of four current transformers measuring the currents and a stabilizing resistor. A varistor is needed if high overvoltages are expected.

The value of the stabilizing resistor is calculated with the formula:

$$R_s = \frac{U_s}{I_{rs}}$$

(Equation 179)

R_s	the resistance of the stabilizing resistor
U_s	the stabilizing voltage of the IED
I_{rs}	the value of the *Low operate value* setting

The stabilizing voltage is calculated with the formula:

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 180)

I_{kmax}	the highest through-fault current
n	the turns ratio of the CT
R_{in}	the secondary internal resistance of the CT
R_m	the resistance of the longest loop of secondary circuit

Additionally, it is required that the current transformers' knee-point voltages U_k are at least twice the stabilizing voltage value U_s.

4.3.5.8 Recommendations for current transformers

The sensitivity and reliability of the protection depends a lot on the characteristics of the current transformers. The CTs must have an identical transformation ratio. It is recommended that all current transformers have an equal burden and characteristics and are of same type, preferably from the same manufacturing batch, that is, an identical construction should be used. If the CT characteristics and burden values are not equal, calculation for each branch in the scheme should be done separately and the worst-case result is then used.

First, the stabilizing voltage, that is, the voltage appearing across the measuring branch during the out-of-zone fault, is calculated assuming that one of the parallel connected CT is fully saturated. The stabilizing voltage can be calculated with the formula

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 181)

I_{kmax}	the highest through-fault current in primary amps. The highest earth-fault or short circuit current during the out-of-zone fault.
n	the turns ratio of the CT
R_{in}	the secondary internal resistance of the CT in ohms
R_m	the resistance (maximum of R_{in} + R_m) of the CT secondary circuit in ohms

The current transformers must be able to force enough current to operate the protection relay through the differential circuit during a fault condition inside the zone of protection. To ensure this, the knee point voltage U_{kn} should be at least two times higher than the stabilizing voltage U_s.

The required knee point voltage U_{kn} of the current transformer is calculated using the formula

$$U_{kn} \geq 2 \times U_s$$

(Equation 182)

U_{kn}	the knee point voltage
U_s	the stabilizing voltage

The factor two is used when no delay in the operating time of the protection in any situation is acceptable. To prevent the knee point voltage from growing too high, it is advisable to use current transformers, the secondary winding resistance of which is of the same size as the resistance of the measuring loop.

As the impedance of the protection relay alone is low, a stabilizing resistor is needed. The value of the stabilizing resistor is calculated with the formula

$$R_s = \frac{U_s}{I_{rs}}$$

(Equation 183)

R_s	the resistance of the stabilizing resistor
U_s	the stabilizing voltage of the protection relay
I_{rs}	the value of the *Operate value* setting in secondary amps.

The stabilizing resistor should be capable to dissipate high energy within a very short time; therefore, the wire wound-type resistor should be used. Because of the possible CT inaccuracy, which might cause some current through the stabilizing resistor in a normal load situation, the rated power should be 25 W minimum.

If U_{kn} is high or the stabilizing voltage is low, a resistor with a higher power rating is needed. Often resistor manufacturers allow 10 times rated power for 5 seconds. Thus the power of the resistor can be calculated with the equation

$$\frac{U_{kn}^2}{R_s \times 10}$$

(Equation 184)

The actual sensitivity of the protection is affected by the protection relay setting, the magnetizing currents of the parallel connected CTs and the shunting effect of the voltage-dependent resistor (VDR). The value of the primary current I_{prim} at which the protection relay operates at a certain setting can be calculated with the formula

$$I_{prim} = n \times (I_{rs} + I_u + m \times I_m)$$

(Equation 185)

I_{prim}	the primary current at which the protection is to start
n	the turn ratio of the current transformer
I_{rs}	the value of the *Operate value* setting
I_u	the leakage current flowing through the VDR at the U_s voltage
m	the number of current transformers included in the protection per phase (=4)
I_m	the magnetizing current per current transformer at the U_s voltage

The I_e value given in many catalogs is the excitation current at the knee point voltage. Assuming $U_{kn} \approx 2 \times U_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for *Equation 185*.

The selection of current transformers can be divided into procedures:

1. In principle, the highest through-fault should be known. However, when the necessary data are not available, approximates can be used:
   - Small power transformers: I_{kmax} = 16 x I_n (corresponds to z_k = 6% and infinite grid)
   - Large power transformers: I_{kmax} = 12 x I_n (corresponds to z_k = 8% and infinite grid)
   - Generators and motors: I_{kmax} = 6 x I_n

   Where I_n = rated current and z_k = short circuit impedance of the protected object
2. The rated primary current I_{1n} of the CT has to be higher than the rated current of the machine.

   The choice of the CT also specifies R_{in}.
3. The required U_{kn} is calculated with *Equation 182*. If the U_{kn} of the CT is not high enough, another CT has to be chosen. The value of the U_{kn} is given by the manufacturer in the case of Class X current transformers or it can be estimated with *Equation 186*.
4. The sensitivity I_{prim} is calculated with *Equation 185*. If the achieved sensitivity is sufficient, the present CT is chosen. If a better sensitivity is needed, a CT with a bigger core is chosen.

If other than Class X CTs are used, an estimate for U_{kn} is calculated with the equation

$$U_{kn} = 0.8 \times F_n \times I_{2n} \times \left(R_{in} + \frac{S_n}{I_{2n}^2} \right)$$

(Equation 186)

F_n	the rated accuracy limit factor corresponding to the rated burden S_n
I_{2n}	the rated secondary current of the CT
R_{in}	the secondary internal resistance of the CT
S_n	the volt-amp rating of the CT

The formulas are based on choosing the CTs according to *Equation 182*, which results an absolutely stable scheme. In some cases, it is possible to achieve stability with knee point voltages lower than stated in the formulas. The conditions in the network, however, have to be known well enough to ensure the stability.

1. If $U_k \geq 2 \times U_s$, fast protection relay operation is secure.
2. If $U_k \geq 1.5 \times U_s$ and $< 2 \times U_s$, protection relay operation can be slightly prolonged and should be studied case by case.

   If $U_k < 1.5 \times U_s$, the protection relay operation is jeopardized. Another CT has to be chosen.

The need for the VDR depends on certain conditions.

First, voltage U_{max}, ignoring the CT saturation during the fault, is calculated with the equation

$$U_{max} = \frac{I_{k\,max\,in}}{n} \times (R_{in} + R_m + R_s) \approx \frac{I_{k\,max\,in}}{n} \times R_s$$

(Equation 187)

I_{kmaxin}	the maximum fault current inside the zone, in primary amps
n	the turns ration of the CT
R_{in}	the internal resistance of the CT in ohms
R_m	the resistance of the longest loop of the CT secondary circuit, in ohms
R_s	the resistance of the stabilized resistor, in ohms

Next, the peak voltage û, which includes the CT saturation, is estimated with the formula (given by P.Mathews, 1955)

$$\hat{u} = 2\sqrt{2U_{kn}(U_{max} - U_{kn})}$$

(Equation 188)

U_{kn}	the knee point voltage of the CT

The VDR is recommended when the peak voltage û ≥ 2kV, which is the insulation level for which the protection relay is tested.

If R_s was smaller, the VDR could be avoided. However, the value of R_s depends on the protection relay operation current and stabilizing voltage. Thus, either a higher setting must be used in the protection relay or the stabilizing voltage must be lowered.

4.3.5.9 Setting examples

Example 1

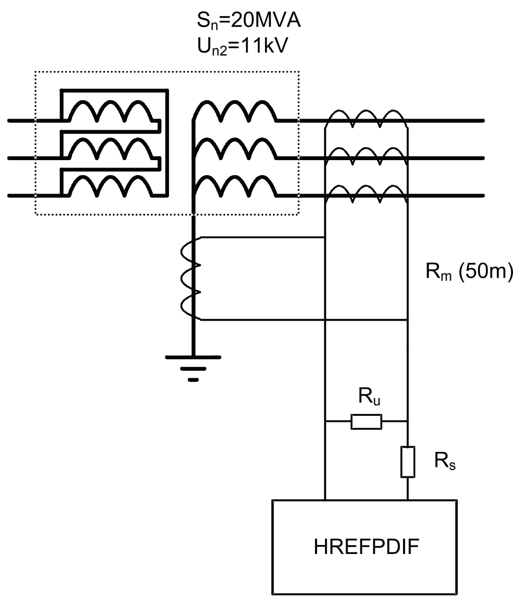


Figure 436: Restricted earth-fault protection of a transformer

The data for the protected power transformer are:

S_n = 20 MVA

U_{2n} = 11 kV

The longest distance of the secondary circuit is 50 m (the whole loop is 100 m) and the area of the cross section is 10 mm ^{2}.

$I_n = S_n / (\sqrt{3} \cdot U_n)$ = 1050 A

$I_{kmax} = 12 \cdot I_n$= 12600 A

In this example, the CT type is IHBF 12, the core size is 35 percent, the primary current is 1200 A and the secondary current is 5 A.

R_{in} = 0.26 Ω (value given by the manufacturer).

U_k = 40 V (value given by the manufacturer).

I_e = 0.055 A (value given by the manufacturer).

R_m = 1.81 Ω/km · 2 · 0.05 km = 0.181 Ω ≈ 0.18 Ω

$$U_s = \frac{12600 \times (0.26 + 0.18)}{240} V \approx 23V$$

According to the criterion, the value of U_k should be $2 \cdot U_s$ = 2 · 23 V = 46 V. It depends on if the stability of the scheme is achieved with U_k = 40 V. Otherwise, it is possible to choose a bigger core of 65 percent with:

R_{in} = 0.47 Ω (value given by the manufacturer).

U_k = 81 V (value given by the manufacturer).

R_m = 0.18 Ω

$$U_s = \frac{12600 \times (0.47 + 0.18)}{240} V \approx 34V$$

$U_k = 2 \cdot U_s = 68$ V (required value).

As mentioned earlier, $I_m = 0.5 \cdot I_e$ gives a realistic value for I_{prim} in *Equation 185*. If $I_u = 0$ and $I_{rs} = m \cdot 0.5 \cdot I_o$, the value for the sensitivity is:

$I_{prim} = n \cdot m \cdot I_e = 240 \cdot 4 \cdot 0.055$ A ≈ 53 A

$I_{rs} = 4 \cdot 0.5 \cdot 0.055$ A = 0.11 A

The setting value can be calculated with:

$$Operate\,value = \left(\frac{I_{rs}}{I_{CT\_n2}}\right) = \left(\frac{0.11A}{5A}\right) \approx 2.2\%$$

The resistance of the stabilizing resistor can be calculated:

$R_s = U_s / I_{rs} = 34$ V / 0.11 A ≈ 309 Ω

However, the sensitivity can be calculated more accurately when the actual values of I_u and I_{rs} are known. The stabilizing resistor of the relay is chosen freely in the above example and it is assumed that the resistor value is not fixed.

Example 2a

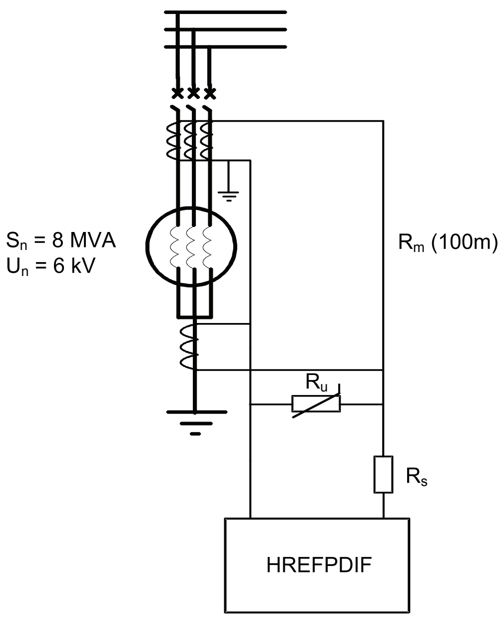


Figure 437: Restricted earth-fault protection of a generator

In the protected generator:

$S_n = 8$ MVA

$U_n = 6$ kV.

I_n = 770 A

$I_{kmax} = 6 \cdot I_n = 6 \cdot 770$ A = 4620 A

In this example, the CT type is KOFD 12 A 21 with:

I_{CT_1n} = 1000 A (value given by the manufacturer).

I_{CT_2n} = 1 A (value given by the manufacturer).

U_k = 323 V (value given by the manufacturer).

R_{in} = 15.3 Ω (value given by the manufacturer).

I_e = 0.012 A (value given by the manufacturer).

If the length of the secondary circuit is 100 m (the whole loop is 200 m) and the area of the cross section is 2.5 mm ^{2}:

$R_m = 7.28\ \Omega/\text{km} \cdot 2 \cdot 0.1\ \text{km} \approx 1.46\ \Omega$

The required knee-point voltage can be calculated using equation

$U_k = 2 \cdot (4620\ \text{A} / 1000) \cdot (15.3 + 1.46) \approx 155$ V.

The value 155 V is lower than the value 323 V, which means that the value of U_k is high enough.

As mentioned earlier, $I_m = 0.5 \cdot I_e$ gives a realistic value for I_{prim} in *Equation 185*. If $I_u = 0$ and $I_{rs} = m \cdot 0.5 \cdot I_e$, the value for the sensitivity is:

$I_{prim} = n \cdot m \cdot I_e = 1000 \cdot 4 \cdot 0.012$ A = 48 A (≈ 6 % x I_n).

$I_{rs} = 4 \cdot 0.5 \cdot 0.012$ A = 0.024 A.

The setting value can be calculated with:

$$Operate\,value = \left(\frac{I_{rs}}{I_{CT\_2n}}\right) = \left(\frac{0.024\,A}{1A}\right) \approx 2.4\%$$

The resistance of the stabilizing resistor can now be calculated:

$R_s = U_s / I_{rs} = 78\ \text{V} / (2 \cdot I_e) = 78\ \text{V} / (2 \cdot 0.012\ \text{A}) = 3250\ \Omega$.

Example 2b

In this example, I_{rs} = 4 x 12 mA = 48 mA and I_u = 30 mA. This results in the sensitivity:

$I_{prim} = n \cdot (I_{rs} + I_u + m \cdot I_m) = 1000 \cdot (48 + 30 + 24)$ mA = 102 A

The setting value can be calculated with:

$$Operate\,value = \left(\frac{I_{rs}}{I_{CT\_2n}}\right) = \left(\frac{0.048\,A}{1A}\right) \approx 4.8\%$$

The resistance of the stabilizing resistor is now:

$R_s = U_s / I_{rs} = 78\ \text{V} / 48\ \text{mA} \approx 1630\ \Omega$

In this example, the relay is of such a type that the stabilizing resistor can be chosen freely.

4.3.5.10 Signals

HREFPDIF Input signals

Table 689: HREFPDIF Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

HREFPDIF Output signals

Table 690: HREFPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.5.11 Settings

HREFPDIF Settings

Table 691: HREFPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...50.0	%In	0.1	5.0	Low operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	1	20	Minimum operate time

Table 692: HREFPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 693: HREFPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.3.5.12 Monitored data

HREFPDIF Monitored data

Table 694: HREFPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HREFPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.5.13 Technical data

Table 695: HREFPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Operate value*	16 ms	21 ms	23 ms
	I_{Fault} = 10.0 × set *Operate value*	11 ms	13 ms	14 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		

4.3.6 High-impedance differential protection HIxPDIF (ANSI 87_A, 87_B, 87_C)

1 Current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2 Includes the delay of the signal output contact.

4.3.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance differential protection for phase A	HIAPDIF	dHi_A>	87_A
High-impedance differential protection for phase B	HIBPDIF	dHi_B>	87_B
High-impedance differential protection for phase C	HICPDIF	dHi_C>	87_C

4.3.6.2 Function block

Figure 438: Function block

4.3.6.3 Functionality

The high-impedance differential protection function HIxPDIF is a general differential protection. It provides a phase-segregated short circuit protection for the busbar. However, the function can also be used for providing generator, motor, transformer and reactor protection.

The function starts and operates when the differential current exceeds the set limit. The operate time characteristics are according to definite time (DT).

The function contains a blocking functionality. It is possible to block the function outputs, timer or the whole function.

4.3.6.4 Analog channel configuration

HIxPDIF has one analog group input which must be properly configured.

Table 696: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.6.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of HIxPDIF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

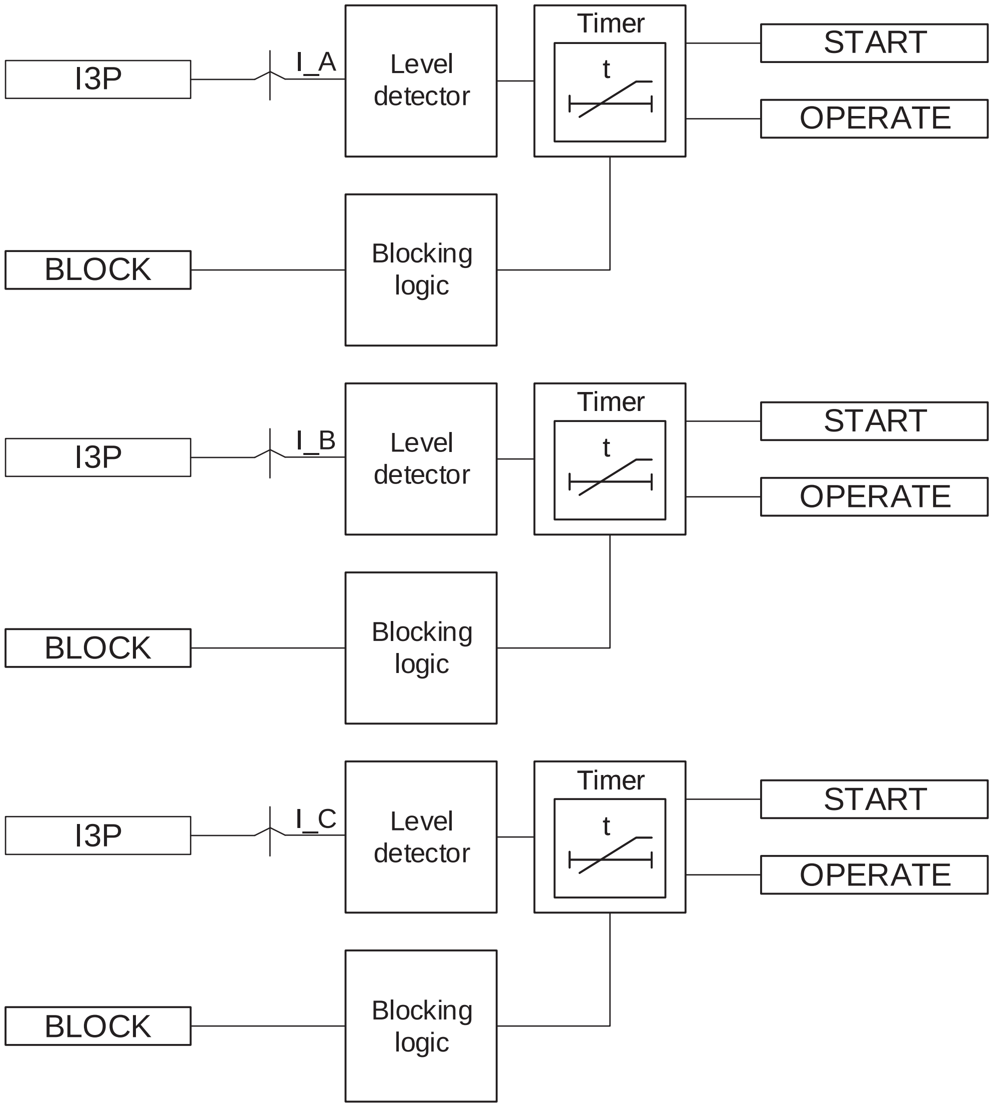


Figure 439: Functional module diagram

The module diagram illustrates all the phases of the function. Functionality for phases A, B and C is identical.

All three phases have independent settings.

Level detector

The module compares differential currents I_A calculated by the peak-to-peak measurement mode to the set *Operate value*. The Timer module is activated if the differential current exceeds the value of the *Operate value* setting.

Timer

Once activated, Timer activates the START output. The time characteristic is according to DT. When the operation timer reaches the value set by *Minimum operate time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

Timer calculates the start duration START_DUR value, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the Monitored data view.

The activation of the BLOCK input resets Timer and deactivates the START and OPERATE outputs.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.3.6.6 Application

HIxPDIF provides a secure and dependable protection scheme against all types of faults. The high-impedance principle is used for differential protection due to its capability to manage the through-faults also with the heavy current transformer (CT) saturation.

For current transformer recommendations, see the Requirements for measurement transformers section in this manual.

High-impedance principle

The phase currents are measured from both the incoming and the outgoing feeder sides of the busbar. The secondary of the current transformer in each phase is connected in parallel with a protection relay measuring branch. Hence, the relay measures only the difference of the currents. In an ideal situation, there is a differential current to operate the relay only if there is a fault between the CTs, that is, inside the protected zone.

If there is a fault outside the zone, a high current, known as the through-fault current, can go through the protected object. This can cause partial saturation in the CTs. The relay operation is avoided with a stabilizing resistor (R_s) in the protection relay measuring branch. R_s increases the impedance of the protection relay; hence the name high-impedance differential scheme.

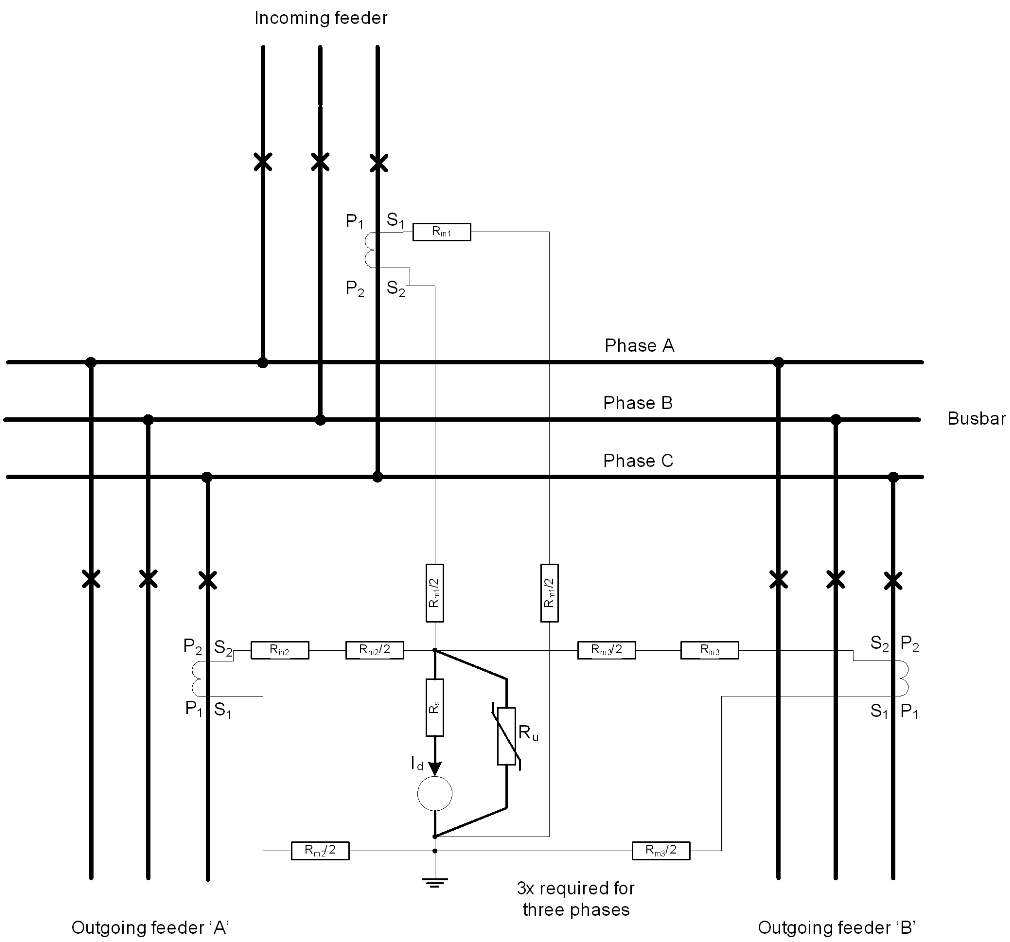


Figure 440: Phase-segregated bus differential protection based on high-impedance principle

CT secondary winding resistances (R_{in}) and connection wire resistances ($R_m/2$) are also shown in *Figure 441*.

Figure 441 demonstrates a simplified circuit consisting only of one incoming and outgoing feeder. To keep it simple, the voltage-dependent resistor (R_u) is not included. The wiring resistances are presented as total wiring resistances R_{m1} and R_{m2}.

R_{m1} is the maximum wiring resistance concerning all incoming feeder sets, whereas R_{m2} is the maximum wiring resistance concerning all outgoing feeder sets.

The lower part of *Figure 441* shows the voltage balance when there is no fault in the system and no CT saturation.

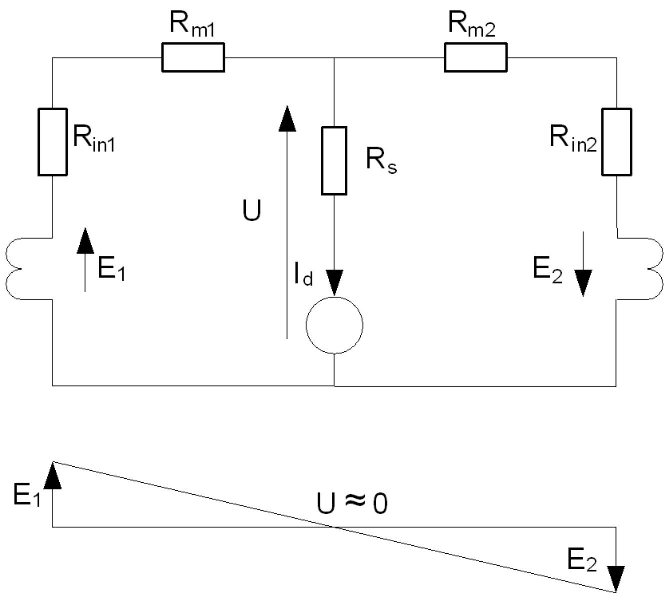


Figure 441: Equivalent circuit when there is no fault or CT saturation

When there is no fault, the CT secondary currents and their emf voltages, E_1 and E_2, are opposite and the protection relay measuring branch has no voltage or current. If an in-zone fault occurs, the secondary currents have the same direction. The relay measures the sum of the currents as a differential and trips the circuit breaker. If the fault current goes through only one CT, its secondary emf magnetizes the opposite CT, that is, $E_1 \approx E_2$.

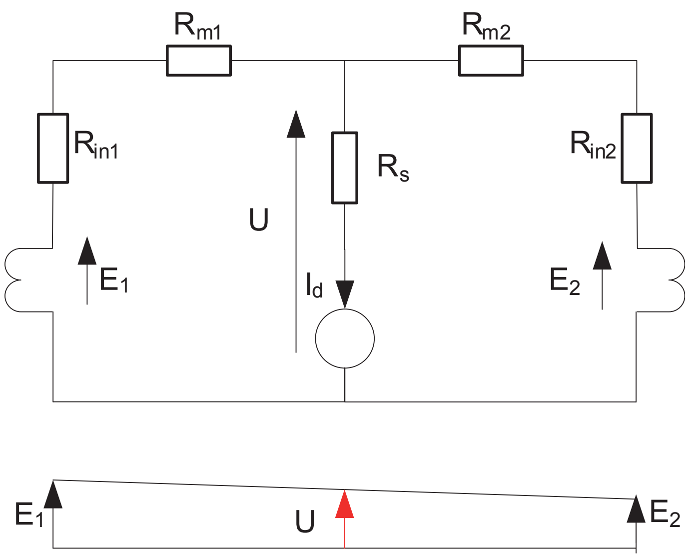


Figure 442: Equivalent circuit in case of in-zone fault

Figure 443 shows CT saturation at a through-fault, that is, out-of-zone, situation. The magnetization impedance of a saturated CT is almost zero. The saturated CT winding can be presented as a short circuit. When one CT is saturated, the current of the non-saturated CT follows two paths, one through the protection relay measuring branch (R_s + relay) and the other through the saturated CT ($R_m + R_{in2}$).

The protection relay must not operate during the saturation. This is achieved by increasing the relay impedance by using the stabilizing resistor (R_s) which forces the majority of the differential current to flow through the saturated CT. As a result, the relay operation is avoided, that is, the relay operation is stabilized against the CT saturation at through-fault current. The stabilizing voltage U_s is the basis of all calculations.

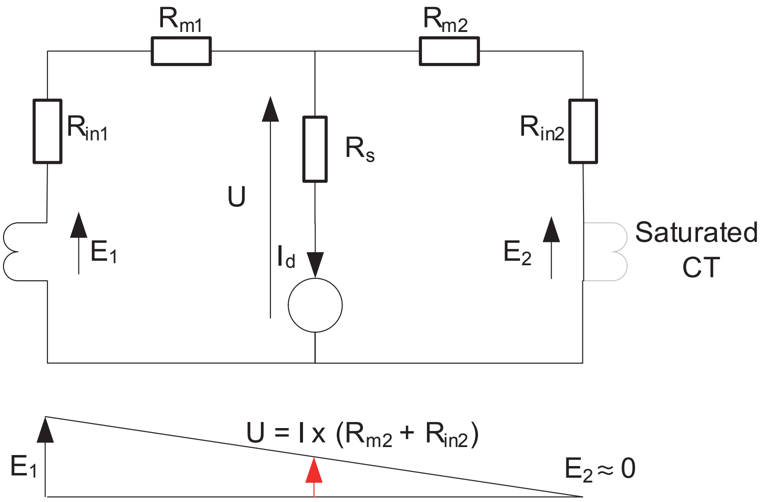


Figure 443: Equivalent circuit in case of the CT saturation at through-fault

The CT saturation happens most likely in the case of an in-zone fault. This is not a problem, because although the operation remains stable (non-operative) during the saturated parts of the CT secondary current waveform, the non-saturated part of the current waveform causes the protection to operate.

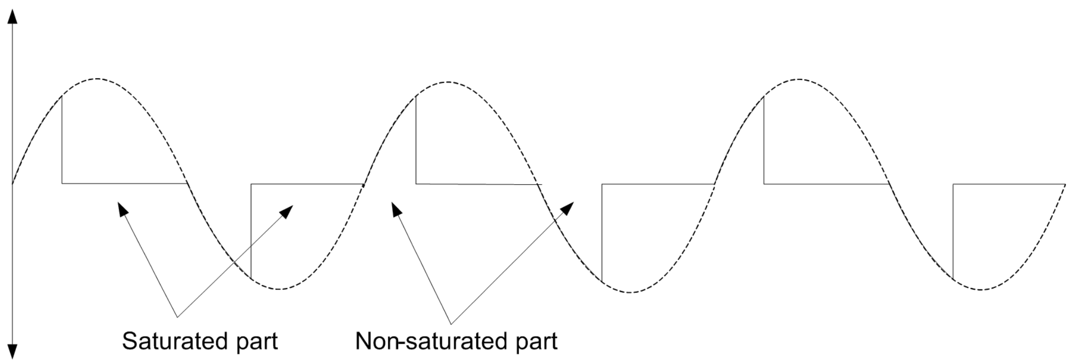


Figure 444: Secondary waveform of a saturated CT

The secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and the protection relay because of the stabilizing resistance and CT saturation. A voltage dependent resistor (VDR, R_u) is used to limit the voltage as shown in *Figure 440*.

Busbar protection scheme

The basic concept for any bus differential protection relay is a direct use of Kirchoff's first law that the sum of all currents connected to one differential protection zone is zero. If the sum is not zero, an internal fault has occurred. In other words, as seen by the busbar differential protection, the sum of all currents that flow into the protection zone, that is, currents with positive value, must be equal to currents that flow out of the protection zone, that is, currents with negative value, at any instant of time.

Figure 445 shows an example of a phase segregated single busbar protection employing high-impedance differential protection. The example system consists of a single incoming busbar feeder and two outgoing busbar feeders. The CTs from both the outgoing busbar feeders and the incoming busbar feeders are connected in parallel with the polarity. During normal load conditions, the total instantaneous incoming current is equal to the total instantaneous outgoing current and the difference current is negligible. A fault in the busbar results in an imbalance between the incoming and the outgoing current. The difference current flows through the protection relay, which generates a trip signal.

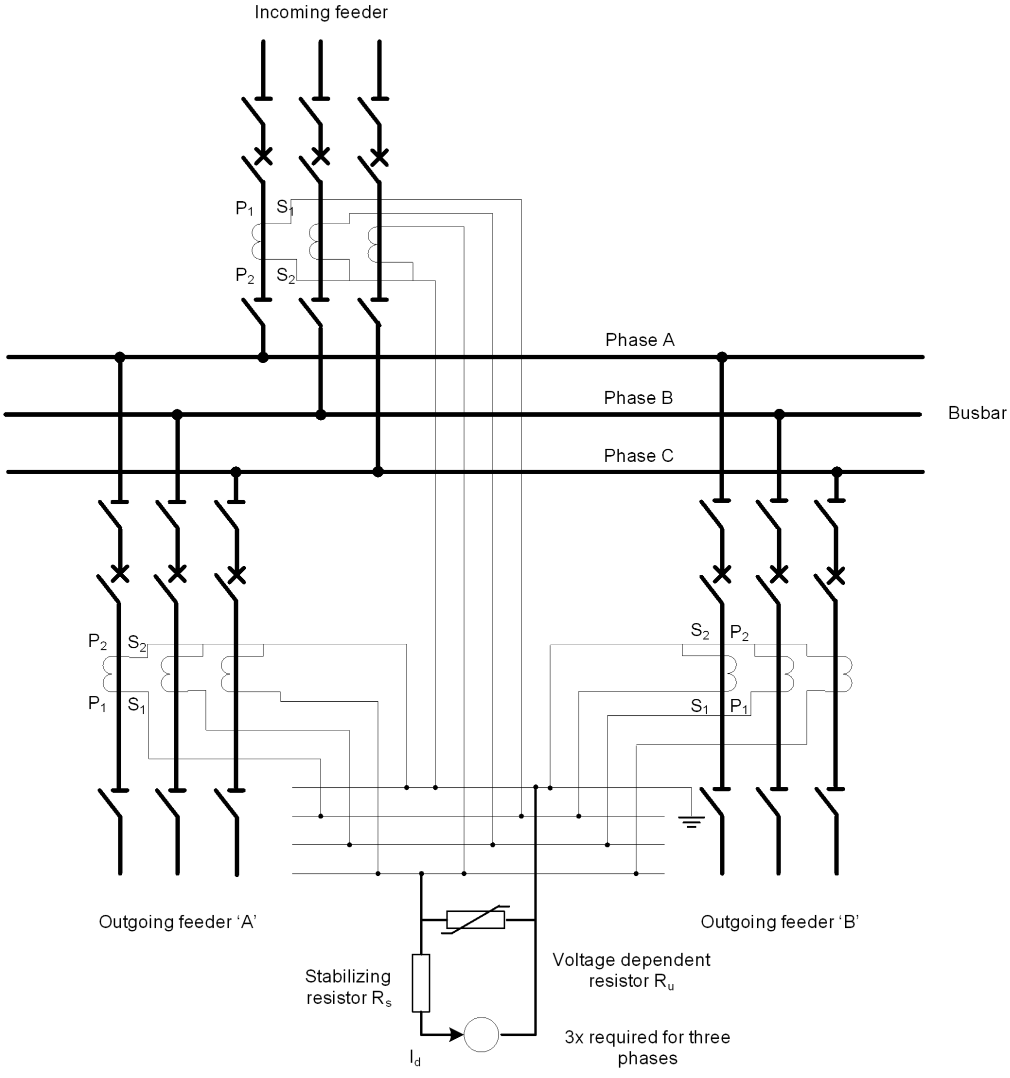


Figure 445: Phase-segregated single busbar protection employing high-impedance differential protection

Figure 446 shows an example for a system consisting of two busbar section coupled with a bus coupler. Each busbar section consists of two feeders and both sections are provided with a separate differential protection to form different zones. The formed zones overlap at the bus coupler.

When the bus coupler is in the open position, each section of the busbar handles the current flow independently, that is, the instantaneous incoming current is equal to the total instantaneous outgoing current and the difference current is negligible. The difference current is no longer zero with a fault in the busbar and the protection operates.

With the bus coupler in the closed position, the current also flows from one busbar section to another busbar section. Thus, the current flowing through the bus coupler needs to be considered in calculating differential current. During normal condition, the summation of the current on each bus section is zero. However, if there is a fault in any busbar section, the difference current is no longer zero and the protection operates.

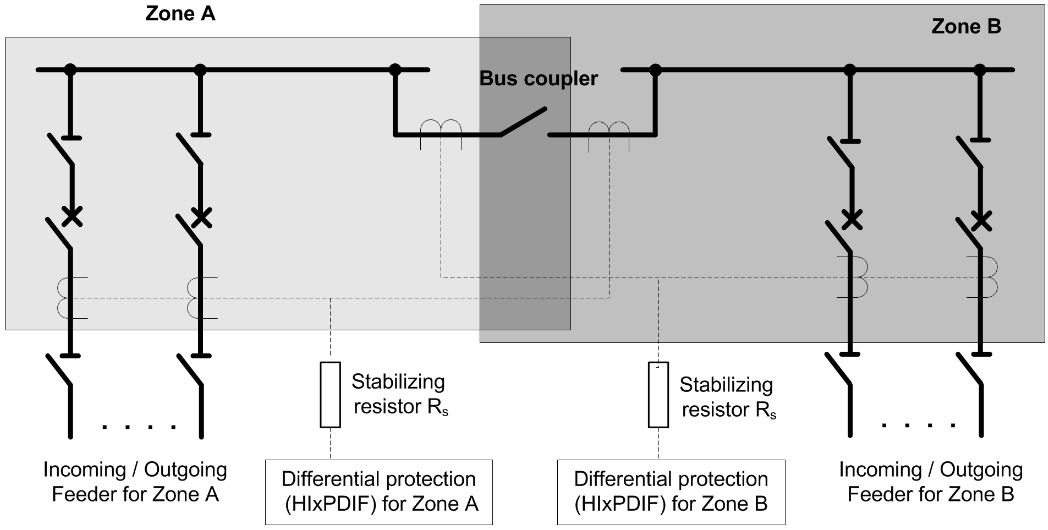


Figure 446: Differential protection on busbar with bus coupler (Single-phase representation)

4.3.6.7 Example calculations for busbar high-impedance differential protection

The protected object in the example for busbar differential protection is a single-bus system with two zones of protection.

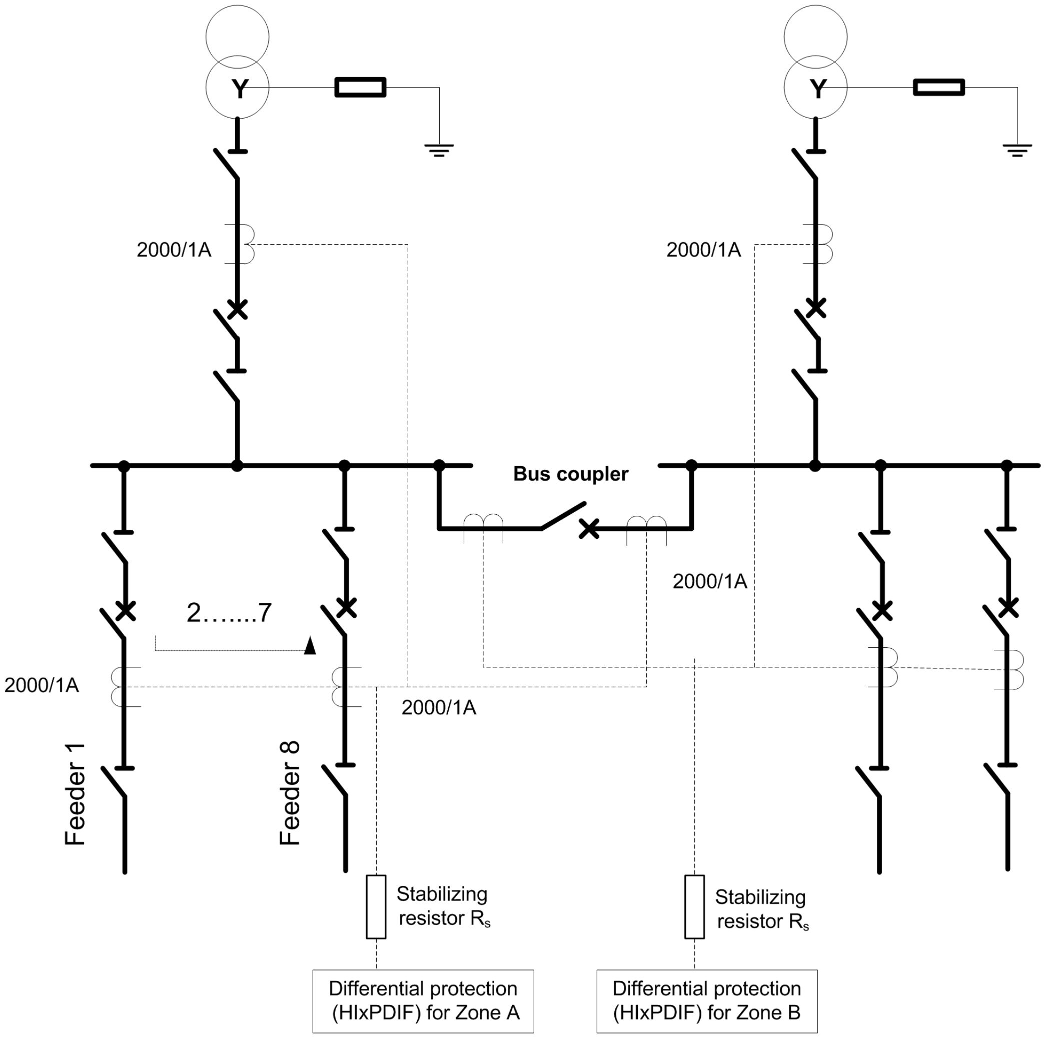


Figure 447: Example for busbar differential protection

Bus data:

U_n	20 kV
I_n	2000 A
I_{kmax}	25 kA

10 feeders per protected zone including bus coupler and incomer.

CT data is assumed to be:

CT	2000/1 A
R_{in}	15.75 Ω
U_{kn}	436 V
I_e	<7 mA (at U_{kn})
R_m	1Ω

The stabilizing voltage is calculated using the formula:

$$U_s = \frac{25000A}{2000}(15.75\Omega + 1.\Omega) \approx 209.37\ V$$

(Equation 189)

In this case, the requirement for the current transformer knee point voltage is fulfilled because $U_{kn} > 2U_s$.

The magnetizing curve of the CT is assumed to be linear. The magnetizing current at the stabilizing voltage can be estimated as:

$$I_m = \frac{U_s}{U_{kn}} \cdot I_e$$

(Equation 190)

$$I_m = \frac{209.37V}{436V} \cdot 7mA \approx 3.4mA$$

(Equation 191)

To obtain adequate protection stability, the setting current I_{rs} must be at the minimum of the sum of magnetizing currents of all connected CTs.

$$I_{rs} = 10 \cdot 3.4mA \approx 34\,mA$$

(Equation 192)

The resistance of the stabilizing resistor is calculated based on *Equation 193*.

$$R_S = \frac{209.37\ V}{0.034A} \approx 6160\,\Omega$$

(Equation 193)

The calculated value is the maximum value for the stabilizing resistor. If the value is not available, the next available value below should be selected and the protection relay setting current is tuned according to the selected resistor. For example, in this case, the resistance value 5900 Ω is used.

$$I_{rs} = \frac{209.37V}{5900\,\Omega} \approx 35\,mA$$

(Equation 194)

The sensitivity of the protection is obtained as per *Equation 195*, assuming $I_u = 0$.

$$I_{prim} = 2000 \cdot (0.035\,A + 10 \cdot 0.0034\,A + 0\,A) \approx 140A$$

(Equation 195)

The power of the stabilizing resistor is calculated:

$$P \geq \frac{(436V)^2}{5900\Omega} \approx 32W$$

(Equation 196)

Based on *Equation 197* and *Equation 198*, the need for voltage-dependent resistor is checked.

$$U_{max} = \frac{25000A}{2000}(5900\Omega + 15.75\Omega + 1.00\Omega) \approx 74.0kV$$

(Equation 197)

$$\breve{u} = 2 \cdot \sqrt{2 \cdot 436V \cdot (74000V - 436V)} \approx 16.0kV$$

(Equation 198)

The voltage-dependent resistor (one for each phase) is needed in this case as the voltage during the fault is higher than 2 kV.

The leakage current through the VDR at the stabilizing voltage can be available from the VDR manual, assuming that to be approximately 2 mA at stabilizing voltage

$$Iu \approx 0.002A$$

(Equation 199)

The sensitivity of the protection can be recalculated taking into account the leakage current through the VDR as per *Equation 200*.

$$I_{prim} = 2000 \cdot (0.035A + 10 \cdot 0.0034A + 0.002A) \approx 142A$$

(Equation 200)

4.3.6.8 Signals

HIAPDIF Input signals

Table 697: HIAPDIF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

HIBPDIF Input signals

Table 698: HIBPDIF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

HICPDIF Input signals

Table 699: HICPDIF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

HIAPDIF Output signals

Table 700: HIAPDIF Output signals

Name	Type	Description
START	BOOLEAN	Start
OPERATE	BOOLEAN	Operate

HIBPDIF Output signals

Table 701: HIBPDIF Output signals

Name	Type	Description
START	BOOLEAN	Start
OPERATE	BOOLEAN	Operate

HICPDIF Output signals

Table 702: HICPDIF Output signals

Name	Type	Description
START	BOOLEAN	Start
OPERATE	BOOLEAN	Operate

4.3.6.9 Settings

HIAPDIF Settings

Table 703: HIAPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...200.0	%In	1.0	5.0	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 704: HIAPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 705: HIAPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

HIBPDIF Settings

Table 706: HIBPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...200.0	%In	1.0	5.0	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 707: HIBPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 708: HIBPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

HICPDIF Settings

Table 709: HICPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	1.0...200.0	%In	1.0	5.0	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 710: HICPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				

Table 711: HICPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

4.3.6.10 Monitored data

HIAPDIF Monitored data

Table 712: HIAPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HIAPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

HIBPDIF Monitored data

Table 713: HIBPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HIBPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

HICPDIF Monitored data

Table 714: HICPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
HICPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.6.11 Technical data

Table 715: HIxPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Start value*	8 ms	11 ms	19 ms
	I_{Fault} = 10 × set *Start value*	7 ms	9 ms	11 ms
Reset time		Typically <40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		

1 *Measurement mode* = default (depends on stage), current before fault = 0.0 × I_n, f_n = 50 Hz, fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.

2 Measured with static signal output (SSO).

4.3.7 Stabilized and instantaneous differential protection for machines MPDIF (ANSI 87M/87G)

4.3.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Stabilized and instantaneous differential protection for machines	MPDIF	3dI>G/M	87M/87G

4.3.7.2 Function block

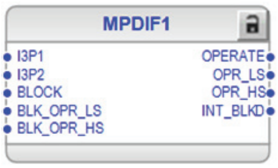


Figure 448: Function block

4.3.7.3 Functionality

The stabilized and instantaneous differential protection for machines function MPDIF is a unit protection function. The possibility of internal failures of the machine is relatively low. However, the consequences in terms of cost and production loss are often serious, which makes the differential protection an important protection function.

The stability of the differential protection is enhanced by a DC restraint feature. This feature decreases the sensitivity of the differential protection optionally for a temporary time period to avoid an unnecessary disconnection of the machine during the external faults that have a fault current with high DC currents. MPDIF also includes a CT saturation-based blocking which prevents unnecessary tripping in case of the detection of the magnetizing inrush currents which can be present at the switching operations, overvoltages or external faults.

4.3.7.4 Analog channel configuration

MPDIF has two analog group inputs which must be properly configured.

Table 716: Analog inputs

Input	Description
I3P1	Three-phase currents
I3P2	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.7.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MPDIF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

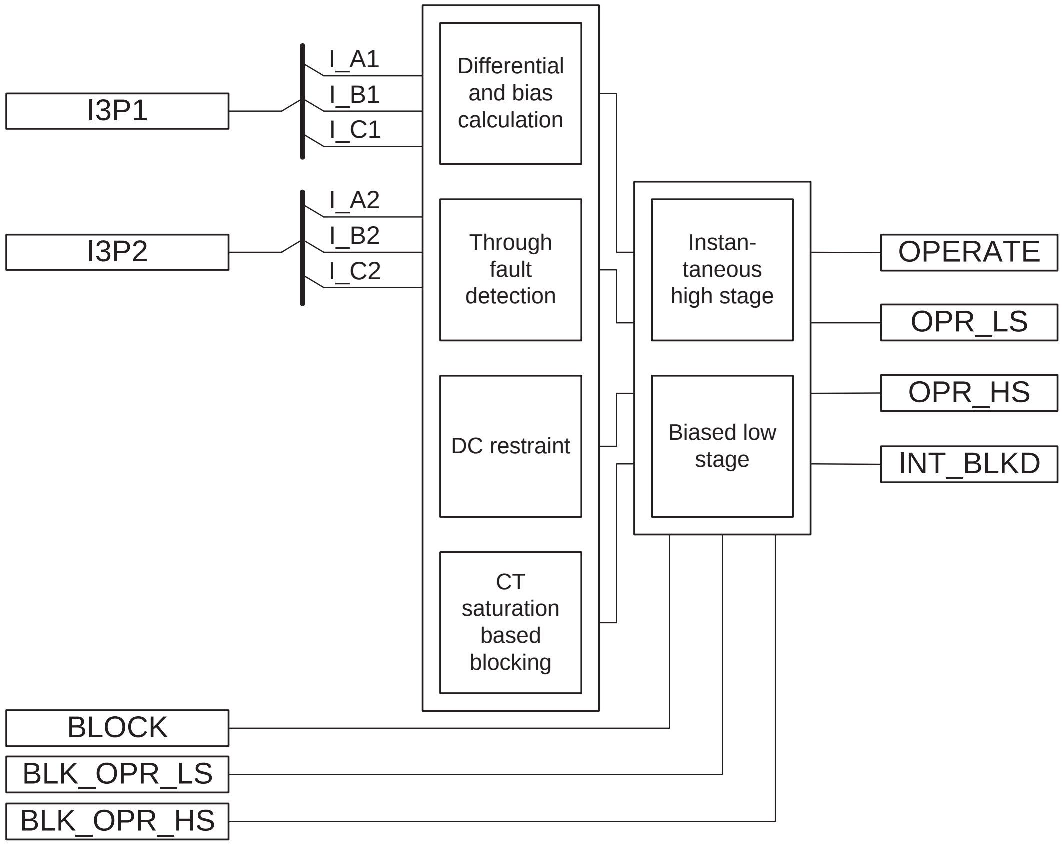


Figure 449: Functional module diagram

Differential and bias calculation

Differential calculation module calculates the differential current. The differential current is the difference in current between the phase and neutral sides of the machine.

The phase currents $\bar{I}_1$ and $\bar{I}_2$ denote the fundamental frequency components on the phase and neutral sides of the current. The amplitude of the differential current I_d is obtained using the equation (assuming that the positive direction of the current is towards the machine):

$$I_d = \left|\bar{I}_1 + \bar{I}_2\right|$$

(Equation 201)

During normal conditions, there is no fault in the area protected by the function block, so the currents $\bar{I}_1$ and $\bar{I}_2$ are equal and the differential current $I_d = 0$. However, in practice some differential current exists due to inaccuracies in the current transformer on the phase and neutral sides, but it is very small during normal conditions.

The module calculates the differential current for all three phases.

The low-stage differential protection is stabilized with a bias current. The bias current is also known as the stabilizing current. Stabilization means that the differential current required for tripping increases according to the bias current and the operation characteristics. When an internal fault occurs, the currents on both sides of the protected object are flowing into it. This causes the biasing current to be considerably smaller, which makes the operation more sensitive during internal faults.

The traditional way for calculating the stabilized current is:

$$I_b = \left|\frac{\bar{I}_1 - \bar{I}_2}{2}\right|$$

(Equation 202)

The module calculates the bias current for all three phases.

Through-fault detection

Through-fault (TF) detection module is for detecting whether the fault is external, that is, going through, or internal. This information is essential for ensuring the correct operation of the protection in case of the CT saturation.

- In a through-fault situation, CTs can saturate because of a high fault current magnitude. Such AC saturation does not happen immediately when the fault begins. Thus, the TF module sees the fault as external because the bias current is high but the differential current remains low. If the AC saturation then occurs, a CT saturation-based blocking is allowed to work to prevent tripping.
- Normally, the phase angle between the machine neutral and line side CTs is 180 degrees. If an internal fault occurs during a through fault, an angle less than 50 degrees clearly indicates an internal fault and the TF module overrules, that is, deblocks the presence of any blocking due to CT saturation.

CT saturation-based blocking

Higher currents during the motor startup or abnormally high magnetizing currents at an overvoltage (transformer-fed motor) or an external fault may saturate the current transformers. The uneven saturation of the star and line side CTs (for example, due to burden differences) may lead to a differential current which can cause a differential protection to operate. This module blocks the operation of MPDIF biased low stage internally in case of the CT saturation. Once the blocking is activated, it is held for a certain time after the blocking conditions have ceased to be fulfilled.

DC restraint

On detection of a DC component, the function temporarily desensitizes the differential protection. The functioning of this module depends on the *DC restrain Enable* setting. The DC components are continuously extracted from the three instantaneous differential currents. The highest DC component of all three is taken as a kind of DC restraint in a sense that the highest effective, temporary sensitivity of the protection is temporarily decreased as a function of this highest DC offset. The calculated DC restraint current is not allowed to decay (from its highest ever measured value) faster than with a time constant of one second. The value of the temporarily effective sensitivity limit is limited upwards to the rated current of the machine or 3.3 times that of *Low operate value*, whichever is smaller. The temporary extra limit decays exponentially from its maximum value with a time constant of one second.

This feature should be used in case of networks where very long time constants are expected. The temporary sensitivity limit is higher to the set operating characteristics. In other words, the temporary limit has superposed the unchanged operating characteristics and temporarily determines the highest sensitivity of the protection. The temporary sensitivity is less than the sensitivity in section 1 of the operating characteristic and is supposed to prevent an unwanted trip during the external faults with lower currents.

Biased low stage

The current differential protection needs to be biased because of the possible appearance of a differential current which can be due to something else than an actual fault in the machine. In case of differential protection, a false differential current can be caused by:

- CT errors
- CT saturation at high currents passing through the machine

The differential current caused by CT errors increases at the same percent ratio as the load current.

The high currents passing through the protected object can be caused by the through fault. Therefore, the operation of the differential protection is biased with respect to the load current. In the biased differential protection, the higher the differential current required for the protection of operation, the higher the load current.

Based on the conditions checked from the through-fault module, the DC (component) detection module and the CT saturation-based blocking modules, the biased low-stage module decides whether the differential current is due to the internal faults or some false reason. In case of detection of the TF, DC or CT saturation, the internal differential blocking signal is generated, which in turn blocks the operating signal. In case of internal faults, the operation of the differential protection is affected by the bias current.

The *Low operate value* setting for the stabilized stage of the function block is determined with the equation:

$$Low\,operate\,value = I_{d1}$$

(Equation 203)

The *Slope section 2* and *Slope section 3* settings are determined correspondingly:

$$Slope\,section\,2 = \frac{I_{d2}}{I_{b2}} \cdot 100\%$$

(Equation 204)

$$Slope\,section\,3 = \frac{I_{d3}}{I_{b3}} \cdot 100\%$$

(Equation 205)

The end of the first section *End section 1* can be set at a desired point within the range of 0 to 100 percent (or % I_r). Accordingly, the end of the second section *End section 2* can be set within the range of 100 percent to 300 percent (or % I_r).

The slope of the operating characteristic for the function block varies in different parts of the range.

In section 1, where $0.0 < I_b/I_n <$ *End section 1*, the differential current required for tripping is constant. The value of the differential current is the same as the *Low operate value* setting selected for the function block. The *Low operate value* setting allows for small inaccuracies of the current transformers but it can also be used to influence the overall level of the operating characteristic.

Section 2, where *End section 1* $< I_b/I_n <$ *End section 2*, is called the influence area of the setting *Slope section 2*. In this section, variations in *End section 2* affect the slope of the characteristic, that is, how big the change in the differential current required for tripping is in comparison to the change in the load current. The *End section 2* setting allows for CT errors.

In section 3, where $I_b/I_n >$ *End section 2*, the slope of the characteristic can be set by *Slope section 3* that defines the increase in the differential current to the corresponding increase in the biasing current.

The required differential current for tripping at a certain stabilizing current level can be calculated using the formulae:

For a stabilizing current lower than *End section 1*

$$I_{doperate}[\%I_r] = Set\,Low\,operate\,value$$

(Equation 206)

For a stabilizing current higher than *End section 1* but lower than *End section 2*

$$I_{doperate}[\%I_r] = Low\,operate\,value + (I_b[\%Ir] - End\,section\,1) \cdot Slope\,section\,2$$

(Equation 207)

For higher stabilizing current values exceeding *End section 2*

$$I_{d\,operate}[\%I_r] = Low\,operate\,value + (End\,section\,2 - End\,section\,1) \cdot Slope\,section\,2 + (I_b\,[\%I_r] - End\,section\,2) \cdot Slope\,section\,3$$

(Equation 208)

When the differential current exceeds the operating value determined by the operating characteristics, the OPR_LS output is activated. The OPERATE output is always activated when the OPR_LS output activates.

The operate signal due to the biased stage can be blocked by the activation of the BLK_OPR_LS or BLOCK input. Also, when the operation of the biased low stage is blocked by the waveform blocking functionality, the INT_BLKD output is activated according to the phase information.

The phase angle difference between the two currents I_A1 and I_A2 is theoretically 180 electrical degrees for the external fault and 0 electrical degrees for the internal fault conditions. If the phase angle difference is less than 50 electrical degrees or if the biasing current drops below 30 percent of the differential current, a fault has most likely occurred in the area protected by MPDIF. Then the internal blocking signals (CT saturation and DC blocking) of the biased stage are inhibited.

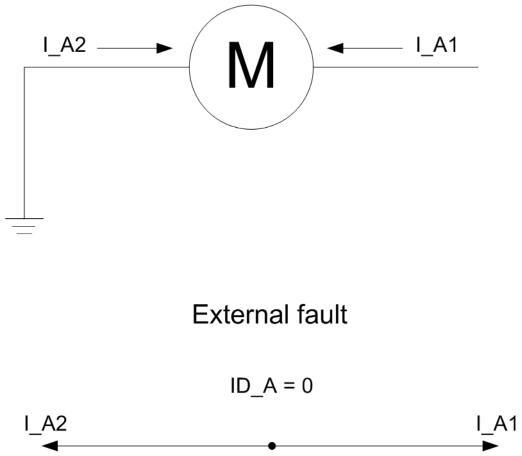


Figure 450: Positive direction of current

Instantaneous high stage

The differential protection includes an unbiased instantaneous high stage. The instantaneous stage operates and the OPR_HS output is activated when the amplitude of the fundamental frequency component of the differential current exceeds the set *High operate value* or when the instantaneous peak values of the differential current exceed 2.5 · *High operate value*. The factor 2.5 (= 1.8 · √2) is due to the maximum asymmetric short circuit current.

The OPERATE output is always activated when the OPR_HS output activates.

The internal blocking signals of the function block do not prevent the operation of the instantaneous stage. When required, the operate signal due to instantaneous operation can be blocked by the binary inputs BLK_OPR_HS or BLOCK.

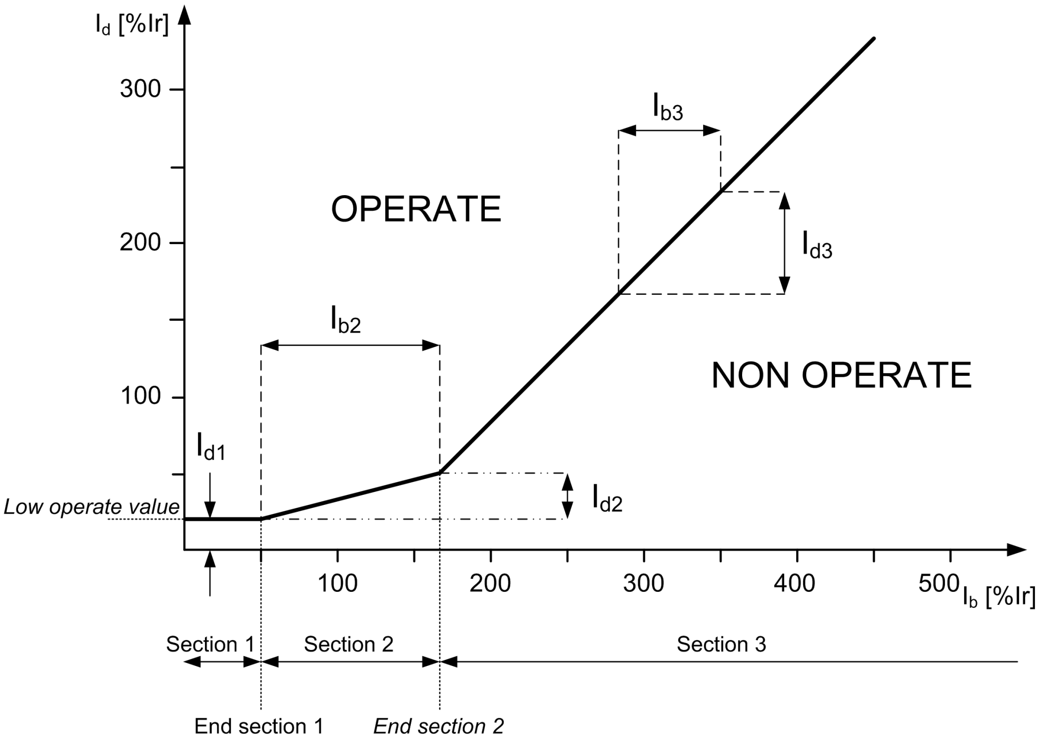


Figure 451: Operating characteristic for the stabilized stage of the generator differential protection function

4.3.7.6 Application

The differential protection works on the principle of calculating the differential current at the two ends of the winding, that is, the current entering the winding is compared to the current exiting the winding. In case of any internal fault, the currents entering and exiting the winding are different, which results in a differential current, which is then used as a base for generating the operating signal. Due to this principle, the differential protection does not trip during external faults. However, it should be noted that interturn faults in the same phase are usually not detected unless they developed into some other kind of fault.

The short circuit between the phases of the stator windings normally causes high fault currents. The short circuit creates a risk of damages to the insulation, windings and stator core. The high short circuit currents cause strong current forces which can damage other components in the machine. The short circuit can also initiate explosion and fire. When a short circuit occurs in a machine, there is a damage that has to be repaired. The severity and the repair time depend on the degree of damage, which is highly dependent on the fault time. The fast fault clearance of this fault type is of greatest importance to limit the damages and the economic loss.

To limit the damages in connection to the stator winding short circuits, the fault clearance time must be as short as possible (instantaneous). The fault current contributions from both the external power system (via the machine or the block circuit breaker) and from the machine itself must be disconnected as fast as possible.

The DC restraint feature should be used in case of an application with a long DC time constant in the fault currents is present. This fault current may be of a lesser magnitude (less than rated current) but is unpleasant and tends to saturate the CT and operate the differential protection for external faults. This feature is effective at moderate through-currents and ineffective at higher through-currents.

Although the short circuit fault current is normally very high, that is, significantly higher than the rated current of the machine, it is possible that a short circuit can occur between phases close to the neutral point of the machine, causing a relatively small fault current. The fault current fed from the synchronous machine can also be limited due to a low excitation of the synchronous generator. This is normally the case at the run-up of the synchronous machine, before synchronization to the network. Therefore, it is desired that the detection of the machine phase-to-phase short circuits shall be relatively sensitive, thus detecting the small fault currents.

It is also important that the machine short circuit protection does not trip for external faults when a high fault current is fed from the machine. To combine fast fault clearance, sensitivity and selectivity, the machine current differential protection is normally the best alternative for the phase-to-phase short circuits.

The risk of an unwanted differential protection operation caused by the current transformer saturation is a universal differential protection problem. If a big synchronous machine is tripped in connection to an external short circuit, it gives an increased risk of a power system collapse. Besides, there is a production loss for every unwanted trip of the machine. Therefore, preventing the unwanted disconnection of machines has a great economical value.

Recommendations for current transformers

The more important the object to be protected is, the more attention is paid to the current transformers. It is not normally possible to dimension the current transformers so that they repeat the currents with high DC components without saturating when the residual flux of the current transformer is high. The differential protection function block operates reliably even though the current transformers are partially saturated.

The accuracy class recommended for current transformers to be used with the differential function block is 5P, in which the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is 5 percent.

The approximate value of the actual accuracy limit factor F_a corresponding to the actual CT burden can be calculated on the basis of the rated accuracy limit factor F_n (ALF) at the rated burden, the rated burden S_n, the internal burden S_{in} and the actual burden S_a of the current transformer.

$$F_a = F_n \times \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 209)

Example 1

The rated burden S_n of the current transformer 5P20 is 10 VA, the secondary rated current 5A, the internal resistance R_{in} = 0.07 Ω and the rated accuracy limit factor F_n corresponding to the rated burden is 20 (5P20). The internal burden of the current transformer is $S_{in} = (5A)^2 \times 0.07\ \Omega = 1.75$ VA. The input impedance of the protection relay at a rated current of 5A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is S_a = (5A)² × (0.113 + 0.020) Ω = 3.33 VA. Thus, the accuracy limit factor F_a corresponding to the actual burden is about 46.

The CT burden can grow considerably at the rated current 5A. The actual burden of the current transformer decreases at the rated current of 1 A while the repeatability simultaneously improves.

At faults occurring in the protected area, the fault currents can be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is sufficient that the current transformers are capable of repeating the current required for an instantaneous tripping during the first cycle.

Thus the current transformers usually are able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault to secure the operating times of the protection relay comply with the retardation time.

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection must fulfill the requirement:

$$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{\frac{-T_m}{T_{dc}}}) + 1)$$

(Equation 210)

Ik_{max}	The maximum through-going fault current (in I_R) at which the protection is not allowed to operate
T_{dc}	The primary DC time constant related to Ik_{max}
ω	The angular frequency, that is, 2 x π x f_n
T_m	The time to saturate, that is, the duration of the saturation-free transformation
K_r	The remanence factor 1/(1-r), where r is the maximum remanence flux in pu from the saturation flux

The parameter r is the maximum remanence flux density in the CT core in pu from the saturation flux density. The value of the parameter r depends on the magnetic material used and also on the construction of the CT. For instance, if the value r = 0.4, the remanence flux density can be 40 percent of the saturation flux density. The manufacturer of the CT has to be contacted when an accurate value for the parameter r is needed. The value r = 0.4 is recommended to be used when an accurate value is not available.

The required minimum time-to-saturate T_m in MPDIF is half-fundamental cycle period (10 ms when f_n = 50 Hz).

Two typical cases are considered for the determination of the sufficient actual accuracy limit factor F_a:

1. A fault occurring at the substation bus.

   The protection must be stable at a fault arising during a normal operating situation. The reenergizing of the transformer against a bus fault leads to very high fault currents and thermal stress. Therefore, reenergizing is not preferred in this case. The remanence can be neglected.

   The maximum through-going fault current Ik_{max} is typically 6 I_R for a motor. At a short circuit fault close to the supply transformer, the DC time constant T_{dc} of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

Ik_{max}	= 6 I_R
T_{dc}	= 100 ms
ω	= 100π Hz
T_m	= 10 ms
K_r	= 1

   Equation 210 with these values gives the result:

   $$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{\frac{-T_m}{T_{dc}}}) + 1) \approx 24$$

2. Reenergizing against a fault occurring further down in the network.

   The protection must be stable also during reenergization against a fault on the line. In this case, the existence of remanence is very probable. It is assumed to be 40 percent here.

   On the other hand, the fault current is now smaller and since the ratio of the resistance and reactance is greater in this location, having a full DC offset is not possible. Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, assumed to be 50 ms here.

   Assuming the maximum fault current is 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

Ik_{max}	= 0.7 × 6 = 4.2 (I_R)
T_{dc}	= 50 ms
ω	= 100π Hz
T_m	= 10 ms
K_r	= 1/(1-0.4) = 1.6667

   Equation 210 with these values gives the result:

   $$F_a > K_r \times Ik_{\max} \times 0.9 \times (T_{dc} \times \omega \times (1 - e^{\frac{-T_m}{T_{dc}}}) + 1) \approx 24$$

If the actual burden of the current transformer S_a in the accuracy limit factor equation cannot be reduced low enough to provide a sufficient value for F_a, there are two alternatives to deal with the situation.

1. A current transformer with a higher rated burden S_n can be chosen (which also means a higher rated accurate limit F_n).
2. A current transformer with a higher nominal primary current I_{1n} (but the same rated burden) can be chosen.

Alternative 2 is more cost-effective and therefore often better, although the sensitivity of the scheme is slightly reduced.

Example 2

Here the actions according to alternative 2 are taken to improve the actual accuracy limit factor.

$$F_a = \left(\frac{I_R CT}{I_R Motor} \right) \times F_n$$

(Equation 211)

$I_R CT$	rated primary current of the CT, for example, 1500A
$I_R Motor$	rated current of the motor under protection, for example, 1000A
F_n	rated accuracy limit factor of the CT, for example, 30
F_a	actual accuracy limit factor due to oversizing the CT, substituting the values in the equation, $F_a = 45$

In differential protection it is important that the accuracy limit factors F_a of the phase current transformers at both sides correspond with each other, that is, the burdens of the current transformers on both sides are to be as close to each other as possible. If high inrush or start currents with high DC components pass through the protected object when it is connected to the network, special attention is required for the performance and the burdens of the current transformers and the settings of the function block.

Connection of current transformers

The connections of the primary current transformers are designated as Type 1 and Type 2.

- If the positive directions of the winding 1 and winding 2 protection relay currents are opposite, the *CT connection type* is of "Type 1". The connection examples of "Type 1" are as shown in figures *Figure 452* and *Figure 453*.
- If the positive directions of the winding 1 and winding 2 protection relay currents equate, the *CT connection type* setting parameter is "Type 2". The connection examples of "Type 2" are as shown in figures *Figure 454* and *Figure 455*.
- The default value of the *CT connection type* setting is "Type 1".

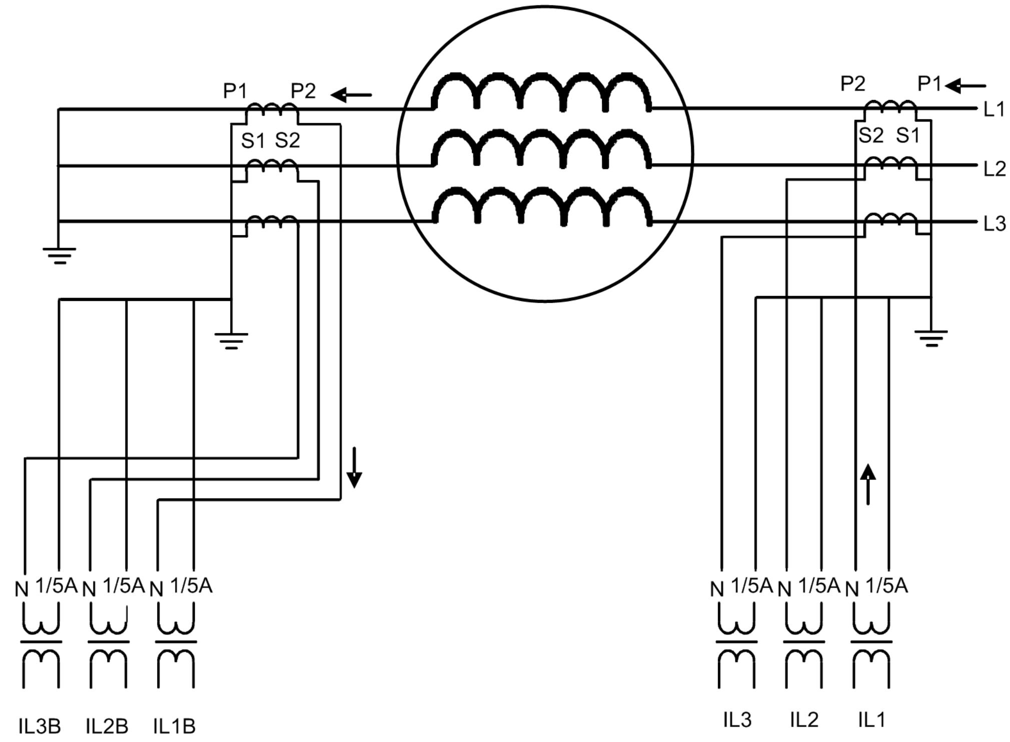


Figure 452: Connection of current transformer of Type 1, example 1

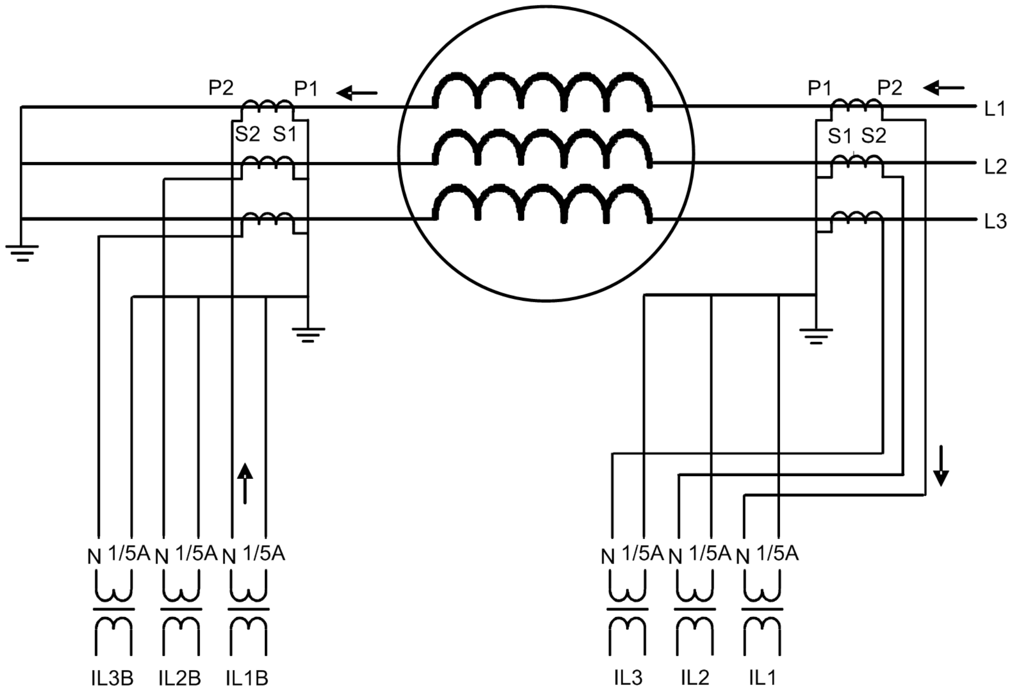


Figure 453: Connection of current transformer of Type 1, example 2

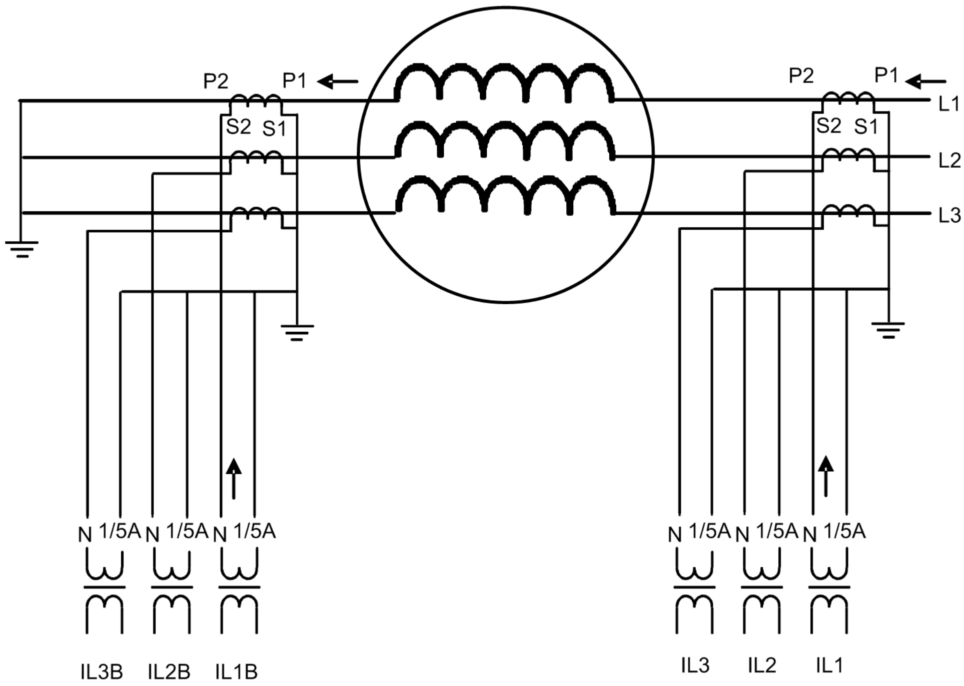


Figure 454: Connection of current transformer of Type 2, example 1

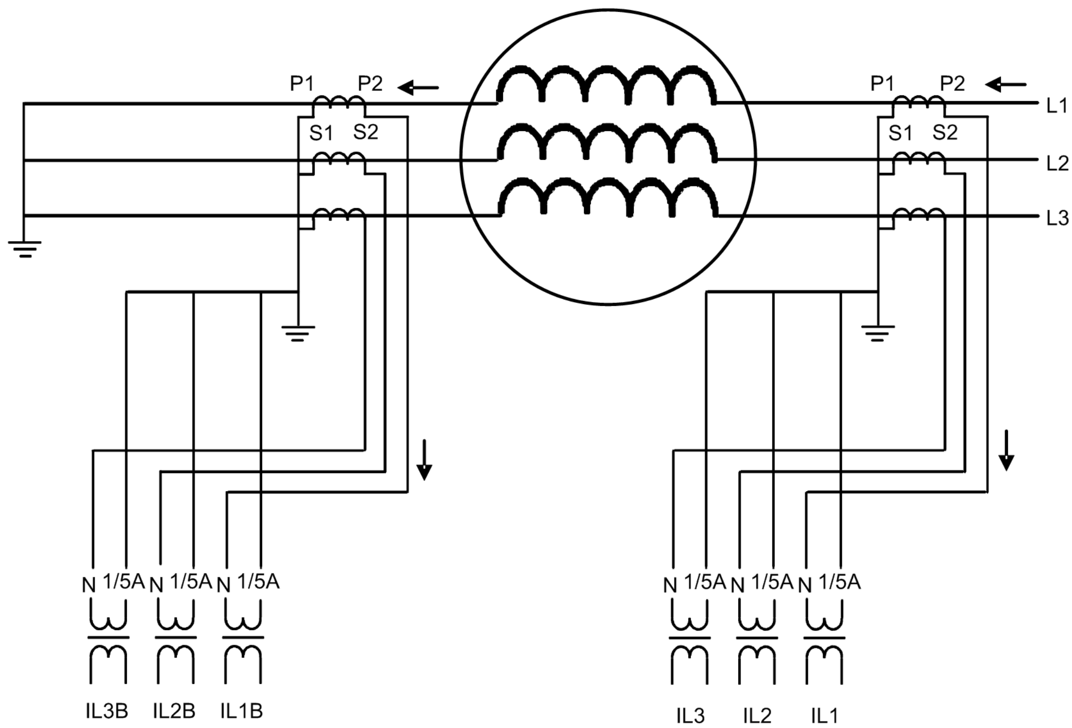


Figure 455: Connection of current transformer of Type 2, example 2

Saturation of current transformers

There are basically two types of saturation phenomena that have to be detected: the AC saturation and the DC saturation. The AC saturation is caused by a high fault current where the CT magnetic flux exceeds its maximum value. As a result, the secondary current is distorted as shown in *Figure 456*. A DC component in the current also causes the flux to increase until the CT saturates. This is known as DC saturation.

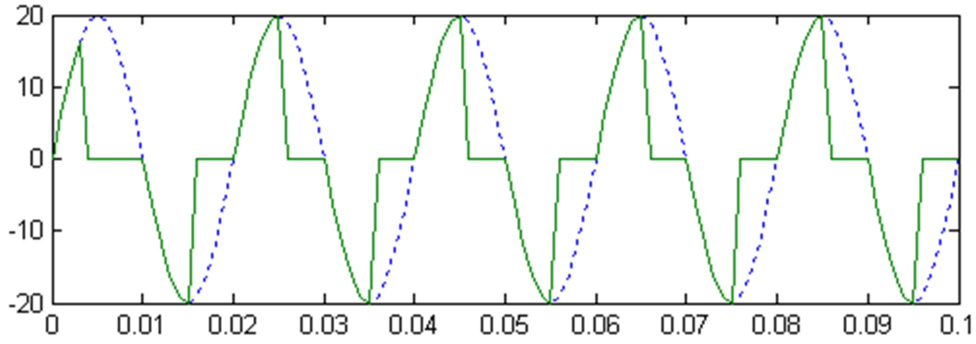


Figure 456: AC saturation

When having a short circuit in a power line, the short circuit current contains a DC component. The magnitude of the DC component depends on the phase angle when the short circuit occurs. *Figure 457* shows the secondary current of the CT in the fault situation. Because of the DC component, the flux reaches its maximum value at 0.07 seconds, causing saturation. As the DC component decays, the CT recovers gradually from the saturation.

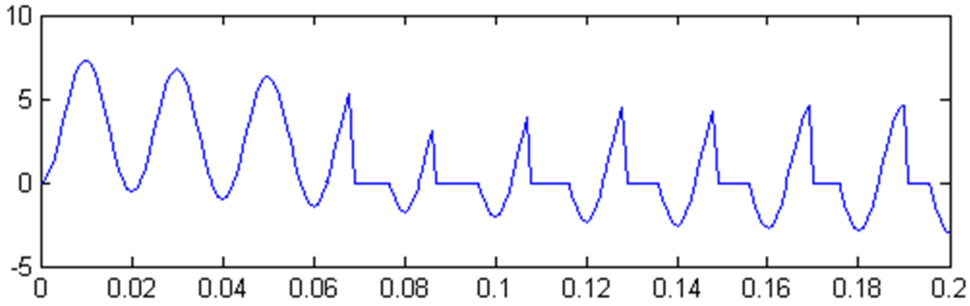


Figure 457: DC saturation

4.3.7.7 Signals

MPDIF Input signals

Table 717: MPDIF Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_OPR_LS	BOOLEAN	0=False	Blocks operate outputs from biased stage
BLK_OPR_HS	BOOLEAN	0=False	Blocks operate outputs from instantaneous stage

MPDIF Output signals

Table 718: MPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_LS	BOOLEAN	Operate from low set
OPR_HS	BOOLEAN	Operate from high set
INT_BLKD	BOOLEAN	Internal block status

4.3.7.8 MPDIF Settings

Table 719: MPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Low operate value	5...30	%Ir	1	5	Basic setting for the stabilized stage start
High operate value	100...1000	%Ir	10	500	Instantaneous stage operate value
Slope section 2	10...50	%	1	30	Slope of the second line of the operating characteristics
End section 1	0...100	%Ir	1	50	Turn-point between the first and the second line of the operating characteristics
End section 2	100...300	%Ir	1	150	Turn-point between the second and the third line of the operating characteristics

Table 720: MPDIF Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Slope section 3	10...100	%	1	100	Slope of the third line of the operating characteristics
DC restrain enable	0=False 1=True			0=False	Setting for enabling DC restrain feature

Table 721: MPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
CT connection type	1=Type 1 2=Type 2			1=Type 1	CT connection type. Determined by the directions of the connected current transformers
CT ratio Cor Line	0.40...4.00		0.01	1.00	CT ratio correction, line side
CT ratio Cor Neut	0.40...4.00		0.01	1.00	CT ratio correction, neutral side

4.3.7.9 MPDIF Monitored data

Table 722: MPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
OPR_A	BOOLEAN	0=False 1=True		Operate phase A
OPR_B	BOOLEAN	0=False 1=True		Operate phase B
OPR_C	BOOLEAN	0=False 1=True		Operate phase C
INT_BLKD_A	BOOLEAN	0=False 1=True		Internal block status phase A
INT_BLKD_B	BOOLEAN	0=False 1=True		Internal block status phase B
INT_BLKD_C	BOOLEAN	0=False 1=True		Internal block status phase C
ID_A	FLOAT32	0.00...80.00	xIr	Differential current phase A
ID_B	FLOAT32	0.00...80.00	xIr	Differential current phase B
ID_C	FLOAT32	0.00...80.00	xIr	Differential current phase C
IB_A	FLOAT32	0.00...80.00	xIr	Biasing current phase A
IB_B	FLOAT32	0.00...80.00	xIr	Biasing current phase B
IB_C	FLOAT32	0.00...80.00	xIr	Biasing current phase C
I_ANGL_A1_B1	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, line side
I_ANGL_B1_C1	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, line side

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_ANGL_C1_A1	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, line side
I_ANGL_A2_B2	FLOAT32	-180.00...180.00	deg	Current phase angle phase A to B, neutral side
I_ANGL_B2_C2	FLOAT32	-180.00...180.00	deg	Current phase angle phase B to C, neutral side
I_ANGL_C2_A2	FLOAT32	-180.00...180.00	deg	Current phase angle phase C to A, neutral side
I_ANGL_A1_A2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase A
I_ANGL_B1_B2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase B
I_ANGL_C1_C2	FLOAT32	-180.00...180.00	deg	Current phase angle diff between line and neutral side, Phase C
MPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
IL1-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL1
IL2-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL2
IL3-diff:1	FLOAT32	0.00...80.00		Measured differential current amplitude phase IL3
IL1-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL1
IL2-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL2
IL3-bias:1	FLOAT32	0.00...80.00		Measured bias current amplitude phase IL3

4.3.7.10 Technical data

Table 723: MPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz ±3.0% of the set value or ±0.002 x I_n		
Operate time [1, 2]	Low stage	Minimum	Typical	Maximum
		32 ms	35 ms	37 ms

Table continues on the next page

[1] F_n = 50 Hz, results based on statistical distribution of 1000 measurements
[2] Measured with static power output (SPO)

Characteristic		Value		
	High stage	9 ms	13 ms	19 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.95		
Retardation time		<20 ms		
Suppression of harmonics		DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5...		

4.3.8 High-impedance or flux-balance based differential protection MHZPDIF (ANSI 87HIM)

4.3.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance or flux-balance based differential protection	MHZPDIF	3dIHi>M	87HIM

4.3.8.2 Function block

Figure 458: Function block

4.3.8.3 Functionality

The high-impedance/flux-balance based differential protection for motors function MHZPDIF provides winding short circuit protection for motors.

MHZPDIF starts and operates when any of the three-phase differential currents, ID_A, ID_B or ID_C, exceeds the set limit. The operation timer characteristic is according to the definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timers or the function itself.

4.3.8.4 Analog channel configuration

MHZPDIF has one analog group input which must be properly configured.

Table 724: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.3.8.5 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "On" and "Off".

The operation of MHZPDIF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

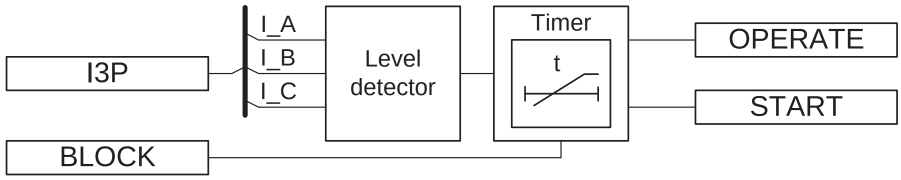


Figure 459: Functional module diagram

Level detector

This module compares the three-phase differential currents to the set *Operate value*. If any of the differential currents ID_A, ID_B or ID_C exceeds the set *Operate value*, the Level detector module sends an enable signal to the Timer module to start the definite timer (DT).

Timer

Once activated, the Timer activates the `START` output. The Timer characteristic is according to DT. When the operation timer has reached the value set by *Minimum operate time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the `START` output is deactivated.

The Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

The activation of the `BLOCK` signal resets the Timer and deactivates the `START` and `OPERATE` outputs.

4.3.8.6 Application

MHZPDIF provides the winding short circuit and earth-fault protection for motors. The high-impedance or flux-balance principle has been used through many years for differential protection due to the capability to manage through-faults with a heavy current transformer (CT) saturation.

High-impedance principle

The high-impedance principle is stable for all types of faults outside the protection zone. The stabilization is obtained by a stabilizing resistor in the differential circuit. This method requires all the CTs to have a similar magnetizing characteristic, same ratio and a relatively high knee point voltage. The CTs in each phase are connected in parallel with a relay measuring branch. The measuring branch is a series connection of the stabilizing resistor and the protection relay.

The stability of the protection is based on the use of the stabilizing resistor (R_S) and the fact that the impedance of the CT secondary quickly decreases as the CT saturates. The magnetization reactance of a fully saturated CT drops to zero and the impedance is formed only by the resistance of the winding (R_{in}) and lead resistance (R_m).

The CT saturation causes a differential current which can flow through the saturated CT, because of the near-zero magnetizing reactance, or through the measuring branch. The stabilizing resistor is selected so that the current in the measuring branch is below the protection relay's operating current during out-of-zone faults. As a result, the operation is stable during the saturation and can still be sensitive at the undistorted parts of the current waveform.

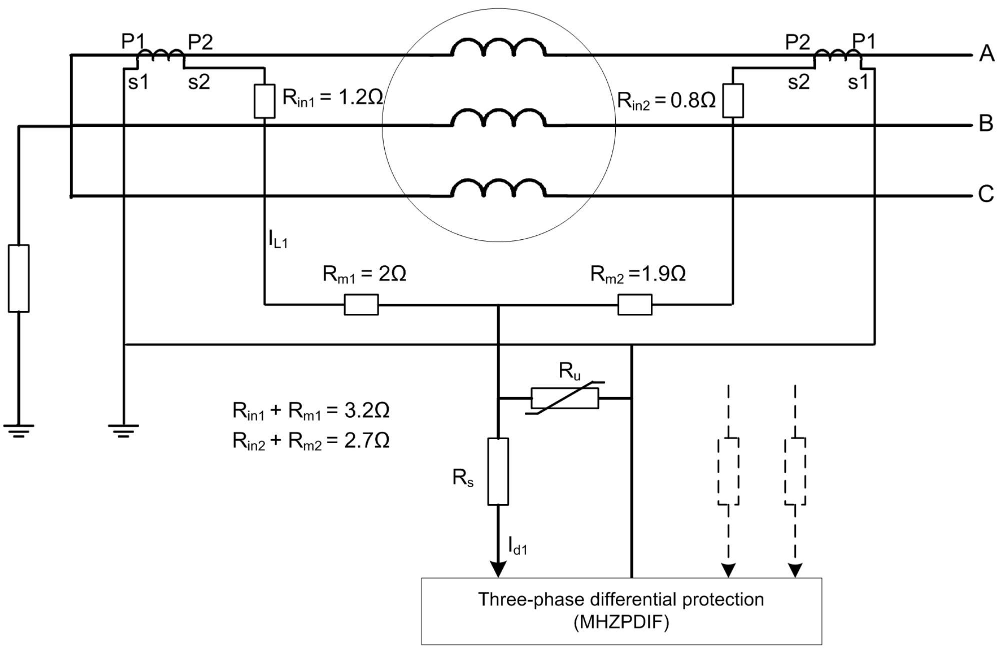


Figure 460: Three-phase differential protection for motors based on highimpedance principle

In case of an internal fault, the fault current cannot circulate through the CTs. It flows through the measuring branch, and the protection operates. A partial CT saturation can occur in case of an internal fault, but the undistorted part of the current waveform causes the protection to operate.

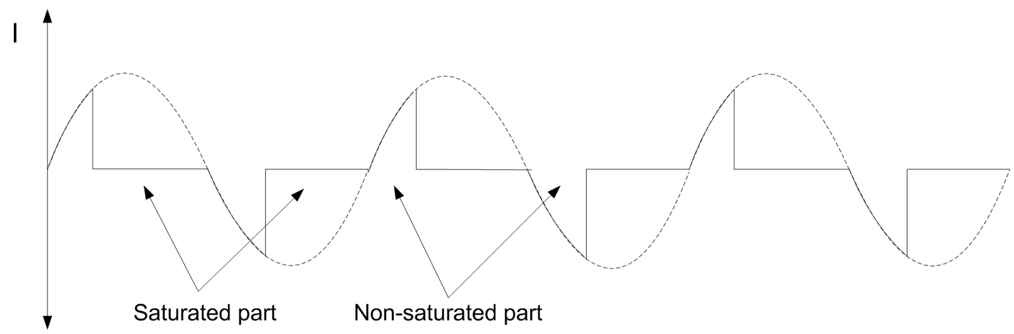


Figure 461: Secondary waveform of a saturated CT

At an internal fault, the secondary circuit voltage can easily exceed the isolation voltage of the CTs, connection wires and the protection relay. To limit this voltage, a voltage-dependent resistor (VDR) is used.

The whole scheme, that is, the stabilizing resistor, voltage-dependent resistor and wiring, must be adequately maintained (operation and insulation tested regularly) to be able to withstand the high-voltage pulses that appear during an internal fault throughout the lifetime of the equipment. Otherwise, during a fault within the zone of protection, any flashover in the CT secondary circuits or any other part of the scheme can prevent the correct operation of MHZPDIF.

Flux-balancing principle

In a measuring configuration for the three-phase differential currents according to the flux-balancing principle, no stabilizing resistors are needed. The configuration, however, requires the use of core balance current transformers. The compared currents, the one at the line end and the other at the neutral end, are both measured by the same core balance current transformer.

In this scheme, the currents flowing through one core balance transformer cancel each other out when there is no fault within the protected zone. When a fault occurs within the protected zone, the currents flowing through the core balance transformer amplify each other and the differential protection operates.

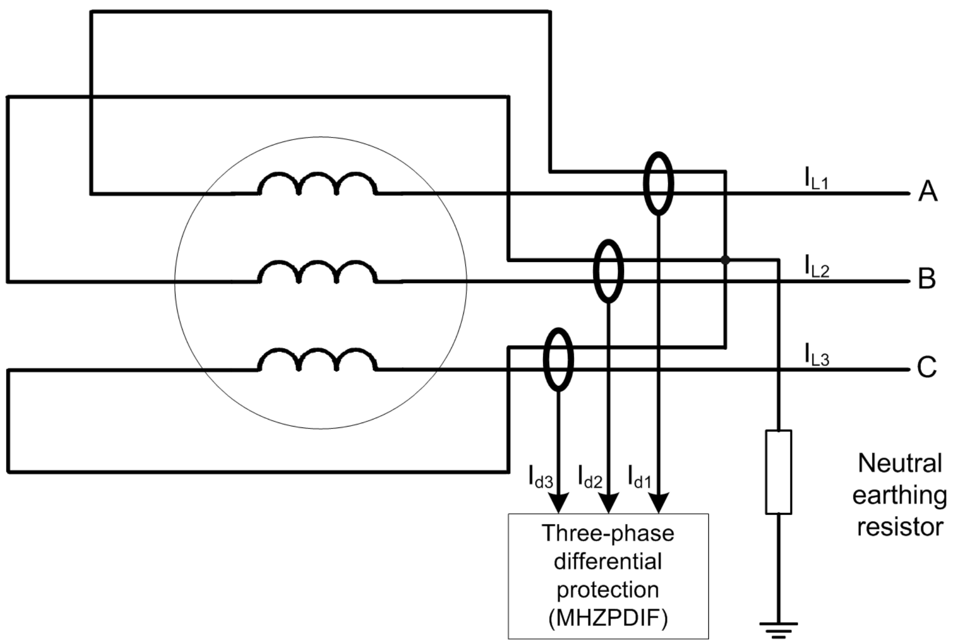


Figure 462: Three-phase differential protection for motors based on fluxbalancing principle

The advantage of this scheme is that the CT rated primary current can be selected smaller than the rated current of the machine.

If six current transformers are used, the flux-balancing principle, that is, summing two CTs in each phase, cannot be used. Instead, the high-impedance principle or stabilized three-phase differential protection must be used.

4.3.8.7 Recommendations for current transformers

High-impedance principle

The sensitivity and reliability of the protection depend on the characteristics of the current transformers. The CTs must have an identical transformation ratio. It is recommended that all current transformers have an equal burden and characteristics and that they are of the same type. This means that they should be preferably from the same manufacturing batch, that is, an identical construction is used. If the CT characteristics and the burden values are not equal, the calculation for each branch in the scheme should be done separately and the worst-case result is used. If the CT winding resistance and the burden of the branches are not equal, the maximum burden equal to 3.2 Ω should be used for calculating the stabilized voltage.

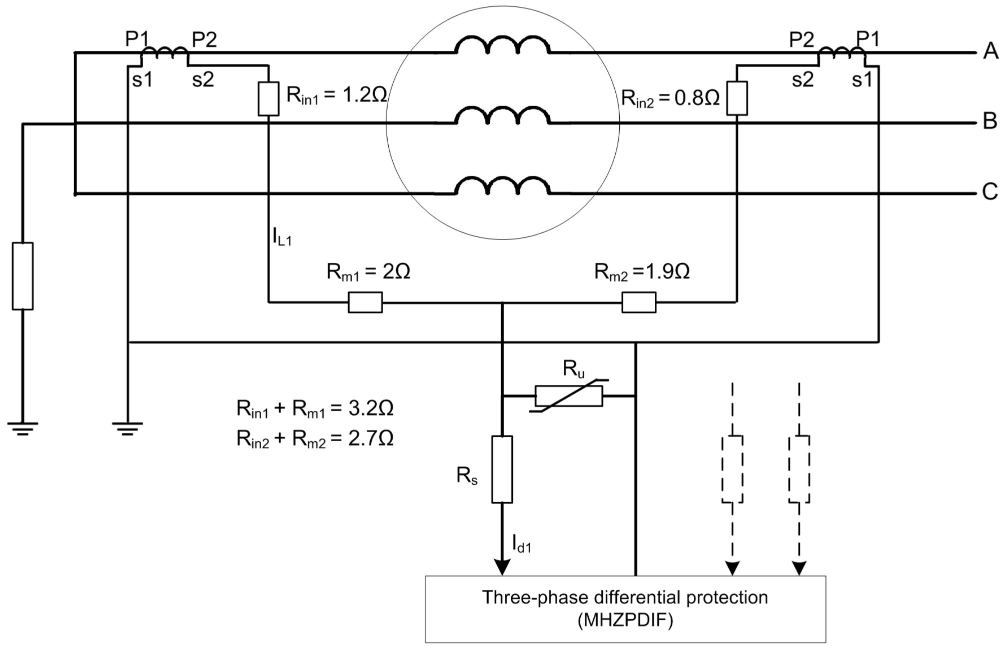


Figure 463: High-impedance differential protection with different CT burden value on each branch

The stabilizing voltage, that is the voltage appearing across the measuring branch during an out-of-zone fault, is calculated assuming that one of the CTs connected in parallel is fully saturated. The stabilizing voltage can be calculated using the formula

$$U_s = \frac{I_{k\max}}{n}(R_{in} + R_m)$$

(Equation 212)

I_{kmax}	The highest through-fault current in primary amps. The highest earth-fault or short circuit current during the out-of-zone fault.
n	The turns ratio of the CT
R_{in}	The secondary internal resistance of the CT in ohms
R_m	The resistance (maximum of R_{in} + R_m) of the CT secondary circuit in ohms

The current transformers must be able to force enough current to operate the IED through the differential circuit during a fault condition inside the zone of protection. To ensure this, the knee point voltage U_{kn} should be at least two times higher than the stabilizing voltage U_s.

The required knee point voltage U_{kn} of the current transformer is calculated using the formula

$$U_{kn} \geq 2 \times U_s$$

(Equation 213)

U_{kn}	The knee point voltage
U_s	The stabilizing voltage

The factor two is used when no delay in the operating time of the protection in any situation is acceptable. To prevent the knee point voltage from growing too high, it is advisable to use current transformers, the secondary winding resistance of which is of the same size as the resistance of the measuring loop.

As the impedance of the IED alone is low, a stabilizing resistor is needed. The value of the stabilizing resistor is calculated with the formula

$$R_s = \frac{U_s}{I_{rs}}$$

(Equation 214)

R_s	The resistance of the stabilizing resistor
U_s	The stabilizing voltage of the protection relay
I_{rs}	The value of the *Operate value* setting in secondary amps.

The stabilizing resistor should be capable to dissipate high energy within a very short time; therefore, the wire wound-type resistor should be used. Because of the possible CT inaccuracy, which might cause some current through the stabilizing resistor in a normal load situation, the rated power should be 25 W minimum.

If U_{kn} is high or the stabilizing voltage is low, a resistor with a higher power rating is needed. Often resistor manufacturers allow 10 times rated power for 5 seconds. Thus the power of the resistor can be calculated with the equation

$$\frac{U_{kn}^2}{R_s \times 10}$$

(Equation 215)

The actual sensitivity of the protection is affected by the protection relay setting, the magnetizing currents of the parallel connected CTs and the shunting effect of the voltage-dependent resistor (VDR). The value of the primary current I_{prim} at which the protection relay operates at a certain setting can be calculated with the formula

$$I_{prim} = n \cdot \left(I_{rs} + I_u + m \cdot I_m \right)$$

(Equation 216)

I_m	The magnetizing current per current transformer at the U_s voltage
I_{prim}	The primary current at which the protection is to start
I_{rs}	The value of the *Operate value* setting
I_u	The leakage current flowing through the VDR at the U_s voltage
n	The turn ratio of the current transforme
m	The number of current transformers included in the protection per phase (=2)

The I_e value given in many catalogs is the excitation current at the knee point voltage.

Assuming $U_{kn} \approx 2 \times U_s$, the value of $I_m \approx \frac{I_e}{2}$ gives an approximate value for *Equation 216*.

The selection of current transformers can be divided into the following steps.

1. The rated current In of the protected machine should be known. The value of In also affects the magnitude of I_{kmax}. Normally the I_{kmax} value for motors is $6 \cdot I_n$.
2. The rated primary current I_{1n} of the CT has to be higher than the rated current of the machine.

   The choice of the CT also specifies R_{in}.
3. The required U_{kn} is calculated with *Equation 213*. If the U_{kn} of the CT is not high enough, another CT has to be chosen. The value of the U_{kn} is given by the manufacturer in the case of Class X current transformers or it can be estimated with *Equation 217*.
4. The sensitivity I_{prim} is calculated with *Equation 216*. If the achieved sensitivity is sufficient, the present CT is chosen. A CT with a bigger core is chosen if a better sensitivity is needed.

If a Class X CT is not used, an estimate for Ukn is calculated using *Equation 216*.

$$U_{kn} = 0.8 \times F_n \times I_{2n} \times \left(R_{in} + \frac{S_n}{I_{2n}^2} \right)$$

(Equation 217)

F_n	The rated accuracy limit factor corresponding to the rated burden S_n
I_{2n}	The rated secondary current of the CT
R_{in}	The secondary internal resistance of the CT
S_n	The volt-amp rating of the CT

The formulas are based on choosing the CTs according to *Equation 213*, which results an absolutely stable scheme. In some cases, it is possible to achieve stability with knee point voltages lower than stated in the formulas. However, the network conditions have to be known well enough to ensure the stability.

- If $U_k \geq 2 \times U_s$, fast relay operation is secure.
- If $U_k \geq 1.5 \times U_s$ and $< 2 \times U_s$, relay operation can be slightly prolonged and should be studied case by case.
- If $U_k < 1.5 \times U_s$, the relay operation is jeopardized. Another CT has to be chosen.

The need for voltage dependent resistor (VDR) depends on the insulation level for which the protection relays are tested.

Voltage Umax, ignoring the CT saturation during the fault is calculated using

First, voltage U_{max}, ignoring the CT saturation during the fault, is calculated with the equation Equation 218.

$$U_{max} = \frac{I_{k\,max\,in}}{n} \times (R_{in} + R_m + R_s) \approx \frac{I_{k\,max\,in}}{n} \times R_s$$

(Equation 218)

I_{kmaxin}	Maximum fault current inside the zone, in primary amps
n	Turns ration of the CT
R_{in}	Internal resistance of the CT in ohms
R_m	Resistance of the longest loop of the CT secondary circuit, in ohms
R_s	Resistance of the stabilized resistor, in ohms

The peak voltage û, which includes the CT saturation, is estimated by using Equation 219 (given by P. Mathews 1955).

$$\hat{u} = 2\sqrt{2U_{kn}(U_{max} - U_{kn})}$$

(Equation 219)

U_{kn}	Knee point voltage of the CT

The VDR is recommended when the peak voltage û ≥ 2kV, which is the insulation level for which the IED is tested.

For example, the maximum fault current in case of a fault inside the zone is 12.6 kA in primary, CT is of 1250/5 A, that is, ratio n = 240, and knee point voltage is 81 V. The stabilizing resistor is 330 Ohms.

$$U_{max} = \frac{12600\,A}{240} \cdot 330\,\Omega = 17325\,V$$

(Equation 220)

$$\breve{u} = 2\sqrt{2 \cdot 81 \cdot (17325 - 81)} \approx 3.34\,kV$$

(Equation 221)

As the peak voltage û = 3.2 kV, VDR must be used. In some cases, VDR can be avoided if R_s is smaller. The value of R_s depends on the protection relay operation current and stabilizing voltage. Thus, a higher setting in the protection relay must be used or the stabilizing voltage lowered.

Flux-balancing principle

When the function block is used with the flux-balancing principle, there are no extra requirements for the measuring devices. The core-balance transformers used in an ordinary overcurrent protection are adequate here as well.

4.3.8.8 Example calculations for high-impedance differential protection

The example shows the calculations for the *Operate value* setting, stabilizing resistor value (R_s) and required knee point voltage (U_{kn}) of the CTs.

Table 725: Protected generator values

Quantity	Value
S_n	8 MVA
U_n	6 kV
I_n	770 A
I_{kmax}	4620 A (6 × I_n) out-of-zone fault
I_{kmaxin}	9.24 kA (12 × I_n) in-zone fault

Table 726: Assumed CT data

Quantity	Value
CT	1000/1 A
R_{in}	15.3 Ω
U_{kn}	323 V
I_e	35 mA (at U_{kn})

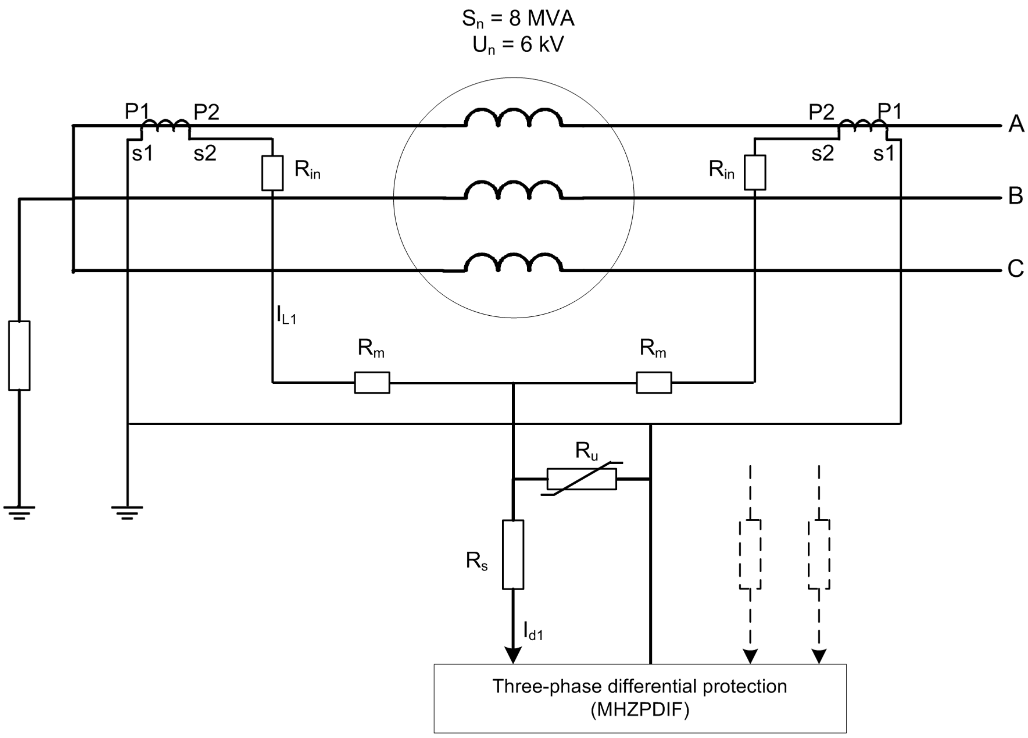


Figure 464: Example calculation for high-impedance differential protection (only one phase is presented in detail)

The length of the secondary circuit loop is 200 m and the area of the cross-section is 2.5 mm^2. Resistance at 75°C is 0.00865 Ω/m.

$$R_m = 0.00865 \frac{\Omega}{m} \cdot 200m \approx 1.73\Omega$$

(Equation 222)

First the stabilizing voltage is calculated based on equation

$$U_s = \frac{6 \cdot 770\,A}{1000} \cdot (15.3\,\Omega + 1.73\,\Omega) \approx 78.7\,V$$

(Equation 223)

In this case the requirement for the current transformer knee point voltage is fulfilled because $U_{kn} > 2U_s$.

The magnetising curve of the CT is assumed to be linear. The magnetizing current at the stabilizing voltage can be estimated.

$$I_m = \frac{U_s}{U_{kn}} \cdot I_e$$

(Equation 224)

$$I_m = \frac{78.7\,V}{323\,V} \cdot 35mA \approx 8.5mA$$

(Equation 225)

The setting current I_{rs} should be at the minimum of the sum of the magnetizing currents of all connected CTs to obtain adequate protection stability.

$$I_{rs} = 2 \cdot 8.5\,mA \approx 17\,mA$$

(Equation 226)

The resistance of the stabilizing resistor is calculated based on equation

$$R_s = \frac{78.7\,V}{0.017\,A} \approx 4629\,\Omega$$

(Equation 227)

The calculated value 4629 Ω is the maximum value for the stabilizing resistor. If this value is not available, the next available value downwards should be chosen and the protection relay setting current is to be tuned according to the selected resistor. For example in this case the resistance value 3900 Ω is used.

$$I_{rs} = \frac{78.7\,V}{3900\,V} \approx 20\,mA$$

(Equation 228)

The sensitivity of the protection is obtained as per equation (assuming I_u to be zero)

$$I_{prim} = 1000 \cdot (0.020\,A + 2 \cdot 0.0085\,A + 0\,A) \approx 37\,A$$

(Equation 229)

The power of the stabilizing resistor is calculated as follows.

$$P \geq \frac{(323\,V)^2}{3900\,\Omega} \approx 27\,W$$

(Equation 230)

The need for voltage dependent resistor is checked with equations

$$U_{\max} = \frac{12 \cdot 770\,A}{1000} \cdot (3900\,\Omega + 15.3\,\Omega + 1.73\,\Omega + 0.10\,\Omega) \approx 36.2\,kV$$

(Equation 231)

$$\breve{u} = 2\sqrt{2 \cdot 323\,V \cdot (36200\,V - 323\,V)} \approx 9.6\,kV$$

(Equation 232)

The voltage dependent resistor, one for each phase, is needed in this case because the voltage during the fault is much higher than 2 kV.

The leakage current through the varistor at the stabilizing voltage can be available from the varistor manual, assuming that to be approximately 2 mA at stabilizing voltage.

$$Iu \approx 0.002\,A$$

(Equation 233)

The sensitivity of the protection can be re-calculated taking into account the leakage current through the varistor as per equation

$$I_{prim} = 1000 \cdot (0.020\,A + 2 \cdot 0.0085\,A + 0.002\,A) \approx 39\,A$$

(Equation 234)

4.3.8.9 Signals

MHZPDIF Input signals

Table 727: MHZPDIF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

MHZPDIF Output signals

Table 728: MHZPDIF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.8.10 MHZPDIF Settings

Table 729: MHZPDIF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operate value	0.5...50.0	%In	0.1	0.5	Operate value, percentage of the nominal current
Minimum operate time	20...300000	ms	10	20	Minimum operate time

Table 730: MHZPDIF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 731: MHZPDIF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	0	Reset delay time

4.3.8.11 MHZPDIF Monitored data

Table 732: MHZPDIF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ID_A	FLOAT32	0.00...80.00	xIn	Differential current phase A
ID_B	FLOAT32	0.00...80.00	xIn	Differential current phase B
ID_C	FLOAT32	0.00...80.00	xIn	Differential current phase C
MHZPDIF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.3.8.12 Technical data

Table 733: MHZPDIF Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz ±1.5% of the set value or 0.002 × I_n		
Start time [1, 2]	I_{Fault} = 2.0 × set *Start Value* (one phase fault)	Minimum	Typical	Maximum
		13 ms	17 ms	21 ms
	I_{Fault} = 2.0 × set *Start Value* (three phases fault)	11 ms	14 ms	17 ms
Reset time		<40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value of ±20 ms		

4.4 Unbalance protection

4.4.1 Negative-sequence overcurrent protection NSPTOC (ANSI 46M)

4.4.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection	NSPTOC	I2>M	46M

1 *Measurement mode* = “Peak-to-Peak”, current before fault = 0.0 × I_n, f_n = 50 Hz, fault current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

2 Includes the delay of the signal output contact

4.4.1.2 Function block

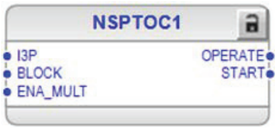


Figure 465: Function block

4.4.1.3 Functionality

The negative-sequence overcurrent protection function NSPTOC is used for increasing sensitivity to detect single-phase and phase-to-phase faults or unbalanced loads due to, for example, broken conductors or unsymmetrical feeder voltages.

NSPTOC can also be used for detecting broken conductors.

The function is based on the measurement of the negative sequence current. In a fault situation, the function starts when the negative sequence current exceeds the set limit. The operate time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the DT mode, the function operates after a predefined operate time and resets when the fault current disappears. The IDMT mode provides current-dependent timer characteristics.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.4.1.4 Analog channel configuration

NSPTOC has one analog group input which must be properly configured.

Table 734: Analog signals

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.4.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of NSPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

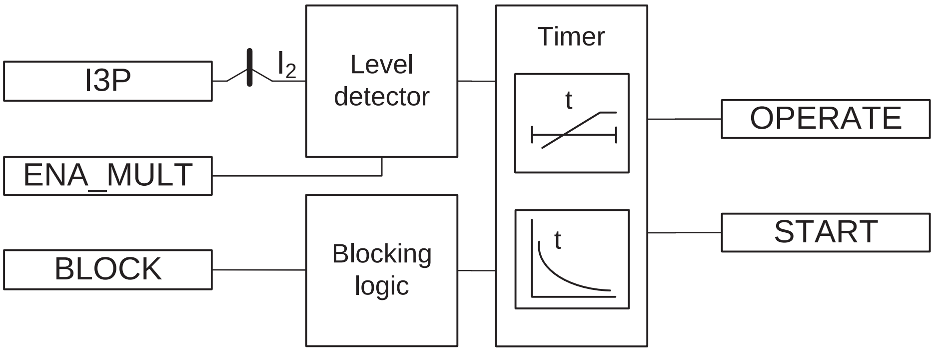


Figure 466: Functional module diagram

Level detector

The measured negative-sequence current is compared to the set *Start value*. If the measured value exceeds the set *Start value*, Level detector activates the Timer module. If the ENA_MULT input is active, the set *Start value* is multiplied by the set *Start value Mult*.

The protection relay does not accept the *Start value* or *Start value Mult* setting if the product of the settings exceeds the *Start value* setting range.

Timer

Once activated, Timer activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of Operate delay time in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the *Type of reset curve* setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation. The START output is deactivated when the reset timer has elapsed.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. The functionality of the timer in the reset state depends on the combination of the *Operating curve type*, *Type of reset curve* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, the Type of reset curve setting can be set to "Immediate", "Def time reset" or "Inverse reset". The reset curve type "Immediate" causes an immediate reset. With the reset curve type "Def time reset", the reset time depends on the *Reset delay time* setting. With the reset curve type "Inverse reset", the reset time depends on the current during the drop-off situation and the value of START_DUR. The START output is deactivated when the reset timer has elapsed.

The "Inverse reset" selection is only supported with ANSI or user programmable types of the IDMT operating curves. If another operating curve type is selected, an immediate reset occurs during the drop-off situation.

The setting *Time multiplier* is used for scaling the IDMT operate and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.2.1 IDMT curves for overcurrent protection* in this manual.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.4.1.6 Application

Since the negative sequence current quantities are not present during normal, balanced load conditions, the negative sequence overcurrent protection elements can be set for faster and more sensitive operation than the normal phase-overcurrent protection for fault conditions occurring between two phases. The negative sequence overcurrent protection also provides a back-up protection functionality for the feeder earth-fault protection in solid and low resistance earthed networks.

The negative sequence overcurrent protection provides the back-up earth-fault protection on the high voltage side of a delta-wye connected power transformer for earth faults taking place on the wye-connected low voltage side. If an earth fault occurs on the wye-connected side of the power transformer, negative sequence current quantities appear on the delta-connected side of the power transformer.

The most common application for the negative sequence overcurrent protection is probably rotating machines, where negative sequence current quantities indicate unbalanced loading conditions (unsymmetrical voltages). Unbalanced loading normally causes extensive heating of the machine and can result in severe damages even over a relatively short time period.

Multiple time curves and time multiplier settings are also available for coordinating with other devices in the system.

4.4.1.7 Signals

NSPTOC Input signals

Table 735: NSPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

NSPTOC Output signals

Table 736: NSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.1.8 NSPTOC Settings

Table 737: NSPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...5.00	xIn	0.01	0.30	Start value
Start value Mult	0.8...10.0		0.1	1.0	Multiplier for scaling the start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...200000	ms	10	40	Operate delay time
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv.			15=IEC Def. Time	Selection of time delay curve type

Parameter	Values (Range)	Unit	Step	Default	Description
	7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type				

Table 738: NSPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 739: NSPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.0086...120.0000		0.0001	28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120		0.0001	0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00		0.01	29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 740: NSPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time

4.4.1.9 NSPTOC Monitored data

Table 741: NSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
NSPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.1.10 Technical data

Table 742: NSPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1,2]		Minimum	Typical	Maximum
	I_{Fault} = 2 × set *Start value*	23 ms	26 ms	28 ms
	I_{Fault} = 10 × set *Start value*	15 ms	18 ms	20 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [3]		
Suppression of harmonics		DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…		

4.4.2 Directional negative-sequence overcurrent protection DNSPDOC (ANSI 67Q)

4.4.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional negative-sequence overcurrent protection	DNSPDOC	I2> ->	67Q

1 Negative sequence current before fault = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2 Includes the delay of the signal output contact.
3 Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20.

4.4.2.2 Function block

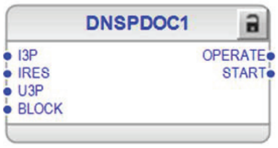


Figure 467: Function block

4.4.2.3 Functionality

The directional negative-sequence overcurrent protection function DNSPDOC is used as directional overcurrent and short-circuit protection.

DNSPDOC starts up when the fundamental value of the operating quantity (negative-sequence or residual current) exceeds the set limit and the directional criterion is fulfilled. The operate time characteristic is according to definite time (DT).

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.4.2.4 Analog channel configuration

DNSPDOC has three analog group inputs which must be properly configured.

Table 743: Analog inputs

Input	Description
I3P	Three-phase currents
IRES [3]	Residual current (measured or calculated) Necessary when *Operating quantity* is "Residual" or "Residual (calc)"
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources. The `GRPOFF` signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 744: Special conditions

Condition	Description
U3P connected real measurements	The function requires that at least two voltage channels are connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing

[3] Can be connected to `GRPOFF` if *Operating quantity* is set to "Negative seq"

blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.4.2.5 Operation principle

The function can be enabled and disabled with the *Operation setting*. The corresponding parameter values are "on" and "off".

The operation of DNSPDOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

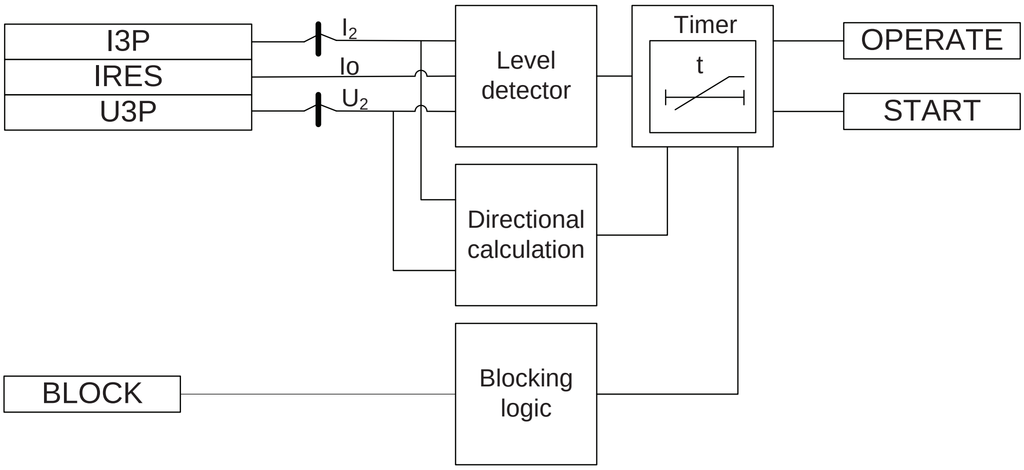


Figure 468: Functional module diagram

Level detector

The operating signal is compared to the set *Start value*. If the operating signal exceeds the set *Start value*, Level detector sends an enabling signal to the Timer module. Timer starts when it is enabled and the directional criterion is fulfilled. A suitable operating quantity can be selected with the *Operating quantity* setting. The options are "Negative seq" or "Residual". The value of operating quantity I_OPER is also available in the Monitored data view.

Irrespective of the operating quantity selected, directional calculation is always determined using the negative-sequence current.

Directional calculation

Directional calculation compares the negative-sequence current phasor with the negative-sequence voltage phasor, that is, the polarizing quantity. The directional operation can be selected with the *Directional mode* setting. The options are "Nondirectional", "Forward" or "Reverse" operation. By setting the value of *Allow Non Dir* to "True", the non-directional operation is allowed when the directional information is invalid.

The *Characteristic angle* setting is used to turn the directional characteristics. The value of *Characteristic angle* should be chosen so that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the non-operating zone. The value of *Characteristic angle* depends on the network configuration.

Reliable directional calculation requires that both negative-sequence current and negative-sequence voltage quantities exceed certain minimum amplitude levels. The minimum amplitude level for the negative-sequence current is set with the *Min operate current* setting. The minimum amplitude level for the polarizing quantity, that is, the negative-sequence voltage, is set with the *Min operate voltage* setting. If the amplitude level of the operating quantity or polarizing quantity is below the set level, the direction information of the corresponding phase is set to “unknown”. If the negative-sequence voltage before the fault situation is below *Min operate voltage*, the voltage direction cannot be determined.

The value for the *Min operate voltage* setting should be carefully selected since the accuracy in low signal levels is strongly affected by the measuring device accuracy.

Timer

Once activated, Timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated if the operating signal persists.

In a drop-off situation, that is, if a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated. The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, the function operates normally but the OPERATE output is not activated.

4.4.2.6 Directional overcurrent characteristics

The forward and reverse sectors are defined separately. The forward operation area is limited with the *Min forward angle* and *Max forward angle* settings. The reverse operation area is limited with the *Min reverse angle* and *Max reverse angle* settings.

The sector limits are always given as positive degree values.

In the forward operation area, the *Max forward angle* setting gives the counterclockwise sector and the *Min forward angle* setting gives the corresponding clockwise sector, measured from the *Characteristic angle* setting.

In the backward operation area, the *Max reverse angle* setting gives the counterclockwise sector and the *Min reverse angle* setting gives the corresponding clockwise sector, a measurement from the *Characteristic angle* setting that has been rotated 180 degrees.

Relay characteristic angle (RCA) is set positive if the operating current lags the polarizing quantity and negative if the operating current leads the polarizing quantity.

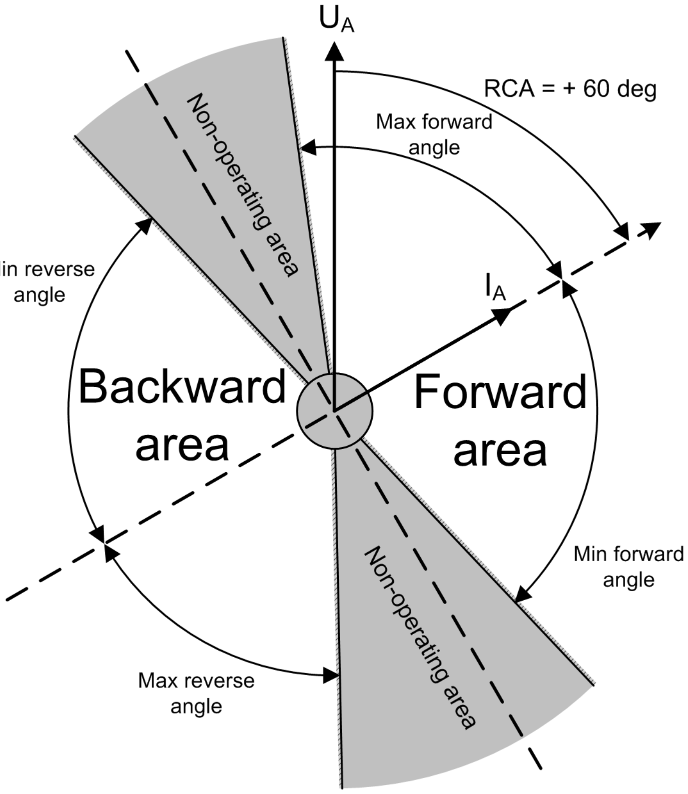


Figure 469: Configurable operating sectors

The angle difference ANGLE between the negative-sequence current and the polarizing quantity is calculated as shown below and is available in the Monitored data view.

$$ANGLE = \phi(-U_2) - \phi(I_2) - \phi_{RCA}$$

(Equation 235)

Based on the ANGLE value, the direction information DIRECTION is evaluated and is made available in the Monitored data view.

Table 745: Momentary direction value for monitored data view

Criterion for direction information	Value for DIRECTION
ANGLE_X is not in any of the defined sectors, or the direction cannot be defined due too low amplitude	0 = unknown
ANGLE_X is in the forward sector	1 = forward
ANGLE_X is in the reverse sector	2 = backward

FAULT_DIR gives the detected direction of the fault during fault situations, that is, when the START output is active.

4.4.2.7 Application

The ability of a protection relay to provide direction information for faults is referred to as its directional security. It is extremely important for the directional protection function to identify the direction of the fault relative to the location of the protection relay. The fault direction can be either downstream (forward fault) or upstream of the protection relay (backward fault).

Different directional elements are used to determine the fault direction. One such element is the negative-sequence voltage. As directional element, the negative-sequence voltage can identify the direction of all unbalance faults. One of the advantages of using negative-sequence elements is that the negative-sequence component is insensitive to zero-sequence mutual coupling. The negative sequence is also used where the source is not strong enough because with such a source the value of the negative sequence near the protection relay has higher magnitude.

4.4.2.8 Signals

DNSPDOC Input signals

Table 746: DNSPDOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

DNSPDOC Output signals

Table 747: DNSPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.2.9 DNSPDOC Settings

Table 748: DNSPDOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.05	Start value
Directional mode	1=Non-directional			2=Forward	Directional mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Forward 3=Reverse				
Operate delay time	40...300000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...90	deg	1	80	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	80	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	80	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	80	Minimum phase angle in reverse direction

Table 749: DNSPDOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operating quantity	1=Negative seq 2=Residual			1=Negative seq	Operating quantity

Table 750: DNSPDOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 751: DNSPDOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Allow Non Dir	0=False 1=True			0=False	Allows prot activation as non-dir when dir info is invalid
Min operate current	0.01...1.00	xIn	0.01	0.01	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage

4.4.2.10 DNSPDOC Monitored data

Table 752: DNSPDOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
FAULT_DIR	Enum	0=unknown 1=forward 2=backward 3=both		Detected fault direction
DIRECTION	Enum	0=unknown 1=forward		Direction information

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		2=backward 3=both		
ANGLE	FLOAT32	-180.00...180.00	deg	Calculated angle differ-ence
I_OPER	FLOAT32	0.00...40.00	xIn	Calculated operating current
DNSPDOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.2.11 Technical data

Table 753: DNSPDOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current measured: f_n ±2 Hz		
		Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n Phase angle: ±2°		
Start time [1, 2]	I_{Fault} = 2 × set *Start value*	Minimum	Typical	Maximum
		31 ms	34 ms	37 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy		±1.0% of the set value of ±20 ms		
Suppression of harmonics		RMS: No suppression DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… Peak-to-Peak: No suppression		

4.4.3 Phase discontinuity protection PDNSPTOC (ANSI 46PD)

4.4.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase discontinuity protection	PDNSPTOC	I2/I1>	46PD

1 Measurement mode NPS, NPS current before fault = 0.0 × I_n, f_n = 50 Hz, fault NPS current with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.

2 Measured with static signal output (SSO).

4.4.3.2 Function block

Figure 470: Function block

4.4.3.3 Functionality

The phase discontinuity protection function PDNSPTOC is used for detecting unbalance situations caused by broken conductors.

The function starts and operates when the unbalance current I_2/I_1 exceeds the set limit. To prevent faulty operation at least one phase current needs to be above the minimum level. PDNSPTOC operates with DT characteristic.

The function contains a blocking functionality. It is possible to block the function output, timer or the function itself.

4.4.3.4 Analog channel configuration

PDNSPTOC has one analog group input which must be properly configured.

Table 754: Analog signals

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.4.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PDNSPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

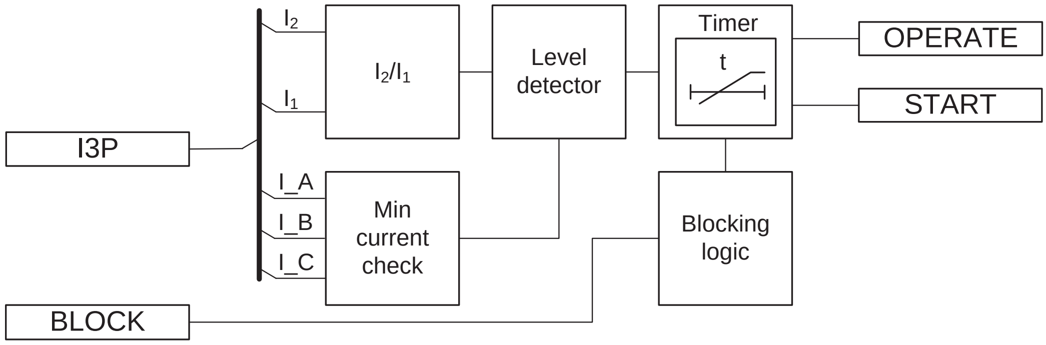


Figure 471: Functional module diagram

I_2/I_1

The I_2/I_1 module calculates the ratio of the negative and positive sequence current. It reports the calculated value to the level detector.

Level detector

The level detector compares the calculated ratio of the negative and positive-sequence currents to the set *Start value*. If the calculated value exceeds the set *Start value* and the min current check module has exceeded the value of *Min phase current*, the level detector reports the exceeding of the value to the timer.

Min current check

The min current check module checks whether the measured phase currents are above the set *Min phase current*. At least one of the phase currents needs to be above the set limit to enable the level detector module.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.4.3.6 Application

In three-phase distribution and subtransmission network applications the phase discontinuity in one phase can cause an increase of zero-sequence voltage and short overvoltage peaks and also oscillation in the corresponding phase.

PDNSPTOC is a three-phase protection with DT characteristic, designed for detecting broken conductors in distribution and subtransmission networks. The function is applicable for both overhead lines and underground cables.

The operation of PDNSPTOC is based on the ratio of the positive-sequence and negative-sequence currents. This gives a better sensitivity and stability compared to plain negative-sequence current protection since the calculated ratio of positive-sequence and negative-sequence currents is relatively constant during load variations.

The unbalance of the network is detected by monitoring the negative-sequence and positive-sequence current ratio, where the negative-sequence current value is I_2 and I_1 is the positive-sequence current value. The unbalance is calculated with the equation.

$$Iratio = \frac{I_2}{I_1}$$

(Equation 236)

Broken conductor fault situation can occur in phase A in a feeder.

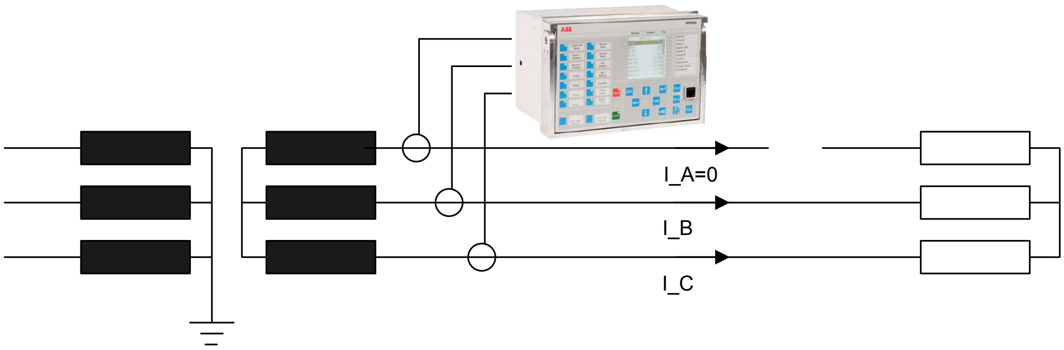


Figure 472: Broken conductor fault situation in phase A in a distribution or subtransmission feeder

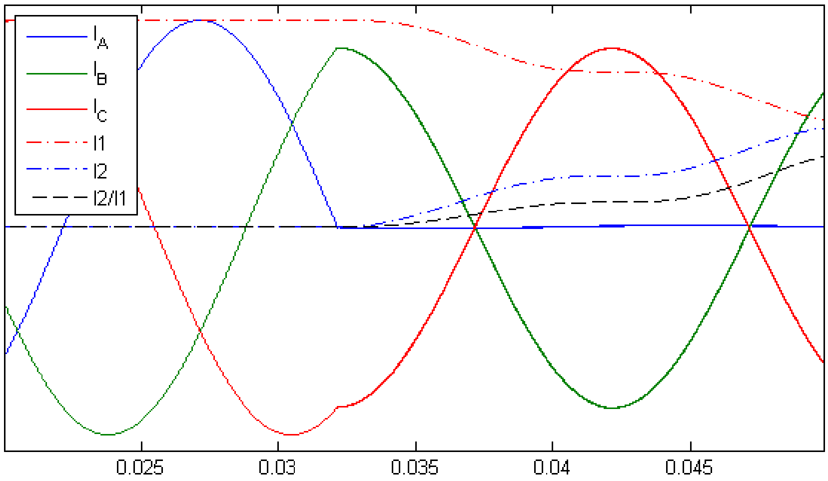


Figure 473: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative-sequence and positive-sequence currents

4.4.3.7 Signals

PDNSPTOC Input signals

Table 755: PDNSPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

PDNSPTOC Output signals

Table 756: PDNSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.3.8 PDNSPTOC Settings

Table 757: PDNSPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	10...100	%	1	10	Start value
Operate delay time	100...30000	ms	1	100	Operate delay time

Table 758: PDNSPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 759: PDNSPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Min phase current	0.05...0.30	xIn	0.01	0.10	Minimum phase current

4.4.3.9 PDNSPTOC Monitored data

Table 760: PDNSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
RATIO_I2_I1	FLOAT32	0.00...999.99	%	Measured current ratio I2 / I1
PDNSPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.3.10 Technical data

Table 761: PDNSPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±2% of the set value
Start time	<70 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

4.4.4 Phase reversal protection PREVPTOC (ANSI 46R)

4.4.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase reversal protection	PREVPTOC	I2>>	46R

4.4.4.2 Function block

Figure 474: Function block

4.4.4.3 Functionality

The phase reversal protection function PREVPTOC is used to detect the reversed connection of the phases to a three-phase motor by monitoring the negative phase sequence current I_2 of the motor.

PREVPTOC starts and operates when I_2 exceeds the set limit. PREVPTOC operates on definite time (DT) characteristics. PREVPTOC is based on the calculated I_2, and the function detects too high I_2 values during the motor start-up. The excessive I_2 values are caused by incorrectly connected phases, which in turn makes the motor rotate in the opposite direction.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.4.4.4 Analog input configuration

PREVPTOC has one analog group input which must be properly configured.

Table 762: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.4.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PREVPTOC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

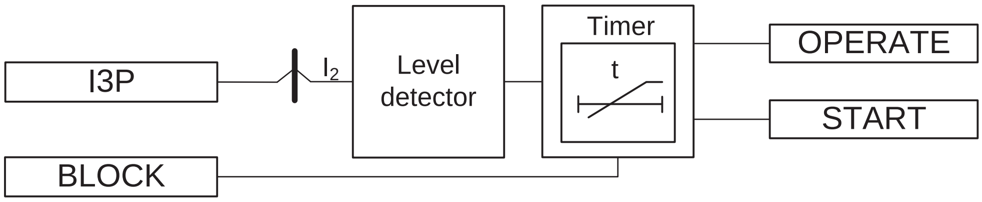


Figure 475: Functional module diagram

Level detector

The level detector compares the negative-sequence current to the set *Start value*. If the I_2 value exceeds the set *Start value*, the level detector sends an enabling signal to the timer module.

Timer

Once activated, the timer activates the `START` output. When the operation timer has reached the set *Operate delay time* value, the `OPERATE` output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value of 200 ms, the operation timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

4.4.4.6 Application

The rotation of a motor in the reverse direction is not a desirable operating condition. When the motor drives fans and pumps, for example, and the rotation direction is reversed due to a wrong phase sequence, the driven process can be disturbed and the flow of the cooling air of the motor can become reversed too. With a motor designed only for a particular rotation direction, the reversed rotation direction can lead to an inefficient cooling of the motor due to the fan design.

In a motor, the value of the negative-sequence component of the phase currents is very negligible when compared to the positive-sequence component of the current during a healthy operating condition of the motor. But when the motor is started with the phase connections in the reverse order, the magnitude of I_2 is very high. So whenever the value of I_2 exceeds the start value, the function detects the reverse rotation direction and provides an operating signal that disconnects the motor from the supply.

4.4.4.7 Signals

PREVPTOC Input signals

Table 763: PREVPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

PREVPTOC Output signals

Table 764: PREVPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.4.8 PREVPTOC Settings

Table 765: PREVPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.00	xIn	0.01	0.75	Start value
Operate delay time	100...60000	ms	10	100	Operate delay time

Table 766: PREVPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

4.4.4.9 PREVPTOC Monitored data

Table 767: PREVPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PREVPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.4.10 Technical data

Table 768: PREVPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]	I_{Fault} = 2.0 × set *Start value*	Minimum	Typical	Maximum
		23 ms	25 ms	28 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.4.5 Negative-sequence overcurrent protection for machines MNSPTOC (ANSI 46M)

4.4.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection for machines	MNSPTOC	I2>M	46M

4.4.5.2 Function block

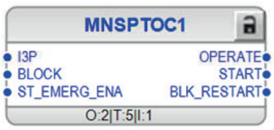


Figure 476: Function block

4.4.5.3 Functionality

The negative-sequence overcurrent protection for machines function MNSPTOC protects electric motors from phase unbalance. A small voltage unbalance can produce a large negative-sequence current flow in the motor. For example, a 5 percent voltage unbalance produces a stator negative-sequence current of 30 percent of the full load current, which can severely heat the motor. MNSPTOC detects the large negative-sequence current and disconnects the motor.

The function contains a blocking functionality. It is possible to block the function outputs, timers or the function itself.

1 Negative-sequence current before = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2 Includes the delay of the signal output contact.

4.4.5.4 Analog channel configuration

MNSPTOC has one analog group input which must be properly configured.

Table 769: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.4.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MNSPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

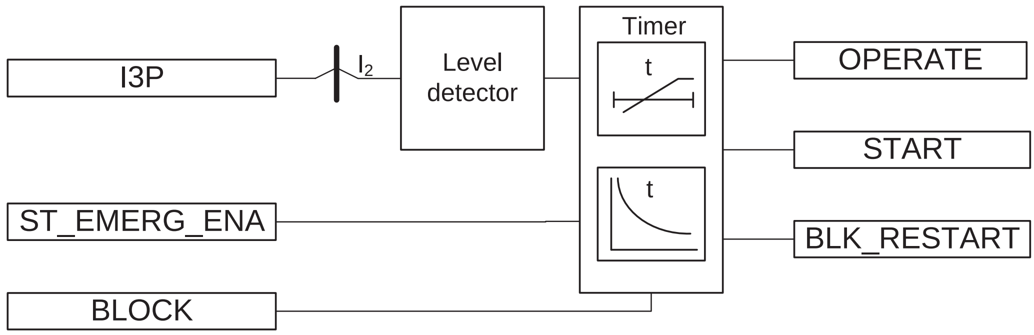


Figure 477: Functional module diagram

Level detector

The calculated negative-sequence current is compared to the *Start value* setting. If the measured value exceeds the *Start value* setting, the function activates the timer module.

Timer

Once activated, the timer activates the `START` output. Depending on the value of the set *Operating curve type*, the time characteristics are according to DT or IDMT. When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the `OPERATE` output is activated.

In a drop-off situation, that is, when the value of the negative-sequence current drops below the *Start value* setting, the reset timer is activated and the START output resets after the time delay of *Reset delay time* for the DT characteristics. For IDMT, the reset time depends on the curve type selected.

For the IDMT curves, it is possible to define minimum and maximum operate times with the *Minimum operate time* and *Maximum operate time* settings. The *Machine time Mult* setting parameter corresponds to the machine constant, equal to the I_2^2t constant of the machine, as stated by the machine manufacturer. In case there is a mismatch between the used CT and the protected motor's nominal current values, it is possible to fit the IDMT curves for the protected motor using the *Current reference* setting.

The activation of the OPERATE output activates the BLK_RESTART output. The deactivation of the OPERATE output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The BLK_RESTART output is kept active until the cooling timer is exceeded. If the negative-sequence current increases above the set value during this period, the OPERATE output is activated immediately.

T_ENARESTART indicates the duration for which the BLK_RESTART output remains active, that is, it indicates the remaining time of the cooling timer. The value is available in the monitored data view.

When the ST_EMERG_ENA emergency start is set high, the value of the T_ENARESTART is immediately set to "False". This disables BLK_RESTART and in turn makes the restart of the motor possible.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

The T_ENARESTART output indicates the duration for which the BLK_RESTART output remains active, that is, it indicates the remaining time of the cooling timer. The value is available in the monitored data view.

When the ST_EMERG_ENA emergency start is set high, the value of the T_ENARESTART is immediately set to "False". This disables BLK_RESTART and in turn makes the restart of the motor possible.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

4.4.5.6 Timer characteristics

MNSPTOC supports both DT and IDMT characteristics. The DT timer characteristics can be selected with "ANSI Def. Time" or "IEC Def. Time" in the *Operating curve type* setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Operate delay time* and *Reset delay time* settings.

The protection relay provides two user-programmable IDMT characteristics curves, "Inv. curve A" and "Inv. curve B".

Current-based inverse definite minimum time curve (IDMT)

In inverse-time modes, the operate time depends on the momentary value of the current: the higher the current, the shorter the operate time. The operate time calculation or integration starts immediately when the current exceeds the set *Start value* and the START output is activated.

The OPERATE output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum operate time* and *Maximum operate time* settings define the minimum operate time and maximum operate time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

Inv. curve A

The inverse time equation for curve type A is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2}$$

(Equation 237)

t[s]	Operate time in seconds
k	Set *Machine time Mult*
I_2	Negative-sequence current
I_r	Set *Rated current*

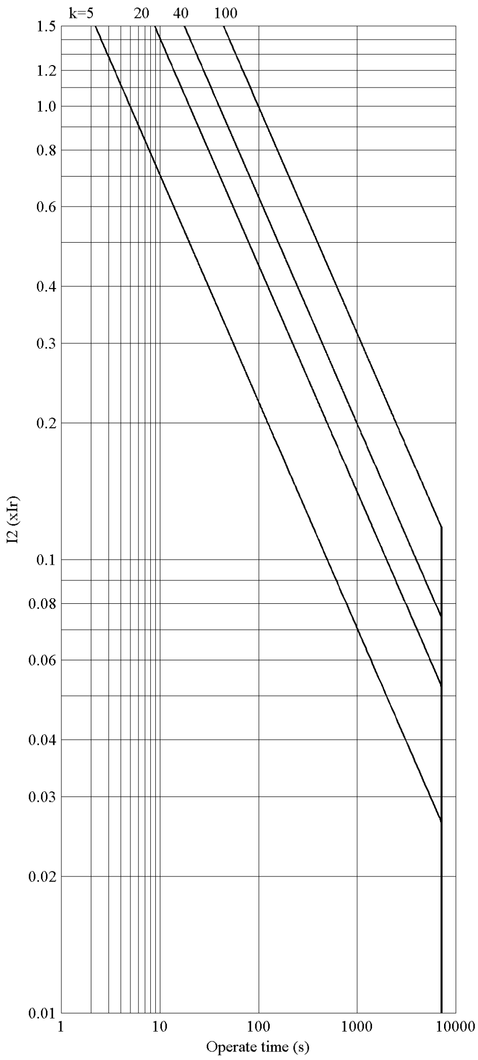


Figure 478: MNSPTOC Inverse Curve A

If the negative sequence current drops below the *Start value* setting, the reset time is defined as:

$$t[s] = a \times \left(\frac{b}{100} \right)$$

(Equation 238)

t[s]	Reset time in seconds
a	set *Cooling time*
b	percentage of start time elapse (START_DUR)

When the reset period is initiated, the time for which START has been active is saved. If the fault reoccurs, that is, the negative-sequence current rises above the set value during the reset period, the operate calculations are continued using the saved values. If the reset period elapses without a fault being detected, the operate timer is reset and the saved values of start time and integration are cleared.

Inv. curve B

The inverse time equation for curve type B is:

$$t[s] = \frac{k}{\left(\frac{I_2}{I_r}\right)^2 - \left(\frac{I_S}{I_r}\right)^2}$$

(Equation 239)

t[s]	Operate time in seconds
k	*Machine time Mult*
I_2	Negative-sequence current
I_S	Set *Start value*
I_r	Set *Rated current*

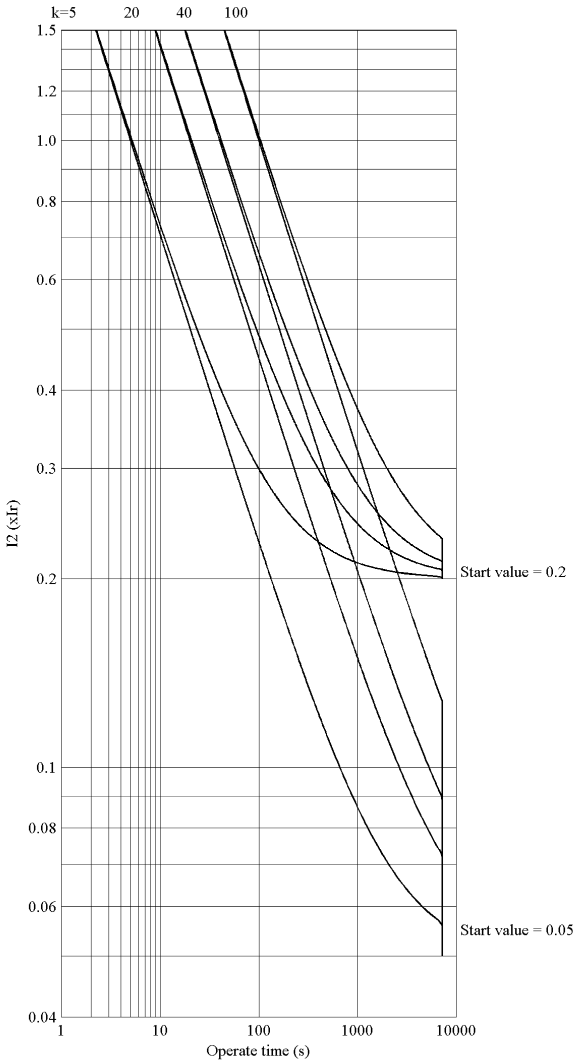


Figure 479: MNSPTOC Inverse Curve B

If the fault disappears, the negative-sequence current drops below the *Start value* setting and the START output is deactivated. The function does not reset instantaneously. Resetting depends on the equation or the *Cooling time* setting.

The timer is reset in three ways:

- When the negative sequence current drops below start value the subtraction in the denominator becomes negative and the cumulative sum starts to decrease. The decrease in the sum indicates the cooling of the machine and the cooling speed depends on the value of the negative-sequence current. If the sum reaches zero without a fault being detected, the accumulation stops and the timer is reset.
- If the reset time set through the *Cooling time* setting elapses without a fault being detected, the timer is reset.
- If ST_EMERG_ENA is activated, the timer is reset.

The reset period thus continues for a time equal to the *Cooling time* setting or until the operate time decreases to zero, whichever is less.

4.4.5.7 Application

In a three-phase motor, the conditions that can lead to unbalance are single phasing, voltage unbalance from the supply and single-phase fault. The negative sequence current damages the motor during the unbalanced voltage condition, and therefore the negative sequence current is monitored to check the unbalance condition.

When the voltages supplied to an operating motor become unbalanced, the positive-sequence current remains substantially unchanged, but the negative-sequence current flows due to the unbalance. For example, if the unbalance is caused by an open circuit in any phase, a negative-sequence current flows and it is equal and opposite to the previous load current in a healthy phase. The combination of positive and negative-sequence currents produces phase currents approximately 1.7 times the previous load in each healthy phase and zero current in the open phase.

The negative-sequence currents flow through the stator windings inducing negative-sequence voltage in the rotor windings. This can result in a high rotor current that damages the rotor winding. The frequency of the induced current is approximately twice the supply frequency. Due to skin effect, the induced current with a frequency double the supply frequency encounters high rotor resistance which leads to excessive heating even with phase currents with value less than the rated current of the motor.

The negative-sequence impedance of induction or a synchronous motor is approximately equal to the locked rotor impedance, which is approximately one-sixth of the normal motor impedance, considering that the motor has a locked-rotor current of six times the rated current. Therefore, even a three percent voltage unbalance can lead to 18 percent stator negative sequence current in windings. The severity of this is indicated by a 30-40 percent increase in the motor temperature due to the extra current.

4.4.5.8 Signals

MNSPTOC Input signals

Table 770: MNSPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ST_EMERG_ENA	BOOLEAN	0=False	Enable emergency start to disable lock of start of motor

MNSPTOC Output signals

Table 771: MNSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_RESTART	BOOLEAN	Overheated machine reconnection blocking

4.4.5.9 MNSPTOC Settings

Table 772: MNSPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...0.50	xIn	0.01	0.20	Start value
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=Inv. Curve A 18=Inv. Curve B			15=IEC Def. Time	Selection of time delay curve type
Machine time Mult	5.0...100.0		0.1	5.0	Machine related time constant
Operate delay time	100...120000	ms	10	1000	Operate delay time

Table 773: MNSPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Maximum operate time	500000...7200000	ms	1000	1000000	Max operate time regardless of the inverse characteristic
Minimum operate time	100...120000	ms	1	100	Minimum operate time for IDMT curves
Cooling time	5...7200	s	1	50	Time required to cool the machine

Table 774: MNSPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Current reference	0.30...2.00	xIn	0.01	1.00	Rated current (Ir) of the machine (used only in the IDMT)
Reset delay time	0...60000	ms	1	20	Reset delay time

4.4.5.10 MNSPTOC Monitored data

Table 775: MNSPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
T_ENARESTART	INT32	0...10000	s	Estimated time to reset of block restart
MNSPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.4.5.11 Technical data

Table 776: MNSPTOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n		
		±1.5% of the set value or ±0.002 × I_n		
Start time [1, 2]	I_{Fault} = 2.0 × set *Start value*	Minimum	Typical	Maximum
		23	25 ms	28 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms [3]		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.4.5.12 Technical revision history

Table 777: MNSPTOC Technical revision history

Product connectivity level	Technical revision	Change
PCL2	E	Added new input `ST_EMERG_ENA` which allows motor energization in an emergency case

4.5 Voltage protection

1 Negative-sequence current before = 0.0, f_n = 50 Hz, results based on statistical distribution of 1000 measurements.
2 Includes the delay of the signal output contact.
3 *Start value* multiples in range of 1.10...5.00.

4.5.1 Three-phase overvoltage protection PHPTOV (ANSI 59)

4.5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overvoltage protection	PHPTOV	3U>	59

4.5.1.2 Function block

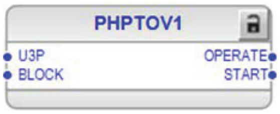


Figure 480: Function block

4.5.1.3 Functionality

The three-phase overvoltage protection function PHPTOV is applied on power system elements, such as generators, transformers, motors and power lines, to protect the system from excessive voltages that could damage the insulation and cause insulation breakdown. The three-phase overvoltage function includes a settable value for the detection of overvoltage either in a single phase, two phases or three phases.

PHPTOV includes both definite time (DT) and inverse definite minimum time (IDMT) characteristics for the delay of the trip.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.5.1.4 Analog channel configuration

PHPTOV has one analog group input which must be properly configured.

Table 778: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 779: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected if *Num of start phases* is set to "1 out of 3". Otherwise, at least two vol-

Condition	Description
	tages must be connected (third one will be derived).

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

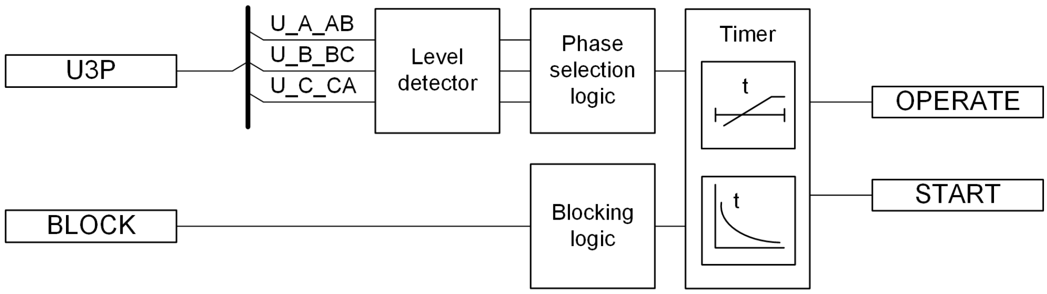


Figure 481: Functional module diagram

Level detector

The fundamental frequency component of the measured three-phase voltages are compared phase-wise to the set value of the *Start value* setting. If the measured value is higher than the set value of the *Start value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly differs from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The *Voltage selection* setting is used for selecting phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT operation mode, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat Relative* setting is used for preventing undesired operation.

For a more detailed description of the IDMT curves and the use of the *Curve Sat Relative* setting, see *Chapter 11.3.1.3 IDMT curve saturation of overvoltage protection* in this manual.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of start phases*, the phase selection logic activates the Timer.

Timer

Once activated, the Timer activates the START output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see *Chapter 11.2.1 IDMT curves for overcurrent protection* in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the IDMT, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operate time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the operate delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operate time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the START output is deactivated.

When the IDMT operate time curve is selected, the functionality of the Timer in the drop-off state depends on the combination of the *Type of reset curve*, *Type of time reset* and *Reset delay time* settings.

Table 780: Reset time functionality when IDMT operation time curve selected

Reset functionality		Setting Type of reset curve	Setting Type of time reset	Setting Reset delay time
Instantaneous reset	Operation timer is “Reset instantaneously” when drop-off occurs	“Immediate”	Setting has no effect	Setting has no effect
Frozen timer	Operation timer is frozen during drop-off	“Def time reset”	“Freeze Op timer”	Operate timer is reset after the set *Reset delay time* has elapsed
Linear decrease	Operation timer value linearly decreases during the drop-off situation	“Def time reset”	“Decrease Op timer”	Operate timer is reset after the set *Reset delay time* has elapsed

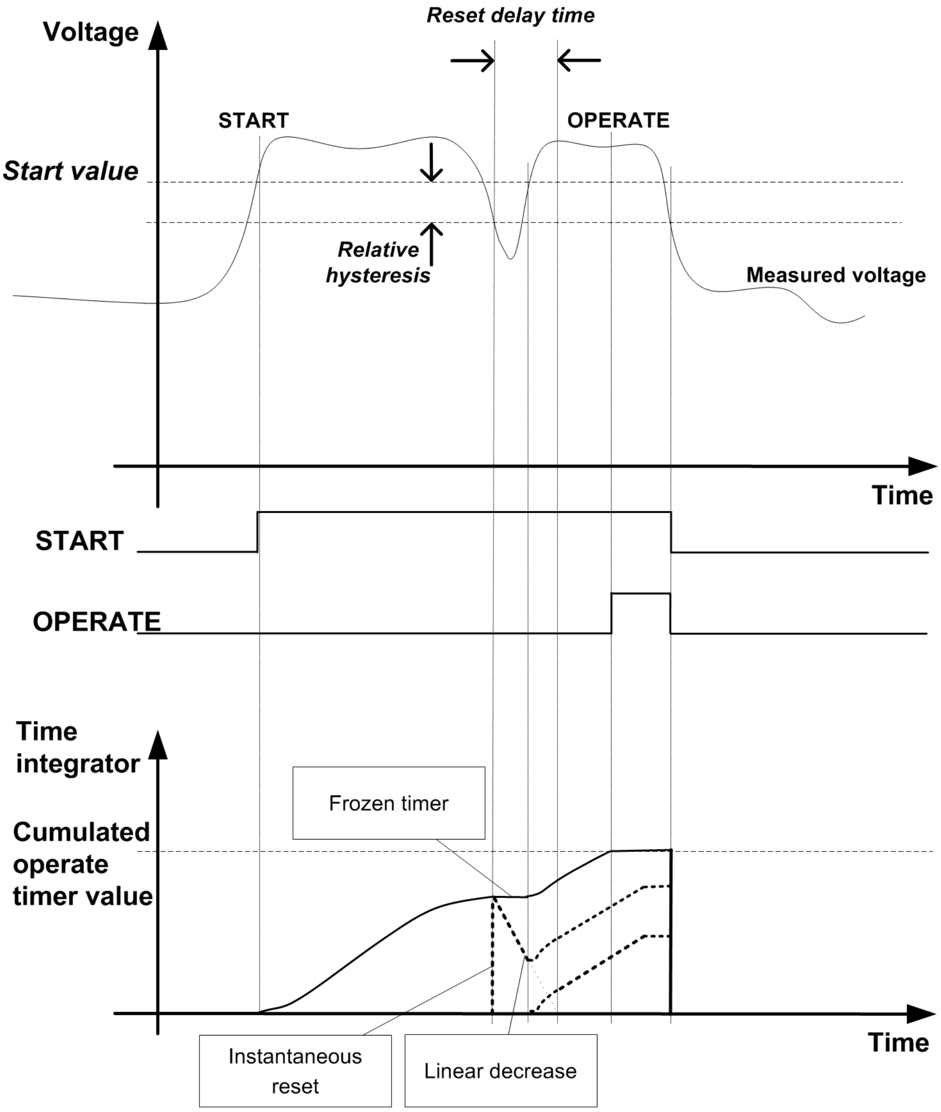


Figure 482: Behavior of different IDMT reset modes. Operate signal is based on settings Type of reset curve = "Def time reset" and Type of time reset= "Freeze Op timer". The effect of other reset modes is also presented

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.3.1 IDMT curves for overvoltage protection* in this manual.

The Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timer" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

The “Freeze timers” mode of blocking has no effect during the inverse reset mode.

4.5.1.6 Timer characteristics

The operating curve types supported by PHPTOV are:

Table 781: Timer characteristics supported by IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(17) Inv. Curve A
(18) Inv. Curve B
(19) Inv. Curve C
(20) Programmable

4.5.1.7 Application

Overvoltage in a network occurs either due to the transient surges on the network or due to prolonged power frequency overvoltages. Surge arresters are used to protect the network against the transient overvoltages, but the relay's protection function is used to protect against power frequency overvoltages.

The power frequency overvoltage may occur in the network due to contingencies such as:

- The defective operation of the automatic voltage regulator when the generator is in isolated operation.
- Operation under manual control with the voltage regulator out of service. A sudden variation of load, in particular the reactive power component, gives rise to a substantial change in voltage because of the inherent large voltage regulation of a typical alternator.
- Sudden loss of load due to the tripping of outgoing feeders, leaving the generator isolated or feeding a very small load. This causes a sudden rise in the terminal voltage due to the trapped field flux and overspeed.

If a load sensitive to overvoltage remains connected, it leads to equipment damage.

It is essential to provide power frequency overvoltage protection, in the form of time delayed element, either IDMT or DT to prevent equipment damage.

4.5.1.8 Signals

PHPTOV Input signals

Table 782: PHPTOV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

PHPTOV Output signals

Table 783: PHPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.1.9 PHPTOV Settings

Table 784: PHPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.60	xUn	0.01	1.10	Start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	40...300000	ms	10	40	Operate delay time
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=Inv. Curve A 18=Inv. Curve B 19=Inv. Curve C 20=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 785: PHPTOV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset			1=Immediate	Selection of reset curve type
Type of time reset	1=Freeze Op timer 2=Decrease Op timer			1=Freeze Op timer	Selection of time reset

Table 786: PHPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.005...200.000		0.001	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00		0.01	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0		0.1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000		0.001	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000		0.001	1.000	Parameter E for customer programmable curve
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 787: PHPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	40...60000	ms	1	40	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve Sat Relative	0.0...10.0		0.1	0.0	Tuning parameter to avoid curve discontinuities
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.1.10 PHPTOV Monitored data

Table 788: PHPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.1.11 Technical data

Table 789: PHPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time[1, 2]	U_{Fault} = 1.1 × set *Start value*	Minimum	Typical	Maximum
		23 ms	27 ms	31 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms[3]		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.2 Three-phase undervoltage protection PHPTUV (ANSI 27)

4.5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase undervoltage protection	PHPTUV	3U<	27

4.5.2.2 Function block

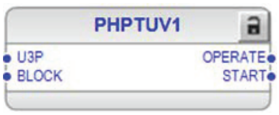


Figure 483: Function block

4.5.2.3 Functionality

The three-phase undervoltage protection function PHPTUV is used to disconnect from the network devices, for example electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV includes a settable value

1 *Start value* = 1.0 × U_n, Voltage before fault = 0.9 × U_n, f_n = 50 Hz, overvoltage in one phase-to-phase with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact
3 Maximum *Start value* = 1.20 × U_n, *Start value* multiples in range of 1.10...2.00

for the detection of undervoltage either in a single phase, two phases or three phases.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.5.2.4 Analog channel configuration

PHPTUV has one analog group input which must be properly configured.

Table 790: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 791: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected if *Num of start phases* is set to "1 out of 3" but the other two channels must be fed with high values (considerably above *Start value*). For other values of *Num of start phases*, all three voltage channels must be connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

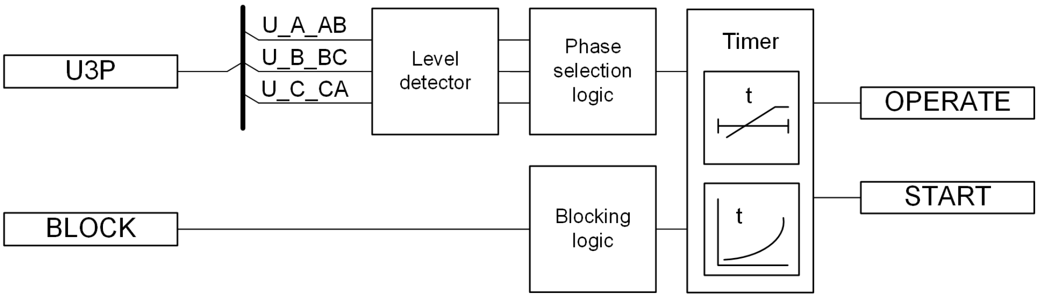


Figure 484: Functional module diagram

Level detector

The fundamental frequency component of the measured three phase voltages are compared phase-wise to the set *Start value*. If the measured value is lower than the set value of the *Start value* setting, the level detector enables the phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies above or below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return back to the hysteresis area.

The *Voltage selection* setting is used for selecting the phase-to-earth or phase-to-phase voltages for protection.

For the voltage IDMT mode of operation, the used IDMT curve equations contain discontinuity characteristics. The *Curve Sat relative* setting is used for preventing unwanted operation.

For more detailed description on IDMT curves and usage of *Curve Sat Relative* setting, see *Chapter 11.3.2 IDMT curves for undervoltage protection* in this manual.

The level detector contains a low-level blocking functionality for cases where one of the measured voltages is below the desired level. This feature is useful when unnecessary starts and operates are wanted to avoid during, for example, an autoreclose sequence. The low-level blocking is activated by default (*Enable block value* is set to "True") and the blocking level can be set with the *Voltage block value* setting.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases match with the set *Num of start phases*, the phase selection logic activates the Timer.

Timer

Once activated, the Timer activates the START output. Depending on the value of the set *Operating curve type*, the time characteristics are selected according to DT or IDMT.

For a detailed description of the voltage IDMT curves, see *Chapter 11.3.2 IDMT curves for undervoltage protection* in this manual.

When the operation timer has reached the value set by *Operate delay time* in the DT mode or the maximum value defined by the IDMT, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operate time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C*, *Curve parameter D* and *Curve parameter E*.

If a drop-off situation occurs, that is, a fault suddenly disappears before the operate delay is exceeded, the reset state is activated. The behavior in the drop-off situation depends on the selected operate time characteristics. If the DT characteristics are selected, the reset timer runs until the set *Reset delay time* value is exceeded. If the drop-off situation exceeds the set *Reset delay time*, the Timer is reset and the START output is deactivated.

When the IDMT operate time curve is selected, the functionality of the Timer in the drop-off state depends on the combination of the *Type of reset curve*, *Type of time reset* and *Reset delay time* settings.

Table 792: Reset time functionality when IDMT operation time curve selected

Reset functionality		**Setting Type of reset curve**	**Setting Type of time reset**	**Setting Reset delay time**
Instantaneous reset	Operation timer is “Reset instantaneously” when drop-off occurs	“Immediate”	Setting has no effect	Setting has no effect
Frozen timer	Operation timer is frozen during drop-off	“Def time reset”	“Freeze Op timer”	Operate timer is reset after the set *Reset delay time* has elapsed
Linear decrease	Operation timer value linearly decreases during the drop-off situation	“Def time reset”	“Decrease Op timer”	Operate timer is reset after the set *Reset delay time* has elapsed

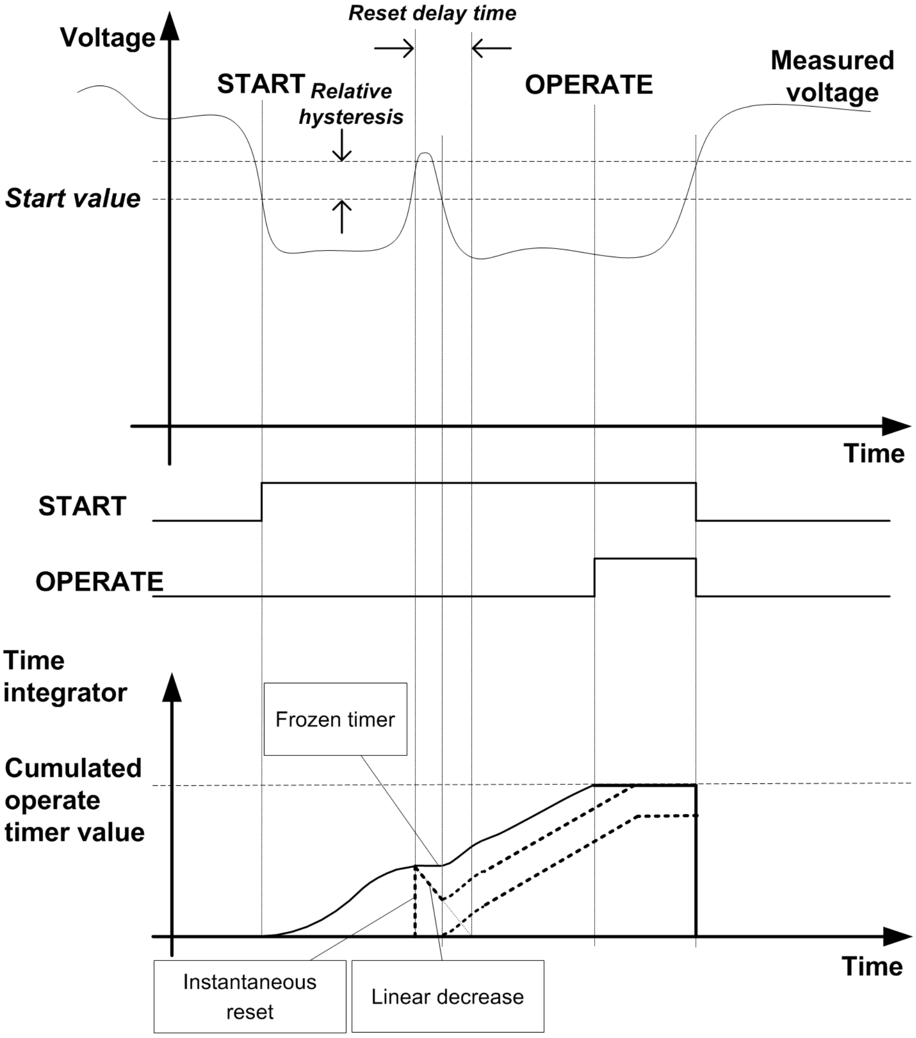


Figure 485: Behavior of different IDMT reset modes. Operate signal is based on settings Type of reset curve = "Def time reset" and Type of time reset= "Freeze Op timer". The effect of other reset modes is also presented

The *Time multiplier* setting is used for scaling the IDMT operate times.

The *Minimum operate time* setting parameter defines the minimum desired operate time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting. For more information, see *Chapter 11.3.2 IDMT curves for undervoltage protection* in this manual.

The Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` input signal activation is preselected with the global *Blocking mode* setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the `OPERATE` output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the Timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

The “Freeze timers” mode of blocking has no effect during the “Inverse reset” mode.

4.5.2.6 Timer characteristics

The operating curve types supported by PHPTUV are:

Table 793: Supported IDMT operate curve types

Operating curve type
(5) ANSI Def. Time
(15) IEC Def. Time
(21) Inv. Curve A
(22) Inv. Curve B
(23) Programmable

4.5.2.7 Application

PHPTUV is applied to power system elements, such as generators, transformers, motors and power lines, to detect low voltage conditions. Low voltage conditions are caused by abnormal operation or a fault in the power system. PHPTUV can be used in combination with overcurrent protections. Other applications are the detection of a no-voltage condition, for example before the energization of a high voltage line, or an automatic breaker trip in case of a blackout. PHPTUV is also used to initiate voltage correction measures, such as insertion of shunt capacitor banks, to compensate for a reactive load and thereby to increase the voltage.

PHPTUV can be used to disconnect from the network devices, such as electric motors, which are damaged when subjected to service under low voltage conditions. PHPTUV deals with low voltage conditions at power system frequency. Low voltage conditions can be caused by:

- Malfunctioning of a voltage regulator or incorrect settings under manual control (symmetrical voltage decrease)
- Overload (symmetrical voltage decrease)
- Short circuits, often as phase-to-earth faults (unsymmetrical voltage increase).

PHPTUV prevents sensitive equipment from running under conditions that could cause overheating and thus shorten their life time expectancy. In many cases, PHPTUV is a useful function in circuits for local or remote automation processes in the power system.

4.5.2.8 Signals

PHPTUV Input signals

Table 794: PHPTUV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

PHPTUV Output signals

Table 795: PHPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.2.9 PHPTUV Settings

Table 796: PHPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.20	xUn	0.01	0.90	Start value
Time multiplier	0.025...15.000		0.005	1.000	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	20...300000	ms	10	60	Operate delay time
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 21=Inv. Curve A 22=Inv. Curve B 23=Programmable			15=IEC Def. Time	Selection of time delay curve type

Table 797: PHPTUV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Type of reset curve	1=Immediate 2=Def time reset			1=Immediate	Selection of reset curve type
Type of time reset	1=Freeze Op timer 2=Decrease Op timer			1=Freeze Op timer	Selection of time reset

Table 798: PHPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Curve parameter A	0.005...200.000		0.001	1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00		0.01	1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0		0.1	0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000		0.001	0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000		0.001	1.000	Parameter E for customer programmable curve
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages

Table 799: PHPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum operate time	20...60000	ms	1	60	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve Sat Relative	0.0...10.0		0.1	0.0	Tuning parameter to avoid curve discontinuities
Voltage block value	0.05...1.00	xUn	0.01	0.20	Low level blocking for undervoltage mode
Enable block value	0=False 1=True			1=True	Enable internal blocking
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.2.10 PHPTUV Monitored data

Table 800: PHPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PHPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.2.11 Technical data

Table 801: PHPTUV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time		Minimum	Typical	Maximum
	U_{Fault} = 0.85 × set *Start value*[1, 2]	17 ms	20 ms	23 ms
	U_{Fault} = 0.85 × set *Start value*[1, 3]	51 ms	55 ms	58 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Operate time accuracy in inverse time mode		±5.0% of the theoretical value or ±20 ms[4]		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.2.12 Technical revision history

Table 802: PHPTUV Technical revision history

Product connectivity level	Technical revision	Change
PCL4	F	New minimum value 20 ms for *Operate delay time* and *Minimum operate time* settings

4.5.3 Residual overvoltage protection ROVPTOV (ANSI 59G/ 59N)

4.5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual overvoltage protection	ROVPTOV	Uo>	59G/59N

1 *Start value* = 0.97 × U_n, voltage level before fault = 1 × U_n, f_n = 50 Hz, undervoltage in one phase-to-phase voltage injected from random phase angle, results based on statistical distribution of 1000 measurements, includes the delay (≈0ms) of the static signal output (SSO) contact
2 Start time is accelerated when set *Operate delay time* < 60ms. The shorter the set delay, the shorter the start time. Here measurements done for *Operate delay time* = 20ms
3 Valid when set *Operate delay time* ≥ 60ms or inverse time curve selected
4 Minimum *Start value* = 0.50, *Start value* multiples in range of 0.90...0.20

4.5.3.2 Function block

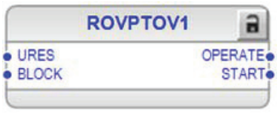


Figure 486: Function block

4.5.3.3 Functionality

The residual overvoltage protection function ROVPTOV is used in distribution networks where the residual overvoltage can reach non-acceptable levels in, for example, high impedance earthing.

The function starts when the residual voltage exceeds the set limit. ROVPTOV operates with the definite time (DT) characteristic.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.5.3.4 Analog channel configuration

ROVPTOV has one analog group input which must be properly configured.

Table 803: Analog inputs

Input	Description
URES	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 804: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected to calculate residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of ROVPTOV can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

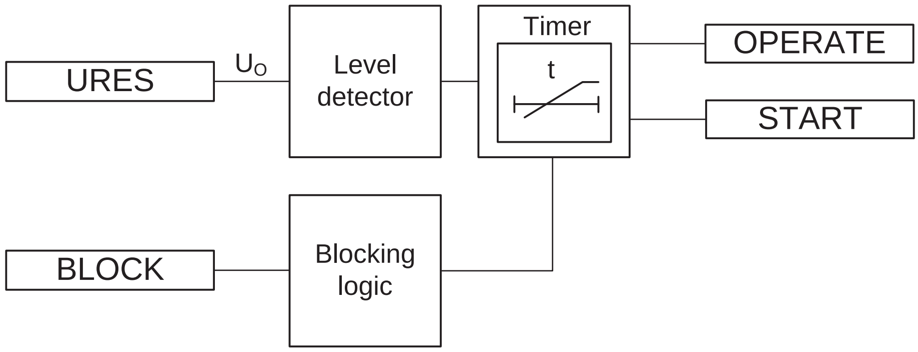


Figure 487: Functional module diagram

Level detector

The residual voltage is compared to the set *Start value*. If the value exceeds the set *Start value*, the level detector sends an enable signal to the timer.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the fault disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.3.6 Application

ROVPTOV is designed to be used for earth-fault protection in isolated neutral, resistance earthed or reactance earthed systems. In compensated networks, starting of the function can be used to control the switching device of the neutral resistor. The function can also be used for the back-up protection of feeders for busbar protection when a more dedicated busbar protection would not be justified.

In compensated and isolated neutral systems, the system neutral voltage, that is, the residual voltage, increases in case of any fault connected to earth. Depending on the type of the fault and the fault resistance, the residual voltage reaches different values. The highest residual voltage, equal to the phase-to-earth voltage, is achieved for a single-phase earth fault. The residual voltage increases approximately the same amount in the whole system and does not provide any guidance in finding the faulty component. Therefore, this function is often used as a backup protection or as a release signal for the feeder earth-fault protection.

The protection can also be used for the earth-fault protection of generators and motors and for the unbalance protection of capacitor banks.

The residual voltage can be calculated internally based on the measurement of the three-phase voltage. This voltage can also be measured by a single-phase voltage transformer, located between a transformer star point and earth, or by using an open-delta connection of three single-phase voltage transformers.

4.5.3.7 Signals

ROVPTOV Input signals

Table 805: ROVPTOV Input signals

Name	Type	Default	Description
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

ROVPTOV Output signals

Table 806: ROVPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.3.8 ROVPTOV Settings

Table 807: ROVPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...1.000	xUn	0.001	0.030	Residual overvoltage start value
Operate delay time	40...300000	ms	1	40	Operate delay time

Table 808: ROVPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 809: ROVPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.5.3.9 ROVPTOV Monitored data

Table 810: ROVPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
ROVPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.3.10 Technical data

Table 811: ROVPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time[1, 2]	U_{Fault} = 2 × set *Start value*	Minimum	Typical	Maximum
		48 ms	51 ms	54 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

1 Residual voltage before fault = 0.0 × U_n, f_n = 50 Hz, residual voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.5.4 Positive-sequence overvoltage protection PSPTOV (ANSI 59PS)

4.5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence overvoltage protection	PSPTOV	U1>	59PS

4.5.4.2 Function block

Figure 488: Function block

4.5.4.3 Functionality

The positive-sequence overvoltage protection function PSPTOV is used as an alternative to the ordinary three-phase overvoltage protection. PSPTOV is used for supervision and for detection of abnormal conditions, and, together with the other protection functions, increases the security of the protection system.

The function starts when the positive-sequence voltage exceeds the set limit. PSPTOV operates on definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.5.4.4 Analog channel configuration

PSPTOV has one analog group input which must be properly configured.

Table 812: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 813: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PSPTOV can be described with a module diagram. All the modules in the diagram are explained in the next sections.

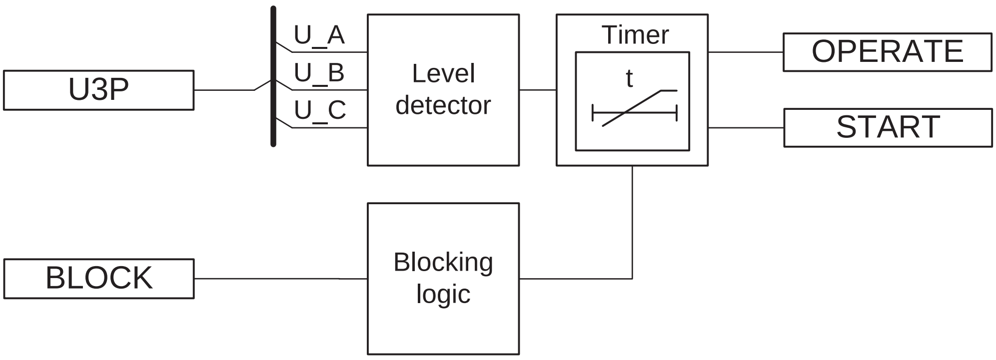


Figure 489: Functional module diagram

Level detector

The calculated positive-sequence voltage is compared to the set *Start value* setting. If the value exceeds the set *Start value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

Timer

Once activated, Timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated if the overvoltage condition persists. If the positive-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

Blocking logic

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all outputs and resets internal timers.

4.5.4.6 Application

A sudden power loss, tap changer regulating failures and open line ends on long lines are abnormal conditions which cause overvoltage in a power system. PSPTOV is applied to power system elements, such as generators, transformers, motors and power lines, to detect overvoltage conditions.

PSPTOV can be used in combination with low-current signals or a directional reactive overpower function to identify the distribution line with an open remote end. PSPTOV can also be used to initiate voltage correction measures, such as insertion of shunt reactors or switching out capacitor banks, to control the voltage.

Overvoltage faced by the power transformer can lead to an overexcitation problem. Overexcitation normally occurs when the voltage-to-frequency ratio increases much above the design value resulting into transformer operation under a nonlinear region. A transformer can be in such an overvoltage situation during a sudden loss of load due to underfrequency load shedding. Overexcitation results in an increase of the exciting current which leads to core heating and thus to transformer damage. PSPTOV along with the underfrequency protection can be used for the protection of the transformer during overexcitation.

Some common reasons leading to positive-sequence overvoltages are:

- Broken conductor falling to a crossing overhead line, transformer flash overfault from high-voltage winding to low-voltage winding
- Malfunctioning of a voltage regulator or wrong settings under manual control (symmetrical voltage increase)
- Low load compared to the reactive power generation (symmetrical voltage increase)

PSPTOV prevents sensitive equipment from running under overvoltage conditions which cause equipment overheating or stress on insulation material.

4.5.4.7 Signals

PSPTOV Input signals

Table 814: PSPTOV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

PSPTOV Output signals

Table 815: PSPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.4.8 PSPTOV Settings

Table 816: PSPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.400...1.600	xUn	0.001	0.650	Start value
Operate delay time	40...120000	ms	10	40	Operate delay time

Table 817: PSPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 818: PSPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.4.9 PSPTOV Monitored data

Table 819: PSPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PSPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.4.10 Technical data

Table 820: PSPTOV Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n
	±1.5% of the set value or ±0.002 × U_n

Table continues on the next page

Characteristic		Value		
Start time [1, 2]		Minimum	Typical	Maximum
	U_{Fault} = 1.1 × set *Start value*	29 ms	32 ms	34 ms
	U_{Fault} = 2.0 × set *Start value*	32 ms	24 ms	26 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.5 Negative-sequence overvoltage protection NSPTOV (ANSI 59NS)

4.5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overvoltage protection	NSPTOV	U2>	59NS

4.5.5.2 Function block

Figure 490: Function block

4.5.5.3 Functionality

The negative-sequence overvoltage protection function NSPTOV is used to detect negative sequence overvoltage conditions. NSPTOV is used for the protection of machines.

The function starts when the negative sequence voltage exceeds the set limit. NSPTOV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

1 Positive-sequence voltage before fault = 0.0 × U_n, f_n = 50 Hz, positive-sequence overvoltage of nominal frequency injected from random phase angle
2 Measured with static signal output (SSO)

4.5.5.4 Analog channel configuration

NSPTOV has one analog group input which must be properly configured.

Table 821: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 822: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that any two voltage channels are connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of NSPTOV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

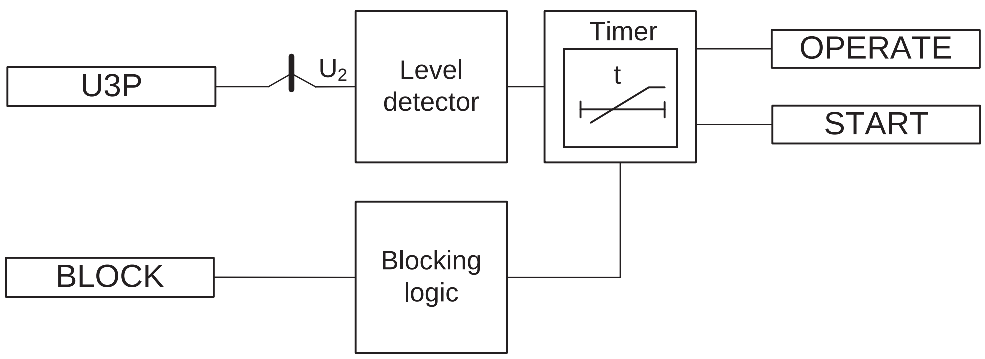


Figure 491: Functional module diagram

Level detector

The calculated negative-sequence voltage is compared to the set *Start value* setting. If the value exceeds the set *Start value*, the level detector enables the timer.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated if the overvoltage condition persists. If the negative-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.5.6 Application

A continuous or temporary voltage unbalance can appear in the network for various reasons. The voltage unbalance mainly occurs due to broken conductors or asymmetrical loads and is characterized by the appearance of a negative-sequence component of the voltage. In rotating machines, the voltage unbalance results in a current unbalance, which heats the rotors of the machines. The rotating machines, therefore, do not tolerate a continuous negative-sequence voltage higher than typically 1-2 percent x U_n.

The negative-sequence component current I_2, drawn by an asynchronous or a synchronous machine, is linearly proportional to the negative-sequence component voltage U_2. When U_2 is P% of U_n, I_2 is typically about 5 x P% x I_n.

The negative-sequence overcurrent NSPTOC blocks are used to accomplish a selective protection against the voltage and current unbalance for each machine separately. Alternatively, the protection can be implemented with the NSPTOV function, monitoring the voltage unbalance of the busbar.

If the machines have an unbalance protection of their own, the NSPTOV operation can be applied as a backup protection or it can be used as an alarm. The latter can be applied when it is not required to trip loads tolerating voltage unbalance better than the rotating machines.

If there is a considerable degree of voltage unbalance in the network, the rotating machines should not be connected to the network at all. This logic can be implemented by inhibiting the closure of the circuit breaker if the NSPTOV operation has started. This scheme also prevents connecting the machine to the network if the phase sequence of the network is not correct.

An appropriate value for the setting parameter *Voltage start value* is approximately 3 percent of U_n. A suitable value for the setting parameter *Operate delay time* depends on the application. If the NSPTOV operation is used as backup protection, the operate time should be set in accordance with the operate time of NSPTOC used as main protection. If the NSPTOV operation is used as main protection, the operate time should be approximately one second.

4.5.5.7 Signals

NSPTOV Input signals

Table 823: NSPTOV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

NSPTOV Output signals

Table 824: NSPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.5.8 NSPTOV Settings

Table 825: NSPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...1.000	xUn	0.001	0.030	Start value
Operate delay time	40...120000	ms	1	40	Operate delay time

Table 826: NSPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 827: NSPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.5.5.9 NSPTOV Monitored data

Table 828: NSPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
NSPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.5.10 Technical data

Table 829: NSPTOV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the voltage measured: f_n		
		±1.5% of the set value or ±0.002 × U_n		
Start time[1, 2]		Minimum	Typical	Maximum
	U_{Fault} = 1.1 × set *Start value*	33 ms	35 ms	37 ms
	U_{Fault} = 2.0 × set *Start value*	24 ms	26 ms	28 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.6 Positive-sequence undervoltage protection PSPTUV (ANSI 27PS)

4.5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence undervoltage protection	PSPTUV	U1<	27PS

1 Negative-sequence voltage before fault = 0.0 × U_n, f_n = 50 Hz, negative-sequence overvoltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.5.6.2 Function block

Figure 492: Function block

4.5.6.3 Functionality

The positive-sequence undervoltage protection function PSPTUV is used to detect positive-sequence undervoltage conditions. PSPTUV is used for the protection of small power generation plants. The function helps in isolating an embedded plant from a fault line when the fault current fed by the plant is too low to start an overcurrent function but high enough to maintain the arc. Fast isolation of all the fault current sources is necessary for a successful autoreclosure from the network-end circuit breaker.

The function starts when the positive-sequence voltage drops below the set limit. PSPTUV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.5.6.4 Analog channel configuration

PSPTUV has one analog group input which must be properly configured.

Table 830: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 831: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.6.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PSPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

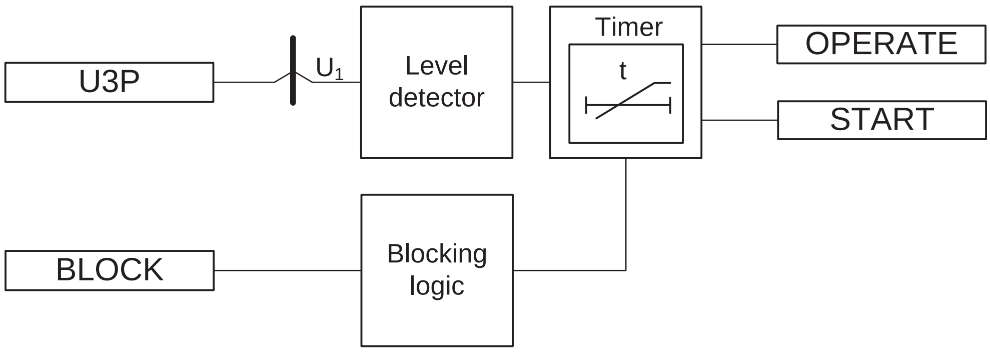


Figure 493: Functional module diagram. U1 is used for representing positive phase sequence voltage.

Level detector

The calculated positive-sequence voltage is compared to the set *Start value* setting. If the value drops below the set *Start value*, the level detector enables the timer. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly varies from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

The level detector contains a low-level blocking functionality for cases where the positive-sequence voltage is below the desired level. This feature is useful when unnecessary starts and operates are wanted to avoid during, for example, an autoreclose sequence. The low-level blocking is activated by default (*Enable block value* is set to “Enabled”) and the blocking level can be set with the *Voltage block value* setting.

Timer

Once activated, the timer activates the `START` output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated if the undervoltage condition persists. If the positive-sequence voltage normalizes before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the `START` output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.6.6 Application

PSPTUV can be applied for protecting a power station used for embedded generation when network faults like short circuits or phase-to-earth faults in a transmission or a distribution line cause a potentially dangerous situations for the power station. A network fault can be dangerous for the power station for various reasons. The operation of the protection can cause an islanding condition, also called a loss-of-mains condition, in which a part of the network, that is, an island fed by the power station, is isolated from the rest of the network. There is then a risk of an autoreclosure taking place when the voltages of different parts of the network do not synchronize, which is a straining incident for the power station. Another risk is that the generator can lose synchronism during the network fault. A sufficiently fast trip of the utility circuit breaker of the power station can avoid these risks.

The lower the three-phase symmetrical voltage of the network is, the higher is the probability that the generator loses the synchronism. The positive-sequence voltage is also available during asymmetrical faults. It is a more appropriate criterion for detecting the risk of loss of synchronism than, for example, the lowest phase-to-phase voltage.

Analyzing the loss of synchronism of a generator is rather complicated and requires a model of the generator with its prime mover and controllers. The generator can be able to operate synchronously even if the voltage drops by a few tens of percent for some hundreds of milliseconds. The setting of PSPTUV is thus determined by the need to protect the power station from the risks of the islanding conditions since that requires a higher setting value.

The loss of synchronism of a generator means that the generator is unable to operate as a generator with the network frequency but enters into an unstable condition in which it operates by turns as a generator and a motor. Such a condition stresses the generator thermally and mechanically. This kind of loss of synchronism should not be mixed with the one between an island and the utility network. In the islanding situation, the condition of the generator itself is normal but the phase angle and the frequency of the phase-to-phase voltage can be different from the corresponding voltage in the rest of the network. The island can have a frequency of its own relatively fast when fed by a small power station with a low inertia.

PSPTUV complements other loss-of-grid protection principles based on the frequency and voltage operation.

Motor stalling and failure to start can lead to a continuous undervoltage. The positive-sequence undervoltage is used as a backup protection against the motor stall condition.

4.5.6.7 Signals

PSPTUV Input signals

Table 832: PSPTUV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

PSPTUV Output signals

Table 833: PSPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.6.8 PSPTUV Settings

Table 834: PSPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...1.200	xUn	0.001	0.500	Start value
Operate delay time	40...120000	ms	10	40	Operate delay time

Table 835: PSPTUV Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage block value	0.01...1.00	xUn	0.01	0.20	Internal blocking level
Enable block value	0=False 1=True			1=True	Enable Internal Blocking

Table 836: PSPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 837: PSPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.6.9 PSPTUV Monitored data

Table 838: PSPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PSPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.6.10 Technical data

Table 839: PSPTUV Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz		
		±1.5% of the set value or ±0.002 × U_n		
Start time [1, 2]		Minimum	Typical	Maximum
	U_{Fault} = 0.99 × set *Start value*	52 ms	55 ms	58 ms
	U_{Fault} = 0.9 × set *Start value*	44 ms	47 ms	50 ms
Reset time		Typically 40 ms		
Reset ratio		Depends on the set *Relative hysteresis*		
Retardation time		<35 ms		
Operate time accuracy in definite time mode		±1.0% of the set value or ±20 ms		
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…		

4.5.7 Overexcitation protection OEPVPH (ANSI 24)

4.5.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Overexcitation protection	OEPVPH	U/f>	24

1 *Start value* = 1.0 × U_n, positive-sequence voltage before fault = 1.1 × U_n, f_n = 50 Hz, positive sequence undervoltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements

2 Includes the delay of the signal output contact

4.5.7.2 Function block

Figure 494: Function block

4.5.7.3 Functionality

The overexcitation protection function OEPVPH is used to protect generators and power transformers against an excessive flux density and saturation of the magnetic core.

The function calculates the U/f ratio (volts/hertz) proportional to the excitation level of the generator or transformer and compares this value to the setting limit. The function starts when the excitation level exceeds the set limit and operates when the set operating time has elapsed. The operating time characteristic can be selected to be either definite time (DT) or overexcitation inverse definite minimum time (overexcitation type IDMT).

This function contains a blocking functionality. It is possible to block the function outputs, reset timer or the function itself.

4.5.7.4 Analog channel configuration

OEPVPH has two analog group inputs which must be properly configured.

Table 840: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 841: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with at least one voltage channel connected (A, B or C according to *Phase selection* “1”, “2” or “3”) if *Voltage selection* is set to "phase-to-earth".
	The function can work with any two voltage channels connected (AB, BC or CA according

Table continues on the next page

Condition	Description
	to *Phase selection* “1”, “2” or “3”) if *Voltage selection* is set to "phase-to-phase".
	The function requires that all three voltage channels are connected if *Voltage selection* is set to "pos sequence".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.7.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of OEPVPH can be described using a module diagram. All the modules in the diagram are explained in the next sections.

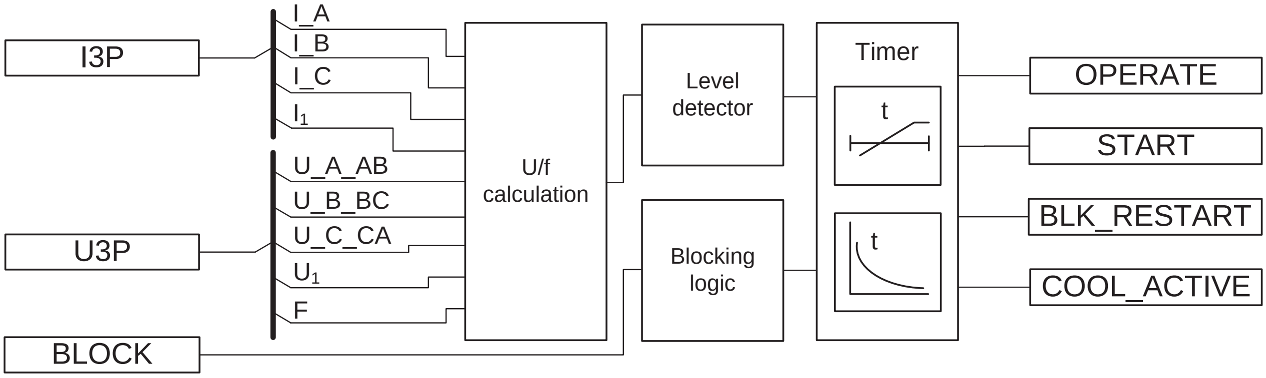


Figure 495: Functional module diagram

U/f calculation

This module calculates the U/f ratio, that is, the excitation level from the internal induced voltage (E) and frequency. The actual measured voltage (U_m) deviates from the internal induced voltage (E), a value the equipment has to withstand. This voltage compensation is based on the load current (I_L) and the leakage reactance (X_{leak}) of the equipment. The leakage reactance of the transformer or generator is set through the *Leakage React* setting in percentage of the Z base.

The internal induced voltage (E) is calculated from the measured voltage. The settings *Voltage selection* and *Phase supervision* determine which voltages and currents are to be used. If the *Voltage selection* setting is set to "phase-to-earth" or "phase-to-phase", the *Phase supervision* setting is used for determining which phases or phase-to-phase voltages ("A or AB", "B or BC" and "C or CA") and currents are to be used for the calculation of the induced voltage.

Table 842: Voltages and currents used for induced voltage (emf) E calculation

Voltage selection setting	Phase supervision setting	Calculation of internal induced voltage (emf) E [1]
phase-to-earth	A or AB	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_A} + \overline{I_A} \cdot (j \cdot X_{leak}) \right)$ (Equation 240)
phase-to-earth	B or BC	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_B} + \overline{I_B} \cdot (j \cdot X_{leak}) \right)$ (Equation 241)
phase-to-earth	C or CA	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_C} + \overline{I_C} \cdot (j \cdot X_{leak}) \right)$ (Equation 242)
phase-to-phase	A or AB	$\overline{E} = \overline{U_{AB}} + \left((\overline{I_A} - \overline{I_B}) \cdot (j \cdot X_{leak}) \right)$ (Equation 243)
phase-to-phase	B or BC	$\overline{E} = \overline{U_{BC}} + \left((\overline{I_B} - \overline{I_C}) \cdot (j \cdot X_{leak}) \right)$ (Equation 244)
phase-to-phase	C or CA	$\overline{E} = \overline{U_{CA}} + \left((\overline{I_C} - \overline{I_A}) \cdot (j \cdot X_{leak}) \right)$ (Equation 245)
Pos sequence	N/A	$\overline{E} = \sqrt{3} \cdot \left(\overline{U_1} + \overline{I_1} \cdot (j \cdot X_{leak}) \right)$ (Equation 246)

If all three phase or phase-to-phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

If the leakage reactance of the protected equipment is unknown or if the measured voltage (U_m) is to be used in the excitation level calculation, then by setting the leakage reactance value to zero the calculated induced voltage (E) is equal to the measured voltage.

The calculated U/f ratio is scaled to a value based on the nominal U_n/f_n ratio. However, the highest allowed continuous voltage (in % U_n) can be defined by setting the parameter *Voltage Max Cont* to change the basis of the voltage. The measured voltage is compared to the new base value to obtain the excitation level.

[1] Voltages, currents and the leakage reactance X_{leak} in the calculations are given in volts, amps and ohms.

The excitation level (M) can be calculated:

$$M = \frac{\frac{E}{f_m}}{\frac{U_n}{f_n} \cdot \frac{Volt\ Max\ continuous}{100}}$$

(Equation 247)

M	excitation level (U/f ratio or volts/hertz) in pu
E	internal induced voltage (emf)
f_m	measured frequency
U_n	nominal phase-to-phase voltage
f_n	nominal frequency

If the input frequency (f_m) is less than 20 percent of the nominal frequency (f_n), the calculation of the excitation level is disabled and forced to zero value. This means that the function is blocked from starting and operating during a low-frequency condition.

The calculated excitation level (U/f ratio or volts/hertz) VOLTPERHZ is available in the Monitored data view.

Level detector

Level detector compares the calculated excitation level to the *Start value* setting. If the excitation level exceeds the set limit, the module sends an enabling signal to start Timer.

Timer

Once activated, Timer activates the `START` output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value set by *Operate delay time* in the DT mode or the value defined by the inverse time curve, the `OPERATE` output is activated.

In a drop-off situation, that is, when the excitation level drops below *Start value* before the function operates, the reset timer is activated and the `START` output resets after the time delay of *Reset delay time* for the DT characteristics. For the IDMT curves, the reset operation is as described in *Chapter 4.5.7.6 Timer characteristics* .

For the IDMT curves, it is possible to define the maximum and minimum operating times via the *Minimum operate time* and *Maximum operate time* settings. The *Maximum operate time* setting is used to prevent infinite start situations at low degrees of overexcitation. The *Time multiplier* setting is used for scaling the IDMT operate times.

The activation of the `OPERATE` output activates the `BLK_RESTART` output.

For the DT characteristics, the deactivation of the `OPERATE` output activates the cooling timer. The timer is set to the value entered in the *Cooling time* setting. The `BLK_RESTART` and `COOL_ACTIVE` outputs are kept active until the cooling timer is reset. If the excitation increases above the set value during this period, the `OPERATE` output is activated immediately. For IDMT, the deactivation of `BLK_RESTART` and `COOL_ACTIVE` depends on the curve type selected.

The T_ENARESTART output indicates in seconds the duration for which the BLK_RESTART output still remains active. The value is available in the Monitored data view.

Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.5.7.6 Timer characteristics

OEPVPH supports both DT and IDMT characteristics. The DT timer characteristics can be selected as "ANSI Def. Time" or "IEC Def. Time" in the *Operating curve type* setting. The functionality is identical in both cases. When the DT characteristics are selected, the functionality is only affected by the *Operate delay time* and *Reset delay time* settings.

OEPVPH also supports four overexcitation IDMT characteristic curves: "OvExt IDMT Crv1", "OvExt IDMT Crv2", "OvExt IDMT Crv3" and "OvExt IDMT Crv4".

Overexcitation inverse definite minimum time curve (IDMT)

In the inverse time modes, the operate time depends on the momentary value of the excitation: the higher the excitation level, the shorter the operate time. The operate time calculation or integration starts immediately when the excitation level exceeds the set *Start value* and the START output is activated.

The OPERATE output is activated when the cumulative sum of the integrator calculating the overexcitation situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used.

The *Minimum operate time* and *Maximum operate time* settings define the minimum operate time and maximum operate time possible for the IDMT mode. For setting these parameters, a careful study of the particular IDMT curves is recommended.

The operation time of the function block can vary much between different operating curve types even if other setting parameters for the curves were not changed.

Once activated, the Timer activates the START output for the IDMT curves. If the excitation level drops below the *Start value* setting before the function operates, the reset timer is activated and the START output resets immediately. If START reoccurs during the reset time, the operation calculation is made based on the effects of the period when START was previously active. This is intended to allow an operating condition to occur in less time to account for the heating effects from the previous active start period.

When START becomes active, the reset time is based on the following equation.

$$reset\ time = \left(\frac{START\_DUR}{100} \right) \cdot Cooling\ time$$

(Equation 248)

For the IDMT curves, when START is deactivated, the integral value calculated during START is continuously decremented by a constant that causes its value to become zero when the reset time elapses during the reset period. If a fault reoccurs, the integration continues from the current integral value and the start time is adjusted, as shown in *Figure 496*. The start time becomes the value at the time when the fault dropped off minus the amount of reset time that occurred. If the reset period elapses without a fault being detected, the saved values of the start time and integration are cleared.

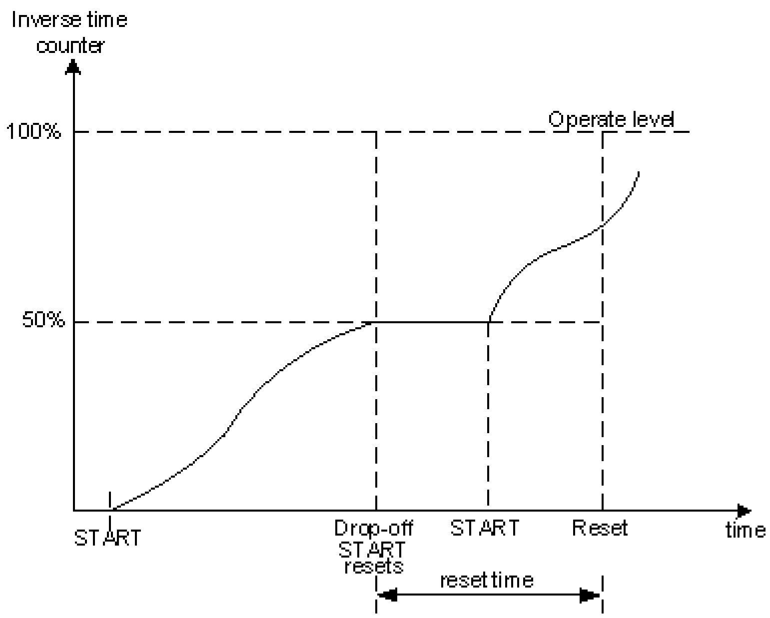


Figure 496: An example of a delayed reset in the inverse time characteristics. When the start becomes active during the reset period, the operate time counter continues from the level corresponding to the drop-off (reset time = 0.50 · Cooling time)

Overexcitation IDMT curves 1, 2 and 3

The base equation for the IDMT curves "OvExt IDMT Crv1", "OvExt IDMT Crv2" and "OvExt IDMT Crv3" is:

$$t(s) = 60 \cdot e^{\left(\frac{ak+b-100M}{c} \right)}$$

(Equation 249)

t(s) Operate time in seconds

M Excitation level (U/f ratio or volts/hertz) in pu

k *Time multiplier* setting

The constant "60" in *Equation 249* converts time from minutes to seconds.

Table 843: Parameters a, b and c for different IDMT curves

Operating curve type setting	a	b	c
OvExt IDMT Crv1	2.5	115.00	4.886
OvExt IDMT Crv2	2.5	113.50	3.040
OvExt IDMT Crv3	2.5	108.75	2.443

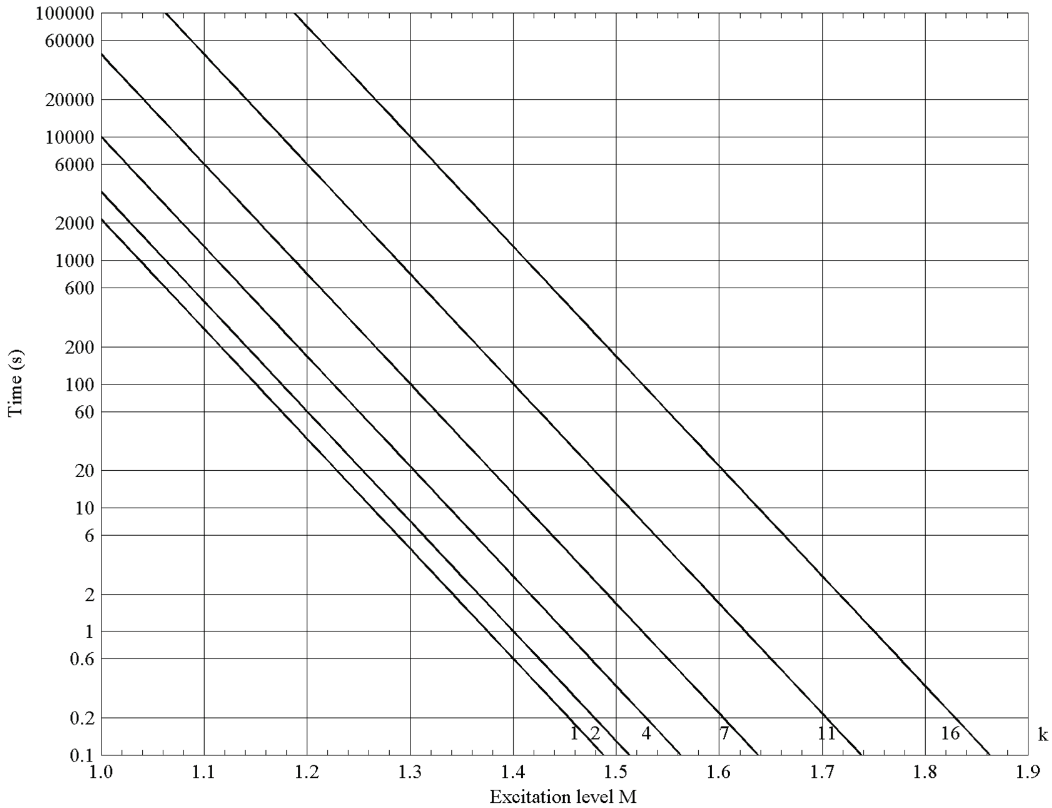


Figure 497: Operating time curves for the overexcitation IDMT curve ("OvExt IDMT Crv1") for parameters a = 2.5, b = 115.0 and c = 4.886

Overexcitation IDMT curve 4

The base equation for the IDMT curve "OvExt IDMT Crv4" is:

$$t(s) = d + \frac{0.18k}{(M-1)^2}$$

(Equation 250)

t(s)	Operate time in seconds
d	*Constant delay* setting in milliseconds
M	Excitation value (U/f ratio or volts/hertz) in pu
k	*Time multiplier* setting

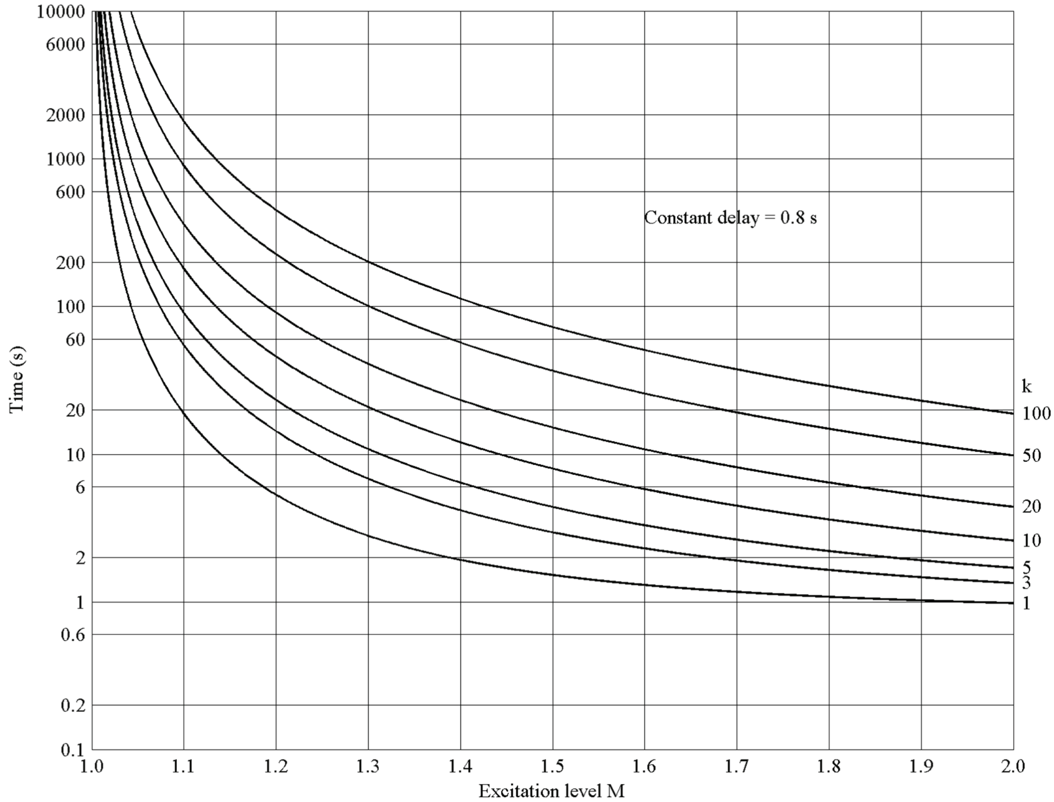


Figure 498: Operating time curves for the overexcitation IDMT curve 4 ("OvExt IDMT Crv4") for different values of the Time multiplier setting when the Constant delay is 800 milliseconds

The activation of the OPERATE output activates the BLK_RESTART output.

If the excitation level increases above the set value when BLK_RESTART is active, the OPERATE output is activated immediately.

If the excitation level increases above the set value when BLK_RESTART is not active but COOL_ACTIVE is active, the OPERATE output is not activated instantly. In this case, the remaining part of the cooling timer affects the calculation of the operate timer as shown in *Figure 499*. This compensates for the heating effect and makes the overall operate time shorter.

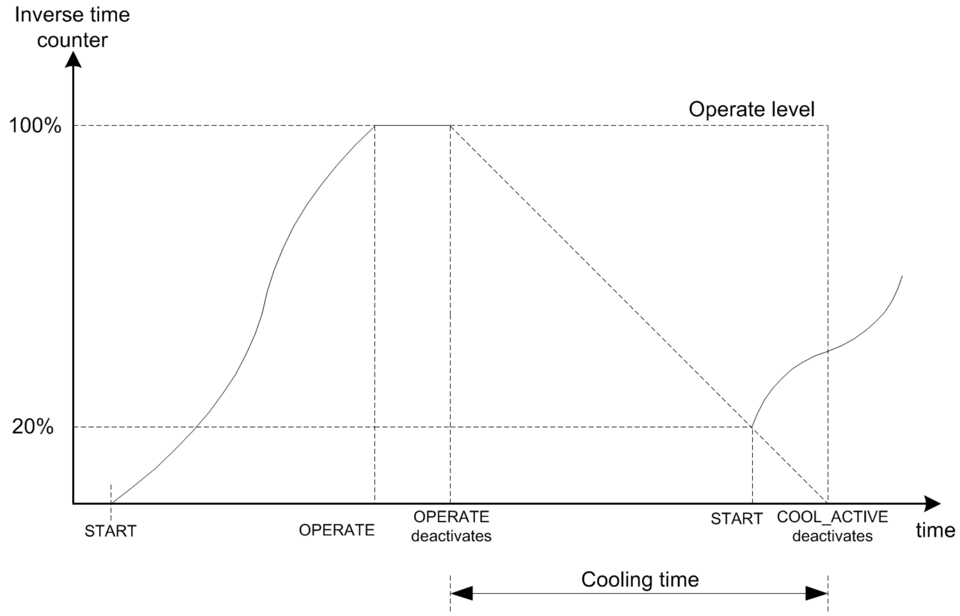


Figure 499: Example of an inverse time counter operation if START occurs when BLK_RESTART is inactive while COOL_ACTIVE is active.

4.5.7.7 Application

If the laminated core of a power transformer or generator is subjected to a magnetic flux density beyond its designed limits, the leakage flux increases. This results in a heavy hysteresis and eddy current losses in the non-laminated parts. These losses can cause excessive heating and severe damage to the insulation and adjacent parts in a relatively short time.

Overvoltage, underfrequency or a combination of the two, results in an excessive flux density level. Since the flux density is directly proportional to the voltage and inversely proportional to the frequency, the overexcitation protection calculates the relative V/Hz ratio instead of measuring the flux density directly. The nominal level (nominal voltage at nominal frequency) is usually considered as the 100 percent level, which can be exceeded slightly based on the design.

The greatest risk for overexcitation exists in a thermal power station when the generator-transformer unit is disconnected from the rest of the network or in the network islands where high voltages or low frequencies can occur.

Overexcitation can occur during the start-up and shutdown of the generator if the field current is not properly adjusted. The loss-of-load or load shedding can also result in overexcitation if the voltage control and frequency governor do not function properly. The low frequency in a system isolated from the main network can result in overexcitation if the voltage-regulating system maintains a normal voltage.

Overexcitation protection for the transformer is generally provided by the generator overexcitation protection, which uses the VTs connected to the generator terminals. The curves that define the generator and transformer V/Hz limits must be coordinated properly to protect both equipment.

If the generator can be operated with a leading power factor, the high-side voltage of the transformer can have a higher pu V/Hz than the generator V/Hz. This needs to be considered in a proper overexcitation protection of the transformer. Also, measurement for the voltage must not be taken from any winding where OLTC is located.

It is assumed that overexcitation is a symmetrical phenomenon caused by events such as loss-of-load. A high phase-to-earth voltage does not mean overexcitation. For example, in an unearthed power system, a single phase-to-earth fault means high voltages of the healthy two phases to earth but no overexcitation on any winding. The phase-to-phase voltages remain essentially unchanged. An important voltage to be considered for the overexcitation is the voltage between the two ends of each winding.

Example calculations for overexcitation protection

Example 1

Nominal values of the machine

Nominal phase-to-phase voltage (U_n)	11000 V
Nominal phase current (I_n)	7455 A
Nominal frequency (f_n)	50 Hz
Leakage reactance (X_{leak})	20% or 0.2 pu

Measured voltage and load currents of the machine

Phase A-to-phase B voltage (U_{AB})	11500∠0° V
Phase A current (I_A)	5600∠-63.57° A
Phase B current (I_B)	5600∠176.42° A
Measured frequency (f_m)	49.98 Hz
The setting *Voltage Max Cont*	100%
The setting *Voltage selection*	phase-to-phase
The setting *Phase supervision*	A or AB

The pu leakage reactance X_{leakPU} is converted to ohms.

$$X_{leak\Omega} = X_{leakPU} \cdot \frac{U_n}{I_n \cdot \sqrt{3}} = 0.2 \cdot \frac{11000}{7455 \cdot \sqrt{3}} = 0.170378\ Ohms$$

(Equation 251)

The internal induced voltage E of the machine is calculated.

$$\overline{E} = \overline{U_{AB}} + (\overline{I_A} - \overline{I_B}) \cdot (jX_{leak})$$

(Equation 252)

E = 11500∠0°+ (5600∠-63.57°- 5600∠176.42°) · (0.170378∠90°) = 12490 V

The excitation level M of the machine is calculated.

$$Excitation\,level\,M = \frac{\frac{12490}{49.98}}{\frac{11000}{50} \cdot 1.00} = 1.1359$$

(Equation 253)

Example 2

The situation and the data are according to Example 1. In this case, the manufacturer of the machine allows the continuous operation at 105 percent of the nominal voltage at the rated load and this value to be used as the base for overexcitation.

Usually, the U/f characteristics are specified so that the ratio is 1.00 at the nominal voltage and nominal frequency. Therefore, the value 100 percent for the setting *Voltage Max Cont* is recommended.

If the *Voltage Max Cont* setting is 105 percent, the excitation level M of the machine is calculated with the equation.

$$Excitation\,level\,M = \frac{\frac{12490}{49.98}}{\frac{11000}{50} \cdot 1.05} = 1.0818$$

(Equation 254)

Example 3

In this case, the function operation is according to IDMT. The *Operating curve type* setting is selected as "OvExt IDMT Crv2". The corresponding example settings for the IDMT curve operation are given as: *Start value* = 110%, *Voltage Max Cont* = 100%, *Time multiplier* = 4, *Maximum operate time* = 1000 s, *Minimum operate time* = 1 s and *Cooling time* = 200 s.

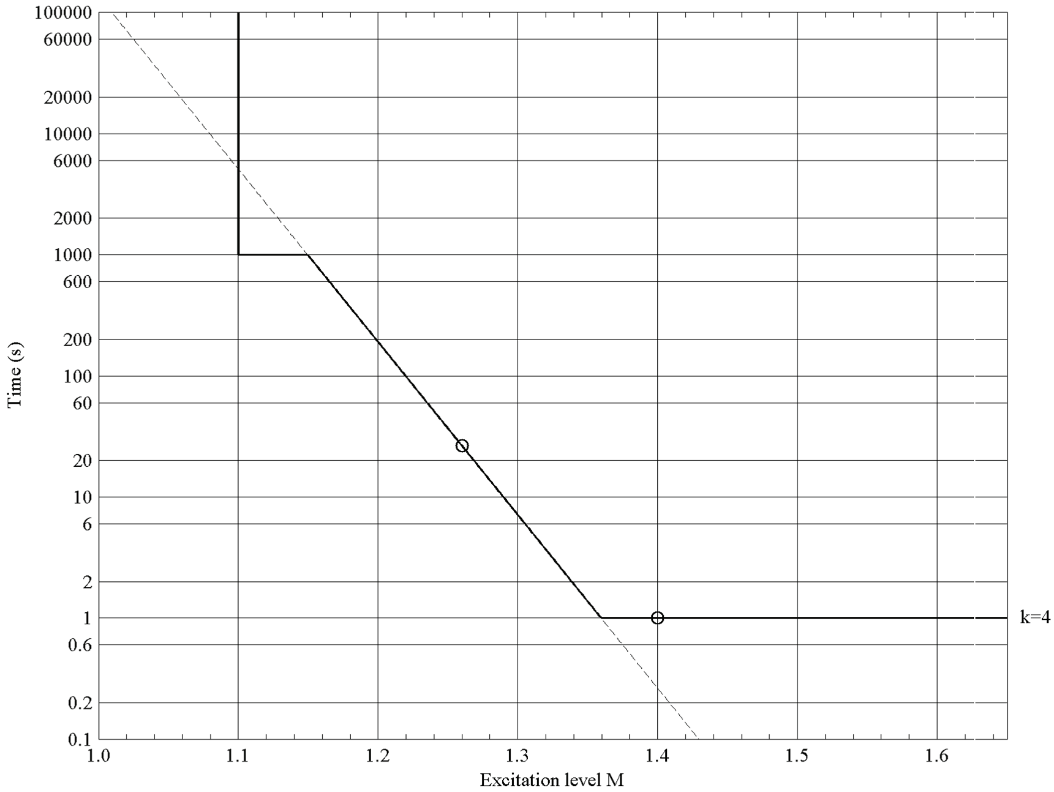


Figure 500: Operating curve of "OvExt IDMT Crv2" based on the settings specified in example 3. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.26, the operation occurs after 26.364 s as per the marked dot in *Figure 500*. For the excitation level of 1.4, the second dot in *Figure 500*, the curve "OvExt IDMT Crv2" gives 0.2636 s as per *Equation 249*, but the *Minimum operate time* setting limits the operate time to 1.0 s.

The *Maximum operate time* setting limits the operate time to 1000 s if the excitation level stays between 1.1 and 1.16.

In general, however, the excitation level seldom remains constant. Therefore, the exact operate times in any inverse time mode are difficult to predict.

Example 4

In this case, the function operation is according to IDMT. The *Operating curve type* setting is selected as "OvExt IDMT Crv4". The corresponding example settings for the IDMT curve operation are given as: *Start value* = 110%, *Voltage Max Cont* = 100%, *Time multiplier* = 5, *Maximum operate time* = 3600 s, *Constant delay* = 0.8 s and *Cooling time* = 100 s.

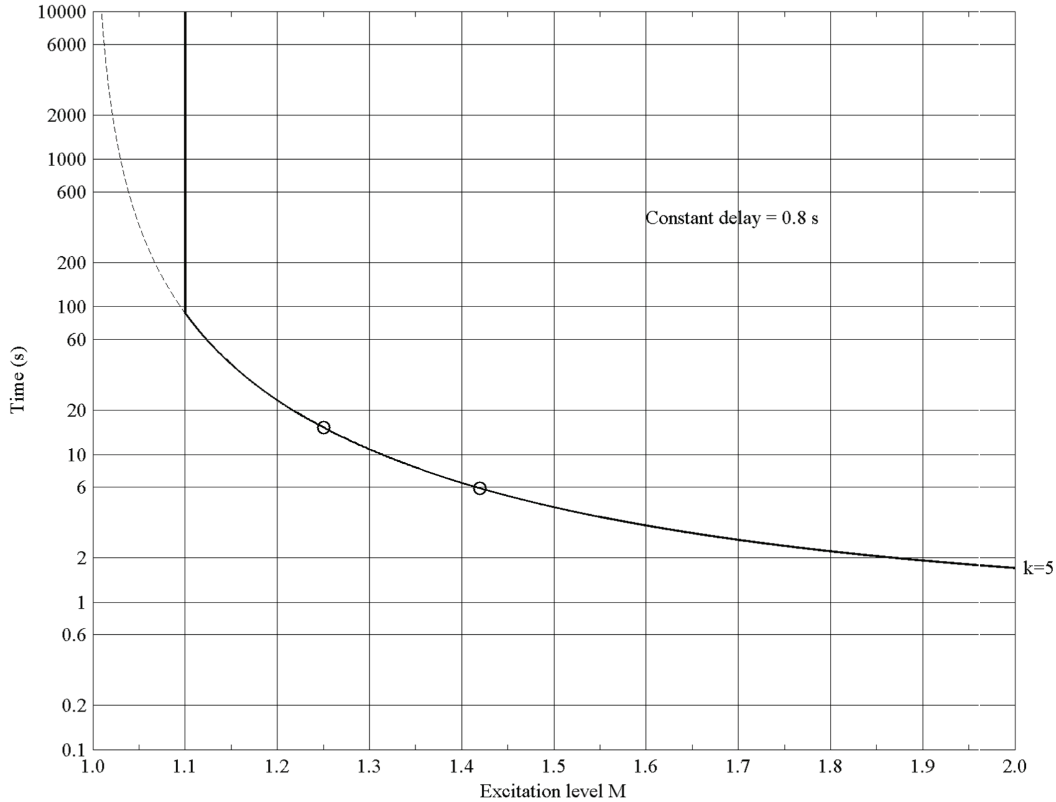


Figure 501: Operating curve of "OvExt IDMT Crv4" based on the specified settings. The two dots marked on the curve are referred to in the text.

If the excitation level stays at 1.25, the operation occurs after 15.20 s. At the excitation level of 1.42, the time to operation would be 5.90 s as per the two dots in *Figure 501*. In this case, the setting *Maximum operate time* 3600 s does not limit the maximum operate time because the operate time at *Start value* = 110% (1.1 pu) is approximately 75 s.

4.5.7.8 Signals

OEPVPH Input signals

Table 844: OEPVPH Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal

OEPVPH Output signals

Table 845: OEPVPH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operated
START	BOOLEAN	Started
BLK_RESTART	BOOLEAN	Signal for blocking reconnection of an overheated machine
COOL_ACTIVE	BOOLEAN	Signal to indicate machine is in cooling process

4.5.7.9 OEPVPH Settings

Table 846: OEPVPH Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	100...200	%	1	100	Over excitation start value
Operating curve type	5=ANSI Def. Time 15=IEC Def. Time 17=OvExt IDMT Crv1 18=OvExt IDMT Crv2 19=OvExt IDMT Crv3 20=OvExt IDMT Crv4			15=IEC Def. Time	Selection of time delay curve type
Time multiplier	0.1...100.0		0.1	3.0	Time multiplier for Overexcitation IDMT curves
Operate delay time	200...200000	ms	10	500	Operate delay time in definite- time mode

Table 847: OEPVPH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Mode Off / On
Cooling time	5...10000	s	1	600	Time required to cool the machine
Constant delay	100...120000	ms	10	800	Parameter constant delay
Maximum operate time	500000...10000000	ms	10	1000000	Maximum operate time for IDMT curves
Voltage selection	1=phase-to-earth 2=phase-to-phase 3=pos sequence			3=pos sequence	Selection of phase / phase-to-phase / pos sequence voltages
Phase selection	1=A or AB 2=B or BC 3=C or CA			1=A or AB	Parameter for phase selection

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Leakage React	0.0...50.0	%	0.1	0.0	Leakage reactance of the machine
Voltage Max Cont	80...160	%	1	110	Maximum allowed continuous operating voltage ratio

Table 848: OEPVPH Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	100	Resetting time of the operate time counter in DT mode
Minimum operate time	200...60000	ms	10	200	Minimum operate time for IDMT curves

4.5.7.10 OEPVPH Monitored data

Table 849: OEPVPH Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time (in %)
T_ENARESTART	INT32	0...10000	s	Estimated time to reset of block restart
VOLTPERHZ	FLOAT32	0.00...10.00	pu	Excitation level, i.e U/f ratio or Volts/Hertz
OEPVPH	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.7.11 Technical data

Table 850: OEPVPH Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±3.0% of the set value
Start time [1]	Frequency change: Typically 200 ms
	Voltage change: Typically 40 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms

Table continues on the next page

[1] Includes the delay of the signal output contact

Characteristic	Value
Operate time accuracy in definite-time mode	±1.0% of the set value or ±20 ms
Operate time accuracy in inverse-time mode	±5.0% of the theoretical value or ±50 ms

4.5.8 Low-voltage ride-through protection LVRTPTUV (ANSI 27RT)

4.5.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Low-voltage ride-through protection	LVRTPTUV	U<RT	27RT

4.5.8.2 Function block

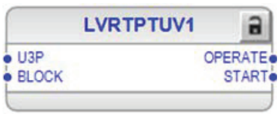


Figure 502: Function block

4.5.8.3 Functionality

The low-voltage ride-through protection function LVRTPTUV is principally a three-phase undervoltage protection. It differs from the traditional three-phase undervoltage protection PHPTUV by allowing the grid operators to define its own Low-Voltage Ride-Through (LVRT) curve for generators, as defined by local or national grid codes. The LVRT curve can be defined accurately according to the requirements by setting the appropriate time-voltage coordinates.

This function contains a blocking functionality. LVRTPTUV can be blocked with the BLOCK input. Blocking resets timers and outputs.

4.5.8.4 Analog channel configuration

LVRTPTUV has one analog group input which must be properly configured.

Table 851: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 852: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that at least two voltage channels are connected as the the third channel can then be derived. However, it is recommended that all three voltage channels are connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.8.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LVRTPTUV is described using a module diagram. All modules in the diagram are explained in the next sections.

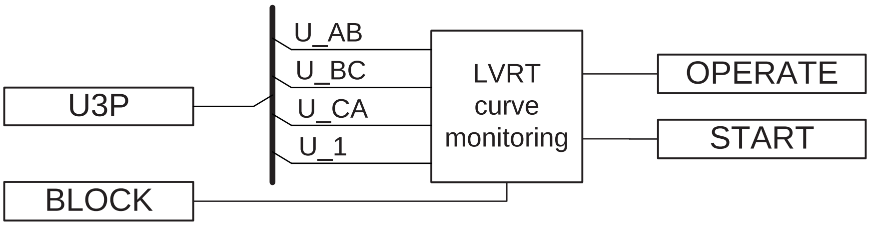


Figure 503: Functional module diagram

LVRT curve monitoring

LVRT curve monitoring starts with detection of undervoltage. Undervoltage detection depends on *Voltage selection* setting. All selectable options are based on fundamental frequency components.

Function uses phase-to-earth voltages when *Voltage selection* is set to “Highest Ph-to-E” or “Lowest Ph-to-E” and phase-to-phase voltages when *Voltage selection* is set to “Highest Ph-to-Ph” or “Lowest Ph-to-Ph”.

When the *Voltage selection* setting is set to “Highest Ph-to-E”, “Lowest Ph-to-E”, “Highest Ph-to-Ph” or “Lowest Ph-to-Ph”, the measured three-phase voltages are compared phase-wise to the set *Voltage start value*. If the measured value is lower than the set *Voltage start value* setting in number of phases equal to that set *Num of start phases*, the START output is activated.

The setting options available for *Num of start phases* are “Exactly 1 of 3”, "Exactly 2 of 3", and “Exactly 3 of 3”, which are different from conventional setting options available in other functions. For example, *Num of start phases* is set to "Exactly 2 of 3", any two voltages should drop below *Voltage start value* within one cycle network for the START output to activate. Even if more than two voltages drop below *Voltage start value*, START output is not activated.

When the *Voltage selection* setting is “Positive Seq”, the positive-sequence component is compared with the set *Voltage start value*. If it is lower than the set *Voltage start value*, the START output is activated.

Once START is activated, the function monitors the behavior of the voltage defined by *Voltage selection setting* with the defined LVRT curve. When defined voltage enters the operating area, the OPERATE output is activated instantaneously. The pulse length of OPERATE is fixed to 100 ms. START also deactivates along with OPERATE.

If a drop-off situation occurs, that is, voltage restores above *Voltage start value*, before OPERATE is activated, the function does not reset until maximum recovery time under consideration has elapsed, that is, START output remains active.

LVRT curve is defined using time-voltage settings coordinates. The settings available are *Recovery time 1*… *Recovery time 10* and *Voltage level 1*… *Voltage level 10*. The number of coordinates required to define a LVRT curve is set by *Active coordinate* settings.

When *Recovery time 1* is set to non-zero value, it results into horizontal characteristics from point of fault till *Recovery time 1.*

Two examples of LVRT curve are defined in *Figure 504* and *Figure 505* with corresponding settings in *Table 853*.

It is necessary to set the coordinate points correctly in order to avoid maloperation. For example, setting for *Recovery time 2* should be greater than *Recovery time 1*. *Recovery time 1*… *Recovery time 10* are the respective time setting from the point of fault.

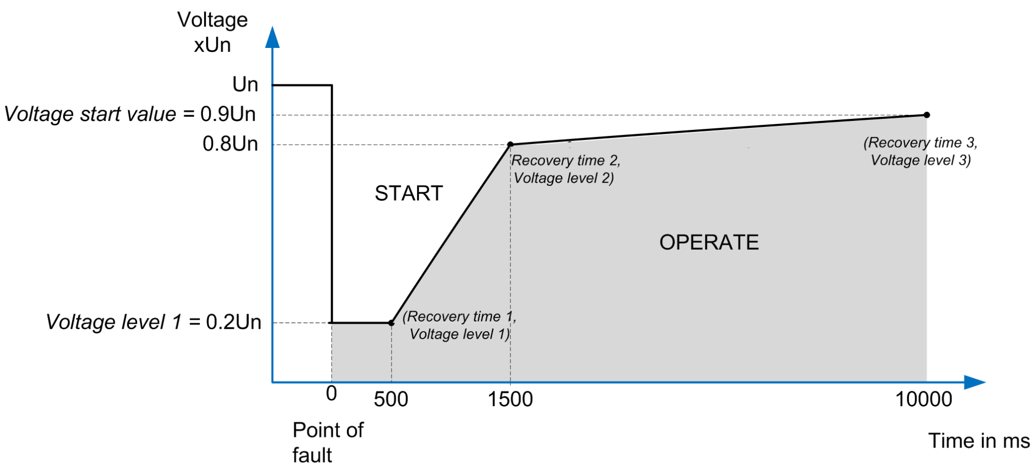


Figure 504: Low voltage ride through example curve A

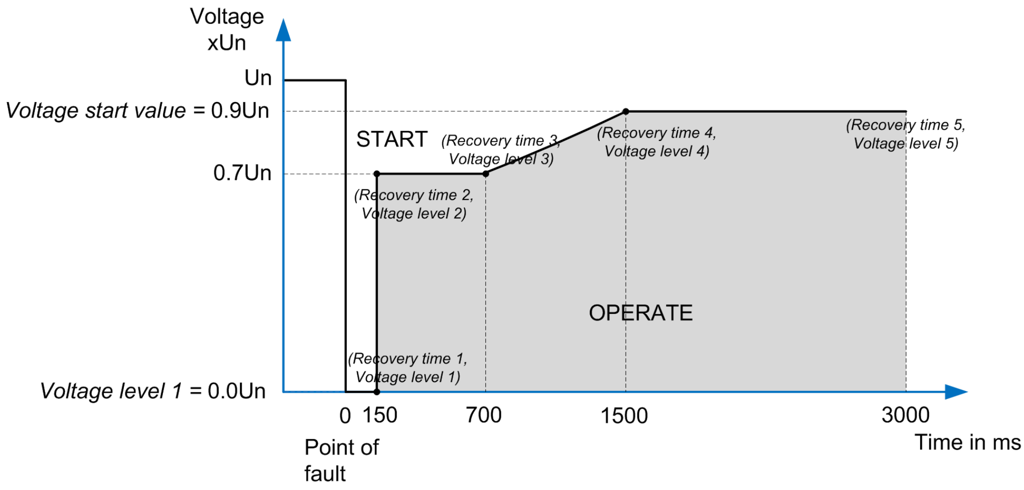


Figure 505: Low voltage ride through example curve B

Table 853: Settings for example A and B

Settings	Curve A	Curve B
Voltage start value	0.9 · Un	0.9 · Un
Active coordinates	3	5
Voltage level 1	0.2 · Un	0 · Un
Recovery time 1	500 ms	150 ms
Voltage level 2	0.8 · Un	0.7 · Un
Recovery time 2	1500 ms	150 ms
Voltage level 3	0.9 · Un	0.7 · Un
Recovery time 3	10000 ms	700 ms
Voltage level 4	-	0.9 · Un
Recovery time 4	-	1500 ms
Voltage level 5	-	0.9 · Un
Recovery time 5	-	3000 ms

It is necessary that the last active *Voltage level X* setting is set greater than or equal to *Voltage start value*. Settings are not accepted if the last active *Voltage level X* setting is not set greater than or equal to *Voltage start value*.

Figure 506 describes an example of operation of LVRTPTUV protection function set to operate with *Num of start phases* set to “Exactly 2 of 3” and *Voltage selection* as “Lowest Ph-to-Ph” voltage.

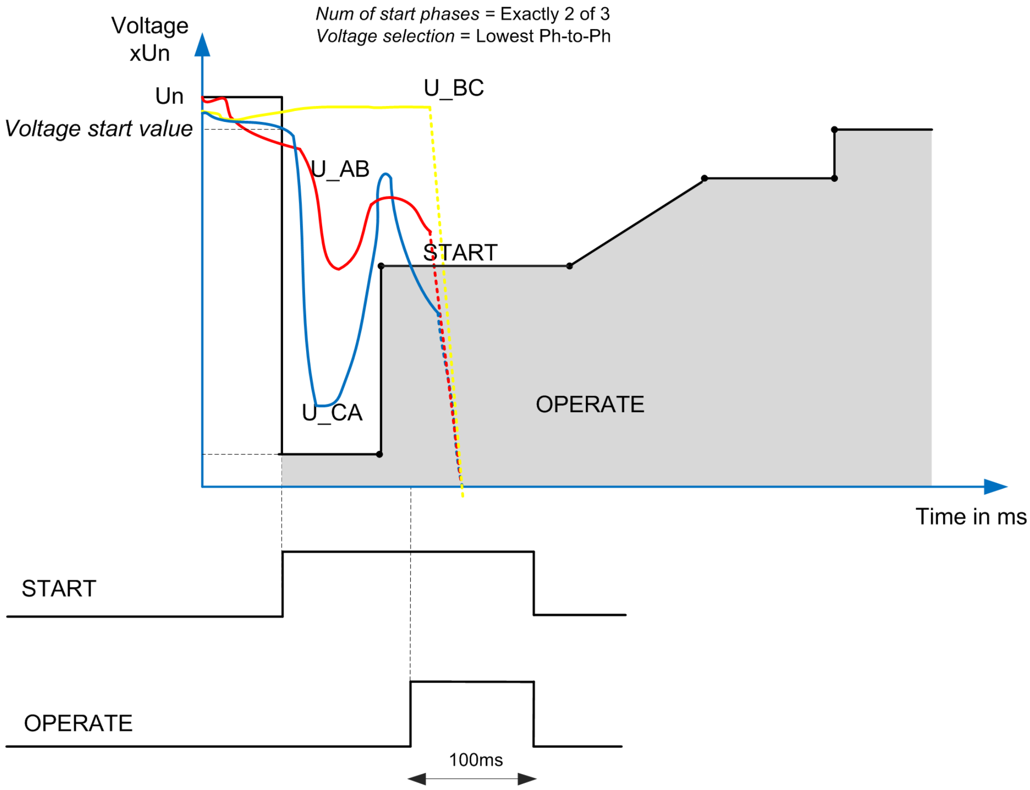


Figure 506: Typical example of operation of LVRTPTUV function

Activation of the BLOCK input resets the timers and deactivates the function outputs.

4.5.8.6 Application

Distributed generation, mainly wind and solar farms, are rapidly increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. These farms are directly connected to grids, and due to their large size may influence the behavior of the grid. These farms are now required to comply with stringent grid connection requirement, which was previously mandatory only for high capacity power plants. These requirements include helping grid in maintaining system stability, reactive power support, transient recovery and voltage-frequency regulation. These requirements make it necessary for the wind and solar farms to remain in operation in the event of network disturbances.

Many grid codes now demand that the distributed generation connected to HV grids must withstand voltage dips to a certain percentage of nominal voltage (down to 0% in some cases) and for a specific duration. Such requirements are known as Low-Voltage Ride-Through (LVRT) or Fault-Ride-Through (FRT) and are described by a voltage versus time characteristics.

Typical LVRT behavior of a distributed generation can be divided into three areas according to the variation in voltage over time.

- At the time of system faults, the magnitude of the voltage may dip to *Voltage level 1* for time defined by *Recovery time 1*. The generating unit has to remain connected to the network during such condition. This boundary defines area A.

- Area B defines the linear growth recovery voltage level from *Voltage level 1* to *Voltage level 2* in a time period from *Recovery time 1* to *Recovery time 2*.
- Area C is the zone where voltage stabilizes. *Voltage level 3* is defined to same value as *Voltage level 2*. The system should remain above this voltage in a time period from *Recovery time 2* to *Recovery time 3*.

The system restores to a normal state and function resets when the voltage is equal or greater than *Voltage level 4* after *Recovery time 4* time period.

When the voltage at the point of common coupling is above the LVRT curve, the generation unit must remain connected, and must be disconnected only if the voltage takes values below the curve.

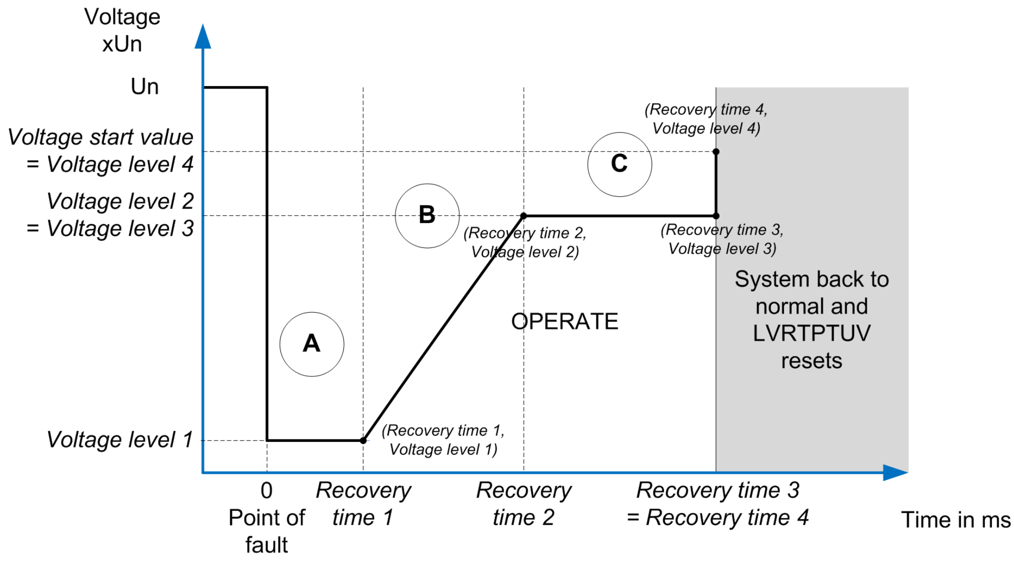


Figure 507: A typical required ride-through voltage capability of generating unit

The LVRT requirement depends on the power system characteristics and the protection employed, varying significantly from each other. The requirement also differs from country to country. LVRTPTUV function incorporates four types of LVRT curves which satisfy most of the power system needs. Grid operators can fine-tune the LVRT curve by setting the parameters as per their requirement, making the use simpler in comparison with different conventional undervoltage protection with different operate time setting and logics.

4.5.8.7 Signals

LVRTPTUV Input signals

Table 854: LVRTPTUV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

LVRTPTUV Output signals

Table 855: LVRTPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.8.8 LVRTPTUV Settings

Table 856: LVRTPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.05...1.20	xUn	0.01	0.90	Voltage value below which function starts

Table 857: LVRTPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	4=Exactly 1 of 3 5=Exactly 2 of 3 6=Exactly 3 of 3			4=Exactly 1 of 3	Number of faulty phases
Voltage selection	1=Highest Ph-to-E 2=Lowest Ph-to-E 3=Highest Ph-to-Ph 4=Lowest Ph-to-Ph 5=Positive Seq			4=Lowest Ph-to-Ph	Parameter to select voltage for curve monitoring
Active coordinates	1...10		1	3	Coordinates used for defining LVRT curve
Voltage level 1	0.00...1.20	xUn	0.01	0.20	1st voltage coordinate for defining LVRT curve
Voltage level 2	0.00...1.20	xUn	0.01	0.80	2nd voltage coordinate for defining LVRT curve
Voltage level 3	0.00...1.20	xUn	0.01	0.90	3rd voltage coordinate for defining LVRT curve
Voltage level 4	0.00...1.20	xUn	0.01	0.90	4th voltage coordinate for defining LVRT curve
Voltage level 5	0.00...1.20	xUn	0.01	0.90	5th voltage coordinate for defining LVRT curve
Voltage level 6	0.00...1.20	xUn	0.01	0.90	6th voltage coordinate for defining LVRT curve
Voltage level 7	0.00...1.20	xUn	0.01	0.90	7th voltage coordinate for defining LVRT curve
Voltage level 8	0.00...1.20	xUn	0.01	0.90	8th voltage coordinate for defining LVRT curve

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage level 9	0.00...1.20	xUn	0.01	0.90	9th voltage coordinate for defining LVRT curve
Voltage level 10	0.00...1.20	xUn	0.01	0.90	10th voltage coordinate for defining LVRT curve
Recovery time 1	0...300000	ms	1	500	1st time coordinate for defining LVRT curve
Recovery time 2	0...300000	ms	1	1000	2nd time coordinate for defining LVRT curve
Recovery time 3	0...300000	ms	1	10000	3rd time coordinate for defining LVRT curve
Recovery time 4	0...300000	ms	1	10000	4th time coordinate for defining LVRT curve
Recovery time 5	0...300000	ms	1	10000	5th time coordinate for defining LVRT curve
Recovery time 6	0...300000	ms	1	10000	6th time coordinate for defining LVRT curve
Recovery time 7	0...300000	ms	1	10000	7th time coordinate for defining LVRT curve
Recovery time 8	0...300000	ms	1	10000	8th time coordinate for defining LVRT curve
Recovery time 9	0...300000	ms	1	10000	9th time coordinate for defining LVRT curve
Recovery time 10	0...300000	ms	1	10000	10th time coordinate for defining LVRT curve

4.5.8.9 LVRTPTUV Monitored data

Table 858: LVRTPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
LVRTPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.8.10 Technical data

Table 859: LVRTPTUV Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±2 Hz
	±1.5% of the set value or ±0.002 × U_n

Table continues on the next page

Characteristic	Value
Start time [1, 2]	Typically 40 ms
Reset time	Based on maximum value of *Recovery time* setting
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.5.9 Voltage vector shift protection VVSPPAM (ANSI 78VS)

4.5.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage vector shift protection	VVSPPAM	VS	78VS

4.5.9.2 Function block

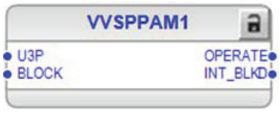


Figure 508: Function block

4.5.9.3 Functionality

The voltage vector shift protection function VVSPPAM, also known as vector surge or delta phi function, measures continuously the duration of a voltage cycle. At the instance of islanding, the duration of measured voltage cycle becomes shorter or longer than the previous one, that is, the measured voltage cycle shifts with time. This shifting of voltage is measured in terms of phase angle. VVSPPAM issues an instantaneous trip when the shift in voltage vector exceeds the set value.

VVSPPAM can be blocked with `BLOCK` input. Blocking resets timers and outputs.

4.5.9.4 Analog channel configuration

VVSPPAM has one analog group input which must be properly configured.

Table 860: Analog inputs

Input	Description
U3P	Three-phase voltages

1 Tested for *Number of Start phases* = 1 out of 3, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 861: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.9.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of VVSPPAM can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

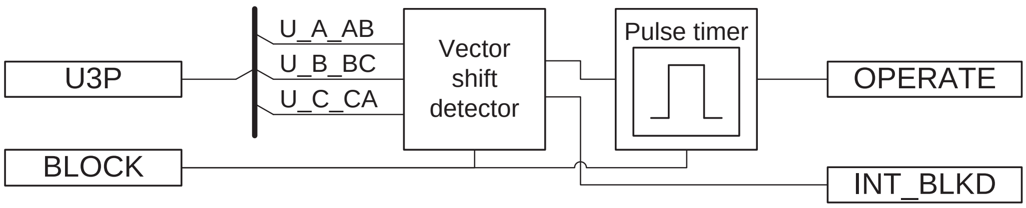


Figure 509: Functional module diagram

Vector shift detector

This module measures the duration of each cycle of the voltage signal phase. The duration of the present cycle is compared to the previous cycle, considered as reference. When the mains is lost, a sudden change is seen in the cycle length, if loading of the generator changes suddenly and power mismatch or unbalance (generation vs. load) in the islanded part of the network is large enough. The cycle shifts with time, that is, the frequency may not change but a vector shift is seen in phase as shown in *Figure 510*.

This step is measured in degrees for each voltage signal defined by the *Phase supervision* setting. The *Phase supervision* setting determines which voltage is used for detecting vector shift. The available *Phase supervision* options are “All” and “Pos sequence”. If the calculated value of Δδ exceeds the set *Start value* setting for all the defined phases, the module sends an enabling signal to start the Pulse timer.

The *Voltage selection* setting is used to select whether the available voltage signal is phase-to-earth or phase-to-phase voltage.

The recommended and the default value for *Phase supervision* is “Pos sequence”.

If the magnitude of the voltage level of any of the monitored voltage signal, defined by the *Phase supervision* setting, drops below *Under Volt Blk value* or exceeds *Over Volt Blk value*, the calculation of vector shift is disabled and the INT_BLKD output is activated.

The function is blocked and LOWAMPL_BLKD is activated, if the measured frequency deviates ±5% from the nominal value.

The magnitude of calculated vector shift for three phase-to-earth or phase-to-phase voltages, USHIFT_A_AB, USHIFT_B_BC and USHIFT_C_CA or positive sequence voltage U1SHIFT, which resulted in the activation of last OPERATE output, are available in the Monitored data view.

The activation of BLOCK input deactivates the INT_BLKD output.

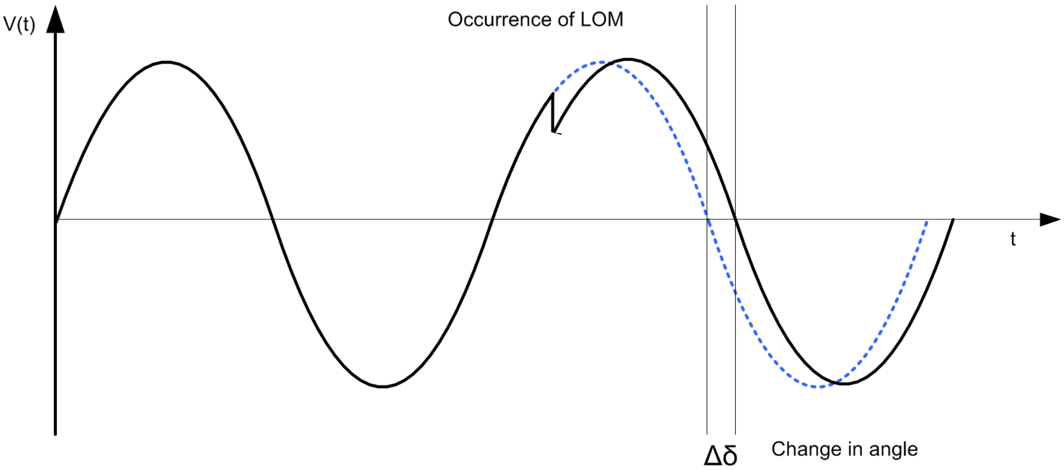


Figure 510: Vector shift during Loss of Mains

Pulse timer

Once the Pulse timer is activated, it activates the OPERATE output. The pulse length of OPERATE is fixed to 100 ms.

The activation of the BLOCK input deactivates the OPERATE binary output and resets the timer.

4.5.9.6 Application

Use of distributed generation (DG) units is increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. They generate power in the range of 10 kW...10 MW and most of them are interconnected to the distribution network. They can supply power into the network as well as to the local loads. It is not common to connect generators directly to the distribution networks and thus the distributed generation can cause some challenges for the protection of distribution networks. From the protection point of view, one of the most challenging issue is islanding.

Islanding is defined as a condition in which a distributed generation unit continues to supply power to a certain part of the distribution network when power from the larger utility main grid is no longer available after the opening of a circuit-breaker. Islanding is also referred as Loss of Mains (LOM) or Loss of Grid (LOG). When LOM occurs, neither the voltage or the frequency is controlled by the utility supply. These distributed generators are not equipped with voltage and frequency control; therefore, the voltage magnitude of an islanded network may not be kept within the desired limits which causes undefined voltage magnitudes during islanding situations and frequency instability. Uncontrolled frequency represents a high risk for drives and other machines. Islanding can occur as a consequence of a fault in the network, due to circuit breaker maloperation or due to circuit breaker opening during maintenance. If the distributed generator continues its operation after the utility supply is disconnected, faults do not clear under certain conditions as the arc is charged by the distributed generators. Moreover, the distributed generators are incompatible with the current reclosing practices. During the reclosing sequence dead time, the generators in the network tend to drift out of synchronism with the grid and reconnecting them without synchronizing may damage the generators introducing high currents and voltages in the neighboring network.

To avoid these technical challenges, protection is needed to disconnect the distributed generation once it is electrically isolated from the main grid supply. Various techniques are used for detecting Loss of Mains. However, the present function focuses on voltage vector shift.

The vector shift detection guarantees fast and reliable detection of mains failure in almost all operational conditions when a distributed generation unit is running in parallel with the mains supply, but in certain cases this may fail.

If the active and reactive power generated by the distributed generation units is nearly balanced (for example, if the power mismatch or unbalance is less than 5...10%) with the active and reactive power consumed by loads, a large enough voltage phase shift may not occur which can be detected by the vector shift algorithm. This means that the vector shift algorithm has a small non-detection-zone (NDZ) which is also dependent on the type of generators, loads, network and start or operate value of the vector shift algorithm. Other network events like capacitor switching, switching of very heavy loads in weak networks or connection of parallel transformer at HV/MV substation, in which the voltage magnitude is not changed considerably (unlike in faults) can potentially cause maloperation of vector shift algorithm, if very sensitive settings are used.

The vector shift detection also protects synchronous generators from damaging due to islanding or loss-of-mains. To detect loss-of-mains with vector shift function, the generator should aim to export or import at least 5...10% of the generated power to the grid, in order to guarantee detectable change in loading after islanding or loss-of-mains.

Multicriteria Loss of Mains

Apart from vector shift, there are other passive techniques which are used for detecting Loss of Mains. Some of these passive techniques are over/under voltage, over/under frequency, rate of change of frequency, voltage unbalance, rate of change of power and so on. These passive methods use voltage and frequency to identify Loss of Mains. The performance of these methods depends on the power mismatch between local generation and load. The advantage of all these methods is that, they are simple and cost effective, but each method has a non detectable zone. To overcome this problem, it is recommended to combine different criteria for detecting Loss of Mains.

Two or more protection functions run in parallel to detect Loss of Mains. When all criteria are fulfilled to indicate Loss of Mains, an alarm or a trip can be generated.

Vector shift and rate of change of frequency are two parallel criteria typically used for detection of Loss of Mains.

Chosen protection criteria can be included in the Application Configuration tool to create multicriteria loss of mains alarm or trip.

4.5.9.7 Signals

VVSPPAM Input signals

Table 862: VVSPPAM Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

VVSPPAM Output signals

Table 863: VVSPPAM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
INT_BLKD	BOOLEAN	Protection function internally blocked

4.5.9.8 VVSPPAM Settings

Table 864: VVSPPAM Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	2.0...30.0	deg	0.1	6.0	Start value for vector shift

Table 865: VVSPPAM Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Over Volt Blk value	0.40...1.50	xUn	0.01	1.20	Voltage above which function will be internally blocked
Under Volt Blk value	0.15...1.00	xUn	0.01	0.80	Voltage below which function will be internally blocked

Table 866: VVSPPAM Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 867: VVSPPAM Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase supervision	7=Ph A + B + C 8=Pos sequence			8=Pos sequence	Monitored voltage phase

4.5.9.9 VVSPPAM Monitored data

Table 868: VVSPPAM Monitored data

Name	Type	Values (Range)	Unit	Description
VEC_SHT_A_AB	FLOAT32	-180.00...180.00	deg	Vector shift for phase to earth voltage A or phase to phase voltage AB
VEC_SHT_B_BC	FLOAT32	-180.00...180.00	deg	Vector shift for phase to earth voltage B or phase to phase voltage BC
VEC_SHT_C_CA	FLOAT32	-180.00...180.00	deg	Vector shift for phase to earth voltage C or phase to phase voltage CA
VEC_SHT_U1	FLOAT32	-180.00...180.00	deg	Vector shift for positive sequence voltage
VVSPPAM	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.9.10 Technical data

Table 869: VVSPPAM Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n ±1 Hz
	±1°
Operate time [1, 2]	Typically 53 ms

4.5.10 Three-phase overvoltage variation protection PHVPTOV (ANSI 59.S1)

[1] f_n = 50 Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

4.5.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overvoltage variation protection	PHVPTOV	3Urms>	59.S1

4.5.10.2 Function block

Figure 511: Function block

4.5.10.3 Functionality

The three-phase overvoltage variation protection function PHVPTOV monitors the quality of the voltages. The function evaluates the power quality in the voltage by calculating the average RMS value of the voltage over a set period. The function includes a settable limit for the detection of overvoltage in a single phase, two phases or three phases.

The function starts when the average RMS value of the voltage exceeds the set limit. PHVPTOV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.5.10.4 Analog channel configuration

PHVPTOV has one analog group input which must be properly configured.

Table 870: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 871: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected if *Num of start phases* is set to "1 out of 3". Otherwise, all three voltage channels must be connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.5.10.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHVPTOV can be described with a module diagram. All the modules in the diagram are explained in the next sections.

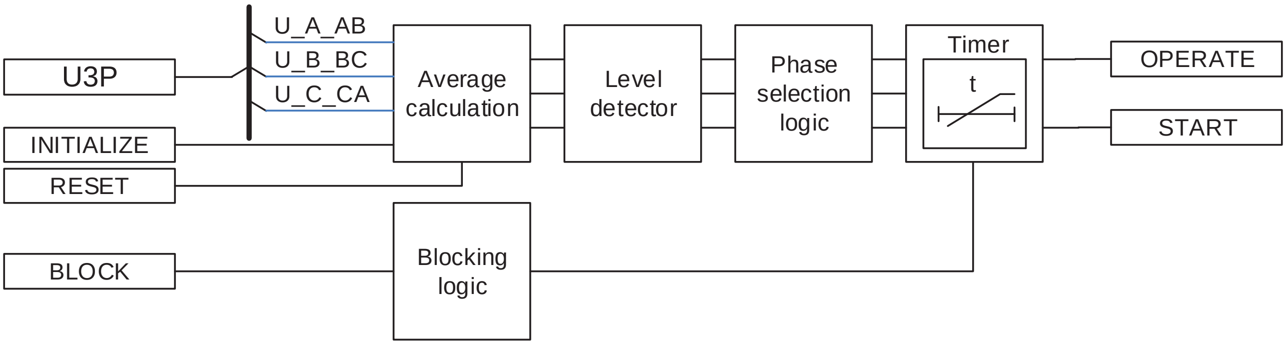


Figure 512: Functional module diagram

Average calculation

The module calculates the average voltage magnitude variation for each of the three input phase voltages. The calculation is done in three successive aggregations.

- 10/12-cycle voltage input samples are aggregated to calculate the 10/12-cycle RMS voltage.
- 10/12-cycle RMS voltages are aggregated over a time period of $T_{refresh}$ to get the refresh value.
- Refresh values are aggregated over a time period $T_{average}$ to get the average RMS voltage magnitude.

The *Voltage selection* setting is used for selecting phase-to-earth or phase-to-phase voltages for protection.

Calculation of 10/12-cycle RMS voltage

The 10/12-cycle RMS voltage is calculated for each of the three input voltages by applying the standard RMS formula using the voltage samples over a range of 0.2 s. Depending on the *Voltage selection* setting, voltage samples are either phase-to-earth or phase-to-phase voltage samples.

Calculation of RMS refresh voltage

The RMS refresh voltage is calculated by aggregating the $U_{10cycles}$ / $U_{12cycles}$ RMS voltage over a time period of $T_{refresh}$. The time period $T_{refresh}$ depends on the setting *Time interval*.

$$T_{refresh} = Roundup\left(\frac{Time\ interval\ in\ seconds}{200}\right)$$

(Equation 255)

The function Roundup rounds up the result to the next higher time multiple of 0.2 s because the result of the division is not a multiple of 0.2 s in case of an odd *Time interval* setting (1, 3, 5…120 mins).

$$U_{Refresh} = \sqrt{\frac{1}{N}\sum_{i=1}^{N} U_{10/12cycles}^{2}(i)}$$

(Equation 256)

N Number of values to be aggregated as defined by *Equation 257*

$$N = \left(\frac{T_{refresh}}{0.2}\right)$$

(Equation 257)

Calculation of RMS average voltage

The RMS average voltage is calculated by aggregating the RMS $U_{refresh}$ voltage over a time period equal to the *Time interval*.

$$U_{Average} = \sqrt{\frac{1}{M}\sum_{i=1}^{M} U_{Refresh}^{2}(i)}$$

(Equation 258)

M Number of values to be aggregated as defined by *Equation 259*

$$M = Round\left(\frac{Time\ interval\ in\ seconds}{T_{Refresh}}\right)$$

(Equation 259)

At the initialization of the function, the average voltage is calculated considering initial values as zero. On the IEC 61850 mapped data, the quality of the calculated average voltage value is indicated as “Questionable” until the first complete time interval passes. The calculated average voltage measurement for the set *Time interval* for all three phase-to-earth and phase-to-phase voltages U_MEAN_A, U_MEAN_B, U_MEAN_C, U_MEAN_AB, U_MEAN_BC and U_MEAN_CA is available in the Monitored data view.

The calculated average voltage can be reset by the `RESET` binary input. The calculated average voltage can also be reset using PHVPTOV1 Reset mean on the Clear menu.

When the `INITIALIZE` input is activated, the average voltage measurement value is initialized with the 10/12-cycle RMS voltage. The average voltage measurement value can also be initialized using PHVPTOV1 Ini mean on the Clear menu.

Level detector

The calculated average voltage for all three voltages is compared phase-wise to the set *Start value* setting. If the calculated voltage value is higher than the set value of the *Start value* setting, Level detector enables the Phase selection logic module. The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal slightly differs from the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area.

Phase selection logic

If the fault criteria are fulfilled in the level detector, the phase selection logic detects the phase or phases in which the fault level is detected. If the number of faulty phases matches with the set *Num of start phases*, the phase selection logic activates the Timer module.

Timer

Once activated, the timer activates the START output. The operate delay time is not settable directly but it depends on the *Operate delay Mult* setting and refresh timer $T_{refresh}$. The operate delay time is calculated as:

$$Operate\ delay\ time\ in\ s = Operate\ delay\ Mult \cdot T_{refresh}$$

(Equation 260)

When the operation timer has reached the value equal to *Operate delay time*, the OPERATE output is activated if the overvoltage condition persists. If the average voltage value normalizes before the module operates, the reset timer is activated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the monitored data view.

When the relay has tripped due to variation overvoltage protection, check that operation is safe before closing the breaker. Clear the average voltage value by using *PHVPTOV1 Reset mean* on the **Clear** menu to prevent immediate retripping of breaker by PHVPTOV.

Considering the slow dynamic of the measurement, the protection may remain in the START status for a long time. If the measured voltage returns to a value lower than *Start value*, the function does not immediately reset. The function resets when the calculated average RMS value drops below *Start value*.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, the function operates normally but the OPERATE output is not activated.

4.5.10.6 Application

Overvoltage in a network occurs either due to the transient surges on the network or due to power frequency overvoltages. Surge arresters are used to protect the network against the transient overvoltages; power frequency overvoltage of magnitude greater than 15...20% of nominal voltage is normally handled by traditional overvoltage protection. However, slow voltage variations are usually quantified by calculating the RMS value of the voltage. To assess the RMS voltage, measurements are taken over a relatively long period of time to avoid any instantaneous effect caused by switching transients or faults.

It is important to monitor such slow voltage variation which can cause sub-optimal operation of the equipment. EN 50160 quantifies slow voltage variation using 10 min mean RMS value. CEI EN 50160 standard indicates that the RMS value of the voltage calculated over a period of 10 min should not exceed 110% of the nominal voltage; if the voltage exceeds this level, the generator must be disconnected from the network within 3 s. PHVPTOV provides overvoltage protection by calculating the RMS value over a period of 10 min.

A sudden change in the magnitude of the supply voltage is not immediately detected by the RMS calculation; hence this is mainly used as an indication of voltage quality supplied by the utility.

4.5.10.7 Signals

PHVPTOV Input signals

Table 872: PHVPTOV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
INITIALIZE	BOOLEAN	0=False	Initialize the voltage average measurement
RESET	BOOLEAN	0=False	Reset the voltage average measurement values

PHVPTOV Output signals

Table 873: PHVPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.5.10.8 PHVPTOV Settings

Table 874: PHVPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...3.00	xUn	0.01	1.10	Start value
Time interval	1...120	min	1	10	Time interval for average voltage calculation
Operate delay Mult	0...100		1	1	Trip delay expressed as a multiple of refresh time

Table 875: PHVPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation
Voltage selection	1=phase-to-earth 2=phase-to-phase			1=phase-to-earth	Parameter to select phase or phase-to-phase voltages

Table 876: PHVPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.5.10.9 PHVPTOV Monitored data

Table 877: PHVPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
U_MEAN_A	FLOAT32	0.00...5.00	xUn	Mean value of phase to earth voltage A
U_MEAN_B	FLOAT32	0.00...5.00	xUn	Mean value of phase to earth voltage B
U_MEAN_C	FLOAT32	0.00...5.00	xUn	Mean value of phase to earth voltage C
U_MEAN_AB	FLOAT32	0.00...5.00	xUn	Mean value of Phase to phase voltage AB
U_MEAN_BC	FLOAT32	0.00...5.00	xUn	Mean value of Phase to phase voltage BC
U_MEAN_CA	FLOAT32	0.00...5.00	xUn	Mean value of Phase to phase voltage CA
PHVPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.5.10.10 Technical data

Table 878: PHVPTOV Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f_n
	±1.5 % of the set value or ±0.002 × U_n
Reset ratio	Depends on the set *Relative hysteresis*
Operate time accuracy in definite time mode	±1.0 % of the set value or ±20 ms

4.6 Frequency protection

4.6.1 Frequency protection FRPFRQ (ANSI 81)

4.6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency protection	FRPFRQ	f>/f<,df/dt	81

4.6.1.2 Function block

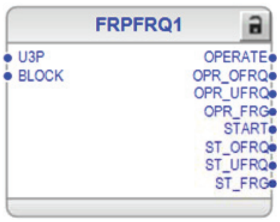


Figure 513: Function block

4.6.1.3 Functionality

The frequency protection function FRPFRQ is used to protect network components against abnormal frequency conditions.

The function provides basic overfrequency, underfrequency and frequency rate-of-change protection. Additionally, it is possible to use combined criteria to achieve even more sophisticated protection schemes for the system.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.6.1.4 Analog channel configuration

FRPFRQ has one analog group input which must be properly configured.

Table 879: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 880: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that at least one phase or phase-to-phase voltage channel is connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.6.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of FRPFRQ can be described using a module diagram. All the modules in the diagram are explained in the next sections.

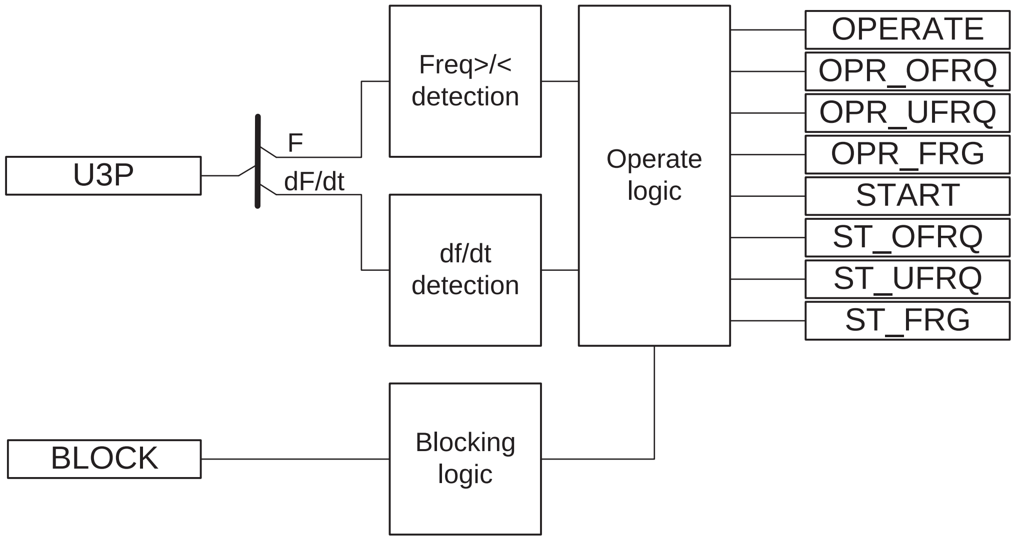


Figure 514: Functional module diagram

Freq>/< detection

The frequency detection module includes an overfrequency or underfrequency detection based on the *Operation mode* setting.

In the “Freq>” mode, the measured frequency is compared to the set *Start value Freq>*. If the measured value exceeds the set value of the *Start value Freq>* setting, the module reports the exceeding of the value to the operate logic module.

In the “Freq<” mode, the measured frequency is compared to the set *Start value Freq<*. If the measured value is lower than the set value of the *Start value Freq<* setting, the module reports the value to the operate logic module.

df/dt detection

The frequency gradient detection module includes a detection for a positive or negative rate-of-change (gradient) of frequency based on the set *Start value df/dt* value. The negative rate-of-change protection is selected when the set value is negative. The positive rate-of-change protection is selected when the set value is positive. When the frequency gradient protection is selected and the gradient exceeds the set *Start value df/dt* value, the module reports the exceeding of the value to the operate logic module.

The protection relay does not accept a value between -0.002...+0.002 for the *Start value df/dt* setting.

Operate logic

This module is used for combining different protection criteria based on the frequency and the frequency gradient measurement to achieve a more sophisticated behavior of the function. The criteria are selected with the *Operation mode* setting.

Table 881: Operation modes for operation logic

Operation mode	Description
Freq<	The function operates independently as the underfrequency ("Freq<") protection function. When the measured frequency is below the set value of the *Start value Freq<* setting, the module activates the START and STR_UFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm Freq* setting, the OPERATE and OPR_UFRQ outputs are activated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the START and STR_UFRQ outputs are deactivated.
Freq>	The function operates independently as the overfrequency ("Freq>") protection function. When the measured frequency exceeds the set value of the *Start value Freq>* setting, the module activates the START and STR_OFRQ outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm Freq* setting, the OPERATE and OPR_OFRQ outputs are activated.

Table continues on the next page

Operation mode	**Description**
	If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the START and STR_OFRQ outputs are deactivated.
df/dt	The function operates independently as the frequency gradient ("df/dt"), rate-of-change, protection function. When the frequency gradient exceeds the set value of the *Start value df/dt* setting, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm df/dt* setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the START and STR_FRG outputs are deactivated.
Freq< + df/dt	A consecutive operation is enabled between the protection methods. When the measured frequency is below the set value of the *Start value Freq<* setting, the frequency gradient protection is enabled. After the frequency has dropped below the set value, the frequency gradient is compared to the set value of the *Start value df/dt* setting. When the frequency gradient exceeds the set value, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm df/dt* setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the START and STR_FRG outputs are deactivated. The OPR_UFRQ output is not active when this operation mode is used.
Freq> + df/dt	A consecutive operation is enabled between the protection methods. When the measured frequency exceeds the set value of the *Start value Freq>* setting, the frequency gradient protection is enabled. After the frequency exceeds the set value, the frequency gradient is compared to the set value of the *Start value df/dt* setting. When the frequency gradient exceeds the set value, the module activates the START and STR_FRG outputs. The time characteristic is according to DT. When the operation timer has reached the value set by the *Operate Tm df/dt* setting, the OPERATE and OPR_FRG outputs are activated. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the START and STR_FRG outputs are deactivated. The OPR_OFRQ output is not active when this operation mode is used.

Table continues on the next page

Operation mode	Description
Freq< OR df/dt	A parallel operation between the protection methods is enabled. The START output is activated when either of the measured values of the protection module exceeds its set value. Detailed information about the active module is available at the STR_UFRQ and STR_FRG outputs. The shortest operate delay time from the set *Operate Tm Freq* or *Operate Tm df/dt* is dominant regarding the OPERATE output. The time characteristic is according to DT. The characteristic that activates the OPERATE output can be seen from the OPR_UFRQ or OPR_FRG output. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the STR_FRG output is deactivated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the STR_UFRQ output is deactivated.
Freq> OR df/dt	A parallel operation between the protection methods is enabled. The START output is activated when either of the measured values of the protection module exceeds its set value. A detailed information from the active module is available at the STR_OFRQ and STR_FRG outputs. The shortest operate delay time from the set *Operate Tm Freq* or *Operate Tm df/dt* is dominant regarding the OPERATE output. The time characteristic is according to DT. The characteristic that activates the OPERATE output can be seen from the OPR_OFRQ or OPR_FRG output. If the frequency gradient restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm df/dt* setting, the operate timer resets and the STR_FRG output is deactivated. If the frequency restores before the module operates, the reset timer is activated. If the timer reaches the value set by the *Reset delay Tm Freq* setting, the operate timer resets and the STR_UFRQ output is deactivated.

The module calculates the start duration value which indicates the percentage ratio of the start situation and set operate time (DT). The start duration is available according to the selected value of the *Operation mode* setting.

Table 882: Start duration value

Operation mode in use	Available start duration value
Freq<	ST_DUR_UFRQ
Freq>	ST_DUR_OFRQ
df/dt	ST_DUR_FRG

The combined start duration START_DUR indicates the maximum percentage ratio of the active protection modes. The values are available via the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.6.1.6 Application

The frequency protection function uses the positive phase-sequence voltage to measure the frequency reliably and accurately.

The system frequency stability is one of the main principles in the distribution and transmission network maintenance. To protect all frequency-sensitive electrical apparatus in the network, the departure from the allowed band for a safe operation should be inhibited.

The overfrequency protection is applicable in all situations where high levels of the fundamental frequency of a power system voltage must be reliably detected. The high fundamental frequency in a power system indicates an unbalance between production and consumption. In this case, the available generation is too large compared to the power demanded by the load connected to the power grid. This can occur due to a sudden loss of a significant amount of load or due to failures in the turbine governor system. If the situation continues and escalates, the power system loses its stability.

The underfrequency is applicable in all situations where a reliable detection of a low fundamental power system voltage frequency is needed. The low fundamental frequency in a power system indicates that the generated power is too low to meet the demands of the load connected to the power grid.

The underfrequency can occur as a result of the overload of generators operating in an isolated system. It can also occur as a result of a serious fault in the power system due to the deficit of generation when compared to the load. This can happen due to a fault in the grid system on the transmission lines that link two parts of the system. As a result, the system splits into two with one part having the excess load and the other part the corresponding deficit.

The frequency gradient is applicable in all the situations where the change of the fundamental power system voltage frequency should be detected reliably. The frequency gradient can be used for both increasing and decreasing the frequencies. This function provides an output signal suitable for load shedding, generator shedding, generator boosting, set point change in sub-transmission DC systems and gas turbine startup. The frequency gradient is often used in combination with a low frequency signal, especially in smaller power systems where the loss of a large generator requires quick remedial actions to secure the power system integrity. In such situations, the load shedding actions are required at a rather high frequency level. However, in combination with a large negative frequency gradient, the underfrequency protection can be used at a high setting.

4.6.1.7 Signals

FRPFRQ Input signals

Table 883: FRPFRQ Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

FRPFRQ Output signals

Table 884: FRPFRQ Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_OFRQ	BOOLEAN	Operate signal for overfrequency
OPR_UFRQ	BOOLEAN	Operate signal for underfrequency
OPR_FRG	BOOLEAN	Operate signal for frequency gradient
START	BOOLEAN	Start
ST_OFRQ	BOOLEAN	Start signal for overfrequency
ST_UFRQ	BOOLEAN	Start signal for underfrequency
ST_FRG	BOOLEAN	Start signal for frequency gradient

4.6.1.8 FRPFRQ Settings

Table 885: FRPFRQ Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Freq< 2=Freq> 3=df/dt 4=Freq< + df/dt 5=Freq> + df/dt 6=Freq< OR df/dt 7=Freq> OR df/dt			1=Freq<	Frequency protection operation mode selection
Start value Freq>	0.9000...1.2000	xFn	0.0001	1.0500	Frequency start value overfrequency
Start value Freq<	0.8000...1.1000	xFn	0.0001	0.9500	Frequency start value underfrequency

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Start value df/dt	-0.2000...0.2000	xFn/s	0.0001	0.0100	Frequency start value rate of change
Operate Tm Freq	80...5400000	ms	10	200	Operate delay time for frequency
Operate Tm df/dt	120...200000	ms	10	400	Operate delay time for frequency rate of change

Table 886: FRPFRQ Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 887: FRPFRQ Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay Tm Freq	0...60000	ms	1	0	Reset delay time for frequency
Reset delay Tm df/dt	0...60000	ms	1	0	Reset delay time for rate of change

4.6.1.9 FRPFRQ Monitored data

Table 888: FRPFRQ Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Start duration
ST_DUR_OFRQ	FLOAT32	0.00...100.00	%	Start duration
ST_DUR_UFRQ	FLOAT32	0.00...100.00	%	Start duration
ST_DUR_FRG	FLOAT32	0.00...100.00	%	Start duration
FRPFRQ	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.6.1.10 Technical data

Table 889: FRPFRQ Technical data

Characteristic		Value
Operation accuracy	f>/f<	±5 mHz
	df/dt	±50 mHz/s (in range |df/dt| <5 Hz/s) ±2.0% of the set value (in range 5 Hz/s < |df/dt| < 15 Hz/s)
Start time	f>/f<	<80 ms[1]

Table continues on the next page

Characteristic		Value
	df/dt	<120 ms
Reset time		<150 ms
Operate time accuracy		±1.0% of the set value or ±30 ms

4.6.1.11 Technical revision history

Table 890: FRPRFQ Technical revision history

Product connectivity level	Technical revision	Change
PCL4	F	Setting *Operate Tm Freq* maximum value extended to 5400000 ms (90 mins).

4.6.2 Load-shedding and restoration LSHDPFRQ (ANSI 81LSH)

4.6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Load-shedding and restoration	LSHDPFRQ	UFLS/R	81LSH

4.6.2.2 Function block

Figure 515: Function block

4.6.2.3 Functionality

The load-shedding and restoration function LSHDPFRQ is capable of performing load-shedding based on underfrequency and the rate of change of the frequency. The load that is shed during the frequency disturbance can be restored once the frequency has stabilized to the normal level.

[1] Applies to sudden frequency change of ≤0.2 Hz or to frequency slope of ≤ 5 Hz/s. When frequency change is outside of these limits, start may be delayed by additional 100 ms to prevent false starts when connecting / disconnecting heavy loads.

The measured system frequency is compared to the set value to detect the underfrequency condition. The measured rate of change of frequency (df/dt) is compared to the set value to detect a high frequency reduction rate. The combination of the detected underfrequency and the high df/dt is used for the activation of the load-shedding. There is a definite time delay between the detection of the underfrequency and high df/dt and the activation of LSHDPFRQ. This time delay can be set and it is used to prevent unwanted load-shedding actions when the system frequency recovers to the normal level.

Throughout this document, “high df/dt” is used to mean “a high rate of change of the frequency in negative direction.”

Once the frequency has stabilized, LSHDPFRQ can restore the load that is shed during the frequency disturbance. The restoration is possible manually or automatically.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.6.2.4 Analog channel configuration

LSHDPFRQ has one analog group input which must be properly configured.

Table 891: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 892: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that at least one phase or phase-to-phase voltage channel is connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.6.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of LSHDPFRQ can be described using a module diagram. All the modules are explained in the next sections.

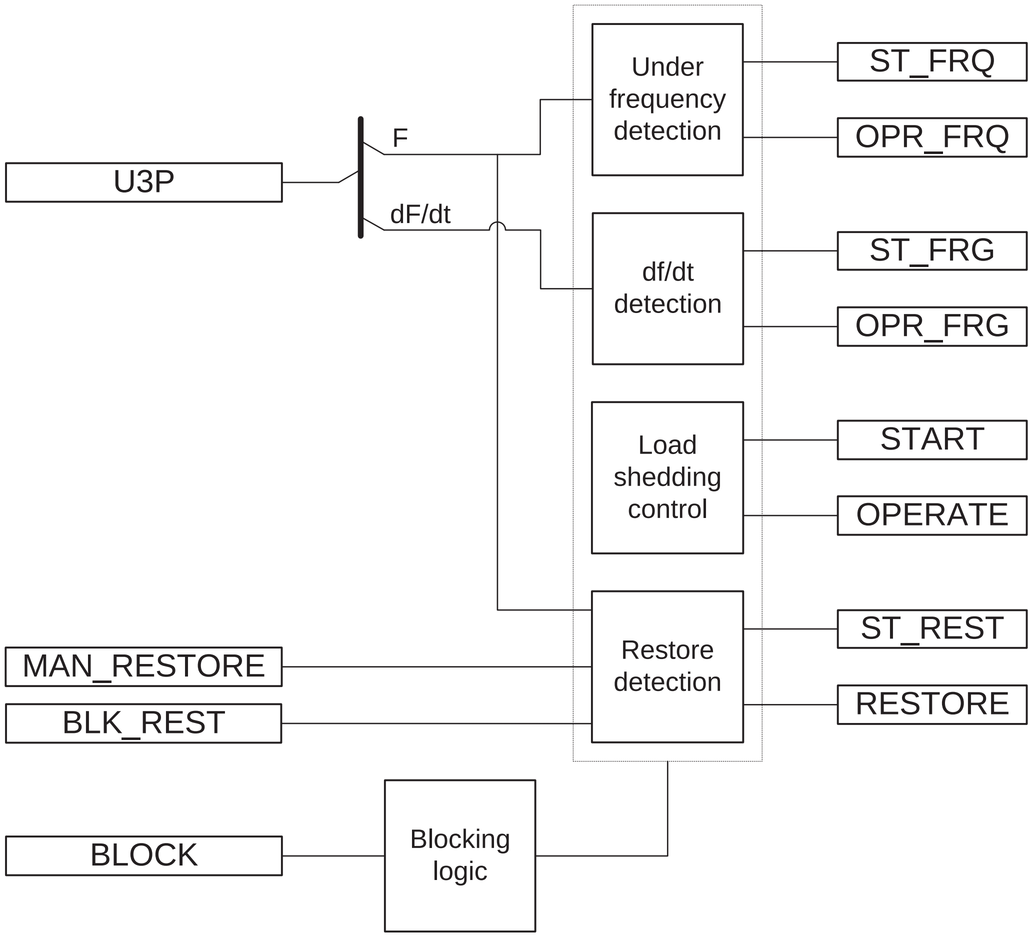


Figure 516: Functional module diagram

Underfrequency detection

The underfrequency detection measures the input frequency calculated from the voltage signal. An underfrequency is detected when the measured frequency drops below the set value of the *Start value Freq* setting.

The underfrequency detection module includes a timer with the definite time (DT) characteristics. Upon detection of underfrequency, operation timer activates the `ST_FRQ` output. When the underfrequency timer has reached the value set by *Operate Tm Freq*, the `OPR_FRQ` output is activated if the underfrequency condition still persists. If the frequency becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the timer resets and the `ST_FRQ` output is deactivated.

df/dt detection

The df/dt detection measures the input frequency calculated from the voltage signal and calculates its gradient. A high df/dt condition is detected by comparing the gradient to the *Start value df/dt* setting. The df/dt detection is activated when the frequency gradient decreases at a faster rate than the set value of *Start value df/dt*.

The df/dt detection module includes a timer with the DT characteristics. Upon detection of df/dt, operation timer activates the ST_FRG output. When the timer has reached the value set by *Operate Tm df/dt*, the OPR_FRG output is activated if the df/dt condition still persists. If df/dt becomes normal before the module operates, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_FRG output is deactivated.

Load-shedding control

The way of load-shedding, that is, whether to operate based on underfrequency or high df/dt or both, is defined with the *Load shed mode* user setting. The valid operation modes for the *Load shed mode* settings are "Freq<", "Freq< AND df/dt" and "Freq< OR df/dt".

Once the selected operation mode conditions are satisfied, the START and OPERATE output signals are activated.

When the START output is active, the percentage of the elapsed delay time can be monitored through START_DUR which is available as monitored data.

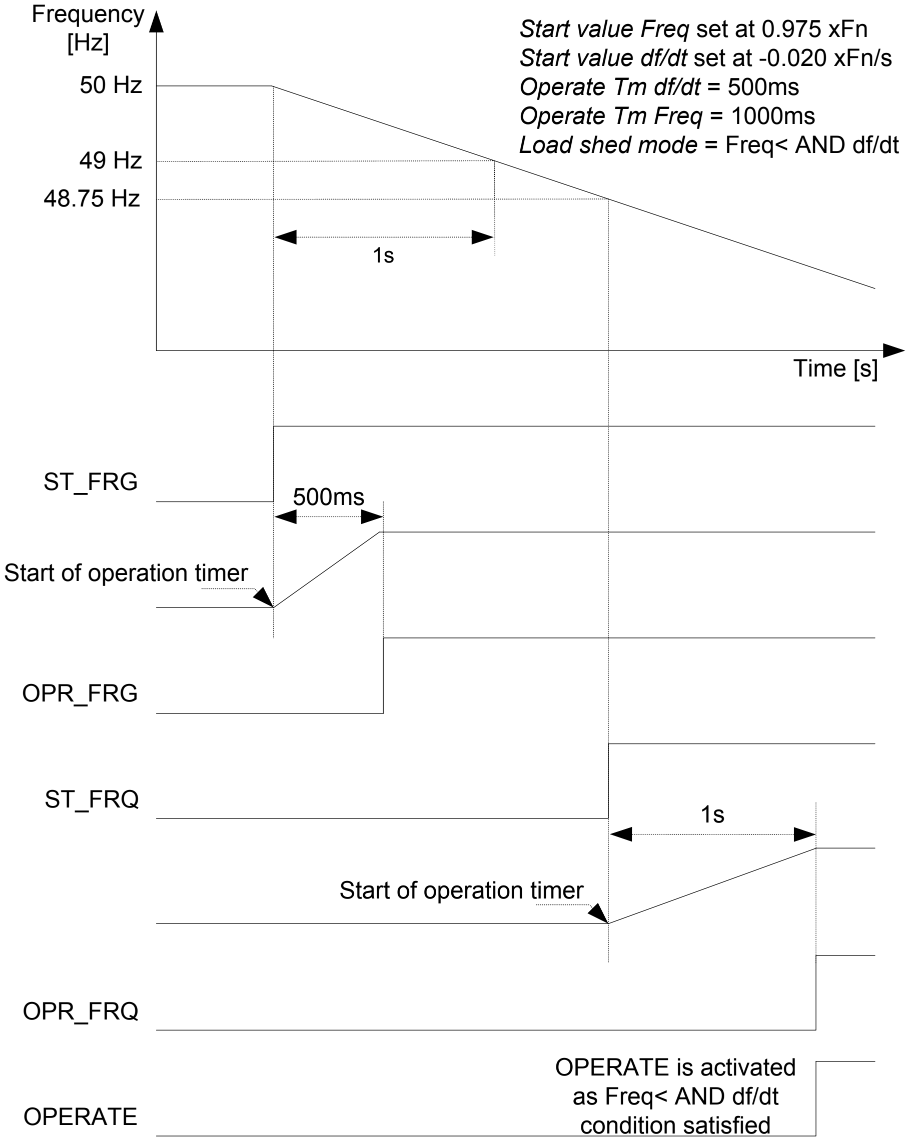


Figure 517: Load-shedding operation in the “Freq< AND df/dt>” mode when both Freq< and df/dt conditions are satisfied (Rated frequency=50 Hz)

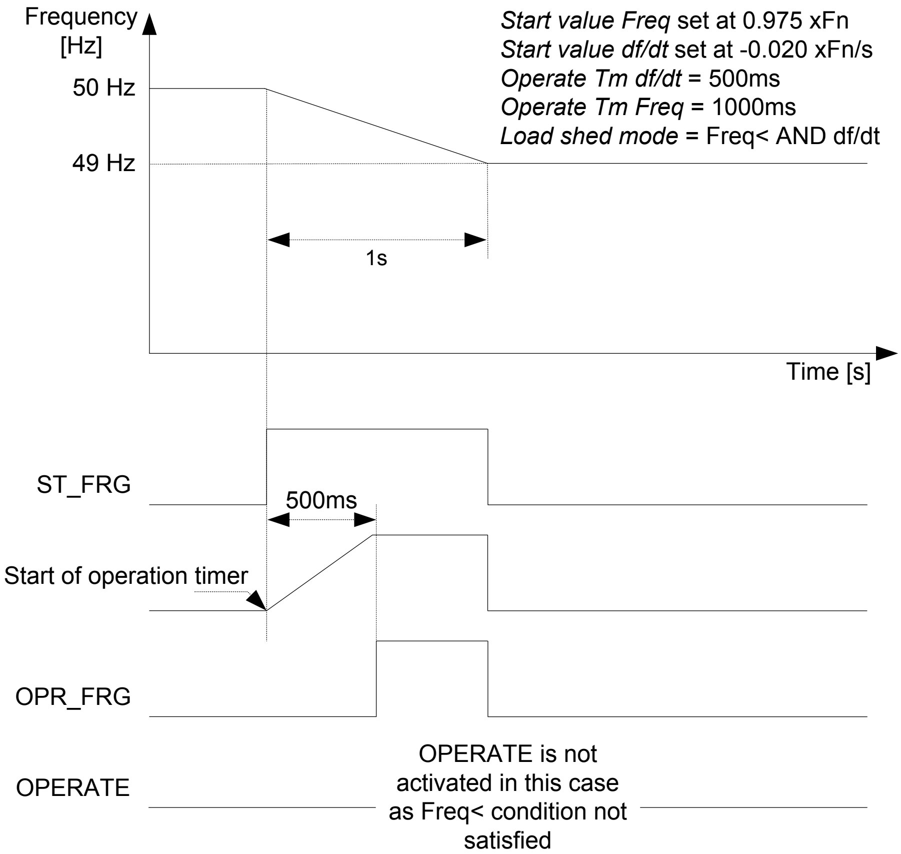


Figure 518: Load-shedding operation in the “Freq< AND df/dt>” mode when only the df/dt condition is satisfied (Rated frequency=50 Hz)

Restore detection

If after the activation of the `OPERATE` output the frequency recovers to a level above the *Restore start Val* setting, the `RESTORE` signal output is activated. The `RESTORE` output remains active for 100 ms. The *Restore mode* setting is used to select the restoring mode to be "Disabled", "Auto" or "Manual".

Restoring mode	Description
Disabled	Load restoration is disabled.
Auto	In the “Auto” mode, input frequency is continuously compared to the *Restore start Val* setting. The restore detection module includes a timer with the DT characteristics. Upon detection of restoring, the operation timer activates the `ST_REST` output. When the timer has reached the value of the *Restore delay time* setting, the `RESTORE` output is activated if the restoring condition still persists. If the frequency drops below the *Restore start Val* before the `RESTORE` output is activated, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the `ST_REST` start output is deactivated.
Manual	In the “Manual” mode, a manual restoration is possible through the `MAN_RESTORE` input or via communication. The `ST_REST` output is activated if the `MAN_RESTORE` command is available and the frequen-

Restoring mode	Description
	cy has exceeded the *Restore start Val* setting. The manual restoration includes a timer with the DT characteristics. When the timer has reached the set value of the *Restore delay time* setting, the RESTORE output is activated if the restoring condition still persists. If the frequency drops below the *Restore start Val* setting before the RESTORE output is activated, the reset timer is activated. If the reset timer reaches the value of the *Reset delay time* setting, the timer resets and the ST_REST start output is deactivated.

A condition can arise where the restoring operation needs to be canceled. Activating the BLK_REST input for the "Auto" or "Manual" modes cancels the restoring operation. In the "Manual" restoring mode, the cancellation happens even if MAN_RESTORE is present.

Once the RESTORE output command is cancelled, the reactivation of RESTORE is possible only after the reactivation of the OPERATE output, that is, when the next load-shedding operation is detected.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** that selects the blocking mode. The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK input signal activation is preselected with the *Blocking mode* global setting.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE, OPR_FRQ and OPR_FRG outputs are not activated.

4.6.2.6 Application

An AC power system operates at a defined rated frequency. The nominal frequency in most systems in the world is 50 Hz or 60 Hz. The system operation is such that the operating frequency remains approximately at the nominal frequency value by a small margin. The safe margin of operation is usually less than ±0.5 Hz. The system frequency stability is one of the main concerns in the transmission and distribution network operation and control. To protect the frequency-sensitive electrical equipment in the network, departure from the allowed band for safe operation should be inhibited.

Any increase in the connected load requires an increase in the real power generation to maintain the system frequency. Frequency variations form whenever there are system conditions that result in an unbalance between the generation and load. The rate of change of the frequency represents the magnitude of the difference between the load and generation. A reduction in frequency and a negative rate of change of the frequency are observed when the load is greater than the generation, and an increase in the frequency along with a positive rate of change of the frequency are observed if the generation is greater than the load. The rate of change of the frequency is used for a faster decision of load-shedding. In an underfrequency situation, the load-shedding trips out the unimportant loads to stabilize the network. Thus, loads are normally prioritized so that the less important loads are shed before the important loads.

During the operation of some of the protective schemes or other system emergencies, the power system is divided into small islands. There is always a load - generation imbalance in such islands that leads to a deviation in the operating frequency from the nominal frequency. This off-nominal frequency operation is harmful to power system components like turbines and motors. Therefore, such situation must be prevented from continuing. The frequency-based load-shedding scheme should be applied to restore the operation of the system to normal frequency. This is achieved by quickly creating the load - generation balance by disconnecting the load.

As the formation of the system islands is not always predefined, several load-shedding relays are required to be deployed at various places near the load centers. A quick shedding of a large amount of load from one place can cause a significant disturbance in the system. The load-shedding scheme can be made most effective if the shedding of load feeders is distributed and discrete, that is, the loads are shed at various locations and in distinct steps until the system frequency reaches the acceptable limits.

Due to the action of load-shedding schemes, the system recovers from the disturbance and the operating frequency value recovers towards the nominal frequency. The load that was shed during the disturbance can be restored. The load-restoring operation should be done stepwise in such a way that it does not lead the system back to the emergency condition. This is done through an operator intervention or in case of remote location through an automatic load restoration function. The load restoration function also detects the system frequency and restores the load if the system frequency remains above the value of the set restoration frequency for a predefined duration.

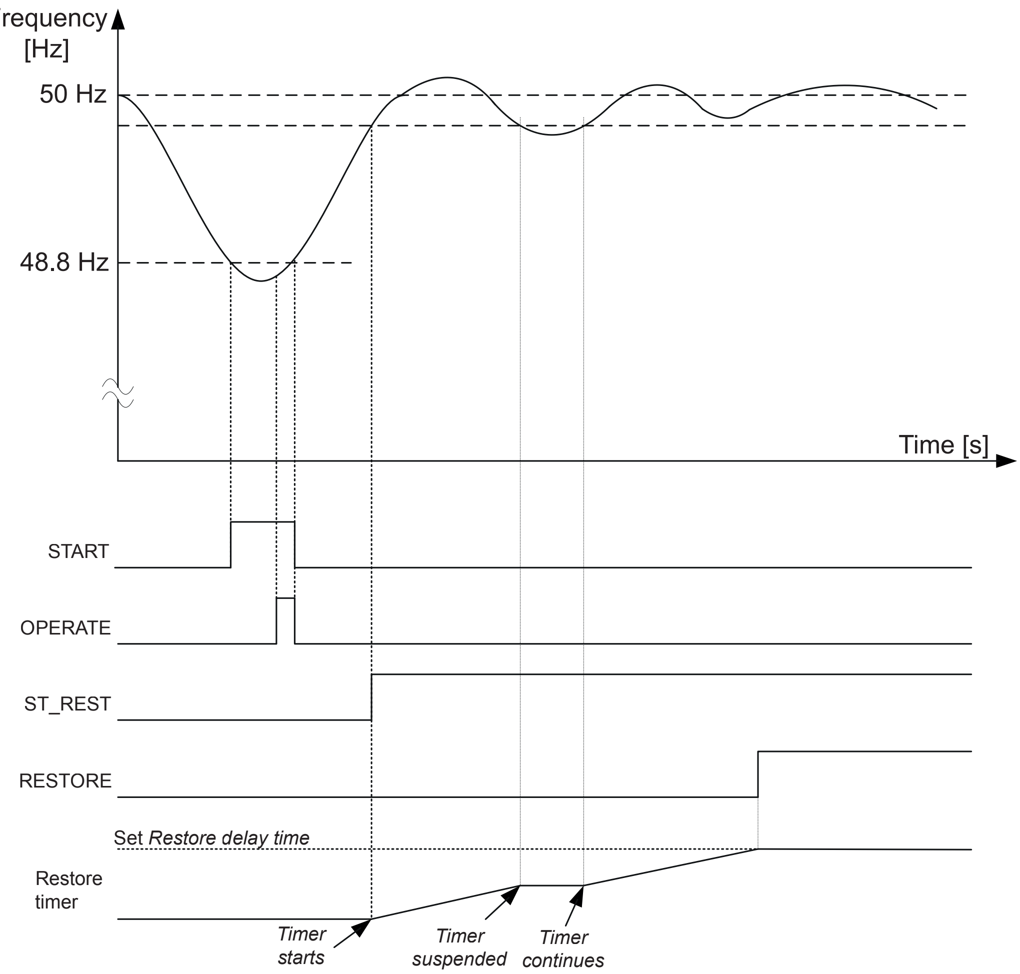


Figure 519: Operation of the load-shedding function

Power system protection by load-shedding

The decision on the amount of load that is required to be shed is taken through the measurement of frequency and the rate of change of frequency (df/dt). At a single location, many steps of load-shedding can be defined based on different criteria of the frequency and df/dt. Typically, the load-shedding is performed in six or four steps with each shedding increasing the portion of load from five to twenty-five percent of full load within a few seconds. After every shedding, the system frequency is read back and further shedding actions are taken only if necessary. In order to take the effect of any transient, a sufficient time delay should be set.

The value of the setting has to be well below the lowest occurring normal frequency and well above the lowest acceptable frequency of the system. The setting level, the number of steps and the distance between two steps (in time or in frequency) depend on the characteristics of the power system under consideration. The size of the largest loss of generation compared to the size of the power system is a critical parameter. In large systems, the load-shedding can be set at a high frequency level and the time delay is normally not critical. In small systems, the frequency start level has to be set at a low value and the time delay must be short.

If a moderate system operates at 50 Hz, an underfrequency should be set for different steps from 49.2 Hz to 47.5 Hz in steps of 0.3 – 0.4 Hz. The operating time for the underfrequency can be set from a few seconds to a few fractions of a second stepwise from a higher frequency value to a lower frequency value.

Table 893: Setting for a five-step underfrequency operation

Load-shedding steps	Start value Freq setting	Operate Tm Freq setting
1	0.984 · Fn (49.2 Hz)	45000 ms
2	0.978 · Fn (48.9 Hz)	30000 ms
3	0.968 · Fn (48.4 Hz)	15000 ms
4	0.958 · Fn (47.9 Hz)	5000ms
5	0.950 · Fn (47.5 Hz)	500 ms

The rate of change of frequency function is not instantaneous since the function needs time to supply a stable value. It is recommended to have a time delay long enough to take care of the signal noise.

Small industrial systems can experience the rate of change of frequency as high as 5 Hz/s due to a single event. Even large power systems can form small islands with a large imbalance between the load and generation when severe faults or combinations of faults are cleared. Up to 3 Hz/s has been experienced when a small island becomes isolated from a large system. For normal severe disturbances in large power systems, the rate of change of the frequency is much less, often just a fraction of 1.0 Hz/s.

Similarly, the setting for df/dt can be from 0.1 Hz/s to 1.2 Hz/s in steps of 0.1 Hz/s to 0.3 Hz/s for large distributed power networks, with the operating time varying from a few seconds to a few fractions of a second. Here, the operating time should be kept in minimum for the higher df/dt setting.

Table 894: Setting for a five-step df/dt< operation

Load-shedding steps	Start value df/dt setting	Operate Tm df/dt setting
1	-0.005 · Fn /s (-0.25 Hz/s)	8000 ms
2	-0.010 · Fn /s (-0.50 Hz/s)	2000 ms
3	-0.015 · Fn /s (-0.75 Hz/s)	1000 ms
4	-0.020 · Fn /s (-1.00 Hz/s)	500 ms
5	-0.025 · Fn /s (-1.25 Hz/s)	250 ms

Once the frequency has stabilized, the shed load can be restored. The restoring operation should be done stepwise, taking care that it does not lead the system back to the emergency condition.

Table 895: Setting for a five-step restoring operation

Load-shedding steps	Restore start Val setting	Restore delay time setting
1	0.990 · Fn (49.5 Hz)	200000 ms
2	0.990 · Fn (49.5 Hz)	160000 ms
3	0.990 · Fn (49.5 Hz)	100000 ms

Table continues on the next page

Load-shedding steps	Restore start Val setting	Restore delay time setting
4	0.990 · Fn (49.5 Hz)	50000 ms
5	0.990 · Fn (49.5 Hz)	10000 ms

4.6.2.7 Signals

LSHDPFRQ Input signals

Table 896: LSHDPFRQ Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_REST	BOOLEAN	0=False	Block restore
MAN_RESTORE	BOOLEAN	0=False	Manual restore signal

LSHDPFRQ Output signals

Table 897: LSHDPFRQ Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operation of load shedding
OPR_FRQ	BOOLEAN	Operate signal for under frequency
OPR_FRG	BOOLEAN	Operate signal for high df/dt
START	BOOLEAN	Start
ST_FRQ	BOOLEAN	Pick-Up signal for under frequency detection
ST_FRG	BOOLEAN	Pick-Up signal for high df/dt detection
RESTORE	BOOLEAN	Restore signal for load restoring purposes
ST_REST	BOOLEAN	Restore frequency attained and restore timer started

4.6.2.8 LSHDPFRQ Settings

Table 898: LSHDPFRQ Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Load shed mode	1=Freq< 6=Freq< OR df/dt			1=Freq<	Set the operation mode for load shedding function

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=Freq< AND df/dt				
Restore mode	1=Disabled 2=Auto 3=Manual			1=Disabled	Mode of operation of restore functionality
Start value Freq	0.8000...1.2000	xFn	0.0001	0.9750	Frequency setting/start value
Start value df/dt	-0.2000...-0.0050	xFn/s	0.0001	-0.0100	Setting of frequency gradient for df/dt detection
Operate Tm Freq	80...200000	ms	10	200	Time delay to operate for under frequency stage
Operate Tm df/dt	120...200000	ms	10	200	Time delay to operate for df/dt stage
Restore start Val	0.8000...1.2000	xFn	0.0001	0.9980	Restore frequency setting value
Restore delay time	80...200000	ms	10	300	Time delay to restore

Table 899: LSHDPFRQ Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 900: LSHDPFRQ Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	50	Time delay after which the definite timers will reset

4.6.2.9 LSHDPFRQ Monitored data

Table 901: LSHDPFRQ Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Start duration
LSHDPFRQ	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.6.2.10 Technical data

Table 902: LSHDPFRQ Technical data

Characteristic		Value
Operation accuracy	f<	±5 mHz
	df/dt	±100 mHz/s (in range |df/dt| < 5 Hz/s)

Table continues on the next page

Characteristic		Value
		± 2.0% of the set value (in range 5 Hz/s < |df/dt| < 15 Hz/s)
Start time	f<	<80 ms
	df/dt	<120 ms
Reset time		<150 ms
Operate time accuracy		±1.0% of the set value or ±30 ms

4.6.2.11 Technical revision history

Table 903: LSHDPFRQ Technical revision history

Product connectivity level	Technical revision	Change
PCL2	E	Changed the *Start value Freq* and *Restore start Val* steps to 0.0001 xFn

4.7 Impedance protection

4.7.1 Distance protection DSTPDIS (ANSI 21P, 21N)

4.7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Distance protection	DSTPDIS	Z<	21P, 21N

4.7.1.2 Function block

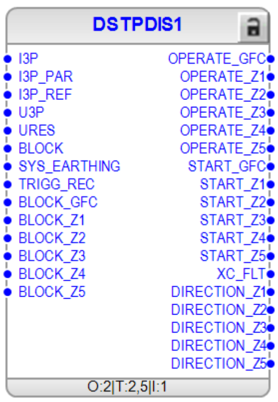


Figure 520: Function block

4.7.1.3 Functionality

The distance protection function DSTPDIS provides a full-scheme distance protection function for distribution networks where three-phase tripping is allowed for all kinds of faults.

DSTPDIS has five flexible, configurable impedance zones for protection (Z1...Z5).

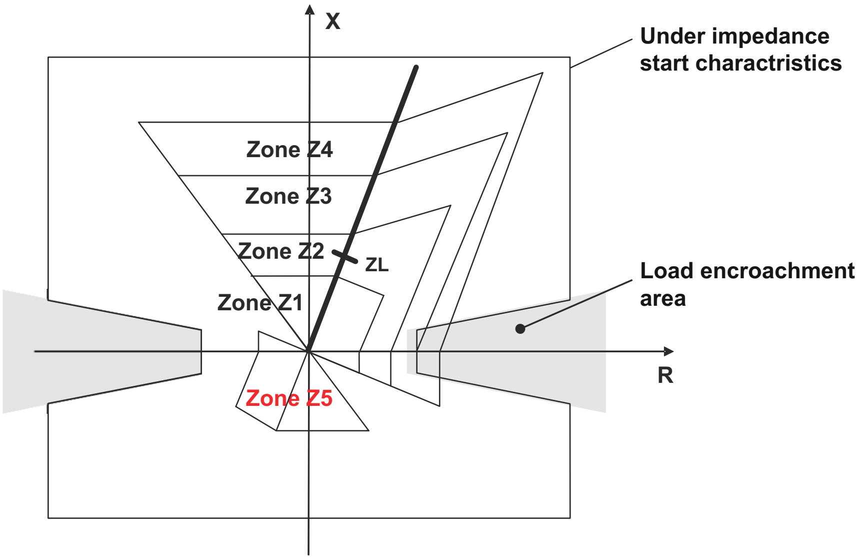


Figure 521: Zones of DSTPDIS function (example 1)

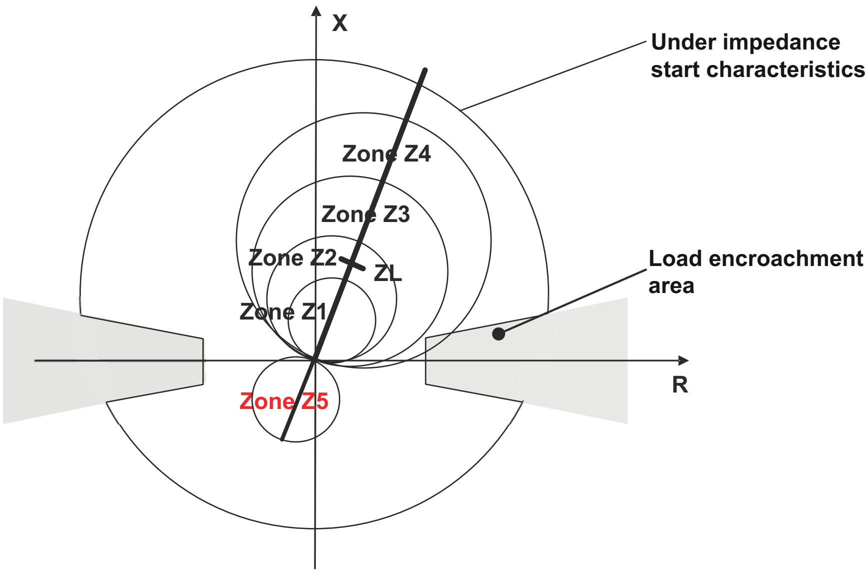


Figure 522: Zones of DSTPDIS function (example 2)

The supported zone characteristic shapes are quadrilateral, mho (circular) or bullet (quadrilateral and mho characteristics combined). Mho can be combined with directional lines to secure directionality and to enable increased fault resistance coverage with an offset mho circle.

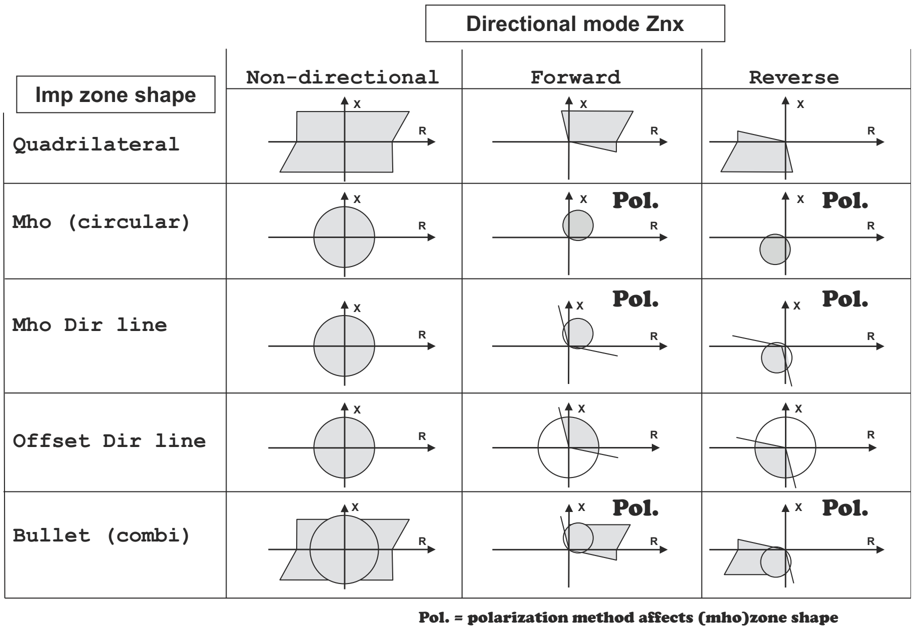


Figure 523: Possible combinations of Directional mode Znx and Zone characteristics settings. Pol. here means that the shape of the characteristic is affected by the selected polarization method of mho circle (Pol quantity zone = "Cross pol", "Pos. seq. volt.", "Self pol")

The directional lines are polarized with the set polarizing quantity of all impedance measuring elements. In addition, the memory voltage that is based on positive-sequence voltage substitute for the measured voltage with any impedance measurement element polarization if the corresponding voltage drops too low.

DSTPDIS has separate and independent measurement elements for each fault loop in the distance protection zone. In addition to the full scheme design, the separate measuring elements are used for general fault detection and faulted phase selection.

DSTPDIS supports both fault detection dependent control of zone timers and zone-dedicated phasewise timer control for maximum application flexibility.

The impedance measurement is always done the same way regardless of the zone shape. The operation is based on the impedance mapping approach where the fault loop impedance is first calculated and then compared to the zone boundaries. If impedance is recognized within the operation zone, the corresponding operate output is activated after the operate time has elapsed.

The impedance measurement is based on full-cycle DFT filtered current and voltage phasors.

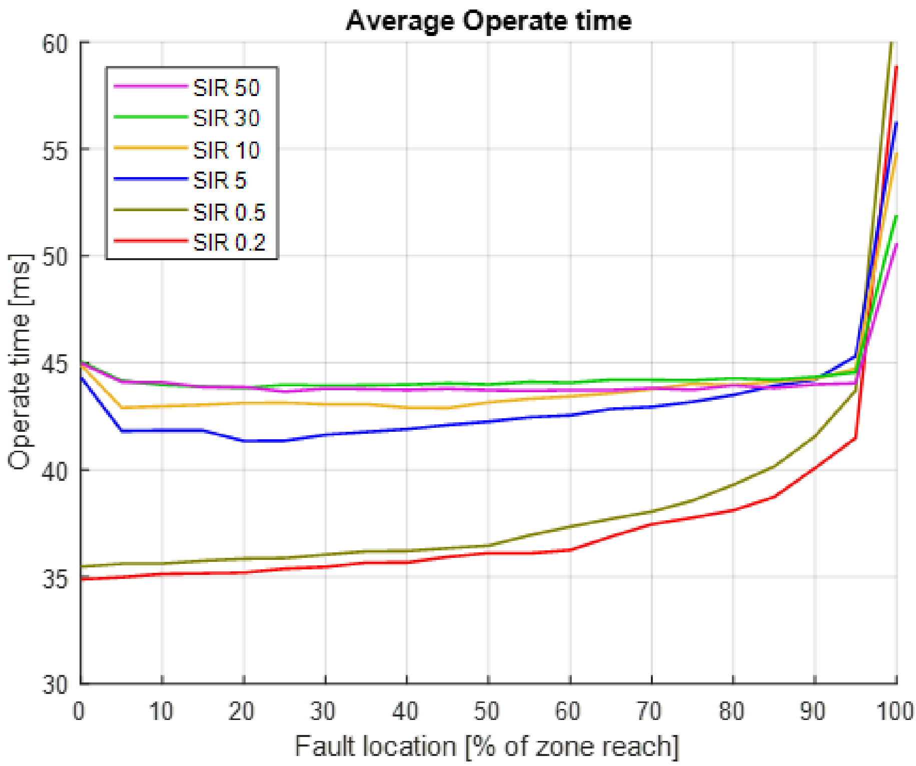


Figure 524: Average operate time of DSTPDIS according to IEC 60255-121 network models Short line and Long line (50 Hz)

SIR curves are plotted from the data which includes variation of fault location (0…100% of zone reach, 5% step), fault type (LN, LL, LLN, LLL) and fault inception angle (0, 30, 60, 90 degrees). Each combination has been repeated ten times giving the total number of 26880 shots. The operate times include the delay of relay output contacts. The SIR curves presented in *Figure 524* were obtained using the static power outputs (SPOs) and with *Zone timer mode* = "common".

4.7.1.4 Analog channel configuration

DSTPDIS has five analog group inputs which must be properly configured.

Table 904: Analog inputs

Input	Description
I3P	Three-phase currents
I3P_PAR [1]	Three-phase currents Necessary when *Par line Comp zone x* is set to True
I3P_REF [2]	Three-phase currents

Table continues on the next page

1 Can be connected to GRPOFF if *Par line Comp zone x* is set to False.
2 Can be connected to GRPOFF if *EF detection Mod GFC* is not set to "Io AND IoRef"

Input	Description
	Necessary when *EF detection Mod GFC* is set to "Io AND IoRef"
U3P	Three-phase voltages
URES [3]	Residual voltage (measured) Necessary when *EF detection Mod GFC* is set to "Io OR Uo" or "Io AND Uo". Necessary also if only main voltages are available but *Phase voltage Meas* is set to "Accurate".

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 905: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.7.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The function consists of sub-functions which are described in the next sections.

[3] Can be connected to GRPOFF if *EF detection Mod GFC* is set to "Io" or "Io AND IoRef" or *Phase voltage Meas* is set to "Ph-to-ph without Uo"

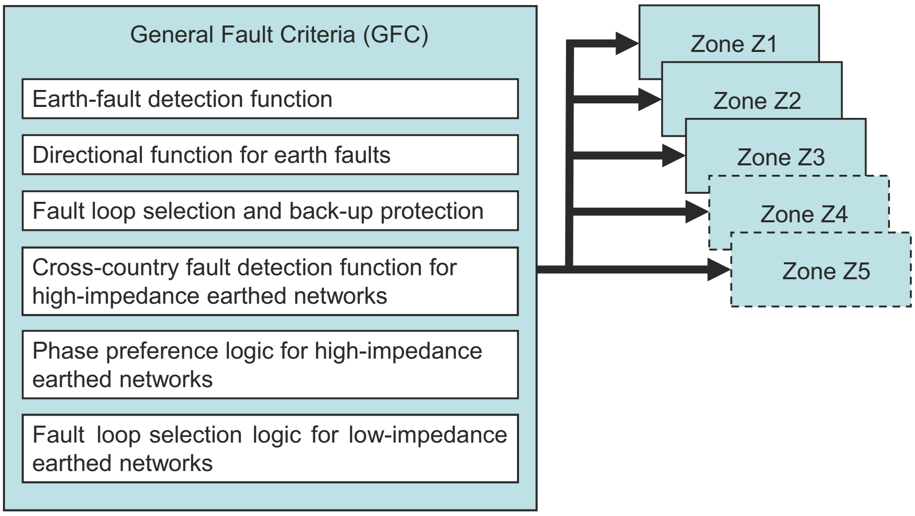


Figure 525: Main functionality of DSTPDIS

All outputs and the operation of all sub-functions can be blocked with the BLOCK binary input signal. In addition, it resets the timers.

Blocking

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE_Z1...5 output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE_Z1...5 output is not activated.

In addition, the function has zone-specific blocking signals BLOCK_Z1...5. The signal resets zone timers disabling the corresponding start and operate output activation.

BLOCK_GFC deactivates START_GFC and OPERATE_GFC. It also resets GFC operate time (set by *Operate delay GFC*). Blocking does not prevent GFC operation.

Earth-fault detection function

The recognition of an earth fault is an important part in identifying the correct fault type. This information is used in faulted loop (phase) selection to release the correct impedance-measuring elements. The earth-fault recognition is always required to release the phase-to-earth impedance-measuring elements.

The earth-fault detection is indicated with the EARTH_FLT monitored data. The earth-fault detection criterion can be defined with the *EF detection Mod GFC* setting. The fundamental criterion is based on the residual current. The residual voltage and reference neutral current, measured from the transformer neutral point, can be used for the earth-fault detection criteria.

Table 906: Selection of earth-fault detection criteria

Setting	Enumerator name
EF detection Mod GFC	• Io • Io OR Uo • Io AND Uo • Io AND IoRef

If the residual current Io is derived from the phase currents either by the summation connection of CTs, that is, the Holmgreen connection, or by internally summing the phase currents, there is a risk of a false earth-fault detection due to apparent residual current from the current transformer errors. This risk can be eliminated using a stabilized residual current measurement. The stabilization is enabled by setting the *EF Cur stabilization* setting to "True". The stabilization increases the residual current *Gnd Op current GFC* threshold setting when the maximum phase current exceeds the nominal current. The increase is defined with the *Stab slope 1 GFC* setting. The apparent residual current may exist during short circuits and in inrush current situations if the CTs saturate partially. The earth-fault detection function takes the CT saturation into account with additional stabilization settings *Gnd Op current 2 GFC, A Ph Stab value GFC* and *Stab slope 2 GFC*.

Setting *EF Cur stabilization* to "False" disables the stabilization of the residual current measurement and should be used only when the residual current is measured with a cable current transformer. The residual current threshold setting for earth-fault detection is *Gnd Op current GFC*. If the residual current is measured from a transformer neural point, *Gnd Op A Ref GFC* is used. This is valid when the setting *EF detection Mod GFC* is "Io AND IoRef".

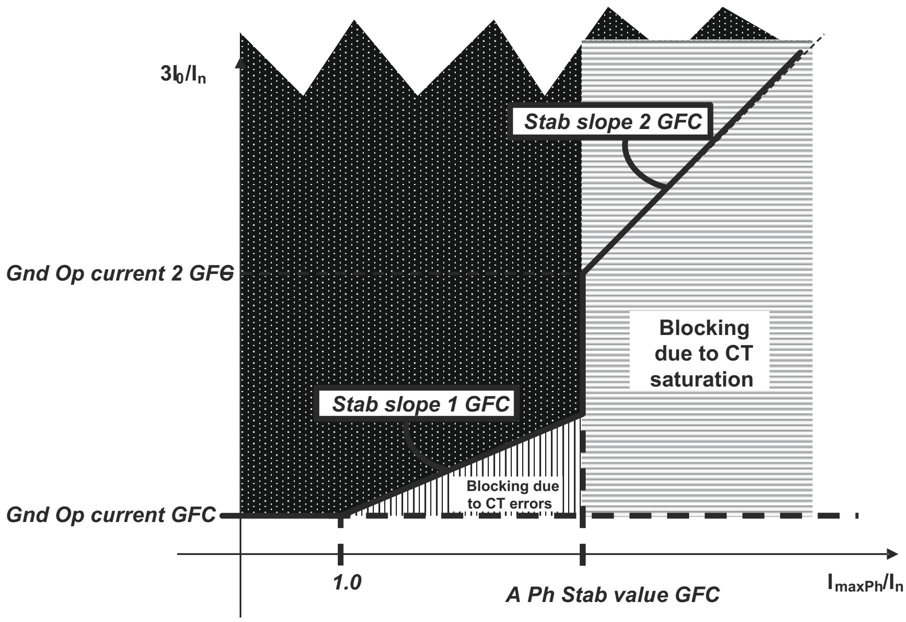


Figure 526: Stabilized residual current measurement for earth-fault detection

The residual voltage can also be used as a complementary criterion for earth-fault detection. This is valid when the setting *EF detection Mod GFC* is "Io OR Uo" or *EF detection Mod GFC* is "Io AND Uo". The threshold setting for the residual voltage is *Gnd Str voltage GFC*.

Directional function for earth faults

In low-impedance earthed networks, when the *System grounding GFC* setting is set to "Low impedance", the earth-fault detection function can be optionally supervised by a directional function which can be enabled with the *Dir mode EF GFC* setting. If *Dir mode EF GFC* is set to "Forward" or "Reverse", the earth-fault direction is also detected. The calculated direction for the earth fault is indicated in the DIR_E_FLT monitored data ("unknown", "forward", "backward" (reverse), "both"). Direction criteria do not directly affect earth-fault detection, but the earth-fault direction information is used for zone starting, when only those directional zones that are set to the indicated earth-fault direction can be started.

The operation characteristic of the directional function is defined by three settings: *Chr angle GFC*, *Min phase angle GFC* and *Max phase angle GFC*.

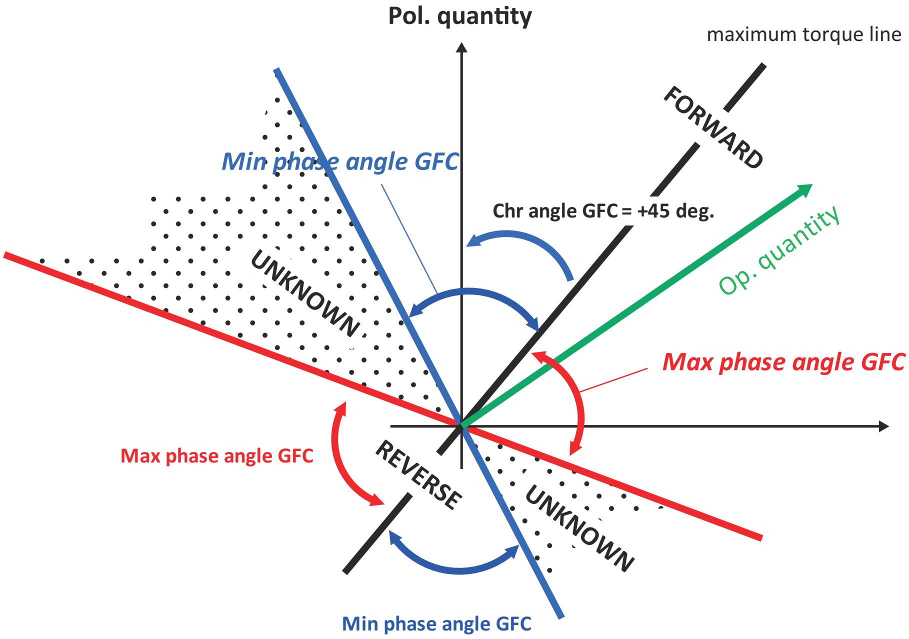


Figure 527: Characteristic of the directional function for earth faults

The *Chr angle GFC* setting, also known as relay characteristic angle or basic angle, is used to turn the directional characteristic. It has a positive value when the operating quantity lags the polarizing quantity and a negative value when the operating quantity leads the polarizing quantity. For low-impedance earthed networks, *Chr angle GFC* equals the angle of the fault loop impedance and is typically positive.

The *Min phase angle GFC* and *Max phase angle GFC* settings define the width of the operating sector. These settings are mirror-symmetric to the origin for reverse (backward).

The directional function for earth faults must operate at fault current values below the magnitude of the load currents. The use of sequence quantities is preferred for polarizing quantity as phase quantities are affected by the load currents. Four possibilities are available and defined by the *Pol quantity GFC* setting.

Table 907: Polarizing quantities for optional directional function for earth faults in low-impedance earthed networks

Pol quantity GFC	Polarizing quantity	Operating quantity	Description
Zero seq. volt.	$-U_0$	I_0	Zero-sequence voltage polarization
Neg. seq. volt.	$-U_2$	I_2	Negative-sequence voltage polarization
Zero seq. cur.	I_{oref}	I_0	Zero-sequence current polarization
Zro vol. OR cur.	$-U_0$ OR I_{0ref}	I_0	Dual polarization

The polarizing quantity is $-U_0$ and the operating quantity is I_0 in case of zero-sequence voltage polarization.

The polarizing quantity is $-U_2$ and the operating quantity is I_2 in case of negative-sequence polarization.

In case of zero-sequence current polarization "Zero seq. cur.", the zero-sequence current I_0 of the protected line is the operating quantity while another reference zero-sequence current I_{0ref} is the polarizing quantity. I_{0ref}, for example, could be the current from the neutral of a power transformer. In case of zero-sequence current polarization, the relay characteristic angle *Chr angle GFC* is internally fixed and is equal to zero degrees. The zero-sequence current direction must remain unchanged during all network configurations and faults. Therefore, all transformer configurations or constructions are not suitable for polarization.

In case of dual polarization "Zro vol. OR cur.", the zero-sequence voltage polarization and zero-sequence current polarization elements are logically OR:ed. Typically, when I_0 is high, U_0 is low, and when I_0 is low, U_0 is high. Hence the protection can benefit from both elements as the two polarization methods complement each other. If the zero-sequence current polarization source is switched off for service, the flexibility is increased as the zero-sequence voltage polarization can be used.

Faulted loop phase selection

A reliable identification of a fault and faulted phases is needed to guarantee a selective operation of the distance protection. This information is used to release correct measuring elements of the protection zones.

In DSTPDIS, the faulted phase selection can be done in various ways and defined with the *Phase Sel mode GFC* setting.

Table 908: Supported methods for phase selection

Setting	Enumerator value
Phase Sel mode GFC	• Overcurrent • Vol Dep Overcur • Under impedance • OC AND Und impedance

- The “Overcurrent” method is the basic method for identifying the faulted phases. It can be used in applications where the fault current magnitude exceeds the load current despite the changes in the network configuration and fault type.

- The “Vol Dep Overcur” method combines overcurrent and undervoltage conditions. An undervoltage condition allows lower current threshold settings and increases the sensitivity of the fault detection.
- The “Under impedance” method uses fault loop impedance for identifying the faulted phases. The underimpedance characteristic can be either quadrilateral or circular in shape. The sensitivity of the fault detection is defined by an independent setting in resistive and reactive reaches. The underimpedance method is supervised by a load encroachment logic which ensures that the load impedance does not interfere with the faulted phase selection.

The ”OC AND Und impedance” method combines “Overcurrent” and “Under impedance” methods so that both criteria have to be fulfilled.

All phase selection methods require that all three phase currents are measured and all three phase-to-earth voltages are available. If only phase-to-phase voltages are available (*Phase voltage Meas* = “Ph-to-ph without Uo”), only phase-to-phase measuring loops can be released for measurement. The release of phase-to-earth fault measuring elements is then blocked, `RELEASE_PE` = “No fault”.

The operation of the faulted phase selection function is highly dependent on the earth-fault detection function. The phase preference or faulted loop selection logic can be set to filter the faulted phases to be released for measurement in the protection zones.

The general indication of a fault is given in the binary output `START_GFC`. The faulted phase information can be found from the integer monitored data signal `STARTS_GFC`.

Table 909: Enumeration values for integer monitored data signal STARTS_GFC

Enumeration name	Value
No fault	-5
AG Fault	1
BG Fault	2
CG Fault	3
AB Fault	4
BC Fault	5
CA Fault	6
ABC Fault	7

The fault loops released for measurement are indicated with the integer monitored data signals `RELEASE_PE` and `RELEASE_PP`. These signals may be filtered by the phase preference of the faulted loop selection logic.

Table 910: Enumeration values for integer monitored data signal RELEASE_PE

Enumeration name	Value
No fault	-5
AG Fault	1
BG Fault	2
CG Fault	3
AB Fault	4

Table continues on the next page

Enumeration name	Value
BC Fault	5
CA Fault	6
ABC Fault	7

Table 911: Enumeration values for integer monitored data signal RELEASE_PP

Enumeration name	Value
No fault	-5
AB Fault	4
BC Fault	5
CA Fault	6
ABC Fault	7

The phase selection function can be set to issue an operate signal as the faulted phase selection uses independent measuring elements from the distance protection zones. This can be applied as a back-up protection for the measurement zones. The time delay of the operate signals is defined with the *Operate delay GFC* setting. The operate signal is the binary output `OPERATE_GFC`.

Faulted loop phase selection by the overcurrent method

The "Overcurrent" method is the basic method used for identifying the faulted phases. It can be used in applications where the fault current magnitude exceeds the load current despite the possible changes in the network configuration and fault type.

In the overcurrent-based faulted phase selection method, the amplitude of each phase current is compared to the *Str A Ph Sel GFC* threshold setting. If the phase current magnitude exceeds the value of *Str A Ph Sel GFC*, that particular phase is faulty.

Earth-fault recognition is always required to release a phase-to-earth impedance-measuring element.

Table 912: Conversion from element start to monitored data signals

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
I_A> & `EARTH_FLT`	TRUE	AG Fault	AG Fault	No fault
I_B> & `EARTH_FLT`	TRUE	BG Fault	BG Fault	No fault
I_C> & `EARTH_FLT`	TRUE	CG Fault	CG Fault	No fault
I_A> & I_B>	TRUE	AB Fault	No fault	AB Fault

Table continues on the next page

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
I_B> & I_C>	TRUE	BC Fault	No fault	BC Fault
I_C> & I_A>	TRUE	CA Fault	No fault	CA Fault
I_A> & I_B> & EARTH_FLT	TRUE	AB Fault	AB Fault	AB Fault
I_B> & I_C> & EARTH_FLT	TRUE	BC Fault	BC Fault	BC Fault
I_C> & I_A> & EARTH_FLT	TRUE	CA Fault	CA Fault	CA Fault
I_A> & I_B> & I_C>[4]	TRUE	ABC Fault	No fault	ABC Fault
I_A> & I_B> & I_C> & EARTH_FLT[5]	TRUE	ABC Fault	ABC Fault	ABC Fault

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the RELEASE_PE signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the RELEASE_PE and RELEASE_PP signals.

Faulted phase selection, the voltage-dependent overcurrent method

The "Voltdep overcur" method combines the overcurrent and undervoltage conditions. The phase current amplitude is compared to the *Str A Ph Sel GFC* threshold setting but a lower current *Lo A Ph Sel GFC* threshold is valid during an undervoltage condition. This increases the sensitivity of the fault detection. The amplitude of phase-to-earth and phase-to-phase voltages is compared to the *Ph V Ph Sel GFC* and *PP V Ph Sel GFC* settings. In case of a three-phase fault, the phase-to-phase voltages are monitored and compared to the *PP V Ph Sel GFC* setting.

Earth-fault recognition is always required to release a phase-to-earth impedance-measuring element.

4 This applies to near three-phase faults. If voltages are still relatively high, all PP releases are given.
5 This applies to near three-phase faults with EF indication. If voltages are still relatively high, all PE and PP releases (except ABC Fault) are given.

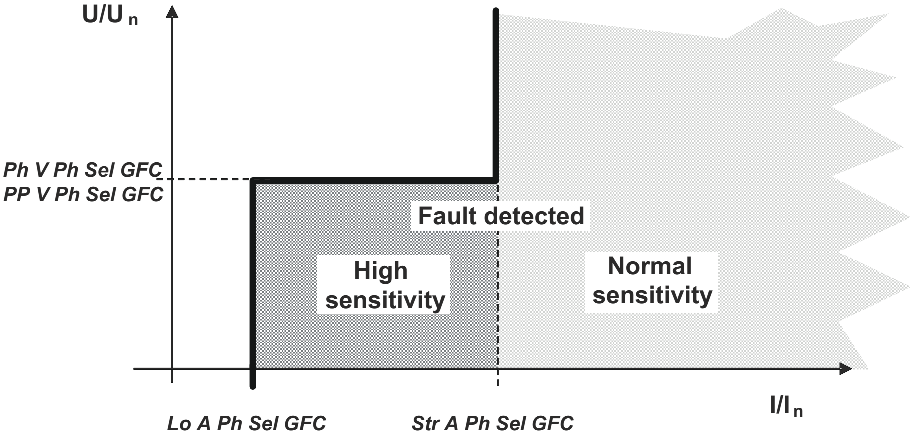


Figure 528: Overcurrent/undervoltage characteristics

Table 913: Conversion from element start to monitored data signals

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
I_A> & U_A< & `EARTH_FLT` | I_A>> & `EARTH_FLT`	TRUE	AG Fault	AG Fault	No fault
I_B> & U_B< & `EARTH_FLT` | I_B>> & `EARTH_FLT`	TRUE	BG Fault	BG Fault	No fault
I_C> & U_C< & `EARTH_FLT` | I_C>>& `EARTH_FLT`	TRUE	CG Fault	CG Fault	No fault
I_A> & I_B> & U_{AB}< | I_A>> & I_B>>	TRUE	AB Fault	No fault	AB Fault
I_B> & I_C> & U_{BC}< | I_B>> & I_C>>	TRUE	BC Fault	No fault	BC Fault
I_C> & I_A> & U_{CA}< | I_C>> & I_A>>	TRUE	CA Fault	No fault	CA Fault
I_A> & I_B> & U_{AB}< & `EARTH_FLT` | I_A>> & I_B>> & `EARTH_FLT`	TRUE	AB Fault	AB Fault	AB Fault
I_B> & I_C> & U_{BC}< & `EARTH_FLT` |	TRUE	BC Fault	BC Fault	BC Fault

Table continues on the next page

Start of element	**START_GFC**	**STARTS_GFC**	**RELEASE_PE**	**RELEASE_PP**
I_B>> & I_C>> & EARTH_FLT				
I_C> & I_A> & U_{CA}< & EARTH_FLT | I_C>> & I_A>> & EARTH_FLT	TRUE	CA Fault	CA Fault	CA Fault
I_A> & I_B> & I_C & U_{AB}< & U_{BC}< U_{CA}< | I_A>> , I_B>> & I_C >> [6]	TRUE	ABC Fault	No fault	ABC Fault
I_A> & I_B> & I_C& U_{AB}< & U_{BC}< U_{CA} < & EARTH_FLT | I_A>>, I_B>> & I_C >> & EARTH_FLT [7]	TRUE	ABC Fault	No fault	ABC Fault

I_x> Phase current exceeds the *Lo A Ph Sel GFC* setting

I_x>> Phase current exceeds the *Str A Ph Sel GFC* setting

U_x< Phase voltage undershoots the *Ph V Ph Sel GFC* setting

U_{xy}< Phase-to-phase voltage undershoots the *PP V Ph Sel GFC* setting

Faulted phase selection, the underimpedance method

The "Under impedance" and "OC AND Und impedance" methods use fault loop impedance for identifying the faulted phases. The advantage of the underimpedance criterion is that the sensitivity of the fault detection is independent of the source impedance. The underimpedance function has six impedance measuring elements. The phase-to-earth measuring elements are calculated:

$$\underline{Z}_A = \frac{\underline{U}_A}{\underline{I}_A}$$

(Equation 261)

6 This applies to near three-phase faults. If voltages are still relatively high, all PP releases are given.
7 This applies to near three-phase faults with EF indication. If voltages are still relatively high, all PE and PP releases (except ABC Fault) are given.

$$\underline{Z}_B = \frac{\underline{U}_B}{\underline{I}_B}$$

(Equation 262)

$$\underline{Z}_C = \frac{\underline{U}_C}{\underline{I}_C}$$

(Equation 263)

The phase-to-phase measuring elements are based on the formula:

$$\underline{Z}_{AB} = \frac{\underline{U}_{AB}}{\underline{I}_{AB}}$$

(Equation 264)

$$\underline{Z}_{BC} = \frac{\underline{U}_{BC}}{\underline{I}_{BC}}$$

(Equation 265)

$$\underline{Z}_{CA} = \frac{\underline{U}_{CA}}{\underline{I}_{CA}}$$

(Equation 266)

The faulted phase identification is done by comparing the measured impedance to the operating characteristics in the impedance domain. If a measured fault loop impedance is inside the characteristics, the corresponding phases are identified as faulty.

The shape of the characteristic is selected with the *Z Chr Mod Ph Sel GFC* setting. Two shapes are available.

- "Mho (circular)", Non-directional mho
- "Quadrilateral", Non-directional quadrilateral

The two shapes can be flexibly configured. It is possible to set the reactive reaches independently in forward and in reverse direction and for phase-to-earth (Gnd) and phase-to-phase (PP) measurement elements, for example, the *X Gnd Fwd reach GFC*, *X Gnd Rv reach GFC*, *X PP Fwd reach GFC* and *X PP Rv reach GFC* settings. Also, the resistive reach in case of quadrilateral characteristic can be set both forward and reverse independently of reactive reaches, for example, the *Ris Gnd Fwd Rch GFC*, *Ris Gnd Rv Rch GFC*, *Ris PP Fwd Rch GFC* and *Ris PP Rv Rch GFC* settings. The characteristic is always mirror-symmetric around the reactance axis.

The impedance settings are in primary ohms.

In case of heavy loaded feeders, the optional load encroachment logic can be enabled with the *Load Dsr mode GFC* setting. The logic reserves an area for load impedance defined by the *Ris Fwd Rch Lod GFC, Ris Rv Rch Lod GFC* and *Angle load area GFC* settings.

The underimpedance characteristics in case of phase-to-earth measuring elements are illustrated in *Figure 529* and *Figure 530*. Similar characteristics apply also to phase-to-phase measuring elements with independent settings.

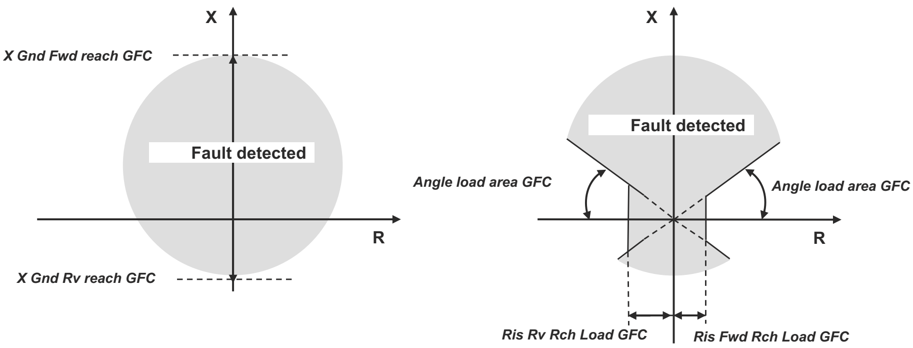


Figure 529: Circular mho underimpedance characteristics

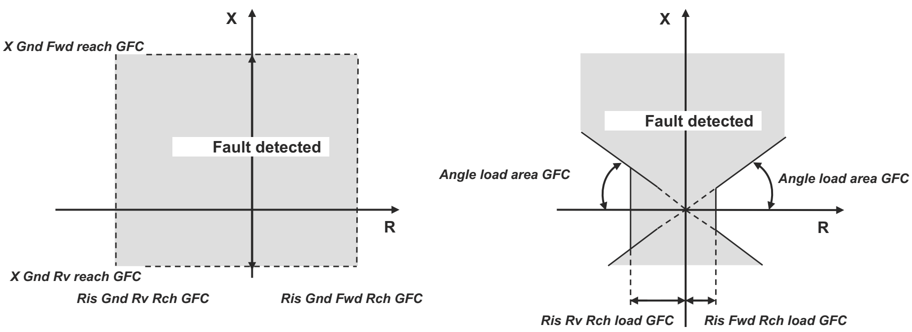


Figure 530: Quadrilateral underimpedance characteristics

Table 914: Conversion from element start to monitored data signals

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
Z_A< & EARTH_FLT	TRUE	AG Fault	AG Fault	No fault
Z_B< & EARTH_FLT	TRUE	BG Fault	BG Fault	No fault
Z_C< & EARTH_FLT	TRUE	CG Fault	CG Fault	No fault
Z_{AB}<	TRUE	AB Fault	No fault	AB Fault
Z_{BC}<	TRUE	BC Fault	No fault	BC Fault
Z_{CA}<	TRUE	CA Fault	No fault	CA Fault

Table continues on the next page

Start of element	START_GFC	STARTS_GFC	RELEASE_PE	RELEASE_PP
Z_{AB}< & EARTH_FLT	TRUE	AB Fault	AB Fault	AB Fault
Z_{BC}< & EARTH_FLT	TRUE	BC Fault	BC Fault	BC Fault
Z_{CA}< & EARTH_FLT	TRUE	CA Fault	CA Fault	CA Fault
Z_{AB}< & Z_{BC}< & Z_{CA}<[8]	TRUE	ABC Fault	No fault	ABC Fault
Z_{AB}< & Z_{BC}< & Z_{CA}<& EARTH_FLT [9]	TRUE	ABC Fault	No fault	ABC Fault

In case of a high-impedance earthed network, a phase preference logic can be added to complement the phase selection in case of a cross-country fault. This can affect the RELEASE_PE signals.

In case of a low-impedance earthed network, a faulted loop selection logic can be added to complement the phase selection in case of a two-phase-to-earth fault. This can affect the RELEASE_PE and RELEASE_PP monitored data signals.

Cross-country fault detection function for high-impedance earthed networks

In isolated and high-impedance earthed networks, the overvoltages produced by a single-phase earth fault may lead to a cross-country fault, where two simultaneous single-phase earth faults are present in the system but in different locations and phases. The cross-country fault is hazardous because the magnitude of the fault current through earth can be as high as in the case of a two-phase short circuit fault. The protection must therefore remove the cross-country fault quickly without sacrificing the selectivity. This can be done with a phase preference logic which is activated by the cross-country fault detection function. The phase preference logic transforms the fault into an ordinary single-phase earth fault by selectively tripping one of the faulted feeders.

The cross-country detecting function can become active only if the network is either isolated or high-impedance earthed (*System grounding GFC* = "High impedance" or selection "From input" and binary input SYS_EARTHING is active).

The fault detection is based on monitoring two quantities.

- Residual current
- Phase-to-phase voltages

A cross-country fault is detected if:

- An earth fault is detected, EARTH_FLT = TRUE.

AND

8 This applies to near three-phase faults. If voltages are still relatively high, all PP releases are given, depending on the impedances seen inside the GFC zone.

9 This applies to near three-phase faults with EF indication. If voltages are still relatively high, all or some PE and PP releases (except ABC Fault) are given, depending on the impedances seen inside the GFC zone.

- The calculated residual current exceeds the value of *Gnd Op A XC GFC* setting. This setting value should exceed the highest expected single-phase earth-fault current (calculated from phase currents). The condition is needed because the cable current transformer saturates easily due to the high fault current.

AND

- The residual overcurrent condition must be valid at least for the duration defined by the *Cross-country Dl GFC* setting. This shows that the detection is not misled by the high-magnitude initial transients of a single-phase earth fault.

OR

- Any phase-to-phase voltage drops below the value of the *PP voltage XC GFC* setting. The undervoltage condition is based on the fact that during a single-phase earth fault, the phase-to-phase voltages are unaffected in isolated and high-impedance earthed networks. The fulfilment of this criterion in combination with the residual overcurrent condition avoids the need for any delays.

The detection of a cross-country fault is indicated by the `XC_FLT` output signal.

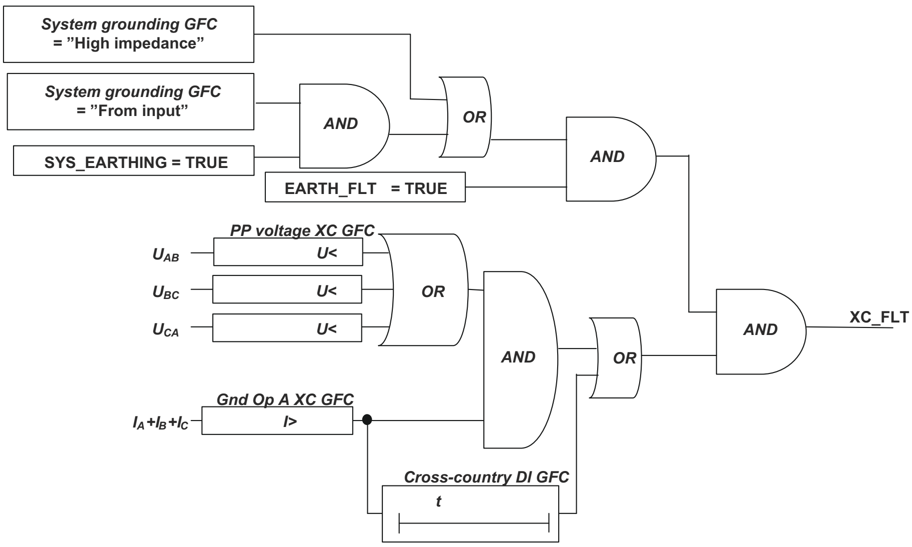


Figure 531: Cross-country fault detection logic for high-impedance earthed networks

Phase preference logic for high-impedance earthed networks

The phase preference logic is applicable only in isolated and high-impedance earthed networks. The phase preference logic for high-impedance earthed networks is a supplement to the faulted phase identification function. It provides selective filtering of phase-to-earth measurement elements in case of a cross-country fault or double earth-fault in isolated and high-impedance earthed networks.

The logic releases the preferred phase-to-earth loop for measurement when a cross-country fault with two faulted phase-to-earth loops is detected. If only one faulted phase-to-earth loop is detected by phase selection logic (GFC), the other faulted phase-to-earth loop is determined by analysing voltages. The phase preference scheme must be set in the same way for the entire system so that all distance relays measure the same preferred phase-to-earth loop. As a result, the cross-country fault is changed into an ordinary single-phase earth-fault by selectively tripping one of the faulted feeders.

The phase preference logic influences only the selection of the phase-earth loops and has no effect on the selection of the phase-to-phase loops. The influence is seen in the `RELEASE_PE` monitored data. The logic does not affect the `RELEASE_PP` monitored data or `START_GFC/STARTS_GFC` outputs.

All schemes, except "No filter", require a cross-country fault detection `XC_FLT =` TRUE; otherwise all the phase-to-earth measuring elements are blocked resulting in RELEASE_PE value "No fault". This guarantees that tripping at a single-phase earth fault in the high-impedance earthed network is blocked.

If a cross-country fault is detected, `XC_FLT =` TRUE and only a single fault loop can be identified as faulty by the faulted phase selection function, then that loop is directly selected for measurement. In such a case, simultaneous tripping of both faulted feeders during a cross-country fault is expected.

Example

Consider a cross-country fault where phases A and B become faulted simultaneously. All relays, R1, R2, R3 and R4, are equipped with an "Acyc C-A-B" phase preference scheme.

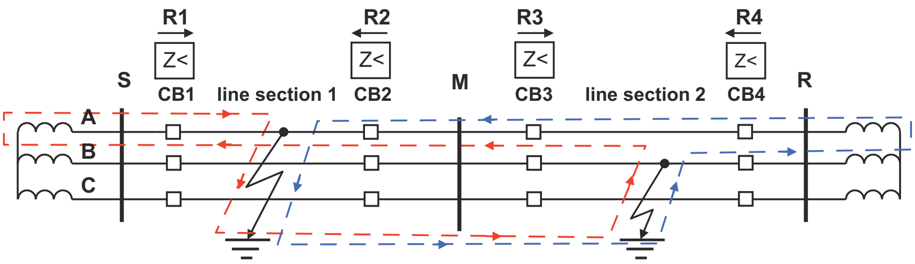


Figure 532: Cross-country fault (or double earth fault) in a high-impedance earthed system

The expected operations of the relays are:

- R1: The cross-country fault cannot be detected as the residual current does not flow through relay R1. The phase-to-phase loop AB is measured in the forward direction but the estimated impedance represents an average impedance between two fault locations and therefore is not seen in zone Z1.
- R2: The cross-country fault is detected as a high residual current flows through relay R2. Phase A earth fault is seen in forward direction and phase B earth fault in reverse direction. Based on "Acyc C-A-B" phase preference scheme, phase A is selected for measurement. Relay R2 operates without delay and opens the CB2 circuit breaker.
- R3: The cross-country fault is detected when a high residual current flows through relay R3. The phase A earth fault is seen in reverse direction and phase B earth fault in forward direction. Based on the "Acyc C-A-B" phase preference scheme, phase A is selected for measurement. As the fault direction does not coincide with the zone direction, relay R3 does not operate.
- R4: Same as relay R1

As a result of the circuit breaker CB2 operation, the cross-country fault is transformed into an ordinary single-phase earth fault.

Table 915, *Table 916* and *Table 917* summarize the available phase preference logic schemes and their operation in different fault scenarios. The logic is selected with the *Ph Prf mode Hi Z GFC* setting. In case the logic is not required, then the "No filter" option should be selected.

"No filter" option does not block the single-phase earth-faults, therefore this option should be used with caution.

Table 915: Supported phase preference logic schemes for high-impedance earthed networks and their operation in case of single phase start with and without cross-country fault detection

Ph Prf mode Hi Z GFC		Faulted loops					
		A & EARTH_FLT	B & EARTH_FLT	C & EARTH_FLT	A & XC_FLT	B & XC_FLT	C & XC_FLT
		RELEASE_PE			RELEASE_PP		
1	No filter	AG Fault	BG Fault	CG Fault	AG Fault	BG Fault	CG Fault
2	No preference	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
3	Cyc A-B-C-A	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
4	Cyc A-C-B-A	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
5	Acyc A-B-C	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
6	Acyc A-C-B	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
7	Acyc B-A-C	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
8	Acyc B-C-A	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
9	Acyc C-A-B	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault
10	Acyc C-B-A	No fault	No fault	No fault	AG Fault	BG Fault	CG Fault

Table 916: Supported phase preference logic schemes for high-impedance earthed networks and their operation in case of two phase starts without cross-country fault detection

Ph Prf mode Hi Z GFC		Faulted loops					
		A & B EARTH_FLT	B & C EARTH_FLT	C & A EARTH_FLT	A & B EARTH_FLT	B & C EARTH_FLT	C & A EARTH_FLT
		RELEASE_PE			RELEASE_PP		
1	No filter	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
2	No preference	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
3	Cyc A-B-C-A	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
4	Cyc A-C-B-A	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
5	Acyc A-B-C	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
6	Acyc A-C-B	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
7	Acyc B-A-C	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
8	Acyc B-C-A	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
9	Acyc C-A-B	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault
10	Acyc C-B-A	No fault	No fault	No fault	AB Fault	BC Fault	CA Fault

Table 917: Supported phase preference logic schemes for high-impedance earthed networks and their operation in case of two phase starts with cross-country fault detection

Ph Pref logic Hi Imp		Faulted loops					
		A & B XC_FLT	B & C XC_FLT	C & A XC_FLT	A & B XC_FLT	B & C XC_FLT	C & A XC_FLT
		RELEASE_PE			RELEASE_PP		
1	No filter	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
2	No preference	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
3	Cyc A-B-C-A	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
4	Cyc A-C-B-A	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
5	Acyc A-B-C	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
6	Acyc A-C-B	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
7	Acyc B-A-C	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault

Table continues on the next page

Ph Pref logic Hi Imp		Faulted loops					
		A & B XC_FLT	B & C XC_FLT	C & A XC_FLT	A & B XC_FLT	B & C XC_FLT	C & A XC_FLT
		RELEASE_PE			RELEASE_PP		
8	Acyc B-C-A	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
9	Acyc C-A-B	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault
10	Acyc C-B-A	AB Fault	BC Fault	CA Fault	AB Fault	BC Fault	CA Fault

Faulted loop phase selection for low-impedance earthed networks

The faulted loop selection logic for low-impedance earthed networks serves as a supplement to the faulted phase identification function and it provides a selective filtering of measurement elements in case of a two-phase-to-earth fault in low-impedance earthed networks. The earth faults can be located close to each other.

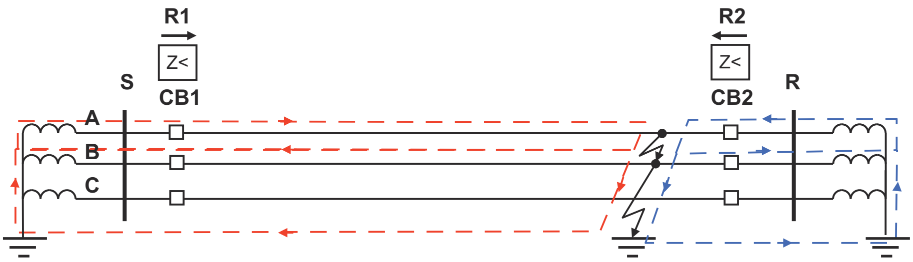


Figure 533: Two-phase-to-earth fault in low-impedance earthed system

Impedance can be measured during a two-phase-to-earth fault when the earth faults are located in the same direction and they are in close proximity to each other. Generally, too large an impedance is measured for the lagging phase-to-earth loop, for example phase B in an AB-E fault. Similarly, low impedance is measured for the leading phase-to-earth loop, for example phase A in an AB-E fault. The corresponding phase-to-phase loop is measured correctly, for example phase-to-phase loop AB in an AB-E fault.

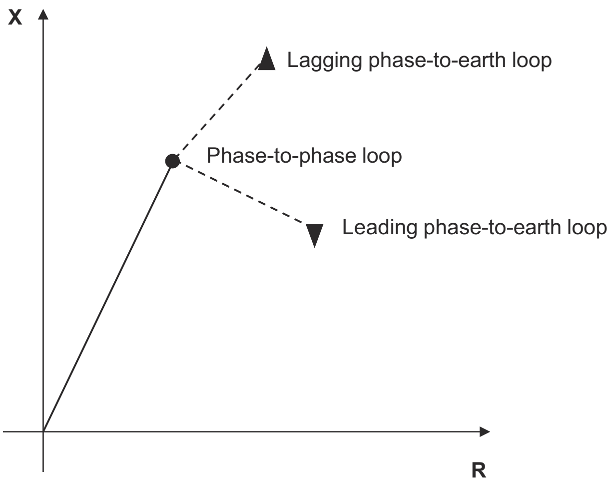


Figure 534: Impedance measured during a two-phase-to-earth fault

The available faulted loop selection logic schemes allow blocking the phase-earth loop of the leading phase to prevent overreaching *Ph Prf mode Lo Z GFC* = "BLK leading PE".

It is also possible to block the lagging phase-earth loop, *Ph Prf mode Lo Z GFC* = "BLK lagging PE". If only the phase-to-phase loop or phase-to-earth loops must be measured, settings *Ph Prf mode Lo Z GFC* = "PP only" or *Ph Prf mode Lo Z GFC* = "PE only" should be used, and if the logic is not required, "All loops" option should be selected.

The tables summarize the available faulted loop selection logic schemes and their operations. The logic is selected with the *Ph Prf mode Lo Z GFC* setting.

Table 918: Supported faulted loop phase selection schemes for low-impedance earthed networks and their influence on the RELEASE_PE monitored data

	Ph Prf mode Lo Z GFC				
Element start	**All loops**	**PE only**	**PP only**	**BLK leading PE**	**BLK lagging PE**
	RELEASE_PE				
A & B & EARTH_FLT	AB Fault	AB Fault	No fault	BG Fault	AG Fault
B & C & EARTH_FLT	BC Fault	BC Fault	No fault	CG Fault	BG Fault
C & A & EARTH_FLT	CA Fault	CA Fault	No fault	AG Fault	CG Fault

Table 919: Supported faulted loop phase selection schemes for low-impedance earthed networks and their influence on the RELEASE_PP monitored data

	Ph Prf mode Lo Z GFC				
Element start	**All loops**	**PE only**	**PP only**	**BLK leading PE**	**BLK lagging PE**
	RELEASE_PP				
A & B & EARTH_FLT	AB Fault	No fault	AB Fault	AB Fault	AB Fault
B & C & EARTH_FLT	BC Fault	No fault	BC Fault	BC Fault	BC Fault
C & A & EARTH_FLT	CA Fault	No fault	CA Fault	CA Fault	CA Fault

Impedance protection zones

DSTPDIS has five flexible and configurable impedance zones Z1..Z5. The number of active zones has to be selected by setting *Select active zones*. For example, all five zones can be set active by selection "All 5 zones" and only zone 1 is activated by "Zone 1". The purpose of this setting is effectively dimming non-active zone settings in PCM600 or the protection relay's HMI.

Example

If only zones 1 and 3 should be activated, "Zones 1-3" should be selected and then zone 2 timers can be disabled or `BLOCK_Z2` can be activated to hide zone 2 operations.

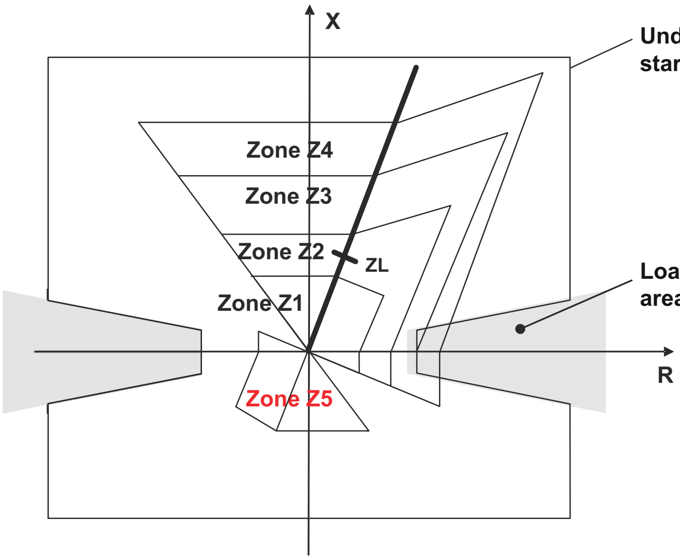


Figure 535: Zones of DSTPDIS function (example 1)

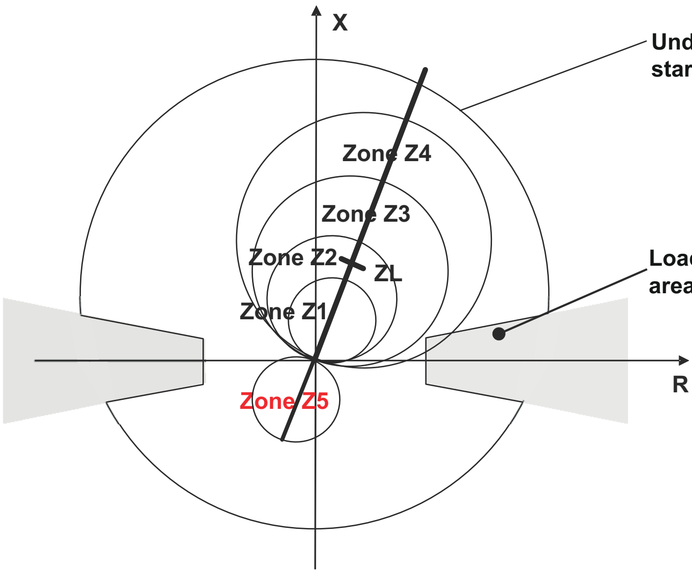


Figure 536: Zones of DSTPDIS function (example 2)

Each zone in DSTPDIS provides three independent phase-to-earth and three phase-to-phase measuring elements. A three-phase fault is measured with a dedicated measuring element. Each measuring element is controlled by the faulted loop phase selection function. Based on the recognized fault type, the release signals are given for the corresponding measuring elements.

DSTPDIS supports both fault detection dependent control of zone timers and zone-dedicated timer control for maximum application flexibility. Zone-dedicated timer control is enabled when configuration parameter *Zone timer mode* is set to "Independent" (change requires relay reboot). In this case, operate delay timers of protection zones are independent of each other and start when a fault is seen in their protection zone. Fault detection dependent control of zone timers is enabled when *Zone timer mode* is set to "Common". In this case, operate delay timers of all protection zones start simultaneously as soon as the fault is seen by the GFC.

The operation of a particular zone is given after the set operate delay time for the particular zone has elapsed (considering the fault type). The actual operate time is the value calculated from the initial fault detection and it is not affected, for example, in case the fault moves between zones.

The general indication of fault for each zone is given in the START_Zx (x = 1...5) binary output. The faulted phase information can be found from the STARTS_Zx (x = 1... 5) integer type output signal. This signal indicates (bitwise) the started measuring elements for the corresponding phase. Value 0 does not exist but due to the IEC 61850 standard requirement, it is shown by value “-5” as “No fault”. Value range is thus -5, 1..63. The three-phase fault is here indicated by “AB Fault, BC Fault, CA Fault”. However, three-phase fault indication for GFC depends also on the additional condition for voltage (see *Table 913*).

Table 920: STARTS_Zx information

Value	Value information
-5	No zone starts
1	AG Fault
2	BG Fault
3	AG Fault, BG Fault
4	CG Fault
5	AG Fault, CG Fault
6	BG Fault, CG Fault
7	AG Fault, BG Fault, CG Fault
8	AB Fault
9	AG Fault, AB Fault
10	BG Fault, AB Fault
11	AG Fault, BG Fault, AB Fault
12	CG Fault, AB Fault
13	AG Fault, CG Fault, AB Fault
14	BG Fault, CG Fault, AB Fault
15	AG Fault, BG Fault, CG Fault, AB Fault
16	BC Fault
17	AG Fault, BC Fault
18	BG Fault, BC Fault
19	AG Fault, BG Fault, BC Fault
20	CG Fault, BC Fault
21	AG Fault, CG Fault, BC Fault
22	BG Fault, CG Fault, BC Fault
23	AG Fault, BG Fault, CG Fault, BC Fault
24	AB Fault, BC Fault
25	AG Fault, AB Fault, BC Fault
26	BG Fault, AB Fault, BC Fault
27	AG Fault, BG Fault, AB Fault, BC Fault
28	CG Fault, AB Fault, BC Fault

Table continues on the next page

Value	Value information
29	AG Fault, CG Fault, AB Fault, BC Fault
30	BG Fault, CG Fault, AB Fault, BC Fault
31	AG Fault, BG Fault, CG Fault, AB Fault, BC Fault
32	CA Fault
33	AG Fault, CA Fault
34	BG Fault, CA Fault
35	AG Fault, BG Fault, CA Fault
36	CG Fault, CA Fault
37	AG Fault, CG Fault, CA Fault
38	BG Fault, CG Fault, CA Fault
39	AG Fault, BG Fault, CG Fault, CA Fault
40	AB Fault, CA Fault
41	AG Fault, AB Fault, CA Fault
42	BG Fault, AB Fault, CA Fault
43	AG Fault, BG Fault, AB Fault, CA Fault
44	CG Fault, AB Fault, CA Fault
45	AG Fault, CG Fault, AB Fault, CA Fault
46	BG Fault, CG Fault, AB Fault, CA Fault
47	AG Fault, BG Fault, CG Fault, AB Fault, CA Fault
48	BC Fault, CA Fault
49	AG Fault, BC Fault, CA Fault
50	BG Fault, BC Fault, CA Fault
51	AG Fault, BG Fault, BC Fault, CA Fault
52	CG Fault, BC Fault, CA Fault
53	AG Fault, CG Fault, BC Fault, CA Fault
54	BG Fault, CG Fault, BC Fault, CA Fault
55	AG Fault, BG Fault, CG Fault, BC Fault, CA Fault
56	AB Fault, BC Fault, CA Fault
57	AG Fault, AB Fault, BC Fault, CA Fault
58	BG Fault, AB Fault, BC Fault, CA Fault
59	AG Fault, BG Fault, AB Fault, BC Fault, CA Fault
60	CG Fault, AB Fault, BC Fault, CA Fault
61	AG Fault, CG Fault, AB Fault, BC Fault, CA Fault
62	BG Fault, CG Fault, AB Fault, BC Fault, CA Fault
63	AG Fault, BG Fault, CG Fault, AB Fault, BC Fault, CA Fault

The operate signal from each zone is the OPERATE_Zx (x = 1...5) binary output signal.

The output from each zone can be blocked and the timers are also reset with the BLOCK_Zx (x = 1...5) binary input signal.

The TLT_ANG_CONFLICT monitored data is an assisting integer output which supervises the validity of a tilt angle of quadrilateral characteristics so that the characteristics always produce a closed boundary.

Impedance measurement

DSTPDIS provides three independent phase-to-earth and phase-to-phase measuring elements per zone. The three-phase fault is measured with a dedicated measurement element.

The impedance measurement is done similarly regardless of the zone shape. The operation is based on impedance mapping where the fault loop impedance is first calculated and then compared with the zone boundaries. If impedance is recognized inside the operation zone, the corresponding operate output is activated after the operate time has elapsed.

Phase-to-earth impedance measuring elements

The phase-to-earth impedance measuring elements provide the basic earth-fault protection in direct or low-impedance earthed networks. The earth-fault protection is enabled with the setting *Op Mod Gnd loops Znx* (x = 1...5) = "True". The enabling requires that all three phase-to-earth voltages are measured. Otherwise, the release of the earth-fault measuring elements is automatically blocked.

The reach of phase-to-earth measuring elements is based on loop impedance

$$\underline{Z}_1 + \underline{Z}_N + RF = \left(R_1 + \frac{R_0 - R_1}{3}\right) + j \cdot \left(X_1 + \frac{X_0 - X_1}{3}\right) + RF$$

(Equation 267)

The earth return path impedance is included in the calculated fault loop impedance of the phase-to-earth measuring element.

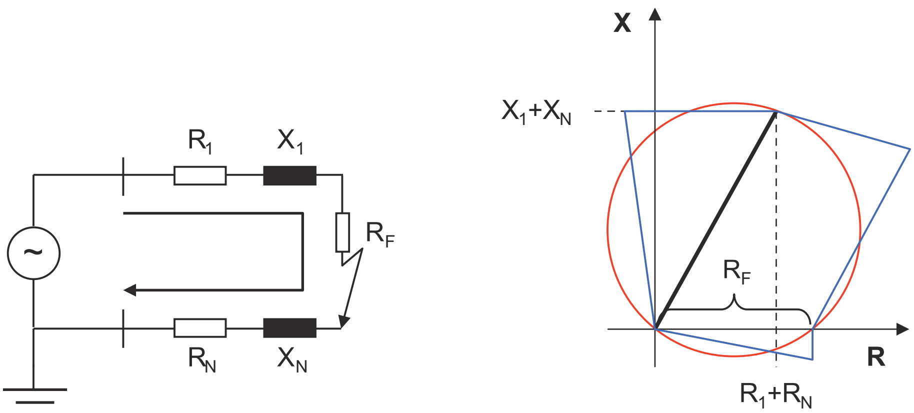


Figure 537: The fault loop impedance model for phase-to-earth impedance measuring elements

R_1	Positive-sequence resistance from measuring point to fault location
X_1	Positive-sequence reactance from measuring point to fault location

Table continues on the next page

R_N Earth return path resistance = (R0 - R1)/3 from measuring point to fault location

X_N Earth return path reactance = (X0 - X1)/3 from measuring point to fault location

R_0 Zero-sequence resistance from measuring point to fault location

X_0 Zero-sequence reactance from measuring point to fault location

R_F Physical fault resistance between phase and earth (includes arc and earthing resistances)

Considering the load in case of a single line-to-earth fault, conventional distance protection might overreach at the exporting end and underreach at the importing end. DSTPDIS has a load compensation functionality which increases the security in such applications. Load compensation is enabled with the setting *Load Comp zone x* (x = 1...5) = "True".

Load compensation is used only with single phase-to-earth faults. Load compensation is not used if multiple phases are included in the fault (more than one single earth fault release).

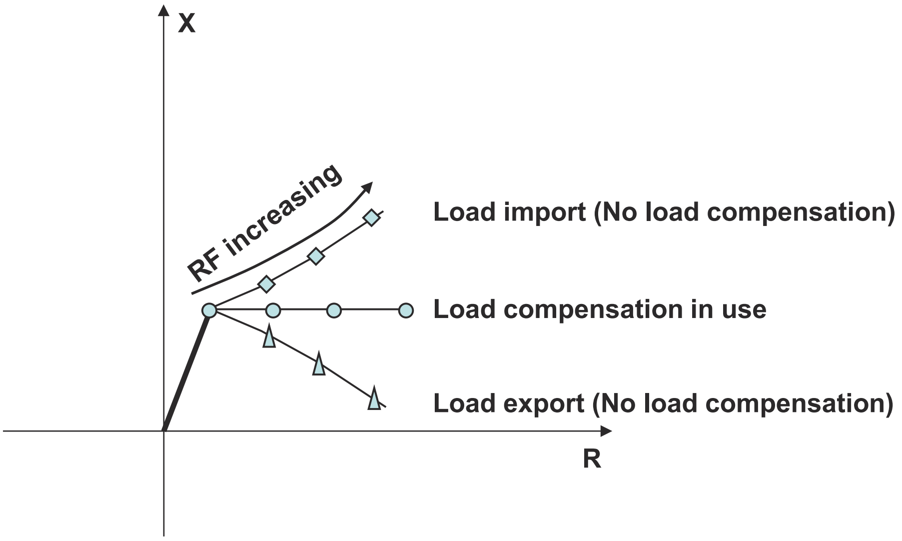


Figure 538: Operation principle of load compensation functionality

When three-phase feeders are placed close to each other, a mutual inductive zero-sequence coupling of the current path exists. This has an impact during earth faults. If no measures are taken, this leads to errors in the impedance calculation. The residual current of the parallel line induces a voltage in the protection line and changes the measured voltage at the relay location. The influence depends on the system configuration, that is, the magnitude and polarity of the residual current in a parallel line.

The phase-to-earth impedance measuring elements in DSTPDIS take the zero-sequence mutual coupling into account in impedance calculation. The compensation is enabled and set with settings *Par line Comp zone x* (="True"), *Mutual R0 zone x* and *Mutual X0 zone x* (x = 1...5). The residual current of the parallel line must be available and connected to the `I3P_PAR` input. The earth-current balance logic is implemented to prevent malfunctioning of the protection relay on the healthy parallel line. This means that the parallel compensation functionality is internally blocked when the ratio between residual current of the parallel line and protected lines exceeds the *Fact EF current Bal* configuration setting.

The parallel line compensation functionality is only used with single phase-to-earth faults. Parallel line compensation is not used if multiple phases are included into fault (more than one single earth fault releases).

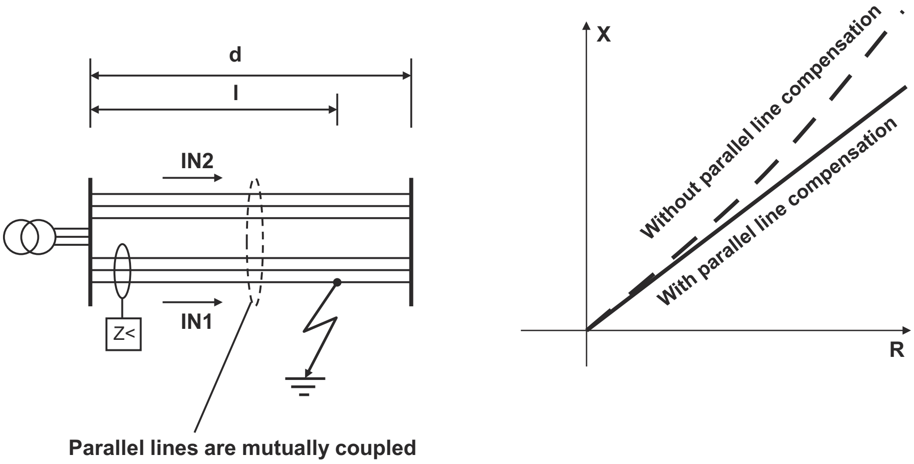


Figure 539: Operation principle of parallel line compensation functionality

The operation time delay is defined with the *Gnd operate Dl Znx* (x = 1...5) setting. The timer can be disabled with the *Gnd Op Dl mode Znx* = "False" setting. This blocks the `OPERATE_Zx` (x = 1...5) output of the phase-to-earth measuring elements.

Phase-to-phase impedance measuring elements

The phase-to-phase distance protection is suitable as a basic protection function against two-phase short circuit faults in various networks, regardless of the treatment of the neutral point. The short circuit fault protection is enabled with the *Op Mod PP loops Znx* (x = 1...5) = "True" setting.

The reach of the phase-to-phase measuring elements is based on the loop impedance

$$\underline{Z}_1 + \frac{R_F}{2} = R_1 + j \cdot X_1 + \frac{R_F}{2}$$

(Equation 268)

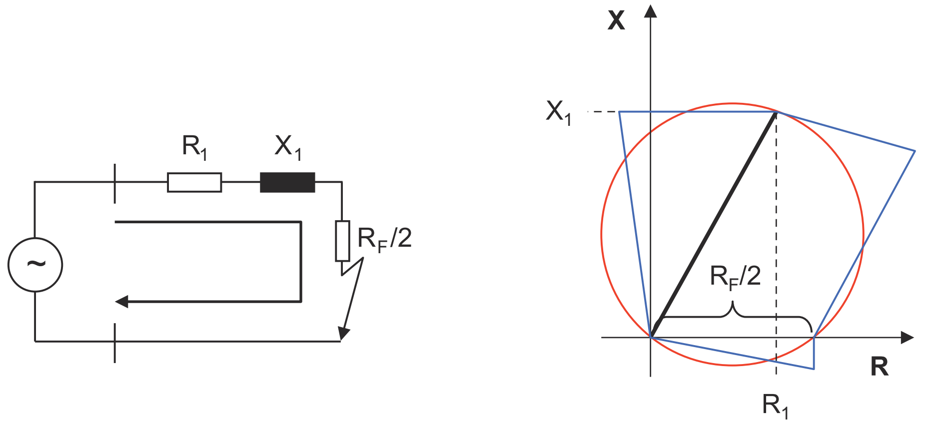


Figure 540: The fault loop impedance model for phase-to-phase impedance measuring elements

R_1	Positive-sequence resistance from measuring point to fault location.
X_1	Positive-sequence reactance from measuring point to fault location.
R_F	Physical fault resistance between phases, for example, arc resistance.

The phase-to-phase impedance measuring elements measure only half of the physical fault resistance between phases. This must be taken into account when the resistive reach of the phase-to-phase elements is set (that is, setting the value of 5 Ω corresponds 5+5=10 Ω of physical arc resistance between phases).

The resistive reach setting is common for phase-to-phase and three-phase impedance measuring elements.

The operation time delay is defined with the setting *PP operate delay Znx* (x = 1... 5). The timer can be disabled with the setting *PP Op delay Mod Znx* = "False". This blocks the `OPERATE_Zx` (x = 1... 5) output of the phase-to-phase measuring elements.

Three-phase impedance measuring element

DSTPDIS has a dedicated measuring element for a three-phase short circuit fault for each zone. The three-phase measuring element uses the positive-sequence quantities for a fault loop impedance estimation which increases the accuracy by reducing the influence of line parameter asymmetry. This is advantageous especially in case of non-transposed, asymmetrical lines. The three-phase impedance measuring element is enabled together with the phase-to-phase impedance elements by the setting *Op Mod PP loops Znx* (x = 1... 5) = "True".

The reach of the three-phase measuring element is based on the loop impedance

$$\text{Three-phase measuring element reach} = Z_1 + R_F = R_1 + j\,X_1 + R_F$$

(Equation 269)

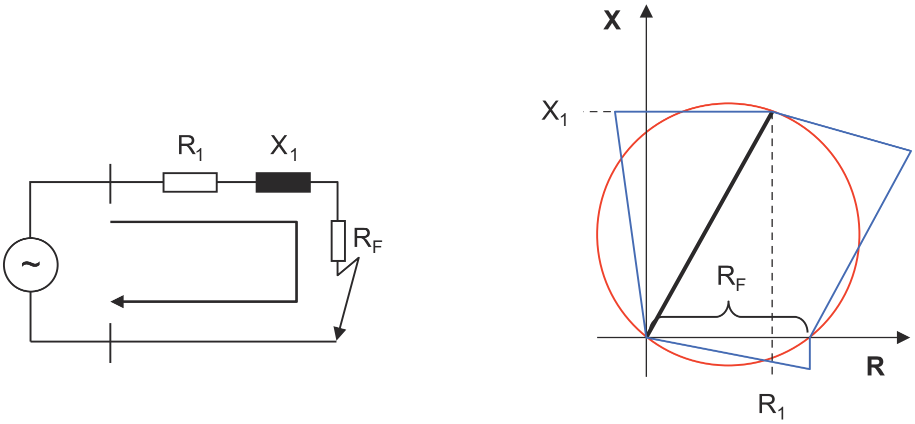


Figure 541: The fault loop impedance model for three-phase impedance measuring element

R_1	Positive-sequence resistance from measuring point to fault location
X_1	Positive-sequence reactance from measuring point to fault location.
R_F	Physical fault resistance per phase, for example, arc resistance.

The three-phase impedance measuring element measures the physical fault resistance per phase. The resistive reach setting is common for three-phase and phase-to-phase impedance measuring elements.

The time delay of operation is defined with the *PP operate delay Znx* (x = 1... 5) setting. The timer can be disabled with the setting *PP Op delay Mod Znx* = "False". This blocks the `OPERATE_Zx` (x = 1... 5) output of the three-phase measuring elements.

Entering the line reach

The line reach is entered in primary ohms. The impedance format is selected with *Impedance mode Zn* = "Rectangular" for the vectors R, X and "Polar" for the magnitude and angle.

Impedance mode Zn = Rectangular

In case of phase-to-phase or three-phase impedance measuring elements, the line reach is defined with:

- Resistive reach: *R1 zone x* (x = 1...5)
- Reactive reach: *X1 zone x* (x = 1...5)

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *X1 reverse zone x* (x = 1...5) setting. The characteristic line angle, denoted as α, is the same for both forward and reverse direction.

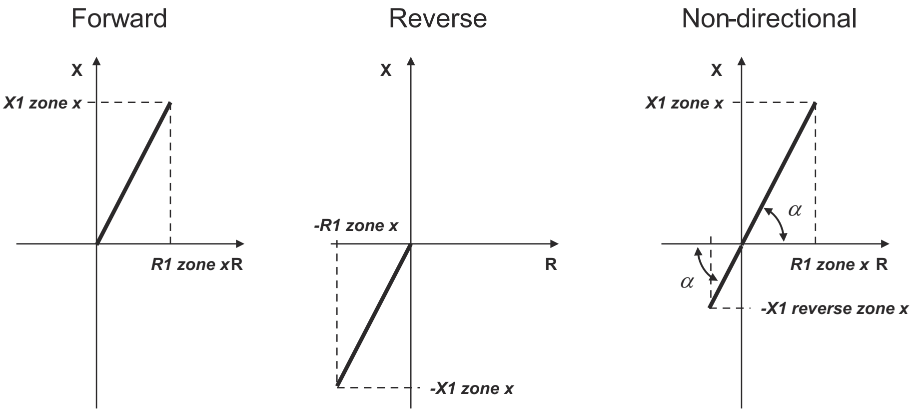


Figure 542: Settings which define the line reach for phase-to-phase or three-phase impedance measuring elements if Impedance mode Zn = "Rectangular"

In case of phase-to-earth impedance measuring elements, the line reach is defined with:

- Resistive reach : (2·*R1 zone x* + *R0 zone x*)/3, (x = 1...5)
- Reactive reach : (2·*X1 zone x* + *X0 zone x*)/3, (x = 1...5)

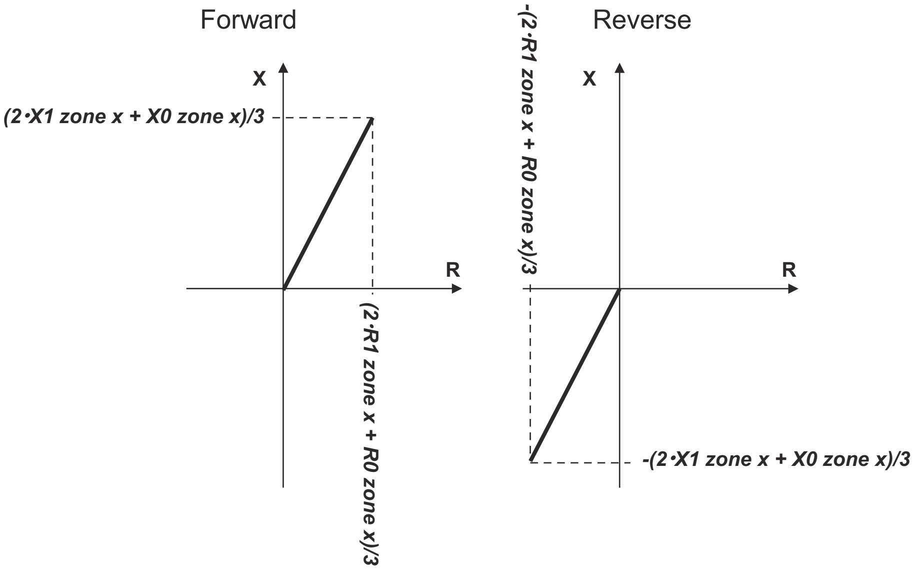


Figure 543: Settings which define the line reach for phase-to-earth impedance measuring elements if Impedance mode Zn = "Rectangular", forward or reverse directionality

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *X1 reverse zone x* (x = 1...5) setting. The total reactive reach in reverse direction includes a part which is common to both forward and reverse direction. This part is automatically calculated based on the values of the settings *R1 zone x, R0 zone 0, X1 zone x* and *X0 zone x*. The characteristic line angle, denoted as α, is the same for forward and reverse direction.

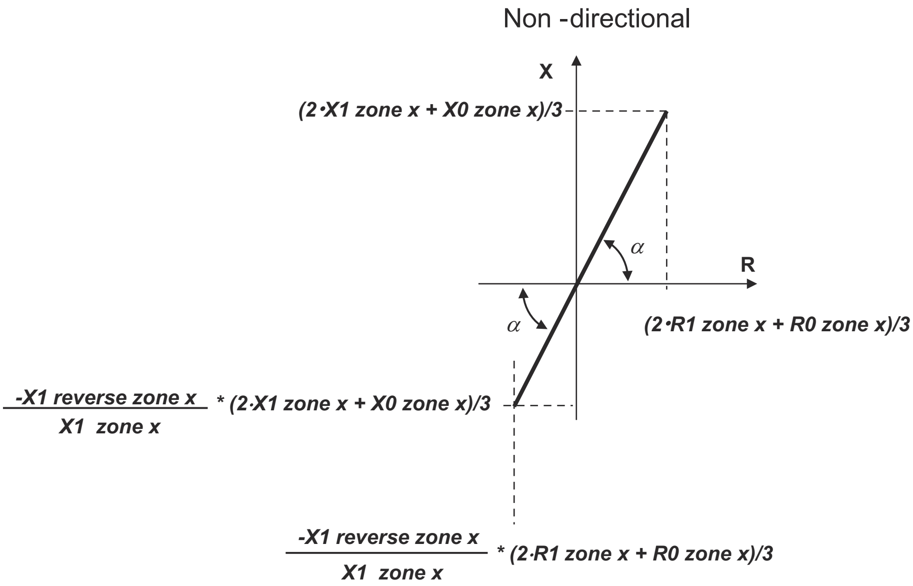


Figure 544: Settings which define the line reach for phase-to-earth impedance measuring elements if Impedance mode Zn = "Rectangular", non-directional directionality

Impedance mode Zn = Polar

In case of phase-to-phase or three-phase impedance measuring elements, the line reach is defined with:

- *Z1 zone x* (x = 1...5)
- *Z1 angle zone x* (x = 1...5)

In case of non-directional characteristics, the reactive reach magnitude in reverse direction is defined with the *Z1 reverse zone x* (x = 1...5) setting. The characteristic line angle, *Z1 angle zone x,* is the same for forward and reverse direction.

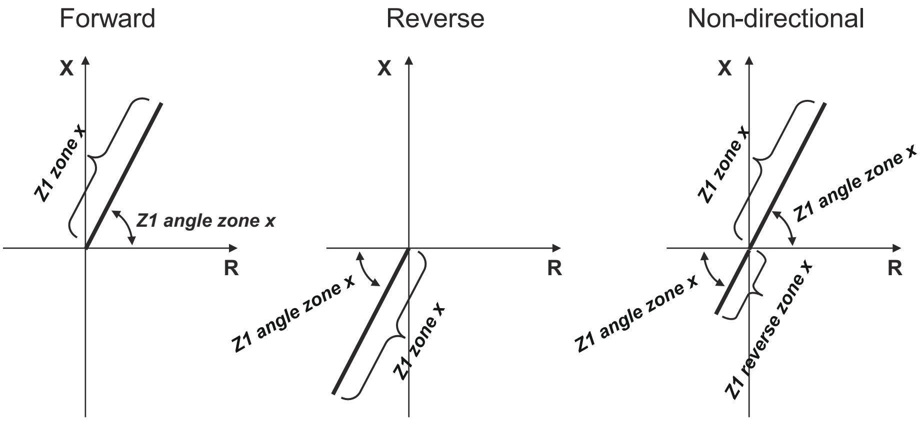


Figure 545: Settings which define the line reach for phase-to-phase or three-phase impedance measuring elements if Impedance mode Zn = "Polar"

In case of phase-to-earth impedance measuring elements, the line reach is defined with:

- *Z1 zone x* (x = 1...5)

- *Z1 angle zone x* (x = 1...5)
- *Factor K0 zone x* (x = 1...5)
- *Factor K0 angle Zn x* (x = 1...5)

The reach magnitude and angle are:

$$Magnitude = abs(\underline{Z}1 + \underline{Z}1 \times \underline{K}_N)$$

(Equation 270)

$$Angle = angle(\underline{Z}1 + \underline{Z}1\underline{K}_N)$$

(Equation 271)

$$\underline{Z}_1 = Z1\ zone\ x(\cos(Z1\,angle\,zone\ x) + j\sin(Z1\,angle\,zone\ x))$$

$$\underline{K}_N = Factor\ K0\ zone\ x(\cos(Factor\ K0\,angle\ znx) + j\sin(Factor\ K0\,angle\ znx))$$

In case of non-directional characteristics, the reactive reach in reverse direction is defined with the *Z1 reverse zone x* (x = 1...5) setting.

$$\underline{Z}_{1R} = Z1\,reverse\ zone\ x(\cos(Z1\,angle\ zone\ x) + j\sin(Z1\,angle\ zone\ x))$$

(Equation 272)

The total reactive reach in reverse direction includes a part which is defined by the residual compensation factor $\underline{K}_N$. The characteristic line angle, denoted as α, is the same for forward and reverse direction.

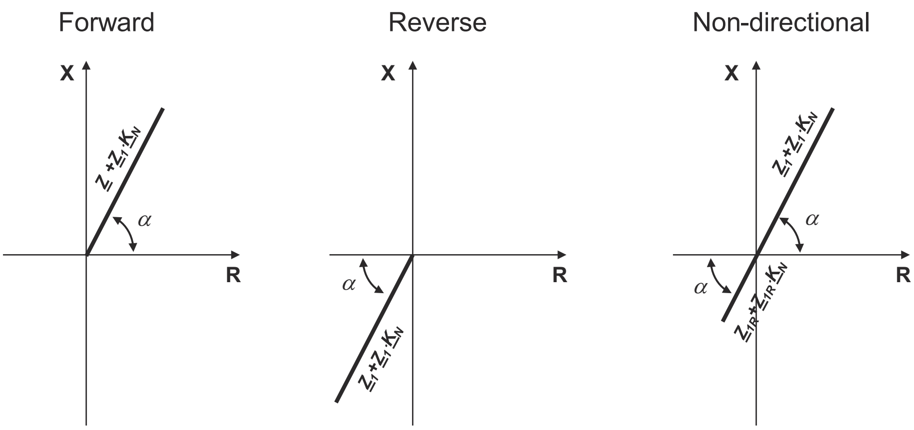


Figure 546: Settings which define the line reach for phase-to-earth impedance measuring elements if Impedance mode Zn = "Polar"

Protection zone characteristics

DSTPDIS has both “Quadrilateral” and “Mho (circular)” characteristics available for the protection zones and they can be combined also with the bullet characteristic. The shape of a tripping characteristic can be set independently for phase-to-earth, phase-to-phase or three-phase impedance elements. The zone shape is defined with the *Impedance Chr Gnd Zn* setting for phase-to-earth impedance elements, and with the *Impedance Chr PP Zn* setting for phase-to-phase or three-phase impedance elements. The alternatives are "Quadrilateral", "Mho (circular)", "Mho Dir line", "Offset Dir line" and "Bullet (combi)".

All impedance values defining the zone shape are entered in primary ohms. Angles are given in degrees.

Quadrilateral characteristic

If the zone has the "Quadrilateral" shape, DSTPDIS has a polygonal tripping characteristic.

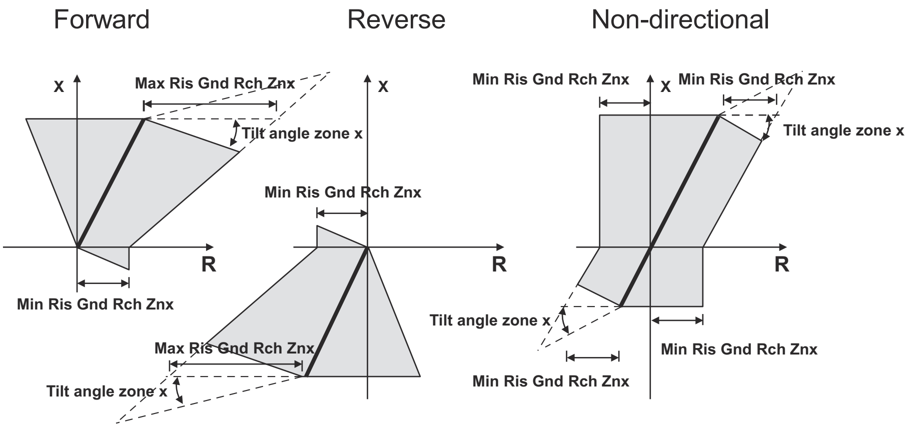


Figure 547: Tripping characteristic for phase-to-earth impedance elements if the zone shape is quadrilateral. The tilt angle is set to compensate for possible under- or overreaching.

The reach in the reactive direction is defined by the line reach independently for phase-to-earth and for phase-to-phase/three-phase elements. The resistive reach is defined at the minimum and maximum resistive reach with settings *Min Ris Gnd Rch Znx, Max Ris Gnd Rch Znx, Min Ris PP Rch Znx, Max Ris PP Rch Znx* (x = 1...5). In case of a non-directional zone, only settings *Min Ris Gnd Rch Znx and Min Ris PP Rch Znx* (x = 1...5) are valid. The resistive reach can be set independently for phase-to-earth and for phase-to-phase or three-phase elements.

In case of phase-to-earth impedance elements, the resistive reach value corresponds to the physical fault resistance between phase and earth including arc and earthing resistance.

The reactive reach can be adjusted by tilting the top reactance boundary line by an angle defined with *Tilt angle zone x* (x = 1...5). The negative value decreases the tripping zone area while the positive value increases the tripping area. The negative value is used in case of underreaching zones to compensate a possible overreaching. The positive value is used in case of overreaching zones to compensate a possible underreaching.

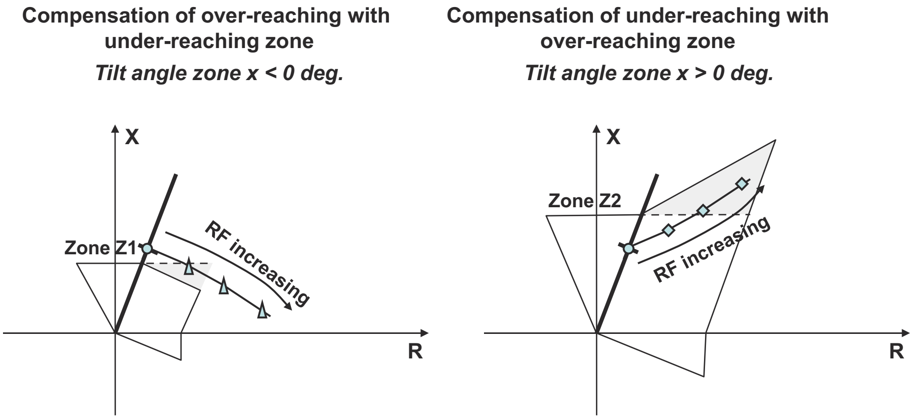


Figure 548: Operation principle of top reactance line tilting

The tilt angle must be carefully set. If the tilt angle has been set to a value where polygon boundaries do not form a close loop for an element, an internal mechanism modifies the tilt angle for that element so that the polygon boundary is always closed. If the set tilt angle is suitable for another element, the tilt angle of that element is not internally modified. Tilt angle conflicts are monitored by TLT_ANG_CONFLICT value. This integer value is a ten-bit value indicating tilt angle modifications per zone and fault type.

Table 921: TLT_ANG_CONFLICT description

TLT_ANG_CONFLICT bit field	Description
(MSB) xx xx xx xx YZ (LSB)	Y active = Zone 1 earth-fault impedance element tilt angle modified Z active = Zone 1 short circuit impedance element tilt angle modified
(MSB) xx xx xx YZ zz (LSB)	Y active = Zone 2 earth-fault impedance element tilt angle modified Z active = Zone 2 short circuit impedance element tilt angle modified
(MSB) xx xx YZ xx xx (LSB)	Y active = Zone 3 earth-fault impedance element tilt angle modified Z active = Zone 3 short circuit impedance element tilt angle modified
(MSB) xx YZ xx xx xx (LSB)	Y active = Zone 4 earth-fault impedance element tilt angle modified Z active = Zone 4 short circuit impedance element tilt angle modified
(MSB) YZ xx xx xx xx (LSB)	Y active = Zone 5 earth-fault impedance element tilt angle modified Z active = Zone 5 short circuit impedance element tilt angle modified

For example, TLT_ANG_CONFLICT value “36” = “00 00 10 01 00” indicates that the tilt angles of the zone 2 earth-fault impedance element and zone 3 short circuit or three-phase impedance element have been modified. These zone settings should be checked to see whether a non-zero TLT_ANG_CONFLICT value has been found although, internally, the polygon boundary has been closed for existing settings.

Directional lines

The direction of a zone is defined with setting *Directional mode Znx* = "Nondirectional", "Forward" or "Reverse". The directionality of each zone can be set independently of other zones. For example, zones Z1 and Z2 can be set in the "Forward" direction and Z3 in the "Reverse" direction. Furthermore, the optionally supervised earth-fault directional criteria (in low-impedance earthed networks) given for GFC are checked here together with zone direction criteria fulfilment.

The directionality of a quadrilateral zone is defined with two independent directional lines. The directional lines can be included into the mho characteristics to secure the directionality or to transform the non-directional mho characteristic into a directional one.

The directional lines are adjusted with the *Min phase angle zone* and *Max phase angle zone* settings, which are common for all the zones. The angles are given in degrees. The directional lines are polarized with the *Pol quantity zone* method. By default, the polarization method is positive-sequence voltage ("Pos. seq. volt.").

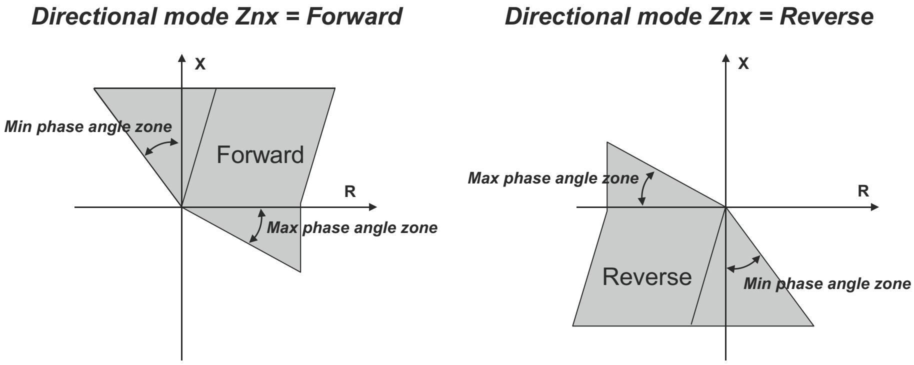


Figure 549: Settings that adjust directional lines in case of quadrilateral characteristics

The calculated direction of the fault or load (if there is no fault present) current is indicated for each zone with outputs DIRECTION_Z1 - Z5 which may have values "unknown", "forward", "backward" or "both". It is important to check setting *X1 reverse zone x* (or *Z1 reverse zone x* reactance part) for quadrilateral directional characteristics (see *Figure 541* and the corresponding phase-to-earth impedance given in *Figure 543*) so that it does not restrict the negative-reactance reach defined by settings *Min Ris Gnd/PP Rch Znx* and *Max phase angle zone.*

Memory voltage

The memory voltage is based on the healthy positive-sequence voltage stored during the network healthy state. This fictive voltage is substituted for the measured voltage with any impedance measurement element polarization if the corresponding voltage drops too low (limit is 5% Un). Fictive voltage use is indicated by the active monitored data output VMEM_USED. The polarized impedance direction for a corresponding impedance element is frozen after a fixed 100 ms of fictive voltage use, but the memory function enables impedance polarization to operate up to a maximum of 300 s. This time can be set with the

Voltage Mem time setting. After set *Voltage Mem time* elapses, fictive voltage (and frozen impedance direction) can no more be used without memory refreshment by a healthy positive-sequence voltage and also the frozen impedance direction is reset.

Switch onto fault function (CVPSOF) should be used together with distance protection. CVPSOF accelerates and secures the operation of the protection if a close-in three-phase fault is detected immediately after circuit breaker closing.

Mho circular characteristic

When the zone characteristic is "Mho (circular)", the distance protection has a circular tripping characteristic. The zone reach is defined independently by the line reach for phase-to-earth and phase-to-phase or three-phase elements. The resistive reach of the tripping characteristic depends on the selected polarization method defined with setting *Pol quantity zone* = "Cross pol", "Pos. seq. volt." or "Self pol". The non-directional mho characteristic is an exception as it is independent of the selected polarization method. It is always explicitly defined by the reach settings and thus fixed in the impedance plane.

Table 922: Polarization methods and corresponding polarization voltages

Fault loop	Self pol	Cross pol	Pos. seq. volt.
Z_A	U_{L1}	$j \cdot U_{L23}/\sqrt{3}$	U_1
Z_B	U_{L2}	$j \cdot U_{L31}/\sqrt{3}$	$U_1 \cdot 1\angle -120°$
Z_C	U_{L3}	$j \cdot U_{L23}/\sqrt{3}$	$U_1 \cdot 1\angle 120°$
Z_{AB}	U_{L12}	$j \cdot (U_{L23}-U_{L31})/\sqrt{3}$	$U_1 \cdot \sqrt{3} \cdot 1\angle 30°$
Z_{BC}	U_{L23}	$j \cdot (U_{L31}-U_{L12})/\sqrt{3}$	$U_1 \cdot \sqrt{3} \cdot 1\angle -90°$
Z_{CA}	U_{L31}	$j \cdot (U_{L12}-U_{L23})/\sqrt{3}$	$U_1 \cdot \sqrt{3} \cdot 1\angle 150°$
Z_{ABC}	U_1		

In case of cross-polarization "Cross pol", the polarization voltages are theoretically quadrature to the fault loop voltage. The phase angle of the polarization voltage is rotated 90° to match the original fault loop voltage. The cross-polarization expands the tripping characteristic according to the prevailing system conditions. In case of short circuit faults, the circle expands as a function of the source impedance magnitude $Z_{1source}$. In case of an earth fault, the circle expands as a function of the source impedance $Z_{1source}$, $Z_{0source}$ and earthing impedance magnitudes Z_E as $(2 \cdot Z_{1source} + Z_{0source})/3 + Z_E$.

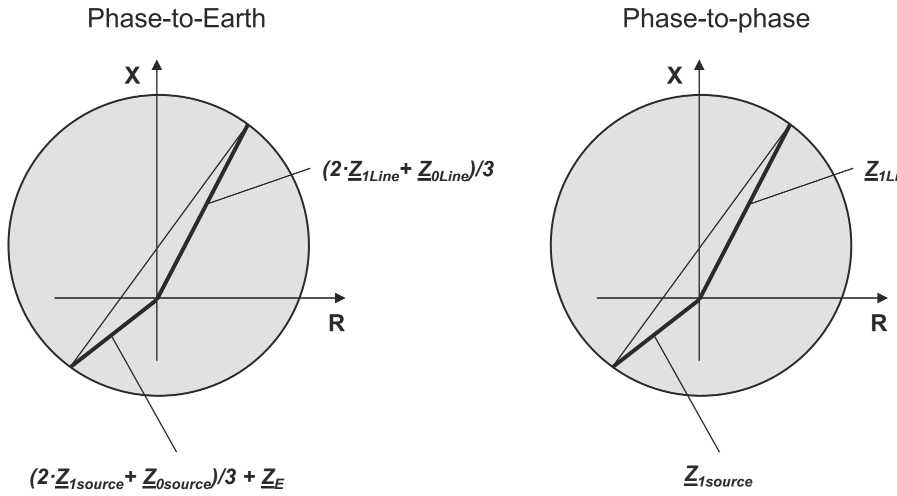


Figure 550: Tripping characteristic in case the zone characteristic is "Mho (circular)" and Pol quantity zone is "Cross pol"

In case of positive-sequence polarization "Pos. seq. volt.", the polarization voltage is the positive-sequence voltage. The voltage phase angle is rotated to match the original fault loop voltage. The positive-sequence polarization expands the tripping characteristic according to the prevailing system conditions. In case of short circuit faults, the circle expands as a function of the source impedance magnitude $\underline{Z}_{1source}/2$. In case of an earth fault, the circle expands as a function of source impedance and earthing impedance magnitudes: $(Z_{1source} + Z_{0source})/3 + Z_E$.

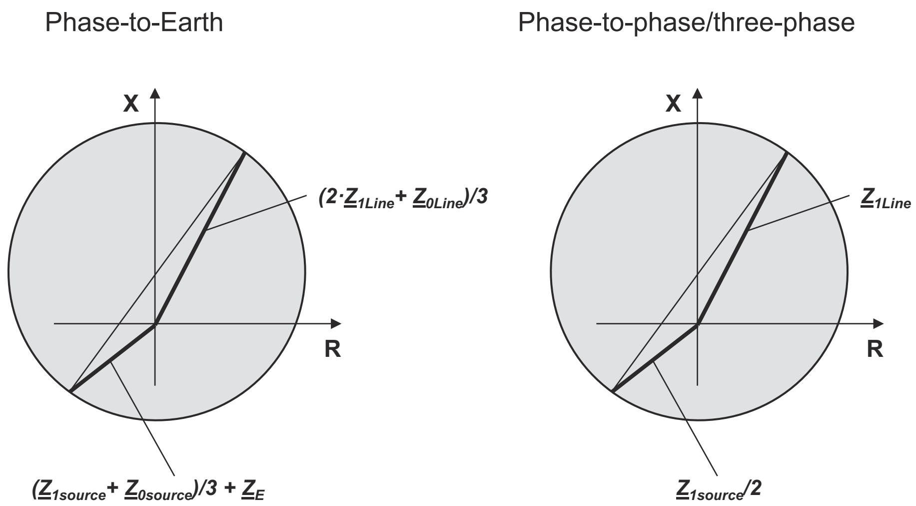


Figure 551: Tripping characteristic in case the zone characteristic is "Mho (circular)" and Pol quantity zone is "Pos. seq. volt."

One alternative for polarization is also "Self pol" despite the drawbacks when using it as a polarization method. The mho circle does not expand when using this polarization method.

In case of cross and positive-sequence polarization, the expansion of the mho circle is a positive feature as the fault resistance coverage is increased. The reach of the zone is not affected by the expansion. The greatest expansion is obtained with cross-polarization.

The directional offset mho is explicitly defined by the reach settings and is thus fixed in the impedance plane. The polarization method does not expand this circle even for directional mode. However, directional lines criteria are defined using polarized signals.

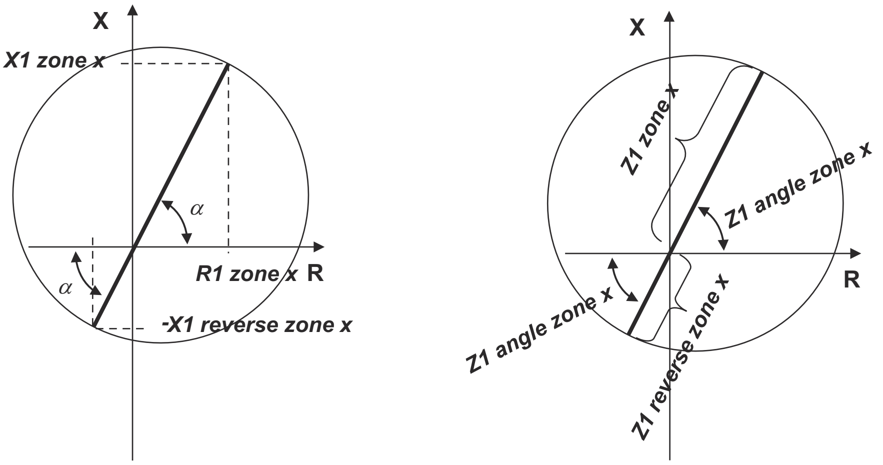


Figure 552: Tripping characteristic for phase-to-phase or three-phase impedance measuring elements if Impedance Chr PP Zn is "Mho (circular)" and Directional mode Znx is "Non-directional". On the left, Impedance mode Zn is "Rectangular". On the right, Impedance mode Zn is "Polar".

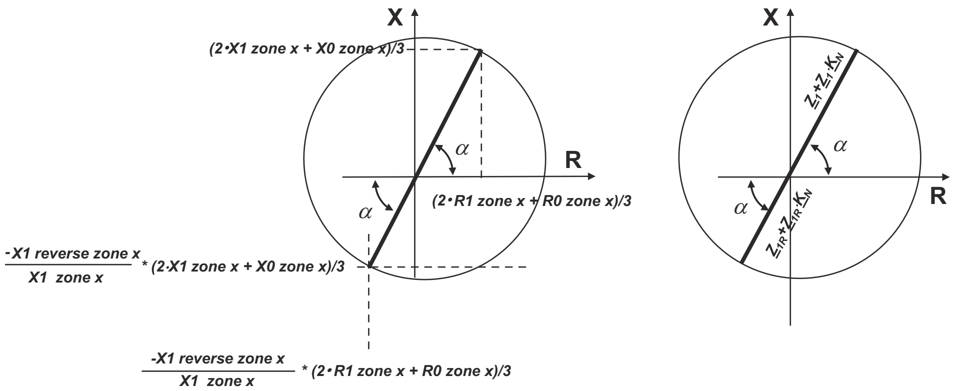


Figure 553: Tripping characteristic for phase-to-earth impedance measuring elements if Impedance Chr GND Zn is "Mho (circular)" and Directional mode Znx is "Non-directional". On the left, Impedance mode Zn is "Rectangular". On the right, Impedance mode Zn is "Polar".

Adding of directional lines into circular mho characteristic

Directional lines which are always included in the directional quadrilateral characteristic can also be included in the mho characteristics to secure the directionality or to transform the non-directional mho characteristics into a directional one.

Directional lines with mho are available only when the zone is set to directional, that is, *Directional mode Znx* is "Forward" or "Reverse".

The directionality of the directional mho characteristic is secured with directional lines by setting *Impedance Chr Gnd Zn and Impedance Chr PP Zn* to "Mho Dir line". The directional mho characteristic can also be created by adding directional lines in the offset mho characteristic. This is done by selecting *Impedance Chr Gnd Zn* and *Impedance Chr PP Zn* as "Offset Dir line".

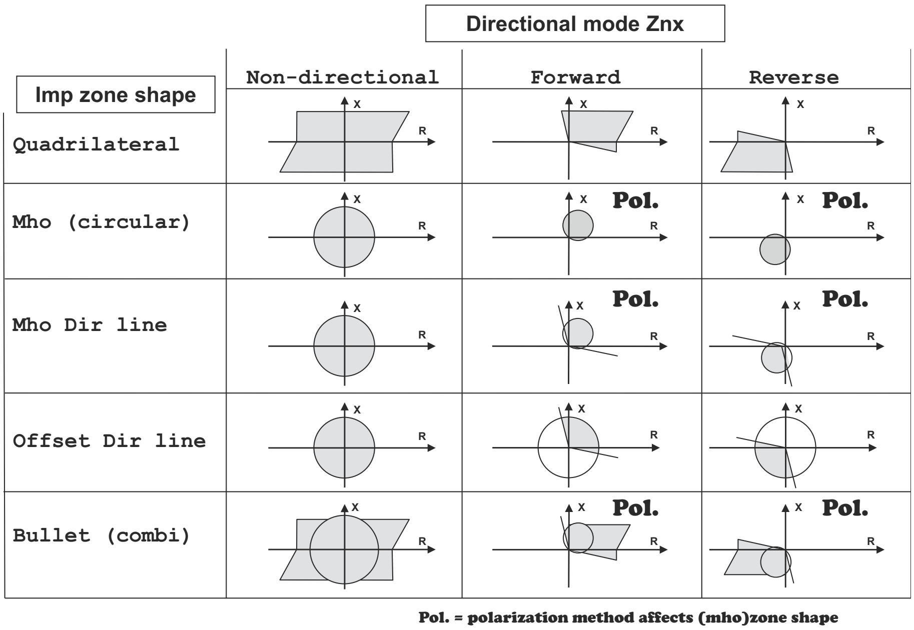


Figure 554: Possible combinations of Directional mode Znx and zone characteristics settings. Pol. in the figure means that the shape of the characteristic is affected by the selected polarization method of the mho circle, Pol quantity zone = "Cross pol", "Pos. seq. volt.", "Self pol").

Bullet combi characteristic

If the impedance zone shape equals "Bullet (combi)", the distance protection has a tripping characteristic which is a combination of the quadrilateral and mho. All settings relevant to the quadrilateral and mho are applicable. The shape of the "Bullet (combi)" characteristic is affected by the selected polarization method of the mho circle (*Pol quantity zone* = "Cross pol", "Pos. seq. volt.", "Self pol").

The directionality of the "Bullet (combi)" characteristic is defined by the directional lines when *Directional mode Znx* is "Forward" or "Reverse". For directional "Bullet (combi)" characteristic, the quadrilateral resistance does not reach negative (positive) values for “Forward” (“Reverse”) direction (see Figure 555).

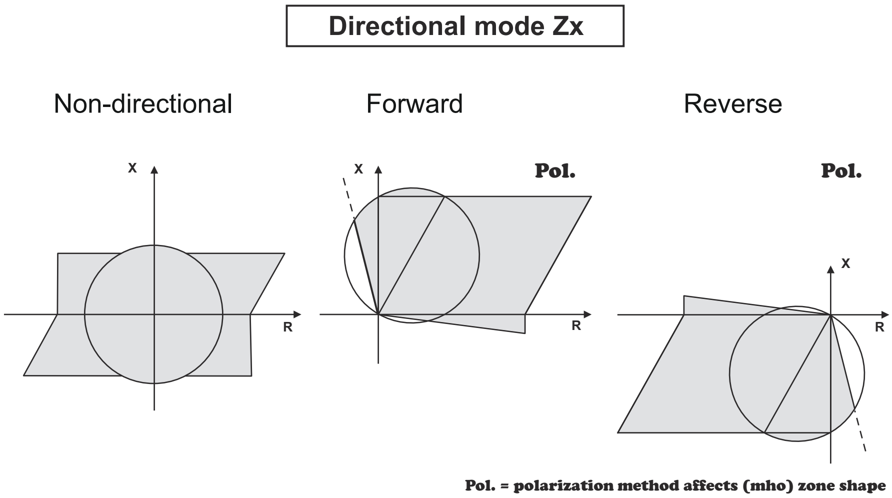


Figure 555: Bullet combi tripping characteristic. Pol. in the figure means the shape of the characteristic is affected by the selected polarization method, Pol quantity zone = "Cross pol", "Pos. seq. volt.", "Self pol"

4.7.1.6 Recorded data

The required information for later fault analysis is recorded when the recording function of DSTPDIS is triggered by activating TRIGG_REC input or writing to the corresponding DO “LD0.GFCPDIS1.RcdTrg.Oper.ctlVal”. During external triggering (input signal TRIGG_REC), the recorded data of all zones and the phase selection function are recorded.

A total of three sets of recorded data are saved in data banks Fault 1, 2 and 3. Data bank Fault 1 holds the most recent recorded data and the older data is moved into the following banks (1->2 and 2->3) when triggering occurs. When all three banks have data and a new triggering occurs, the latest data is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2.

Table 923: Recorded data for the phase selection function

Parameter name	Description
Time	Recorded data time stamp
Release PE-loop	Release signals for PE loops, GFC
Release PP-loop	Release signals for PP/3P loops, GFC
Earth fault detected	Indication of a single-phase earth fault, GFC
Cross country fault	Indication of a cross-country fault (high imp. earthed), GFC
Earth fault direction	Earth-fault direction (low imp. earthed), GFC
Operate of all zones	Operate signals of all zones (this is zone information but it is taken here because it represents all zone information combined)

The values of parameter Operate of all zones indicate by a number (0...31) which zones have been operated.

Table 924: Enumerator values for parameter Operate of all zones

Enumerator value	Description
0	No zone operates
1	Zone 1
2	Zone 2
3	Zones 1 and 2
4	Zone 3
5	Zones 1 and 3
6	Zones 2 and 3
7	Zones 1,2 and 3
8	Zone 4
9	Zones 1 and 4
10	Zones 2 and 4
11	Zones 1,2 and 4
12	Zones 3 and 4
13	Zones 1,3 and 4
14	Zones 2,3 and 4
15	Zones 1,2,3 and 4
16	Zone 5
17	Zones 1 and 5
18	Zones 2 and 5
19	Zones 1,2 and 5
20	Zones 3 and 5
21	Zones 1,3 and 5
22	Zones 2,3 and 5
23	Zones 1,2,3 and 5
24	Zones 4 and 5
25	Zones 1,4 and 5

Table continues on the next page

Enumerator value	Description
26	Zones 2,4 and 5
27	Zones 1,2,4 and 5
28	Zones 3,4 and 5
29	Zones 1,3,4 and 5
30	Zones 2,3,4 and 5
31	Zones 1,2,3,4 and 5

Table 925: Recorded data parameters regarding specific zones

Parameter	Description
Fault/load Dir Znx	Direction of fault or load zone Zx
Dir resistance Znx	Direction resistance, zone Zx
Dir reactance Znx	Direction reactance, zone Zx
Flt loop 1st Ris Znx	First PE-Loop resistance, zone Zx
Flt loop 1st Rea Znx	First PE-Loop reactance, zone Zx
Flt loop 2nd Ris Znx	Second PE-Loop resistance, zone Zx
Flt loop 2nd Rea Znx	Second PE-Loop reactance, zone Zx
Flt PP-loop Ris Znx	PP-Loop resistance, zone Zx
Flt PP-loop Rea Znx	PP-Loop reactance, zone Zx
Phase reactance Znx	Phase reactance Znx

In case of a no-fault condition, the direction of the load current seen by a three-phase fault measuring element (based on positive-sequence signal data) is indicated. DIR_LOOP_R and DIR_LOOP_X are the loop resistance and reactance from the impedance calculation used in directional discrimination for zone 1. Depending on the released fault loops, the calculated fault loop impedance can be read from the parameters FLTLOOP_RFST, FLTLOOP_XFST, FLTLOOP_RPP and FLTLOOP_XPP. If two phase-to-earth loops are released simultaneously for measurement, the second phase-to-earth impedance can be found from the parameters FLTLOOP_RSND and FLTLOOP_XSND. The corresponding positive-sequence phase-to-earth fault reactance can be found from parameter FLTPH_X.

The impedances are shown in primary ohms.

4.7.1.7 Application

DSTPDIS provides a fast and reliable protection for overhead lines and power cables. The function is applied in distribution and sub-transmission networks where three-phase tripping is allowed for all kinds of faults.

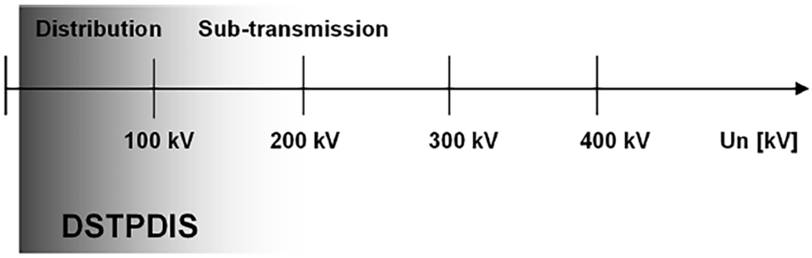


Figure 556: Application scope of DSTPDIS

Typically these networks are operated in ring or meshed type configurations. The switching state of these networks is changed frequently due to daily operation and load flow considerations. The networks also include varying capacities of distributed generation which makes it impossible to apply simple overcurrent-based schemes. In these networks, DSTPDIS is used to provide a fast and selective protection for overhead lines and power cables. It can also be applied for radial feeders to increase the sensitivity of the protection, especially if the short circuit power of the source is low or it changes due to network operation.

From the selectivity point of view, it is advantageous that in the protection chain all functions in different positions operate according to the same measuring principle. Therefore, DSTPDIS can also be applied for the backup protection of main transformers and buses. This way, selectivity in the distance protection of the outgoing lines is easier to achieve.

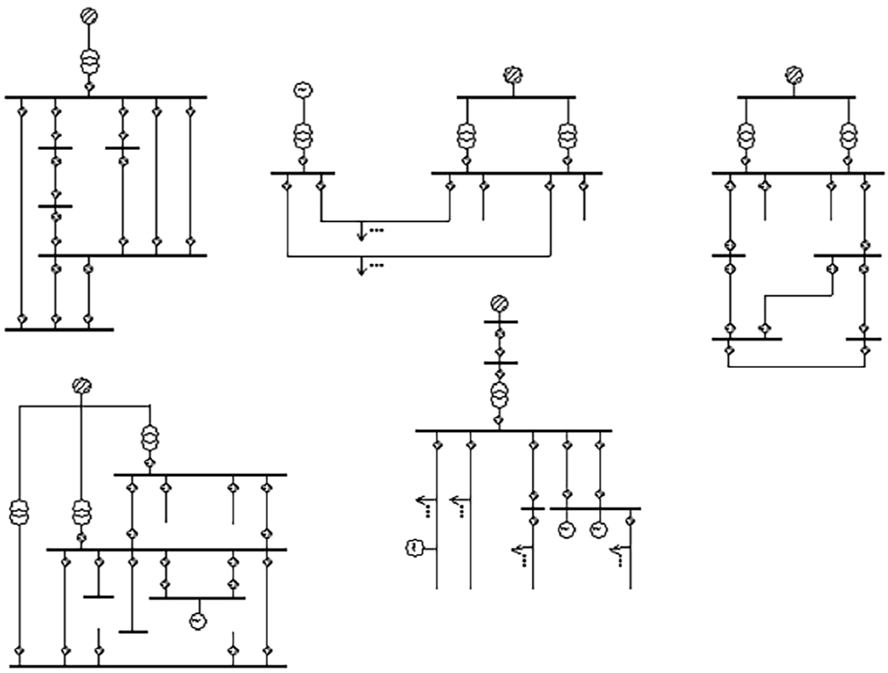


Figure 557: Typical network configurations for DSTPDIS application

DSTPDIS has five flexible configurable impedance zones for protection (Z1...Z5).

Phase-to-earth distance protection is a basic earth-fault protection in solidly or low-impedance earthed networks. Together with the phase preference logic, it also serves as a selective protection function at cross-country faults in isolated or Petersen coil compensated networks. In certain applications, system earthing is changed during operation from high-impedance to low-impedance earthed system due to fault location procedures. DSTPDIS can be used in such applications by setting System grounding GFC to "From input" and by providing information about the type of earthing through binary input SYS_EARTHING. Low (inactive) SYS_EARTHING input indicates low-impedance earthing system.

DSTPDIS is suitable as a basic protection function against two- and three-phase faults in various networks, regardless of the treatment of the neutral point. The independent setting of the reach in the reactive and the resistive directions makes it possible to create a fast and selective short circuit protection in many applications.

4.7.1.8 Signals

DSTPDIS Input signals

Table 926: DSTPDIS Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
I3P_PAR	SIGNAL	-	Three-phase currents
I3P_REF	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
SYS_EARTHING	BOOLEAN	0=False	Network earthing method
TRIGG_REC	BOOLEAN	0=False	External triggering for all recorded data
BLOCK_GFC	BOOLEAN	0=False	Block GFC operate
BLOCK_Z1	BOOLEAN	0=False	Block zone 1
BLOCK_Z2	BOOLEAN	0=False	Block zone 2
BLOCK_Z3	BOOLEAN	0=False	Block zone 3
BLOCK_Z4	BOOLEAN	0=False	Block zone 4
BLOCK_Z5	BOOLEAN	0=False	Block zone 5

DSTPDIS Output signals

Table 927: DSTPDIS Output signals

Name	Type	Description
OPERATE_GFC	BOOLEAN	Time delayed operate signal, GFC
OPERATE_Z1	BOOLEAN	Time delayed operate signal, zone 1
OPERATE_Z2	BOOLEAN	Time delayed operate signal, zone 2
OPERATE_Z3	BOOLEAN	Time delayed operate signal, zone 3
OPERATE_Z4	BOOLEAN	Time delayed operate signal, zone 4
OPERATE_Z5	BOOLEAN	Time delayed operate signal, zone 5
START_GFC	BOOLEAN	Start, GFC
START_Z1	BOOLEAN	General start signal, zone 1
START_Z2	BOOLEAN	General start signal, zone 2
START_Z3	BOOLEAN	General start signal, zone 3
START_Z4	BOOLEAN	General start signal, zone 4
START_Z5	BOOLEAN	General start signal, zone 5
XC_FLT	BOOLEAN	Indication of a cross-country-fault (high imp. earthed), GFC
DIRECTION_Z1	Enum	Direction of fault or load zone 1
DIRECTION_Z2	Enum	Direction of fault or load zone 2
DIRECTION_Z3	Enum	Direction of fault or load zone 3
DIRECTION_Z4	Enum	Direction of fault or load zone 4
DIRECTION_Z5	Enum	Direction of fault or load zone 5

4.7.1.9 DSTPDIS Settings

Table 928: DSTPDIS Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase Sel mode GFC	1=Overcurrent 2=Vol Dep Overcur 3=Under impe-dance			1=Overcurrent	Phase selection method

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=OC AND Und impedance				
EF detection Mod GFC	1=Io 2=Io OR Uo 3=Io AND Uo 4=Io AND IoRef			1=Io	Earth-fault (EF) detection method
Operate delay GFC	100...60000	ms	10	3000	Time delay to operate, GFC
Str A Ph Sel GFC	0.10...10.00	xIn	0.01	2.00	Phase current start value, PSL
Lo A Ph Sel GFC	0.10...10.00	xIn	0.01	0.80	Phase current start value, voltage dep. over current, PSL
Ph V Ph Sel GFC	0.05...1.00	xUn	0.01	0.46	PE-voltage start value, voltage dep. over current, PSL
PP V Ph Sel GFC	0.10...1.00	xUn	0.01	0.80	PP-voltage start value, voltage dep. over current, PSL
Z Chr Mod Ph Sel GFC	1=Quadrilateral 2=Mho (circular)			1=Quadrilateral	Impedance characteristic, underimpedance, PSL
Load Dsr mode GFC	0=False 1=True			0=False	Enable load discrimination, underimpedance, PSL
X Gnd Fwd reach GFC	0.00...3000.00	ohm	0.01	40.00	Reactive forward reach for PE-loops, underimpedance, PSL
X Gnd Rv reach GFC	0.00...3000.00	ohm	0.01	40.00	Reactive reverse reach for PE-loops, underimpedance, PSL
Ris Gnd Fwd Rch GFC	0.00...500.00	ohm	0.01	100.00	Resistive forward reach for PE-loops, underimpedance, PSL
Ris Gnd Rv Rch GFC	0.00...500.00	ohm	0.01	100.00	Resistive reverse reach for PE-loops, underimpedance, PSL
X PP Fwd reach GFC	0.00...3000.00	ohm	0.01	40.00	Reactive forward reach for PP-loops, underimpedance, PSL
X PP Rv reach GFC	0.00...3000.00	ohm	0.01	40.00	Reactive reverse reach for PP-loops, underimpedance, PSL
Ris PP Fwd Rch GFC	0.00...100.00	ohm	0.01	30.00	Resistive forward reach for PP-loops, underimpedance, PSL
Ris PP Rv Rch GFC	0.00...100.00	ohm	0.01	30.00	Resistive reverse reach for PP-loops, underimpedance, PSL
Ris Fwd Rch Lod GFC	0.00...3000.00	ohm	0.01	80.00	Resistive forward reach for load discrimination, underimpedance, PSL
Ris Rv Rch Lod GFC	0.00...3000.00	ohm	0.01	80.00	Resistive reverse reach for load discrimination, un-

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					drerimpedance, PSL
Angle load area GFC	5.0...45.0	deg	0.1	25.0	Load discrimina-tion angle, PSL
Gnd Op current GFC	0.00...10.00	xIn	0.01	0.10	Basic start value for residual curr., EF-detection function
Gnd Op A Ref GFC	0.01...10.00	xIn	0.01	0.10	Transformer neu-tral curr. start val., EF-detection func-tion
Gnd Str voltage GFC	0.02...1.00	xUn	0.01	0.15	Residual voltage start value, EF-de-tection function
Gnd Op A XC GFC	0.10...10.00	xIn	0.01	0.20	Residual current start value, XC-fault detection function
PP voltage XC GFC	0.10...1.00	xUn	0.01	0.80	PP-voltage start value, XC-fault de-tection function
Directional mode Zn1	2=Forward 3=Reverse 1=Non-directional			2=Forward	Directional mode, zone 1
Op Mod PP loops Zn1	0=False 1=True			0=False	Enable PP/3P-loop measurement, zone 1
PP Op delay Mod Zn1	0=False 1=True			1=True	Enable operate tim-er for PP/3P-loops, zone 1
R1 zone 1	0.00...3000.00	ohm	0.01	40.00	Positive sequence resistive reach, zone 1
X1 zone 1	0.00...3000.00	ohm	0.01	40.00	Positive sequence reactive reach, zone 1
X1 reverse zone 1	0.00...3000.00	ohm	0.01	40.00	Pos. seq. reactive reach in rev. dir., non-dir. zone 1
Z1 zone 1	0.01...3000.00	ohm	0.01	56.57	Positive sequence reach, zone 1
Z1 angle zone 1	15.0...90.0	deg	0.1	45.0	Positive sequence line angle, zone 1
Z1 reverse zone 1	0.00...3000.00	ohm	0.01	56.57	Positive sequence reach in rev. dir., non-dir. zone 1
Min Ris PP Rch Zn1	0.00...100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, zone 1
Max Ris PP Rch Zn1	0.00...100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, zone 1
PP operate delay Zn1	20...60000	ms	1	20	Time delay to oper-ate of PP/3P-loops, zone 1
Op Mod Gnd loops Zn1	0=False 1=True			0=False	Enable PE-loop measurement, zone 1
Gnd Op Dl mode Zn1	0=False 1=True			1=True	Enable operate tim-er for PE-loops, zone 1
Load Comp zone 1	0=False 1=True			1=True	Enable load com-pensation for PE-loops, zone 1

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
R0 zone 1	0.00...3000.00	ohm	0.01	160.00	Zero sequence resistive reach, zone 1
X0 zone 1	0.00...3000.00	ohm	0.01	160.00	Zero sequence reactive reach, zone 1
Factor K0 zone 1	0.00...5.00		0.01	1.00	Residual compensation factor magnitude, zone 1
Factor K0 angle Zn1	-179...180	deg	1	0	Residual compensation factor angle, zone 1
Min Ris Gnd Rch Zn1	0.00...500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, zone 1
Max Ris Gnd Rch Zn1	0.00...500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, zone 1
Gnd operate Dl Zn1	20...60000	ms	1	20	Time delay to operate of PE-loops, zone 1
Directional mode Zn2	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode, zone 2
Op Mod PP loops Zn2	0=False 1=True			0=False	Enable PP/3P-loop measurement, zone 2
PP Op delay Mod Zn2	0=False 1=True			1=True	Enable operate timer for PP/3P-loops, zone 2
R1 zone 2	0.00...3000.00	ohm	0.01	40.00	Positive sequence resistive reach, zone 2
X1 zone 2	0.00...3000.00	ohm	0.01	40.00	Positive sequence reactive reach, zone 2
X1 reverse zone 2	0.00...3000.00	ohm	0.01	40.00	Pos. seq. reactive reach in rev. dir., non-dir. zone 2
Z1 zone 2	0.01...3000.00	ohm	0.01	56.57	Positive sequence reach, zone 2
Z1 angle zone 2	15.0...90.0	deg	0.1	45.0	Positive sequence line angle, zone 2
Z1 reverse zone 2	0.00...3000.00	ohm	0.01	56.57	Positive sequence reach in rev. dir., non-dir. zone 2
Min Ris PP Rch Zn2	0.00...100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, zone 2
Max Ris PP Rch Zn2	0.00...100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, zone 2
PP operate delay Zn2	20...60000	ms	1	20	Time delay to operate of PP/3P-loops, zone 2
Op Mod Gnd loops Zn2	0=False 1=True			0=False	Enable PE-loop measurement, zone 2
Gnd Op Dl mode Zn2	0=False 1=True			1=True	Enable operate timer for PE-loops, zone 2
Load Comp zone 2	0=False 1=True			1=True	Enable load compensation for PE-loops, zone 2

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
R0 zone 2	0.00...3000.00	ohm	0.01	160.00	Zero sequence resistive reach, zone 2
X0 zone 2	0.00...3000.00	ohm	0.01	160.00	Zero sequence reactive reach, zone 2
Factor K0 zone 2	0.00...5.00		0.01	1.00	Residual compensation factor magnitude, zone 2
Factor K0 angle Zn2	-179...180	deg	1	0	Residual compensation factor angle, zone 2
Min Ris Gnd Rch Zn2	0.00...500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, zone 2
Max Ris Gnd Rch Zn2	0.00...500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, zone 2
Gnd operate Dl Zn2	20...60000	ms	1	20	Time delay to operate of PE-loops, zone 2
Directional mode Zn3	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode, zone 3
Op Mod PP loops Zn3	0=False 1=True			0=False	Enable PP/3P-loop measurement, zone 3
PP Op delay Mod Zn3	0=False 1=True			1=True	Enable operate timer for PP/3P-loops, zone 3
R1 zone 3	0.00...3000.00	ohm	0.01	40.00	Positive sequence resistive reach, zone 3
X1 zone 3	0.00...3000.00	ohm	0.01	40.00	Positive sequence reactive reach, zone 3
X1 reverse zone 3	0.00...3000.00	ohm	0.01	40.00	Pos. seq. reactive reach in rev. dir., non-dir. zone 3
Z1 zone 3	0.01...3000.00	ohm	0.01	56.57	Positive sequence reach, zone 3
Z1 angle zone 3	15.0...90.0	deg	0.1	45.0	Positive sequence line angle, zone 3
Z1 reverse zone 3	0.00...3000.00	ohm	0.01	56.57	Positive sequence reach in rev. dir., non-dir. zone 3
Min Ris PP Rch Zn3	0.00...100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, zone 3
Max Ris PP Rch Zn3	0.00...100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, zone 3
PP operate delay Zn3	20...60000	ms	1	20	Time delay to operate of PP/3P-loops, zone 3
Op Mod Gnd loops Zn3	0=False 1=True			0=False	Enable PE-loop measurement, zone 3
Gnd Op Dl mode Zn3	0=False 1=True			1=True	Enable operate timer for PE-loops, zone 3
Load Comp zone 3	0=False 1=True			1=True	Enable load compensation for PE-loops, zone 3

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
R0 zone 3	0.00...3000.00	ohm	0.01	160.00	Zero sequence resistive reach, zone 3
X0 zone 3	0.00...3000.00	ohm	0.01	160.00	Zero sequence reactive reach, zone 3
Factor K0 zone 3	0.00...5.00		0.01	1.00	Residual compensation factor magnitude, zone 3
Factor K0 angle Zn3	-179...180	deg	1	0	Residual compensation factor angle, zone 3
Min Ris Gnd Rch Zn3	0.00...500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, zone 3
Max Ris Gnd Rch Zn3	0.00...500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, zone 3
Gnd operate Dl Zn3	20...60000	ms	1	20	Time delay to operate of PE-loops, zone 3
Directional mode Zn4	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode, zone 4
Op Mod PP loops Zn4	0=False 1=True			0=False	Enable PP/3P-loop measurement, zone 4
PP Op delay Mod Zn4	0=False 1=True			1=True	Enable operate timer for PP/3P-loops, zone 4
R1 zone 4	0.00...3000.00	ohm	0.01	40.00	Positive sequence resistive reach, zone 4
X1 zone 4	0.00...3000.00	ohm	0.01	40.00	Positive sequence reactive reach, zone 4
X1 reverse zone 4	0.00...3000.00	ohm	0.01	40.00	Pos. seq. reactive reach in rev. dir., non-dir. zone 4
Z1 zone 4	0.01...3000.00	ohm	0.01	56.57	Positive sequence reach, zone 4
Z1 angle zone 4	15.0...90.0	deg	0.1	45.0	Positive sequence line angle, zone 4
Z1 reverse zone 4	0.00...3000.00	ohm	0.01	56.57	Positive sequence reach in rev. dir., non-dir. zone 4
Min Ris PP Rch Zn4	0.00...100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, zone 4
Max Ris PP Rch Zn4	0.00...100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, zone 4
PP operate delay Zn4	20...60000	ms	1	20	Time delay to operate of PP/3P-loops, zone 4
Op Mod Gnd loops Zn4	0=False 1=True			0=False	Enable PE-loop measurement, zone 4
Gnd Op Dl mode Zn4	0=False 1=True			1=True	Enable operate timer for PE-loops, zone 4
Load Comp zone 4	0=False 1=True			1=True	Enable load compensation for PE-loops, zone 4

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
R0 zone 4	0.00...3000.00	ohm	0.01	160.00	Zero sequence resistive reach, zone 4
X0 zone 4	0.00...3000.00	ohm	0.01	160.00	Zero sequence reactive reach, zone 4
Factor K0 zone 4	0.00...5.00		0.01	1.00	Residual compensation factor magnitude, zone 4
Factor K0 angle Zn4	-179...180	deg	1	0	Residual compensation factor angle, zone 4
Min Ris Gnd Rch Zn4	0.00...500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, zone 4
Max Ris Gnd Rch Zn4	0.00...500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, zone 4
Gnd operate Dl Zn4	20...60000	ms	1	20	Time delay to operate of PE-loops, zone 4
Directional mode Zn5	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode, zone 5
Op Mod PP loops Zn5	0=False 1=True			0=False	Enable PP/3P-loop measurement, zone 5
PP Op delay Mod Zn5	0=False 1=True			1=True	Enable operate timer for PP/3P-loops, zone 5
R1 zone 5	0.00...3000.00	ohm	0.01	40.00	ositive sequence resistive reach, zone 5
X1 zone 5	0.00...3000.00	ohm	0.01	40.00	Positive sequence reactive reach, zone 5
X1 reverse zone 5	0.00...3000.00	ohm	0.01	40.00	Pos. seq. reactive reach in rev. dir., non-dir. zone 5
Z1 zone 5	0.01...3000.00	ohm	0.01	56.57	Positive sequence reach, zone 5
Z1 angle zone 5	15.0...90.0	deg	0.1	45.0	Positive sequence line angle, zone 5
Z1 reverse zone 5	0.00...3000.00	ohm	0.01	56.57	Positive sequence reach in rev. dir., non-dir. zone 5
Min Ris PP Rch Zn5	0.00...100.00	ohm	0.01	30.00	Minimum resistive reach of PP/3P-loops, zone 5
Max Ris PP Rch Zn5	0.00...100.00	ohm	0.01	30.00	Maximum resistive reach of PP/3P-loops, zone 5
PP operate delay Zn5	20...60000	ms	1	20	Time delay to operate of PP/3P-loops, zone 5
Op Mod Gnd loops Zn5	0=False 1=True			0=False	Enable PE-loop measurement, zone 5
Gnd Op Dl mode Zn5	0=False 1=True			1=True	Enable operate timer for PE-loops, zone 5
Load Comp zone 5	0=False 1=True			1=True	Enable load compensation for PE-loops, zone 5

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
R0 zone 5	0.00...3000.00	ohm	0.01	160.00	Zero sequence resistive reach, zone 5
X0 zone 5	0.00...3000.00	ohm	0.01	160.00	Zero sequence reactive reach, zone 5
Factor K0 zone 5	0.00...5.00		0.01	1.00	Residual compensation factor magnitude, zone 5
Factor K0 angle Zn5	-179...180	deg	1	0	Residual compensation factor angle, zone 5
Min Ris Gnd Rch Zn5	0.00...500.00	ohm	0.01	100.00	Minimum resistive reach of PE-loops, zone 5
Max Ris Gnd Rch Zn5	0.00...500.00	ohm	0.01	100.00	Maximum resistive reach of PE-loops, zone 5
Gnd operate Dl Zn5	20...60000	ms	1	20	Time delay to operate of PE-loops, zone 5

Table 929: DSTPDIS Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Gnd Op current 2 GFC	0.10...10.00	xIn	0.01	1.00	Res. curr. start value for slope 2, EF-detection function
Stab slope 1 GFC	0.00...0.30		0.01	0.10	Slope 1 for res. curr. stabilization, EF-detection function
Stab slope 2 GFC	0.00...1.00		0.01	1.00	Slope 2 for res. current stabilization, EF-detection function
A Ph Stab value GFC	1.00...10.00	xIn	0.01	2.00	Phase current start value for slope 2, EF-detection function
Dir mode EF GFC	1=Non-directional 2=Forward 3=Reverse			1=Non-directional	Directional mode, earth-fault directional function
Pol quantity GFC	-1=Zro vol.OR cur. 2=Zero seq. cur. 3=Zero seq. volt. 4=Neg. seq. volt.			3=Zero seq. volt.	Polarization method, earth-fault directional function
Chr angle GFC	-179...180	deg	1	75	Characteristic angle, earth-fault directional function
Max phase angle GFC	0...90	deg	1	80	Right hand side angle, earth-fault directional function
Min phase angle GFC	0...90	deg	1	80	Left hand side angle, earth-fault directional function
Cross-country Dl GFC	0...10000	ms	10	100	Time delay for residual current, XC-fault detection function
Tilt angle zone 1	-45...45	deg	1	0	Tilt angle (positive value increases zone area), zone 1

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Par line Comp zone 1	0=False 1=True			0=False	Enable parallel line compensation for PE-loops, zone 1
Mutual R0 zone 1	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, zone 1
Mutual X0 zone 1	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, zone 1
Tilt angle zone 2	-45...45	deg	1	0	Tilt angle (positive value increases zone area), zone 2
Par line Comp zone 2	0=False 1=True			0=False	Enable parallel line compensation for PE-loops, zone 2
Mutual R0 zone 2	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, zone 2
Mutual X0 zone 2	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, zone 2
Tilt angle zone 3	-45...45	deg	1	0	Tilt angle (positive value increases zone area), zone 3
Par line Comp zone 3	0=False 1=True			0=False	Enable parallel line compensation for PE-loops, zone 3
Mutual R0 zone 3	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, zone 3
Mutual X0 zone 3	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, zone 3
Tilt angle zone 4	-45...45	deg	1	0	Tilt angle (positive value increases zone area), zone 4
Par line Comp zone 4	0=False 1=True			0=False	Enable parallel line compensation for PE-loops, zone 4
Mutual R0 zone 4	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, zone 4
Mutual X0 zone 4	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, zone 4
Tilt angle zone 5	-45...45	deg	1	0	Tilt angle (positive value increases zone area), zone 5
Par line Comp zone 5	0=False 1=True			0=False	Enable parallel line compensation for PE-loops, zone 5
Mutual R0 zone 5	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual resistance, zone 5
Mutual X0 zone 5	0.00...3000.00	ohm	0.01	40.00	Parallel line zero sequence mutual reactance, zone 5

Table 930: DSTPDIS Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Phase voltage Meas	1=Accurate 2=Ph-to-ph without Uo			1=Accurate	Phase voltage measurement principle
Select active zones	1=Zone 1 2=Zones 1-2 3=Zones 1-3 4=Zones 1-4 5=All 5 zones			1=Zone 1	Active zones selection
System grounding GFC	1=High impedance 2=Low impedance 3=From input			2=Low impedance	Network neutral earthing method
Ph Prf mode Lo Z GFC	1=All loops 2=PE only 3=PP only 4=BLK leading PE 5=BLK lagging PE			1=All loops	Loop selection mode for low impedance earthed network
Ph Prf mode Hi Z GFC	1=No filter 2=No preference 3=Cyc A-B-C-A 4=Cyc A-C-B-A 5=Acyc A-B-C 6=Acyc A-C-B 7=Acyc B-A-C 8=Acyc B-C-A 9=Acyc C-A-B 10=Acyc C-B-A			1=No filter	Phase preference mode for high impedance earthed network
Impedance mode Zn	1=Rectangular 2=Polar			1=Rectangular	Impedance characteristic, underimpedance, PSL
Impedance Chr Gnd Zn	1=Quadrilateral 2=Mho (circular) 3=Mho Dir line 4=Offset Dir line 5=Bullet (combi)			1=Quadrilateral	Impedance characteristic for PE-loops, zones
Impedance Chr PP Zn	1=Quadrilateral 2=Mho (circular) 3=Mho Dir line 4=Offset Dir line 5=Bullet (combi)			1=Quadrilateral	Impedance characteristic for PP/3P-loops, zones
Pol quantity zone	5=Cross pol 7=Pos. seq. volt. 1=Self pol			7=Pos. seq. volt.	Mho polarization method for zones
Max phase angle zone	0...60	deg	1	15	Angle from R-axis to right hand side directional line
Min phase angle zone	90...150	deg	1	115	Angle from R-axis to left hand side directional line

Table 931: DSTPDIS Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
EF Cur stabilization	0=False 1=True			0=False	EF current stabili-zation enabled
Fact EF current Bal	1.000...2.000		0.001	1.200	Residual current ra-tio for parallel line compensation
Zone timer mode	1=Independent 2=Common			1=Independent	Operate timer start mode, zones
Voltage Mem time	0...300000	ms	10	40	Voltage memory time

4.7.1.10 DSTPDIS Monitored data

Table 932: DSTPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
STARTS_GFC	Enum	4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault -5=No fault 1=AG Fault 2=BG Fault 3=CG Fault		Start signals for phases A, B and C, GFC
RELEASE_PE	Enum	-5=No fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Release signals for PE-loops, GFC
RELEASE_PP	Enum	5=BC Fault 6=CA Fault 7=ABC Fault 4=AB Fault -5=No fault		Release signals for PP/3P loops, GFC
EARTH_FLT	BOOLEAN	0=False 1=True		Indication of a single phase earth-fault, GFC
DIR_E_FLT	Enum	0=unknown 1=forward 2=backward 3=both		Earth-fault direction (low imp. earthed), GFC
STARTS_Z1	INT32	-5...63		Start signals for phases A, B and C, zone 1
STARTS_Z2	INT32	-5...63		Start signals for phases A, B and C, zone 2
STARTS_Z3	INT32	-5...63		Start signals for phases A, B and C, zone 3

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
STARTS_Z4	INT32	-5...63		Start signals for phases A, B and C, zone 4
STARTS_Z5	INT32	-5...63		Start signals for phases A, B and C, zone 5
DIR_LOOP_R	FLOAT32	-3000.00...3000.00	ohm	Resistance used in dir. evaluation, zone 1
DIR_LOOP_X	FLOAT32	-3000.00...3000.00	ohm	Reactance used in dir. eval., zone 1
FLTLOOP_RFST	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 1
FLTLOOP_XFST	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 1
FLTLOOP_RSND	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 1
FLTLOOP_XSND	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reac-tance, zone 1
FLTLOOP_RPP	FLOAT32	-3000.00...3000.00	ohm	PP/3P-loop resistance, zone 1
FLTLOOP_XPP	FLOAT32	-3000.00...3000.00	ohm	PP/3P-loop reactance, zone 1
FLTPH_X	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reac-tance in phase domain, zone 1
VMEM_USED	BOOLEAN	0=False 1=True		Voltage memory in use status
TLT_ANG_CONFLICT	INT32	0...1023		Tilt angle conflict
DSTPDIS	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Time	Timestamp			Time
Release PE-loop	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault -2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Release signals for PE-loops, GFC
Release PP-loop	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault -2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault		Release signals for PP/3P loops. GFC

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		5=BC Fault 6=CA Fault 7=ABC Fault		
Cross country fault	BOOLEAN	0=False 1=True		Indication of a cross-country-fault (high imp. earthed), GFC
Earth fault detected	BOOLEAN	0=False 1=True		Indication of a single phase earth-fault, GFC
Earth-fault direction	Enum	0=unknown 1=forward 2=backward 3=both		Earth-fault direction (low impedance earth-ed), GFC
Operate of all zones	INT32	0...31		Operate signal of all zones
Fault/load Dir Zn1	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 1
Dir resistance Zn1	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 1
Dir reactance Zn1	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 1
Flt loop 1st Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 1
Flt loop 1st Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 1
Flt loop 2nd Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 1
Flt loop 2nd Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reac-tance, zone 1
Flt PP-loop Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 1
Flt PP-loop Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 1
Phase reactance Zn1	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reac-tance in phase domain, zone 1
Fault/load Dir Zn2	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 2
Dir resistance Zn2	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 2
Dir reactance Zn2	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 2
Flt loop 1st Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 2
Flt loop 1st Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 2
Flt loop 2nd Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 2
Flt loop 2nd Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reac-tance, zone 2
Flt PP-loop Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 2

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Flt PP-loop Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 2
Phase reactance Zn2	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 2
Fault/load Dir Zn3	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 3
Dir resistance Zn3	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 3
Dir reactance Zn3	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 3
Flt loop 1st Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 3
Flt loop 1st Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 3
Flt loop 2nd Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 3
Flt loop 2nd Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 3
Flt PP-loop Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 3
Flt PP-loop Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 3
Phase reactance Zn3	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 3
Fault/load Dir Zn4	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 4
Dir resistance Zn4	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 4
Dir reactance Zn4	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 4
Flt loop 1st Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 4
Flt loop 1st Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 4
Flt loop 2nd Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 4
Flt loop 2nd Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 4
Flt PP-loop Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 4
Flt PP-loop Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 4
Phase reactance Zn4	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 4
Fault/load Dir Zn5	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 5
Dir resistance Zn5	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 5
Dir reactance Zn5	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 5

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Flt loop 1st Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 5
Flt loop 1st Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 5
Flt loop 2nd Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 5
Flt loop 2nd Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 5
Flt PP-loop Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 5
Flt PP-loop Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 5
Phase reactance Zn5	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 5
Time	Timestamp			Time
Release PE-loop	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault -2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Release signals for PE-loops, GFC
Release PP-loop	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault -2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Release signals for PP/3P loops. GFC
Cross country fault	BOOLEAN	0=False 1=True		Indication of a cross-country-fault (high imp. earthed), GFC
Earth fault detected	BOOLEAN	0=False 1=True		Indication of a single phase earth-fault, GFC
Earth-fault direction	Enum	0=unknown 1=forward 2=backward 3=both		Earth-fault direction (low impedance earthed), GFC
Operate of all zones	INT32	0...31		Operate signal of all zones
Fault/load Dir Zn1	Enum	0=unknown		Direction of fault or load zone 1

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=forward 2=backward 3=both		
Dir resistance Zn1	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 1
Dir reactance Zn1	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 1
Flt loop 1st Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 1
Flt loop 1st Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 1
Flt loop 2nd Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 1
Flt loop 2nd Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reac-tance, zone 1
Flt PP-loop Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 1
Flt PP-loop Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 1
Phase reactance Zn1	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reac-tance in phase domain, zone 1
Fault/load Dir Zn2	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 2
Dir resistance Zn2	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 2
Dir reactance Zn2	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 2
Flt loop 1st Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 2
Flt loop 1st Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 2
Flt loop 2nd Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 2
Flt loop 2nd Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reac-tance, zone 2
Flt PP-loop Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 2
Flt PP-loop Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 2
Phase reactance Zn2	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reac-tance in phase domain, zone 2
Fault/load Dir Zn3	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 3
Dir resistance Zn3	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 3
Dir reactance Zn3	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 3
Flt loop 1st Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 3
Flt loop 1st Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 3
Flt loop 2nd Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 3

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Flt loop 2nd Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 3
Flt PP-loop Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 3
Flt PP-loop Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 3
Phase reactance Zn3	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 3
Fault/load Dir Zn4	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 4
Dir resistance Zn4	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 4
Dir reactance Zn4	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 4
Flt loop 1st Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 4
Flt loop 1st Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 4
Flt loop 2nd Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 4
Flt loop 2nd Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 4
Flt PP-loop Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 4
Flt PP-loop Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 4
Phase reactance Zn4	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 4
Fault/load Dir Zn5	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 5
Dir resistance Zn5	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 5
Dir reactance Zn5	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 5
Flt loop 1st Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 5
Flt loop 1st Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 5
Flt loop 2nd Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 5
Flt loop 2nd Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 5
Flt PP-loop Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 5
Flt PP-loop Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 5
Phase reactance Zn5	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 5
Time	Timestamp			Time
Release PE-loop	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault		Release signals for PE-loops, GFC

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		-2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		
Release PP-loop	Enum	-5=No fault -4=ABCG Fault -3=CAG Fault -2=BCG Fault -1=ABG Fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Release signals for PP/3P loops. GFC
Cross country fault	BOOLEAN	0=False 1=True		Indication of a cross-country-fault (high imp. earthed), GFC
Earth fault detected	BOOLEAN	0=False 1=True		Indication of a single phase earth-fault, GFC
Earth-fault direction	Enum	0=unknown 1=forward 2=backward 3=both		Earth-fault direction (low impedance earth-ed), GFC
Operate of all zones	INT32	0...31		Operate signal of all zones
Fault/load Dir Zn1	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 1
Dir resistance Zn1	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 1
Dir reactance Zn1	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 1
Flt loop 1st Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resist-ance, zone 1
Flt loop 1st Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 1
Flt loop 2nd Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resist-ance, zone 1
Flt loop 2nd Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reac-tance, zone 1
Flt PP-loop Ris Zn1	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 1
Flt PP-loop Rea Zn1	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 1

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Phase reactance Zn1	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 1
Fault/load Dir Zn2	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 2
Dir resistance Zn2	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 2
Dir reactance Zn2	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 2
Flt loop 1st Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 2
Flt loop 1st Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 2
Flt loop 2nd Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 2
Flt loop 2nd Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 2
Flt PP-loop Ris Zn2	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 2
Flt PP-loop Rea Zn2	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 2
Phase reactance Zn2	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 2
Fault/load Dir Zn3	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 3
Dir resistance Zn3	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 3
Dir reactance Zn3	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 3
Flt loop 1st Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 3
Flt loop 1st Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 3
Flt loop 2nd Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 3
Flt loop 2nd Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 3
Flt PP-loop Ris Zn3	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 3
Flt PP-loop Rea Zn3	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 3
Phase reactance Zn3	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 3
Fault/load Dir Zn4	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 4
Dir resistance Zn4	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 4
Dir reactance Zn4	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 4
Flt loop 1st Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 4

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Flt loop 1st Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 4
Flt loop 2nd Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 4
Flt loop 2nd Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 4
Flt PP-loop Ris Zn4	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 4
Flt PP-loop Rea Zn4	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 4
Phase reactance Zn4	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 4
Fault/load Dir Zn5	Enum	0=unknown 1=forward 2=backward 3=both		Direction of fault or load zone 5
Dir resistance Zn5	FLOAT32	-3000.00...3000.00	ohm	Direction resistance, zone 5
Dir reactance Zn5	FLOAT32	-3000.00...3000.00	ohm	Direction reactance, zone 5
Flt loop 1st Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	First PE-loop resistance, zone 5
Flt loop 1st Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	First PE-loop reactance, zone 5
Flt loop 2nd Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop resistance, zone 5
Flt loop 2nd Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	Second PE-loop reactance, zone 5
Flt PP-loop Ris Zn5	FLOAT32	-3000.00...3000.00	ohm	PP-loop resistance, zone 5
Flt PP-loop Rea Zn5	FLOAT32	-3000.00...3000.00	ohm	PP-loop reactance, zone 5
Phase reactance Zn5	FLOAT32	-3000.00...3000.00	ohm	Phase to earth reactance in phase domain, zone 5

4.7.1.11 Technical data

Table 933: DSTPDIS Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$ Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n Impedance: ±2.5% of the set value or ±0.05 Ω Phase angle: ±2°
Shortest operate time [1] SIR [2]: 0.1...50	25 ms

Table continues on the next page

[1] Measured with static power output (SPO)

Characteristic	Value
Transient overreach SIR = 0.1...50	<8.5%
Reset time	Typically 45 ms
Reset ratio	Typically 0.96/1.04
Operate time accuracy	±1.0% of the set value or ±20 ms

4.7.1.12 Technical revision history

Table 934: DSTPDIS Technical revision history

Product connectivity level	Technical revision	Change
PCL4	B	New outputs added: DIRECTION_Z1...Z5. Setting *Factor K0 zone 1...5* range extended to 0.00...5.00. Setting *Factor K0 angle Zn1...5* range extended to -180...180. Setting *Min phase angle zone* range extended to 90....150. Setting *Max phase angle zone* range extended to 0...60

4.7.2 Out of step OOSRPSB (ANSI 78PS)

4.7.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Out-of-step protection with double blinders	OOSRPSB	OOS	78PS

4.7.2.2 Function block

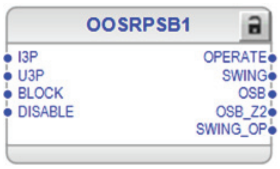


Figure 558: Function block

4.7.2.3 Functionality

The Out-of-step protection with double blinders function OOSRPSB detects out of step conditions by monitoring impedance.

[2] SIR = Source impedance ratio

The protection uses two impedance measurement elements known as inner and outer blinders on mho characteristics with a timer. The function calculates the impedance. If the measured impedance stays between inner and outer blinder for a predetermined time and moves farther inside the inner blinder, then an out of step condition is indicated. Operate is generated if out of step is indicated and impedance moves out of mho characteristics. The mho characteristic can be divided into two zones so separate trips can be generated based on the zone. Operating can also be selected to occur when the impedance is on the way into the zone or for when the impedance is on the way out of the zone.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.7.2.4 Analog channel configuration

OOSRPSB has two analog group inputs which must be properly configured.

Table 935: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 936: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.7.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of OOSRPSB can be described using a module diagram. All the modules in the diagram are explained in the next sections.

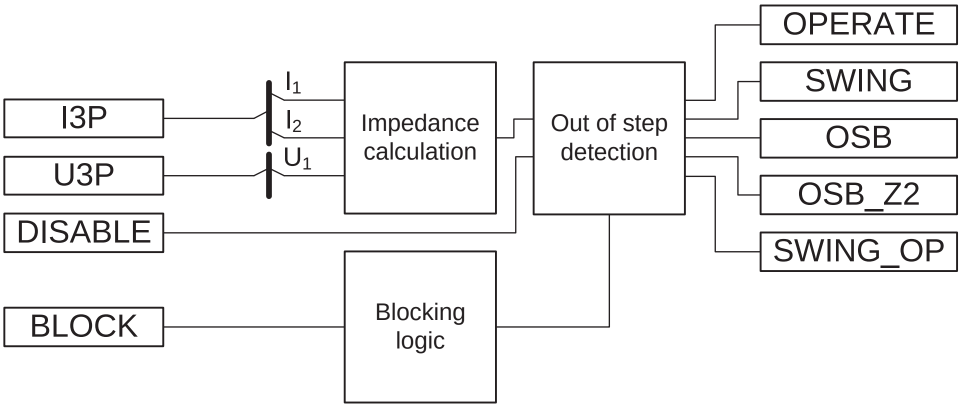


Figure 559: Functional module diagram

Impedance calculation

This module calculates the positive-sequence impedance (Z1) using positive-sequence voltage and current. For the module to calculate impedance it is required that the positive-sequence current is above *Min Ps Seq current* setting and the negative-sequence current is below the *Max Ng Seq current* setting.

The calculated positive-sequence impedance amplitude Z1_AMPL and angle Z1_ANGLE are available in ohms and degrees, respectively, in the Monitored data view.

The calculated impedance is converted to ohms as the operating characteristics are defined with the ohm settings.

Out of step detection

The operating characteristic is a circular offset mho on the impedance plane with two pair of blinders. The mho characteristic is defined with the *Forward reach*, *Reverse reach*, and *Impedance angle* settings. *Forward reach* defines the impedance from the origin to the edge of circle on the top side. *Reverse reach* defines the impedance from the origin to the edge of the circle on the bottom side. The diameter of the mho characteristics is the sum of *Forward reach* and *Reverse reach* settings. Two sets of blinders are defined by *Inner blinder R* and *Outer blinder R* intercepting at R-axis. The blinders are at the same angle as the *Impedance angle*. The second blinder of each outer and inner pair is automatically made symmetrical with the origin of the R-X plane.

For a correct operation, it is required that the setting for *Inner blinder R* is less than the setting for *Outer blinder R*.

The circular mho characteristic can be further divided into two zones by setting *Zone 2 enable* to “Yes”. The boundary between zones is set using the setting *Zone 1 reach*. The lower portion of the circle, Zone 1, is separated from the upper portion, Zone 2, by a line, perpendicular to the blinders, located at a set percentage of the *Forward reach* setting from the origin.

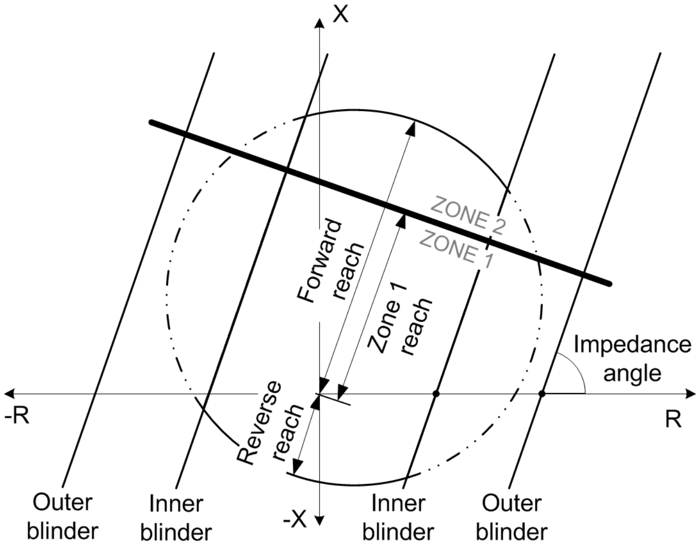


Figure 560: Operating region for out of step with double blinder

An impedance is only considered to be within the mho circle if it is also between the inner blinders.

A third zone, Zone 3, can be enabled by setting *Zone 3 enable* to “Yes”. Zone 3 is defined to include the area outside of the circular mho characteristic but inside the area that is bound with the magnitude of the minimum positive-sequence current defined by setting *Min Ps Seq*. *Figure 561* shows the three zones. Settings that determine the shape of the zones should be coordinated with the settings for any distance protection functions. The zones and their respective slip counters are applicable only for Way out operations when the *Oos operation mode* setting option is “Way out” or “Adaptive”.

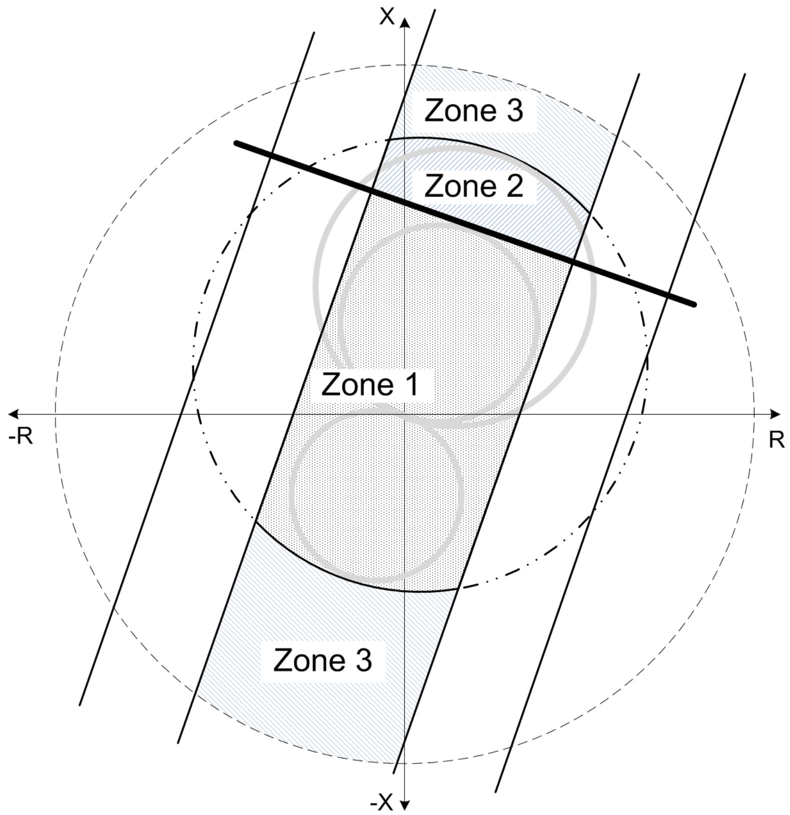


Figure 561: Defined zones

The impedance is continuously monitored for detecting an out of step condition. When the impedance enters inside from the outer blinder, the out of step detection timer is triggered. If impedance remains between outer and inner blinder for the duration of the *Swing time* setting, output SWING is activated. If the impedance enters the mho circle in zone 1, out of step blocking (OSB) for zone 1 is detected and output OSB is activated, or if the impedance enters the mho circle in zone 2, OSB for zone 2 is detected and output OSB_Z2 is activated if setting *Zone 2 enable* is set to "Yes". Both OSB and OSB_Z2 can be activated if the impedance passes through zone 1 and zone 2 while inside the mho circle. The OSB or OSB_Z2 output deactivates when impedance exits and remains outside the mho circle and the inner blinder for a duration of five cycles.

Activation of the OPERATE output depends on the *Oos operate mode* selected. The available options are "Way in", "Way out", and "Adaptive". If the "Way in" option is selected, the function triggers the delay timer after detecting an OSB condition. When the set *Operate delay time* has elapsed, the OPERATE output is activated. When using the "Way in" option, the zone-related settings and zone slip counters are not applicable.

If the "Way out" option is selected, after detecting an OSB condition, the function further checks if impedance exits the outer blinder. On exiting the outer blinder, Way out timer defined by *Operate delay time* setting is triggered and the respective zone slip counter is incremented after the set *Operate delay time* has elapsed. If the slip counter value is equal to the set number of slips in the respective enabled zone, the OPERATE output is activated. If the swing impedance passes through both zone 1 and zone 2, only the zone 1 slip counter is incremented. The zone 2 slip counter is incremented if the impedance passes through the Mho circle but only through the zone 2 portion. The zone 3 slip counter is incremented if the impedance misses the

Mho circle entirely and the setting *Zone 3 enable* is also set to “Yes”. Increment of the slip counter triggers also the Reset timer. All of the zone slip counters reset after the set *Reset time* has elapsed and the impedance does not cross into the outer blinder again, or on activation of the OPERATE output.

When the “Way out” or "Adaptive" option is selected, the breaker open time, if known, can be incorporated to optimize breaker trip time when a way out trip command is issued. The ideal time for the breaker to interrupt current is when the swing angle approaches zero. If the swing angle is δ_0 when the impedance exits the outer blinder, the dynamic Trip delay, T_{od}, can be set as shown in *Equation 273*.

$$T_{od} = \frac{1 - 2 \cdot f_{slip} \cdot (T_{co} + BrkopenTm)}{2 \cdot f_{slip}}$$

(Equation 273)

T_{od}	Dynamic Trip delay
T_{co}	The time for the impedance to travel from the center impedance line (where the swing angle is π radians) to the outer blinder on the opposite side from which it entered.
BrkopenTm	Set *Breaker open time*
f_{slip}	Slip frequency

The *Breaker open time* setting should include the time from when the relay issues a trip command to the time when the breaker receives the command. The function uses the *Breaker open time* setting to determine the trip delay time if it is not set to “0”. If the *Breaker open time* is set to “0”, the function does not dynamically calculate a trip delay but uses the fixed *Operate delay time* before activating the OPERATE output.

The slip frequency is calculated using *Equation 274*.

$$f_{slip} = \frac{\delta_i - \delta_0}{2 \cdot \pi \cdot T_{oi}}$$

(Equation 274)

f_{slip}	Slip frequency
T_{oi}	The time for the impedance to pass from the outer to the inner blinder.
δ_0	Swing angle at the outer blinder
δ_I	Swing angle at the inner blinder

The swing angles, δ_0 and δ_I, are estimated from the measured impedance when crossing the blinders. It is the difference in these quantities that is important for determining the slip frequency.

If the “Adaptive” option is selected, after detecting an OSB condition, the function further examines the slip frequency f_{slip}, *V dip time* setting, and swing angle at the outer blinder (δ_0) to determine if the operate is asserted on the way in or on the way out. OPERATE is activated on the way in, entering the mho circle from an inner blinder, if the relationship in *Equation 275* is true.

$$f_{slip} \le \frac{(\pi - \delta_0)}{\pi \cdot VoltagedipTm}$$

(Equation 275)

f_{slip}	Slip frequency
δ_0	Swing angle at the outer blinder
VoltagedipTm	Set *V dip time*

Otherwise, OPERATE is activated on the way out, when the impedance exits an outer blinder and the swing repeats for the set *Max number slips* count in the respective enabled zone that the swing has passed through.

If the *Swing time* has elapsed but the impedance exits the inner blinder and continues through the opposite blinders without passing through the mho circle, the SWING output is activated. The SWING output remains activated for a time determined by the *Reset time* setting unless another swing occurs before the reset time expires causing the output to remain active for another *Reset time* interval. If this swing is repeated for the set *Max Num slips Zn3* count and the *Zone 3 enable* setting is “Yes”, the SWING_OP output is activated. The SWING_OP output remains activated for a time determined by the *Operate dropout time* setting.

If the “Adaptive” option is selected and an OSB condition is not detected, but the impedance enters the mho circle after remaining between the inner and outer blinders for greater than 1.5 cycles, the function assumes a severe swing and assert the OPERATE output.

The drop out delay for OPERATE output can be set by *Operate dropout time* setting.

If the polarity of the voltage signal is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to “Yes”, which rotates the impedance vector by 180 degrees.

The DISABLE input can be used to coordinate the correct operation during the start-up situation. The function is blocked by activating the DISABLE signal. Once the DISABLE signal is deactivated, the function remains blocked (outputs disabled) for additional time duration as set through the setting *Disable time*.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, the function operates normally but the OPERATE output is not activated.

4.7.2.6 Application

Out of step protection functions detect stable power swings and out of step conditions based on the fact that the voltage/current variation during a power swing is slow compared to the step change during a fault. Both faults and power swings may cause the measured impedance to enter into the operating characteristic of a distance relay element. The apparent impedance moves from the pre-fault value to a fault value in a very short time, a few milliseconds, during a fault condition. However, the rate of change of the impedance is much slower during a power swing or out of step condition than during a fault depending on the slip frequency of the out of step. The impedance measurement should not be used by itself to distinguish between a fault condition and an out of step condition from a phase fault. The fundamental method for discriminating between faults and power swings is to track the rate of change of the measured impedance.

The function measures the rate of change of the impedance using two impedance measurement elements known as blinders together with a timing device. If the measured impedance stays between the blinders for a predetermined time, the function declares a power swing condition and asserts an output that can be used to block the distance protection. However, if the impedance passes the inner blinder and exits on the other side of the mho characteristics (that is, the resistive component of impedance has opposite sign as at the time of point of entry) an out of step operate is issued by the function. *Figure 562* gives an example of out of step detection.

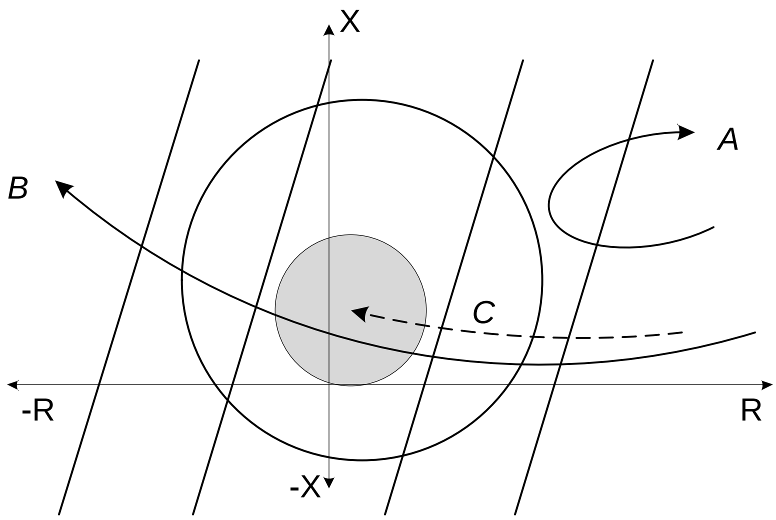


Figure 562: Example of out of step detection

The shaded region indicates a fault zone in a distance protection function. For curve A, the impedance moves into the out of step zone and leaves slowly, indicating the occurrence of a swing that quickly stabilizes. For curve B, the impedance moves slowly into the out of step zone and exits the zone indicating that the network is becoming unstable. For curve C, impedance rapidly moves into, and remains in, the fault zone indicating an actual fault and not an out of step condition.

4.7.2.7 Signals

OOSRPSB Input signals

Table 937: OOSRPSB Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
DISABLE	BOOLEAN	0=False	Disable input

OOSRPSB Output signals

Table 938: OOSRPSB Output signals

Name	Type	Description
OPERATE	BOOLEAN	Out of step operate on zone 1 or zone 2
SWING	BOOLEAN	Swing condition detected
OSB	BOOLEAN	Out of step block for zone 1
OSB_Z2	BOOLEAN	Out of step block for zone 2
SWING_OP	BOOLEAN	Out of step operate on zone 3

4.7.2.8 OOSRPSB Settings

Table 939: OOSRPSB Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Oos operate mode	1=Way in 2=Way out 3=Adaptive			2=Way out	Operate mode for tripping when out of step condition is detected
Forward reach	0.00...6000.00	ohm	0.01	1000.00	Forward reach of mho circle
Reverse reach	0.00...6000.00	ohm	0.01	100.00	Reverse reach of mho circle
Inner blinder R	1.00...6000.00	ohm	0.01	150.00	Resistance value if inner blinder at R axis
Outer blinder R	1.01...10000.00	ohm	0.01	400.00	Resistance value of outer blinder at R axis
Impedance angle	10.0...90.0	deg	0.1	90.0	Angle of mho circle and blinders with respect to R axis
Swing time	20...300000	ms	10	500	Time between blinders for swing to be detected

Table 940: OOSRPSB Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Zone 1 reach	1...100	%	1	70	Percent of Mho forward reach indicating the end of zone 1 and the beginning of zone 2
Max number slips	1...10		1	1	Number of pole slips before operating zone 1
Max Num slips Zn2	1...20		1	1	Number of pole slips before operating zone 2
Max Num slips Zn3	1...20		1	1	Number of pole slips before operating zone 3
Operate delay time	20...60000	ms	10	300	Delay after OOS operate detected
Operate dropout time	20...60000	ms	10	100	Time operate output remains active
V dip time	500...5000	ms	10	2000	Maximum allowable time for voltage to dip
Zone 2 enable	1=Yes 0=No			0=No	Enable zone 2 feature
Zone 3 enable	1=Yes 0=No			0=No	Enable zone 3 feature

Table 941: OOSRPSB Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 942: OOSRPSB Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min Ps Seq current	0.01...10.00	xIn	0.01	0.10	Minimum positive sequence current for operation
Max Ng Seq current	0.01...10.00	xIn	0.01	0.20	Maximum negative sequence current for operation
Breaker open time	0...300	ms	1	30	Opening time of the breaker
Disable time	20...60000	ms	10	5000	Additional time function is disabled after removal of DISABLE input
Reset time	20...60000	ms	10	5000	Time to reset OOS condition and counters
Voltage reversal	0=No 1=Yes			0=No	Rotate voltage signals by 180 degrees

4.7.2.9 OOSRPSB Monitored data

Table 943: OOSRPSB Monitored data

Name	Type	Values (Range)	Unit	Description
Z1_AMPL	FLOAT32	0.00...99999.00	ohm	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-180...180	deg	Positive sequence impedance phase angle
SLIP_CNT_Z1	INT32	0...9999		Zone 1 slip counter
SLIP_CNT_Z2	INT32	0...9999		Zone 2 slip counter
SLIP_CNT_Z3	INT32	0...9999		Zone 3 slip counter
OOSRPSB	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.7.2.10 Technical data

Table 944: OOSRPSB Technical data

Characteristic	Value
Impedance reach	Depending on the frequency of the measured current and voltage: f_n ±2 Hz
	±3.0% of the reach value or ±0.2% of $U_n/(\sqrt{3} \times I_n)$
Reset time	±1.0% of the set value or ±40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5...

4.7.3 Three-phase underexcitation protection UEXPDIS (ANSI 40)

4.7.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase underexcitation protection	UEXPDIS	X<	40

4.7.3.2 Function block

Figure 563: Function block

4.7.3.3 Functionality

The three-phase underexcitation protection function UEXPDIS is used to protect the synchronous machine against the underexcitation or loss of excitation condition.

The protection is based on the offset-mho circular characteristics on the impedance plane. The function calculates the apparent impedance from the machine terminal voltages and currents. If the impedance vector enters the offset-mho circle, the function gives the operating signal after a set definite time. The operating time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself.

4.7.3.4 Analog channel configuration

UEXPDIS has two analog group inputs which all must be properly configured.

Table 945: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 946: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected (*Phase Sel for Z Clc* set to "A or AB", "B or BC" or "C or CA"), if the setting *Impedance Meas mode* is set to "1Phase-to-earth" or "1Phaseto- phase".
	The function requires that at least two (the third voltage will be derived) or all three voltage channels are connected if *Impedance Meas mode* is set to "3Phase-to-earth", "3Phase-to-phase" or "Pos sequence".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.7.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of UEXPDIS can be described using a module diagram. All the modules in the diagram are explained in the next sections.

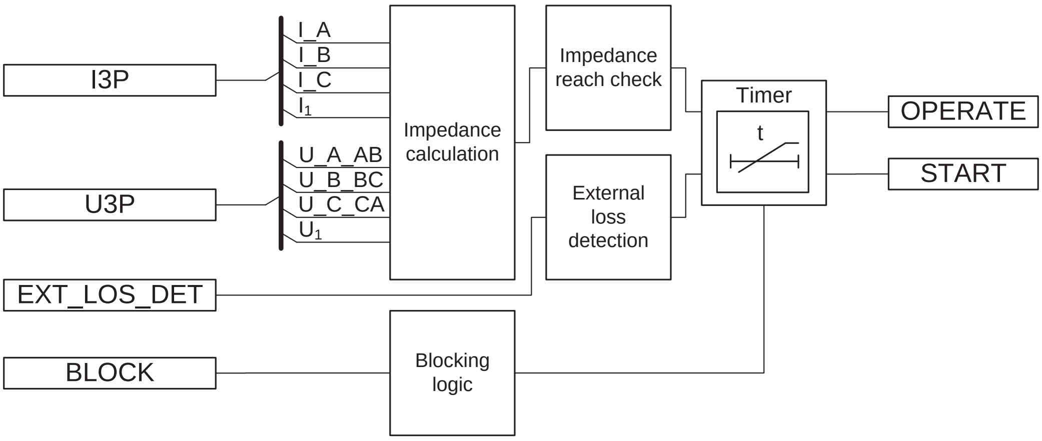


Figure 564: Functional module diagram

Impedance calculation

This module calculates the apparent impedance based on the selected voltages and currents. The *Measurement mode* and *Phase Sel for Z Clc* settings determine which voltages and currents are to be used. If the *Measurement mode* is set to "1Phase-earth" or "1Phase-phase", the *Phase Sel for Z Clc* setting is needed for determining which phase or phase-phase voltages ("A or AB", "B or BC" and "C or CA") and currents should be used for calculating the impedance.

Table 947: Voltages and currents used in impedance calculation

Measurement mode	Phase Sel for Z Clc	Voltages and currents
1Phase-earth	A or AB	U_A, I_A
1Phase-earth	B or BC	U_B, I_B
1Phase-earth	C or CA	U_C, I_C
1Phase-phase	A or AB	U_AB, I_A, I_B
1Phase-phase	B or BC	U_BC, I_B, I_C
1Phase-phase	C or CA	U_CA, I_C, I_A
3Phase-earth	N/A	U_A, U_B, U_C, I_A, I_B, I_C

Table continues on the next page

Measurement mode	Phase Sel for Z Clc	Voltages and currents
3Phase-phase	N/A	U_AB, U_BC, U_CA, I_A, I_B, I_C
Pos seqn	N/A	{ U_A,U_B,U_C } or { U_AB,U_BC,U_CA } and I_A, I_B, I_C

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

If the polarity of the voltage signals is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to "Yes", which rotates the impedance vector by 180 degrees.

If the magnitude of the voltage is less than $0.05 \cdot U_N$, the calculated impedance is not reliable and the impedance calculation is disabled. U_N is the rated phase-to-phase voltage.

The calculated impedance magnitudes and angles are available in the Monitored data view. The impedance angles are provided between -180...180 degrees.

The calculated apparent impedance is converted to pu impedance as the operating characteristics are defined with the pu settings.

Impedance reach check

The operating characteristic is a circular offset mho on the impedance plane. The operating characteristics are defined with the *Offset*, *Diameter* and *Displacement* settings. If the calculated impedance value enters the circle in the impedance plane, the module sends an enabling signal to start the Timer.

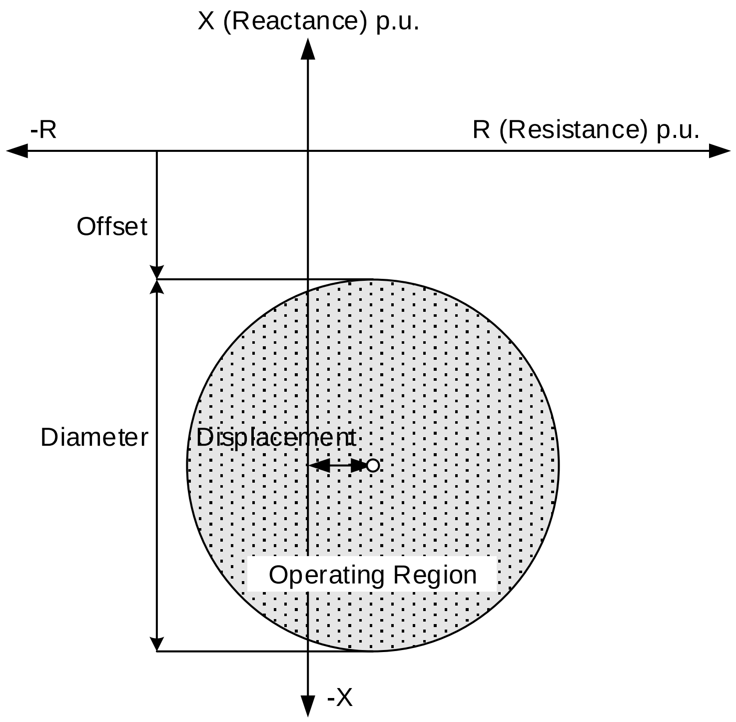


Figure 565: Operating region of the impedance mho circle

It is possible to add a restraint with the help of settings *Restraint enable*, *Rst offset X* and *Rst offset X angle*, as shown in the Figure *Figure 566*.

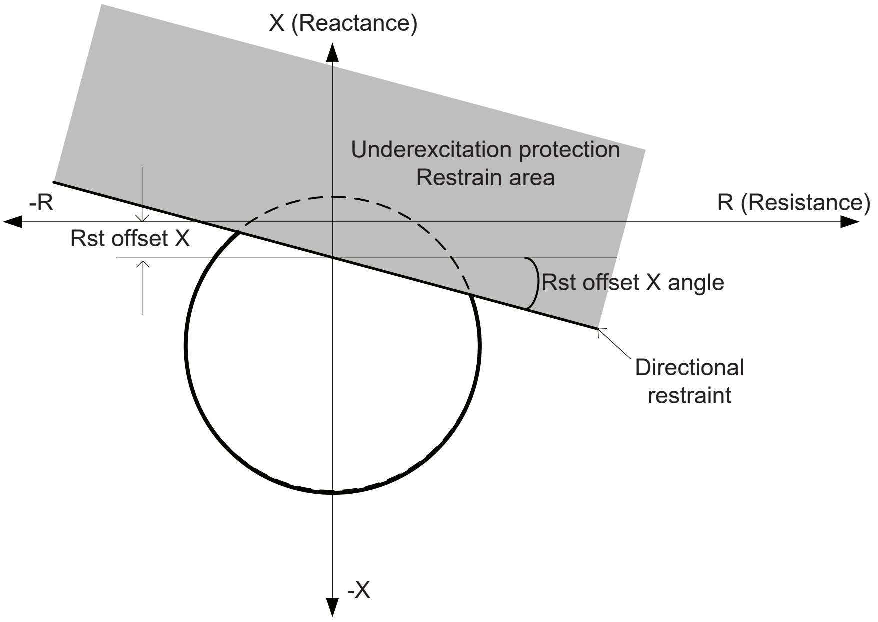


Figure 566: Settings Restraint enable, Rst offset X and Rst offset X angle

The directional restraint shown in *Figure 566* is obtained when both *Rst offset X* and *Rst offset X angle* are set with negative signs.

A fault in Automatic Voltage Regulator (AVR) or in the excitation system may cause a total loss of excitation. A short circuit on the slip rings reduces the excitation voltage to zero. This causes a gradual reduction of the excitation current and eventually a loss of excitation. An open circuit in the field circuit also causes a loss of excitation. These are typical examples which cause underexcitation in synchronous machines. This module detects the underexcitation condition for the above cases when the calculated impedance enters the operating characteristics.

External loss detection

The module checks the status information of the excitation system. It is activated when the *External Los Det Ena* setting is set to "Enable". The total loss of excitation current or a failure in the excitation system is indicated by connecting the external binary signal to the `EXT_LOS_DET` input. The Timer is enabled immediately when the `EXT_LOS_DET` input is activated.

Timer

Once activated, the Timer activates the `START` output. The time characteristic is according to DT. When the duration of the underexcitation exceeds the set definite *Operate delay time*, the `OPERATE` output is activated. If the impedance locus moves out of the offset-mho operating characteristics before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operating timer resets and the `START` output is deactivated.

The Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value isavailable in the Monitored data view.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the `BLOCK` signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the `OPERATE` output is not activated.

4.7.3.6 Application

There are limits for the underexcitation of a synchronous machine. A reduction of the excitation current weakens the coupling between the rotor and the external power system. The machine may lose the synchronism and start to operate like an induction machine, which increases the consumption of the reactive power. Even if the machine does not lose synchronism, it is not recommended to operate in this state. The underexcitation causes excessive heating in the end region of the stator winding. This can damage the insulation of the stator winding and even the iron core.

The underexcitation also causes the generator to operate in the asynchronous mode. This increases the rotor speed, which causes heating in the rotor iron and damps the windings. A high intake of the reactive power from the network during underexcitation causes problems in the network, for example voltage dip, stability and power swings. Power swings stress the prime mover, causing for example turbine blade cavitation and mechanical stress in the gearbox.

The capability curve of a synchronous generator describes the underexcitation capability of the machine. An excessive capacitive load on the synchronous machine causes it to drop out-of-step. The reason is the steady-state stability limit as defined by the load angle being 90°, which can only be reached when the unit is underexcited.

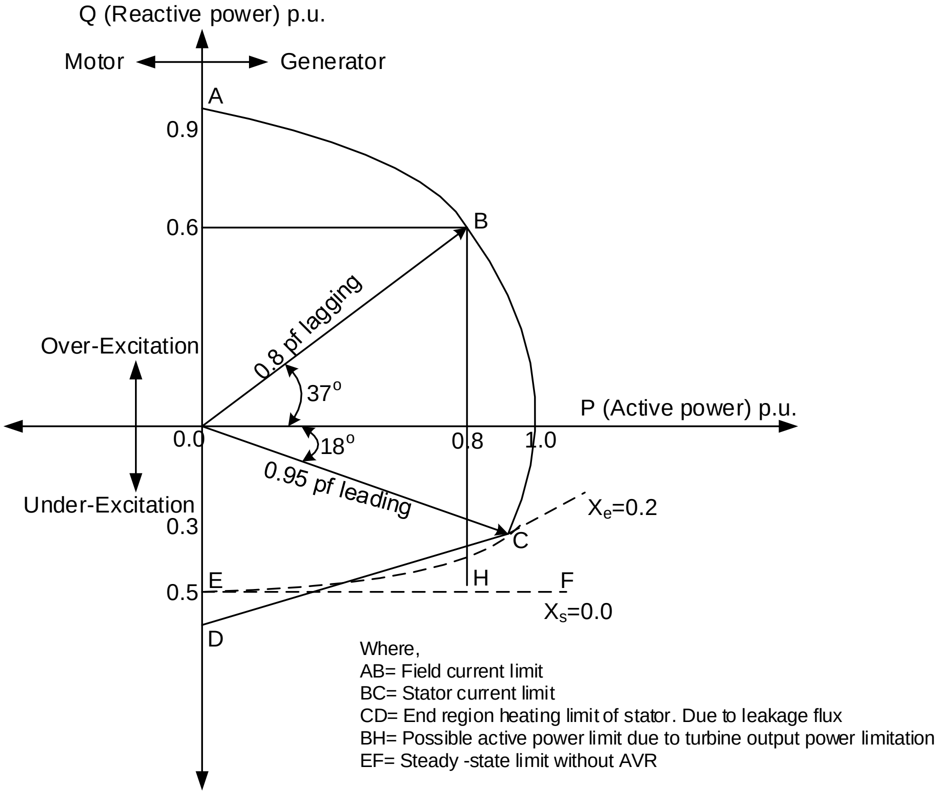


Figure 567: Capability curve of a synchronous generator

UEXPDIS protects the synchronous machines against an unstable operation due to loss of excitation. A partial or total loss of excitation causes a reactive power intake from the network to the machine, and the reactance of the system viewed from the machine terminals turns negative. This kind of drop-of-reactance condition can be detected by measuring the impedance of the system.

The operating characteristic is an offset-mho circle in the impedance plane, and the circle is parameterized with the *Offset*, *Diameter* and *Displacement* setting values. To avoid unwanted operation of the UEXPDIS function, a restrain area can be defined which is enabled with *Restraint enable* and parameterized with *Rst offset X* and *Rst offset X angle* setting values.

Table 948: Parameters of the circle

Setting values	Description
Offset	Distance of the top of the circle from the R-axis. This is usually set equal to - x_d'/2, where x_d' is the transient reactance of the machine. The sign of the setting value determines the top of the circle regarding the R-axis. If the sign is negative, the circle lies below the R-axis.
Diameter	Normally set equal to the machine's synchronous reactance x_d, which determines the size of the impedance circle.
Displacement	Displacement of the center of the circle from the reactance axis or the R-coordinate of the center. The setting can be used to adjust the sensitivity of the underexcitation protection. If the sign of the setting is positive, the circle is shifted to the right, that is, closer to the normal operating point. Respectively, if the sign is negative, the circle is shifted to the left and thus moves away from the normal operating point.
Rst offset X	Displacement from origin to a point on reactance axis (X-axis) through which the directional restraint line passes. The setting can be used to adjust the restrain area of the underexcitation protection along with *Rst offset X angle*. If the sign of the *Rst offset X* setting is positive, the restraint line passes through a point on X-axis which is above the R-axis and if it is negative, it passes through a point on X-axis which is below the R-axis.
Rst offset X angle	Angle between the R-axis (or *Rst offset X* line) and the directional restraint line. If the sign of the *OffsetXAng* setting is positive, the angle is taken in anti-clockwise direction from the R-axis (or *Rst offset X* line). Respectively, if the sign is negative, the angle is taken in clockwise direction from R-axis (or *Rst offset X* line).

The setting parameters of the off-set mho circle are to be given in pu values. The base impedance (Z_N) in ohms is:

$$Z_N = \left| \frac{U_N^{\ 2}}{S_N} \right|$$

(Equation 276)

U_N	rated (phase-to-phase) voltage in kV
S_N	rated power of the protected machine in MVA

The corresponding calculation to convert ohms to pu values is:

$$X_{pu} = \frac{X_{ohm}}{Z_N}$$

(Equation 277)

X_{pu}	pu value
X_{ohm}	reactance in ohms
Z_N	base impedance

Example of impedance locus in underexcitation

In an example of a typical impedance locus, once the impedance locus enters the relay operation characteristics, the relay operates after a settable definite time.

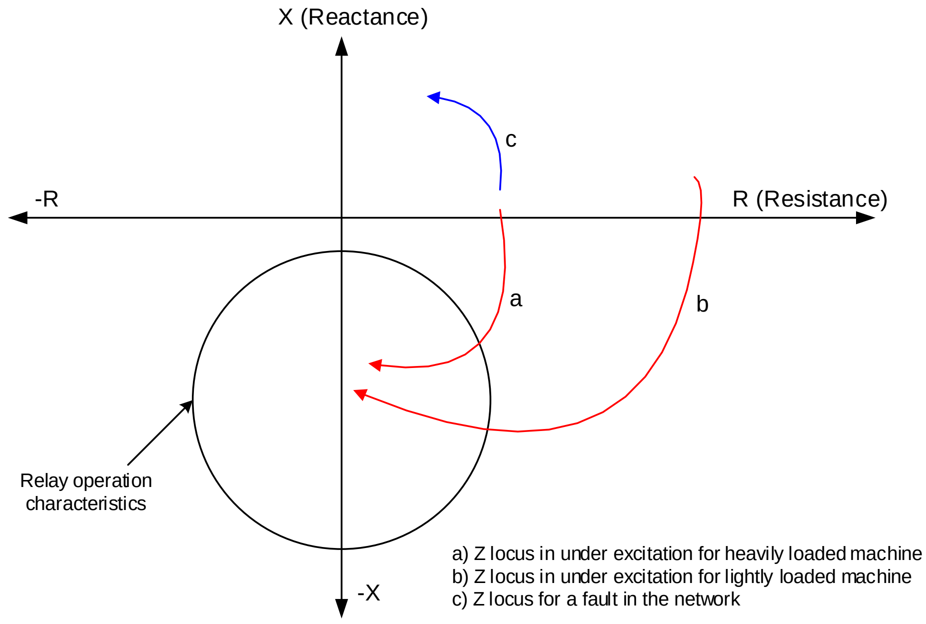


Figure 568: Typical impedance locus in underexcitation: a) heavy load b) light load c) fault in the network

4.7.3.7 Signals

UEXPDIS Input signals

Table 949: UEXPDIS Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
EXT_LOS_DET	BOOLEAN	0=False	External signal for excitation loss detection

UEXPDIS Output signals

Table 950: UEXPDIS Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.7.3.8 UEXPDIS Settings

Table 951: UEXPDIS Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Diameter	1...6000	%Zn	1	200	Diameter of the Mho diagram
Offset	-1000...1000	%Zn	1	-10	Offset of top of the impedance circle from the R-axis
Displacement	-1000...1000	%Zn	1	0	Displacement of impedance circle centre from the X-axis
Operate delay time	60...200000	ms	10	5000	Operate delay time

Table 952: UEXPDIS Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Restraint enable	0=Disable 1=Enable			0=Disable	Enable restrain area
Rst offset X	-1000...1000	%Zn	1	0	Offset of directional line from origin along X-axis
Rst offset X angle	-180.0...180.0	deg	0.1	-13.0	Angle between R-axis and directional line

Table 953: UEXPDIS Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
External Los Det Ena	0=Disable 1=Enable			1=Enable	Enable external excitation loss detection
Voltage reversal	0=No 1=Yes			0=No	Rotate voltage signals by 180 degrees
Impedance Meas mode	1=1Phase-to-earth 2=1Phase-to-phase 3=3Phase-to-earth 4=3Phase-to-phase 5=Pos sequence			5=Pos sequence	Select voltage and currents for impedance calculation
Phase Sel for Z Clc	1=A or AB 2=B or BC 3=C or CA			1=A or AB	Voltage phase selection

Table 954: UEXPDIS Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	3000	Reset delay time

4.7.3.9 UEXPDIS Monitored data

Table 955: UEXPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time (in %)
Z_AMPL_A	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase A
Z_ANGLE_A	FLOAT32	-180.00...180.00	deg	Impedance angle phase A
Z_AMPL_B	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase B
Z_ANGLE_B	FLOAT32	-180.00...180.00	deg	Impedance angle phase B
Z_AMPL_C	FLOAT32	0.00...200.00	xZn	Impedance amplitude phase C
Z_ANGLE_C	FLOAT32	-180.00...180.00	deg	Impedance angle phase C
Z_AMPL_AB	FLOAT32	0.00...200.00	xZn	Phase-to-phase A-B impedance amplitude
Z_ANGLE_AB	FLOAT32	-180.00...180.00	deg	Phase-to-phase A-B impedance phase angle
Z_AMPL_BC	FLOAT32	0.00...200.00	xZn	Phase-to-phase B-C impedance amplitude
Z_ANGLE_BC	FLOAT32	-180.00...180.00	deg	Phase-to-phase B-C impedance phase angle
Z_AMPL_CA	FLOAT32	0.00...200.00	xZn	Phase-to-phase C-A impedance amplitude
Z_ANGLE_CA	FLOAT32	-180.00...180.00	deg	Phase-to-phase C-A impedance phase angle
Z1_AMPL	FLOAT32	0.00...200.00	xZn	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-180.00...180.00	deg	Positive sequence impedance phase angle
UEXPDIS	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.7.3.10 Technical data

Table 956: UEXPDIS Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: $f = f_n \pm 2$ Hz
	±3.0% of the set value or ±0.2% Zb
Start time [1, 2]	Typically 45 ms
Reset time	Typically 30 ms

Table continues on the next page

[1] f_n= 50Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

Characteristic	Value
Reset ratio	Typically 1.04
Retardation time	Total retardation time when the impedance returns from the operating circle <40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.7.3.11 Technical revision history

Table 957: UEXPDIS Technical revision history

Product connectivity level	Technical revision	Change
PCL4	C	Added support for settable blinder in offset mho characteristic.

4.7.4 Three-phase underimpedance protection UZPDIS (ANSI 21G)

4.7.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase underimpedance protection	UZPDIS	Z<G	21G

4.7.4.2 Function block

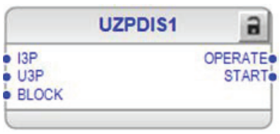


Figure 569: Function block

4.7.4.3 Functionality

The three-phase underimpedance protection UZPDIS is generally applied as a backup protection for generators and transformers against short circuit faults.

The protection is based on the origin-centric circular characteristics on the impedance plane. The function calculates the impedance value from the voltage and current phasors. If the impedance vector enters the origin-centric circle, the function produces the operating signal after a set delay. The operating time characteristics are according to definite time (DT).

However, it is also possible to enable separate zones of offset-mho based protection with multiple instances of the function.

This function contains a blocking functionality. It is possible to block the function outputs, reset timer or the function itself.

4.7.4.4 Analog channel configuration

UZPDIS has two analog group inputs which all must be properly configured.

Table 958: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 959: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected (*Phase Sel for Z Clc set* to "AB", "BC" or "CA"), if the setting *Impedance Meas* mode is set to "1Phase-to-phase".
	The function requires that at least two (the third voltage will be derived) or all three voltage channels are connected if *Impedance Meas mode* is set to "3Phase-to-phase".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.7.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of UZPDIS can be described with a module diagram. All the modules in the diagram are explained in the next sections.

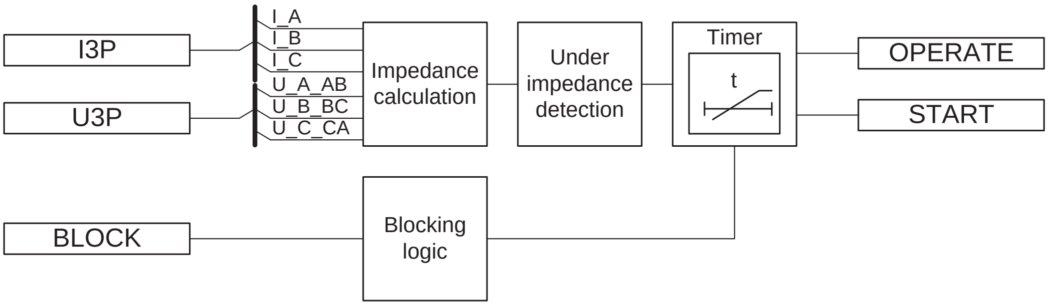


Figure 570: Functional module diagram

Impedance calculation

This module calculates the impedance based on the selected voltages and currents. The *Impedance Meas mode* and *Phase Sel for Z Clc* settings determine which voltages and currents are to be used. If *Impedance Meas mode* is set to "1Phase-phase", the *Phase Sel for Z Clc* setting is needed for determining which phase-phase voltages ("AB", "BC" and "CA") and currents should be used for calculating the impedance.

Table 960: Voltages and currents used in impedance calculation

Impedance Meas mode	Phase Sel for Z Clc	Voltages and currents used in impedance calculation [1]
1Phase-phase	AB	$\overline{ZAB} = \frac{U\_AB}{I\_A - I\_B}$
1Phase-phase	BC	$\overline{ZBC} = \frac{U\_BC}{I\_B - I\_C}$
1Phase-phase	CA	$\overline{ZCA} = \frac{U\_CA}{I\_C - I\_A}$
3Phase-phase	N/A	$\overline{ZAB} = \frac{U\_AB}{I\_A - I\_B}$ $\overline{ZBC} = \frac{U\_BC}{I\_B - I\_C}$ $\overline{ZCA} = \frac{U\_CA}{I\_C - I\_A}$

If all three phase or phase-phase voltages and phase currents are fed to the protection relay, the "3Phase-phase" mode is recommended.

[1] Voltages and currents in the calculations are given in volts and amps.

The current measurement of the function is based on two alternative measurement modes, "DFT" and "Peak-To-Peak". The measurement mode is selected using the *Measurement mode* setting.

If the current magnitude is below $0.02 \cdot I_N$, where I_N is the nominal phase current, the impedance value is not evaluated and the maximum impedance value (99.999 pu) is shown in the Monitored data view.

The calculated impedances are converted to a pu impedance as the operating characteristics are defined using the *Polar reach* setting in %Zb.

The calculated phase-phase impedance amplitudes Z_AMPL_AB, Z_AMPL_BC and Z_AMPL_CA are available as pu values in the Monitored data view.

Underimpedance detection

The operating characteristic is an origin-centric circle on the impedance plane. The origin-centric circular characteristic is defined using the *Polar reach* setting. If the calculated impedance value enters the circle in the impedance plane, the module sends an enabling signal to start the Timer.

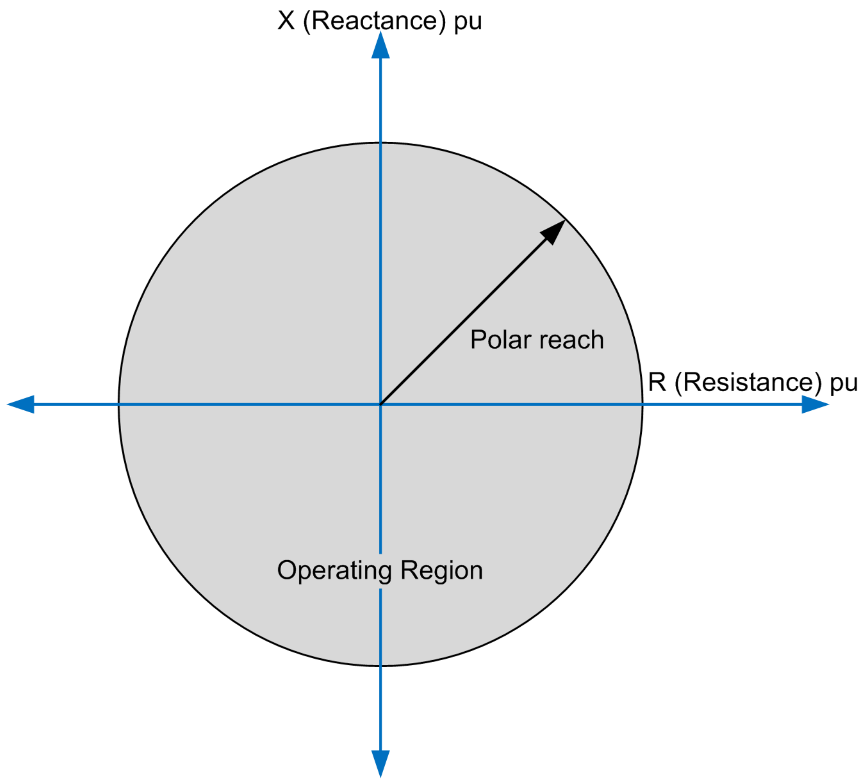


Figure 571: Origin-centric circular operating characteristics

Separate zones with an offset-mho characteristic can be designed using multiple instances of the UZPDIS function with *Offset enable* setting and parameterized with *Offset* and *Displacement* setting values as shown in Figure *Figure 572*. *Offset* is the distance of the top of the circle from R-axis. If the sign of the *Offset* is positive, the top of the circle is above the R-axis and if it is negative, the top of the circle will be below the R-axis. *Displacement* is the distance by which the center of the circle is displaced from the X-axis. If the sign of the *Displacement* setting is positive, the circle is shifted to the right of the X-axis and if the sign is negative, the circle is shifted to the left of the X-axis. For an origin-centric mho characteristic, *Offset enable* is kept disabled.

When using the mho-characteristics, the *Offset* and *Displacement* settings are as given in the UEXPDIS function, but *Polar reach* is half of UEXPDIS *Diameter* setting.

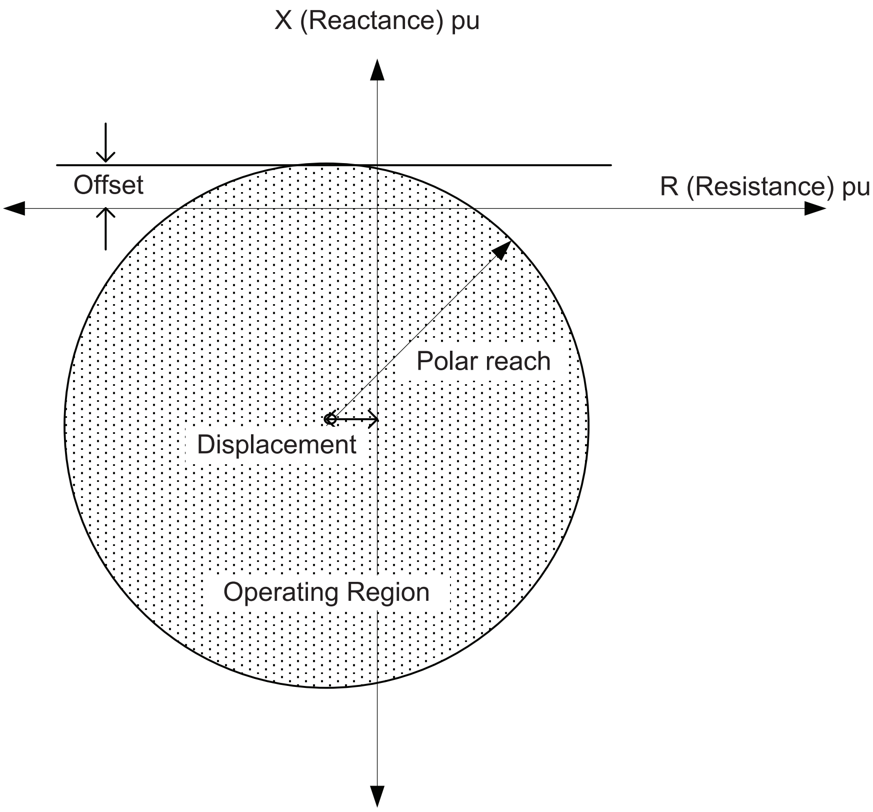


Figure 572: Designing zones with Offset and Displacement

The offset-mho characteristic shown in Figure *Figure 572* is designed with a positive value for *Offset* and a negative value for *Displacement*.

More than one impedance value is available when *Impedance Meas mode* is set to "3Phase-phase", and the function considers the lowest impedance value for starting and operating.

Timer

Once activated, the Timer activates START output. The time characteristic is according to DT. When the duration of the underimpedance condition exceeds the set definite *Operate delay time*, the OPERATE output is activated. If the impedance locus moves out of circular operating characteristics before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operating timer resets and the START output is deactivated.

The Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.7.4.6 Application

The three-phase underimpedance protection is used as a backup protection against short circuit faults at the generator terminals or on the high-voltage side of a step-up transformer. This function can be used either instead of the definite time voltage-dependent overcurrent protection or to obtain a limited protection zone and the optimum operating time instead of the non-directional overcurrent protection.

Comparison between overcurrent and underimpedance protection

Phase current for three-phase short circuit is shown in *Figure 573*. In this case, with an ordinary over current relay having the current setting as $1.2 \cdot I_n$, the time setting should be less than 0.2 seconds, since with a higher value the short-circuit current decays below the set value and the relay drops off. The current setting can also be reduced to $1.1 \cdot I_n$, although this provides no substantial rise in the time setting. In some situations, either of the above current settings is appropriate, but if longer tripping times are required to maintain the time selectivity, the underimpedance protection is needed.

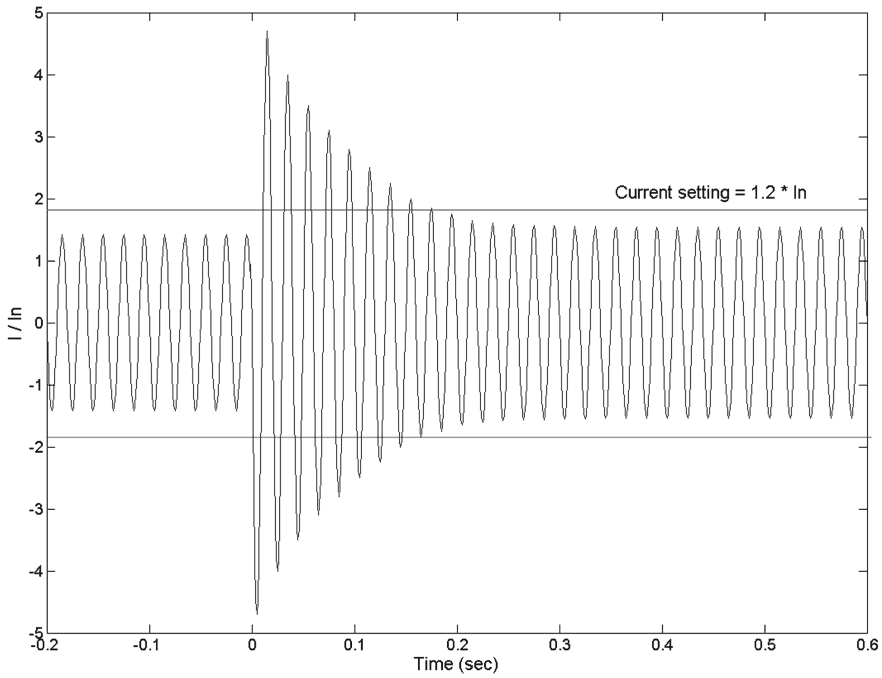


Figure 573: Short circuit current waveform, fault occurs at time 0 seconds (Current setting limit is multiplied by the square root of 2)

The phase voltage in a three-phase short circuit when a fault occurs at time = 0 s is shown in *Figure 574*. The voltage drop caused by a three-phase fault provides more time for determining the fault by means of an underimpedance protection.

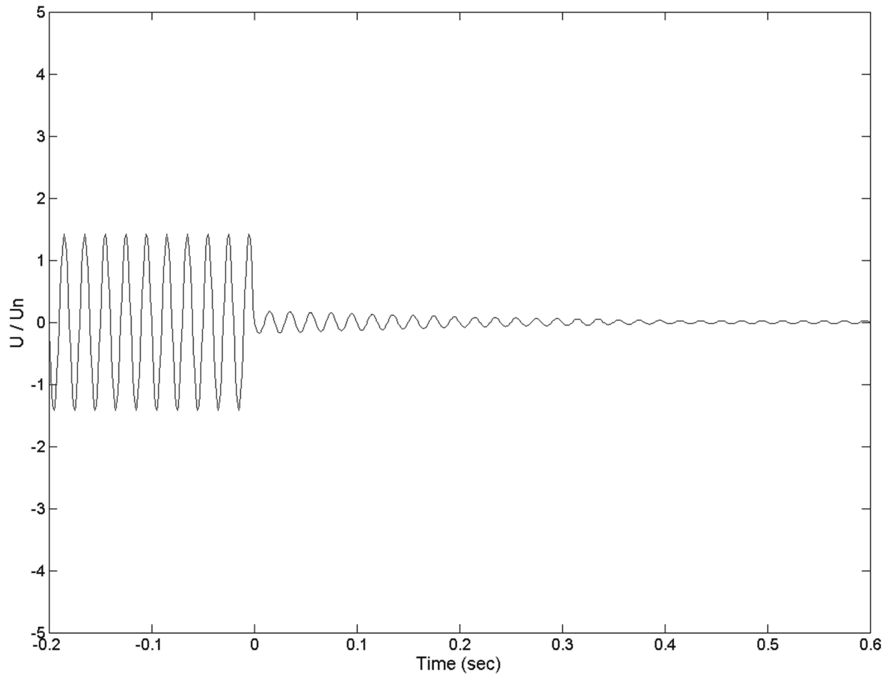


Figure 574: Short-circuit voltage waveform, fault occurs at time 0 seconds

In a typical impedance trajectory during a short circuit, the fault impedance remains inside the impedance circle for a longer time, in which case the underimpedance protection provides longer tripping delay times to maintain the time selectivity.

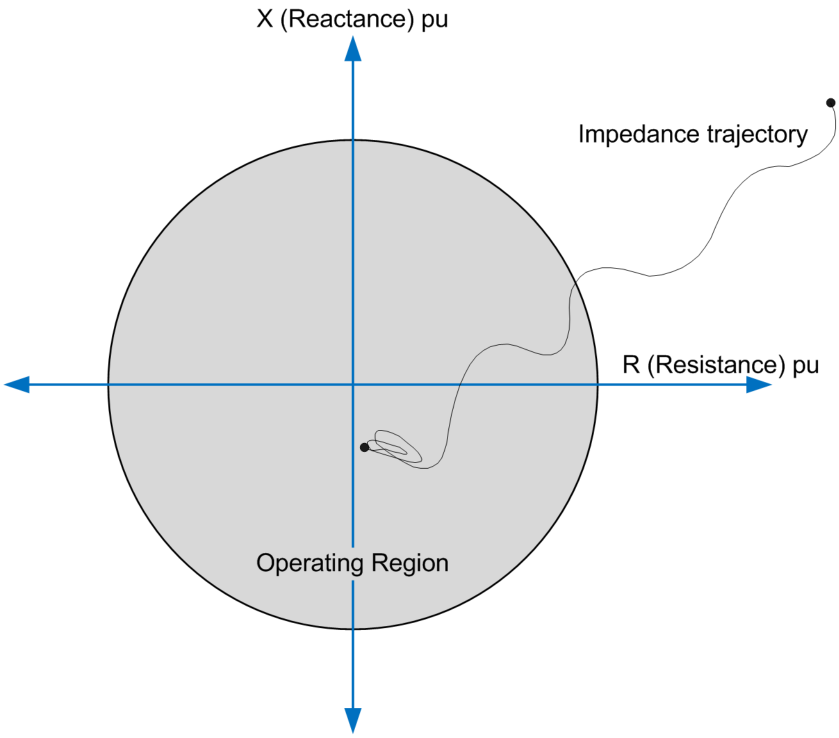


Figure 575: Typical impedance trajectory during a short circuit

Underimpedance protection for transformers

The underimpedance function is used as a short circuit protection instead of the overcurrent protection. It is also used as a backup to the differential protection of transformers.

The voltage and current phasors are measured with the VTs and CTs connected on the HV side of the transformer.

The phase and current shifts due to transformer D/Y connections and other factors complicate the settings for the faults in the secondary winding (as seen from the protection relay), and detailed calculations are necessary for a good coverage.

The *Polar reach* setting is set to a value equal to 150 percent of the transformer short circuit impedance. The setting also provides a backup protection for the busbar and feeder faults on the HV side.

Underimpedance protection for generators

The underimpedance protection is set to protect the zone between the generator windings and the generator side windings of the step-up transformer. The function mainly protects the generator bus, the low-voltage part of the step-up transformer and a part of the stator winding against any short circuits.

The voltages should be measured from the generator terminals and the phase currents from the neutral point of the generator.

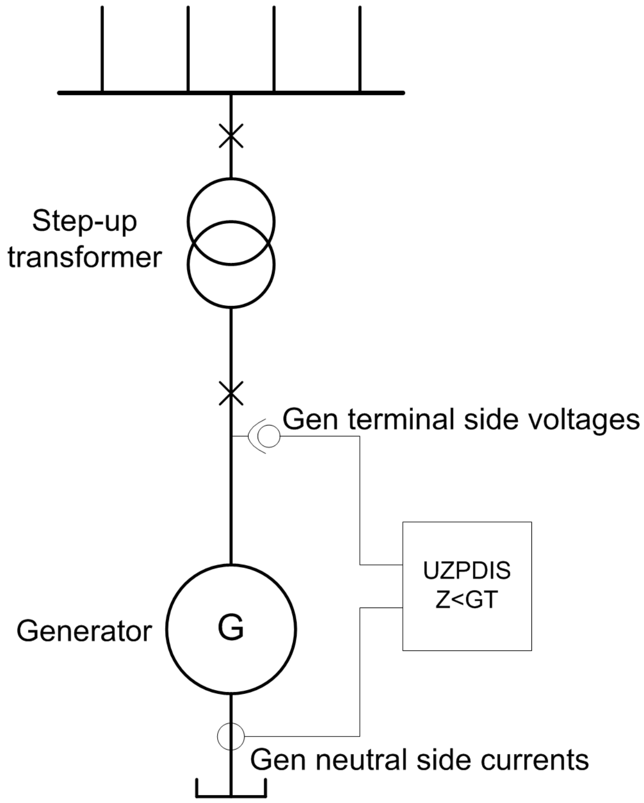


Figure 576: Current and voltage signals for underimpedance protection

To prevent malfunctioning of the underimpedance protection in case of nearby faults, the *Polar reach* setting is set to a value equal to 70 percent of the step-up transformer short circuit impedance.

In directly connected machines where the impedance towards the network is limited only by the lines or bus bars, it must be secured that the function does not cause any selectivity problems. In such cases, it is recommended to use the voltage-dependent overcurrent protection instead of the underimpedance protection.

Function blocking guidelines

The operation of the underimpedance protection must be restrained if the voltage in one or more phases suddenly drops close to zero without any significant change in the current observed at the same time. This situation is considered as a fuse failure or a miniature circuit breaker operation in the voltage transformer secondary circuit. The voltage drop could cause an unwanted operation of the function block since the calculated impedance could fall below the set operating limit even if there is no actual fault in the primary system.

The blocking operation is provided by an external function block, the fuse failure supervision SEQSPVC, whose output is connected to the `BLOCK` input of UZPDIS.

4.7.4.7 Signals

UZPDIS Input signals

Table 961: UZPDIS Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode

UZPDIS Output signals

Table 962: UZPDIS Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.7.4.8 UZPDIS Settings

Table 963: UZPDIS Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Polar reach	1...6000	%Zn	1	7	Impedance start value, i.e. radius of impedance circle
Operate delay time	40...200000	ms	10	200	Operate delay time

Table 964: UZPDIS Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Offset enable	0=Disable 1=Enable			false	Enable offset-mho characteristic
Offset	-1000...1000	%Zn	1	-10	Offset of top of the impedance cir-cle from the R-axis
Displacement	-1000...1000	%Zn	1	0	Displacement of impedance circle centre from the X-axis

Table 965: UZPDIS Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used meas-urement mode
Impedance Meas mode	2=1Phase-to-phase			4=3Phase-to-phase	Select voltage and current signals for

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=3Phase-to-phase				impedance calculation
Phase Sel for Z Clc	1=AB 2=BC 3=CA			1=AB	Select phase/ phase-phase voltages and currents for Z calculation.

Table 966: UZPDIS Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time

4.7.4.9 UZPDIS Monitored data

Table 967: UZPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time (in %)
Z_AMPL_AB	FLOAT32	0.00...200.00	xZn	Phase-to-phase A-B impedance amplitude
Z_AMPL_BC	FLOAT32	0.00...200.00	xZn	Phase-to-phase B-C impedance amplitude
Z_AMPL_CA	FLOAT32	0.00...200.00	xZn	Phase-to-phase C-A impedance amplitude
UZPDIS	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.7.4.10 Technical data

Table 968: UZPDIS Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: f_n ±2 Hz
	±3.0% of the set value or ±0.2 %Zb
Start time [1, 2]	Typically 50 ms
Reset time	Typically 40 ms
Reset ratio	Typically 1.04
Retardation time	<40 ms
Operate time accuracy	±1.0% of the set value or ±20 ms

[1] f_n = 50 Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

4.7.4.11 Technical revision history

Table 969: UZPDIS Technical revision history

Product connectivity level	Technical revision	Change
PCL4	C	Support for separate zones with an offset mho characteristic.

4.7.5 Directional negative sequence impedance protection DNZPDIS (ANSI Z2Q)

4.7.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional negative sequence impedance protection	DNZPDIS	Z2 ->	Z2Q

4.7.5.2 Function block

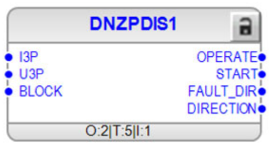


Figure 577: Function block

4.7.5.3 Functionality

Directional negative sequence impedance protection function (DNZPDIS) is used to detect the unsymmetrical fault such as the phase to phase fault, phase-ground fault and double phase to ground fault on power system network.

Operating principle is based on negative sequence impedance. Function compares the negative sequence impedance value against given setting values. Directional operation is based on following theory, impedance value is positive for forward faults and negative for reverse faults. Operate time is according to definite time characteristics.

4.7.5.4 Analog channel configuration

DNZPDIS has two analog group inputs which must be properly configured.

Table 970: Analog Inputs

Input	Description
I3P	Three phase currents
U3P	Three phase voltages

Table 971: Special conditions

Condition	Description
U3P connected real measurements	The function requires that at least two voltage channels are connected

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings.

4.7.5.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of DNZPDIS can be described by using a module diagram (see *Figure 578* below). All the modules in the diagram are explained in the next sections.

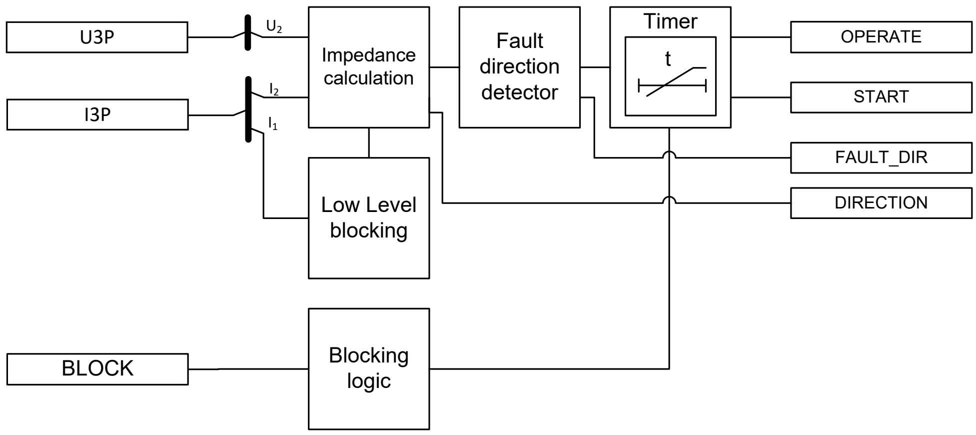


Figure 578: Functional module diagram

Low level blocking

This module receives positive sequence current (I_1) and negative sequence current (I_2). Both are calculated from fundamental frequency three phase currents.

Low level blocking is used to block the Impedance calculation if negative sequence current does not satisfy minimum level criteria. If negative sequence current exceeds setting *Min Ng Seq current Fw* value, impedance calculation is allowed in forward direction. Alternatively, if negative sequence current is exceeds setting *Min Ng Seq current Rv* value, impedance calculation is allowed in reverse direction.

The negative sequence current to positive sequence current ratio (I_2/I_1) should also exceed the setting *Restrain factor* to enable impedance calculation.

Impedance calculation

This module receives positive sequence voltage (U_1) and negative sequence voltage (U_2) which are calculated from fundamental frequency three phase voltages. Also positive sequence current (I_1) and negative sequence current (I_2) which are respectively calculated from fundamental frequency three phase currents.

Once activated the negative sequence impedance (Z_2) is calculated from the negative sequence current, the negative sequence voltage and Relay characteristic angle (RCA) using the below equation.

$$Z_2 = \left|\frac{U_2}{I_2}\right| * \cos(\angle U_2 + 180 - \angle I_2 - \angle RCA)$$

(Equation 278)

The RCA in the above equation can be obtained from *Characteristic angle* setting.

The Z_2 value in primary ohms is available as Z2_VALUE in monitored data.

Table 972: Direction value for monitored data view

Criterion for direction information	The value for DIRECTION
Default (low level blocking active)	0 = unknown
$Z_2 > 0$	1 = forward
$Z_2 < 0$	2 = backward

Fault direction detector

This module checks if the value of Z_2 meets the operation criteria. Detection to only forward direction can be achieved by setting the *Direction mode* to “Forward”. Thus, forward fault is detected if the value of Z_2 is higher than the *Ng Seq impedance Fw* setting. Respectively operation to only reverse direction can be activated by setting *Direction mode* is set to “Reverse”. Reverse fault is detected if the value of Z_2 is below the setting *Ng Seq impedance Rv* setting. In case *Direction mode* is set to “Non-directional”, operation is allowed if condition for forward or reverse direction is fulfilled.

The *Ng Seq impedance Fw* setting and *Ng Seq impedance Rv* settings are set in primary ohms.

FAULT_DIR gives the direction information during fault, if operation criteria is satisfied. that is, when the `START` output is active. The fault direction (FAULT_DIR) is available in monitored data and as function block output. FAULT_DIR values are the same as for `DIRECTION` output given in the *Table 972*. The FAULT_DIR is set to value 0 = unknown after the `START` output is deactivated.

Figure 579 illustrates the directional operating characteristics on negative sequence impedance level as shown in the vertical line.

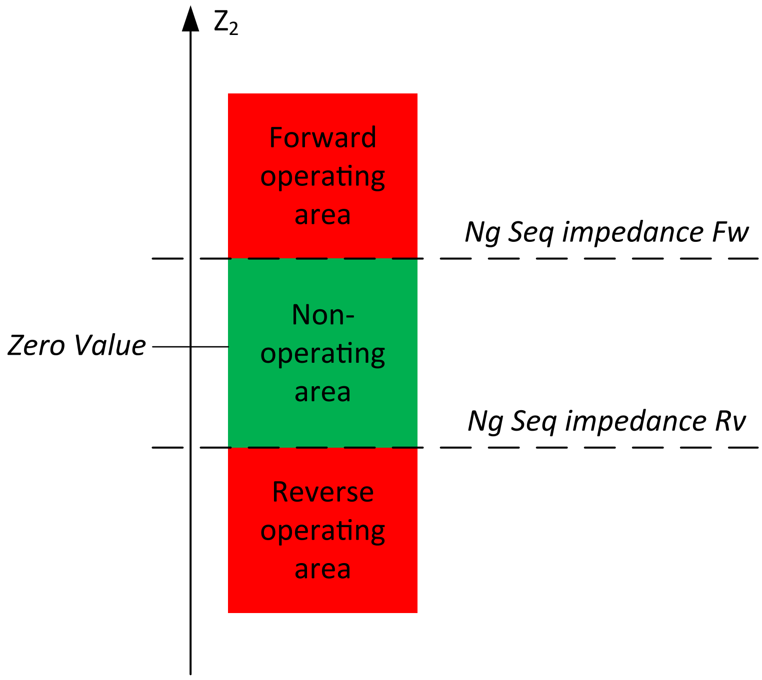


Figure 579: Fault direction estimation on negative sequence impedance level

Timer

Once activated, the Timer activates the START output. The timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated if the operating conditions persists.

If a drop-off situation happens, that is, a fault suddenly disappears before the operate delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated. The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the relay program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timer" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.7.5.6 Application

The directional negative sequence impedance function is normally used on incoming line or feeder connected to the busbar, which is made to operate in the specified direction for secured operation. The fault direction can be either referred as forward or reverse of the relay.

There are different directional elements used to determine the direction of faults, one such element is negative sequence impedance. The calculated negative sequence impedance is sensitive enough to identify fault in power system networks with strong source where less negative-sequence voltage and current will be present during faults.

By using suitable restraint factor, it is also possible to avoid false tripping with systems having un-transposed lines where some default negative sequence current will be present during normal operation.

Application example

Relay setting calculation for the DNZPDIS function is shown with below application example of parallel lines with two end sources of power system network.

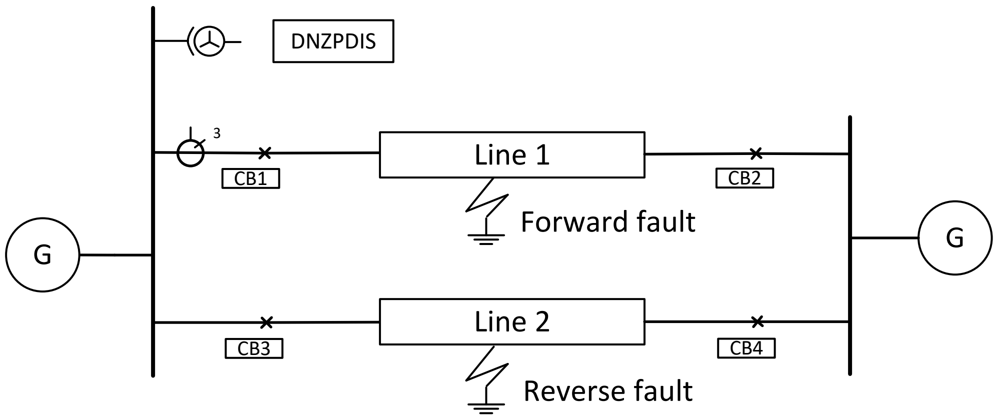


Figure 580: Power system network with parallel line and two sources

Setting value calculation

Line parameters:

Resistance = 0.126 ohm/km

Reactance = 0.600 ohm/km

Line length = 100 km

Total impedance (Z_1tot) of line1 or line2 is calculated below

$$Z_1tot = (0.126 + j0.60 \text{ ohm/km}) * 100 \text{ km}$$
$$= 12.6 + j60.1 \text{ in ohm}$$

(Equation 279)

Magnitude of positive sequence impedance (Z_1tot) = 60.4 ohm. The following settings are obtained to set the relay located at circuit breaker 1(CB1).

- *Ng Seq impedance Fw* can be set to 50% of the Z_1tot magnitude of the line 1 which equals in primary ohms 60.4/2 = 30.2.
- *Ng Seq impedance Rv* can be set to 50% of the Z_1tot magnitude of the line 2. Setting is for reverse fault in parallel line and therefore magnitude is negative. Thus setting value is in primary ohms -60.4/2 = -30.2.
- If *Characteristic angle* mode is set to “Fixed”, then the value for *Characteristic angle* setting can be calculated as below.

$$\begin{aligned} \text{Characteristic angle} &= \arctan(X/R) \\ &= \arctan(60.1/12.6) \\ &= 78.3 \text{ deg} \end{aligned}$$

(Equation 280)

The setting *Restrain factor* is set based on the minimum unbalance loading allowed in the power system network. In this case 10% unbalance is allowed in the given example system, hence the *Restrain factor* is set to 0.1.

Fault simulation

The phase to ground faults are simulated in the given example shown in *Figure 580*, the relay is located at the sending end of the line1 and the output is captured for forward and reverse direction fault.

The phase A to ground fault is applied on the line1 in the forward direction, the Z_2 value is positive as well as exceeds the *Ng seq impedance Fw* setting threshold, hence the START output issued, FAULT_DIR indicates the fault in the forward direction and the OPERATE output will be issued after the *Operate delay time* setting has passed as shown in below *Figure 581*.

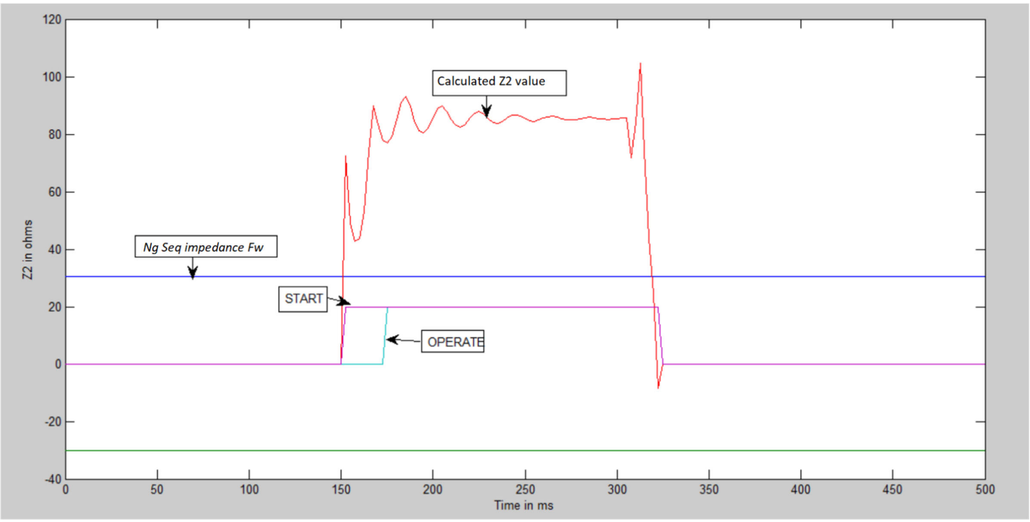


Figure 581: Phase A to ground fault on forward direction

The phase A to ground fault is applied on the line2 in the reverse direction, the calculated Z_2 value is negative as well as lower the *Ng seq impedance Rv* setting threshold, hence the START output issued, FAULT_DIR indicates the fault in the reverse direction and the OPERATE output will be issued after the *Operate delay time* setting has passed as shown in below *Figure 582*.

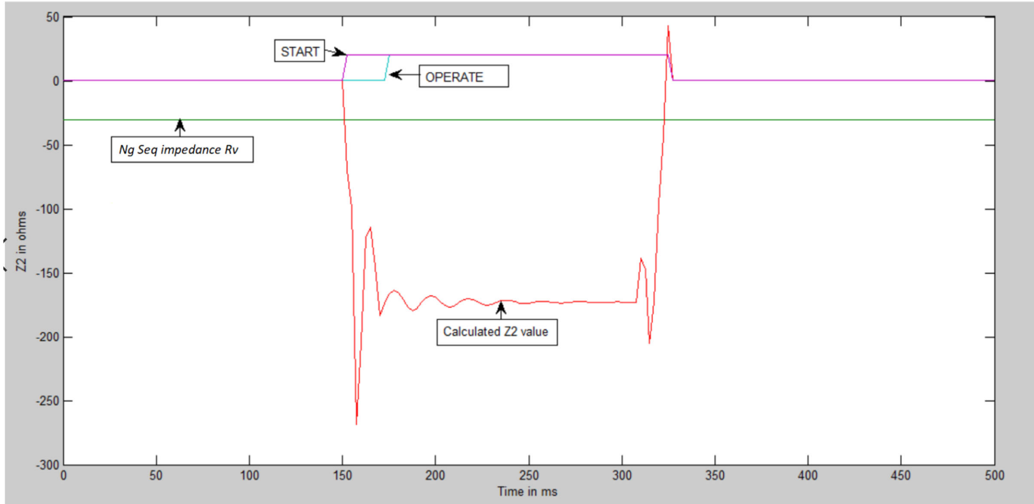


Figure 582: Phase A to ground fault on reverse direction

4.7.5.7 Signals

DNZPDIS Input signals

Table 973: DNZPDIS Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

DNZPDIS Output signals

Table 974: DNZPDIS Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
FAULT_DIR	Enum	Detected fault direction
DIRECTION	Enum	Direction information

4.7.5.8 Settings

DNZPDIS Settings

Table 975: DNZPDIS Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Direction mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Direction mode
Restrain factor	0.02...0.50		0.01	0.20	The restrain factor
Operate delay time	60...300000	ms	10	60	Operate delay time
Ng Seq impedance Fw	0.01...3000.00	ohm	0.01	40.00	Forward negative sequence impedance primary threshold in ohm
Ng Seq impedance Rv	-3000.00...-0.01	ohm	0.01	-40.00	Reverse negative sequence impedance primary threshold in ohm
Min Ng Seq current Fw	0.05...1.00	xIn	0.01	0.05	Minimum forward negative sequence current threshold
Min Ng Seq current Rv	0.05...1.00	xIn	0.01	0.05	Minimum reverse negative sequence current threshold
Characteristic angle	1...90	deg	1	67	Characteristic angle

Table 976: DNZPDIS Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 977: DNZPDIS Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.7.5.9 Monitored data

DNZPDIS Monitored data

Table 978: DNZPDIS Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time (in %)
Z2_VALUE	FLOAT32	-99999.00...99999.00	ohm	Calculated negative sequence impedance value
DNZPDIS	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.7.5.10 Technical data

Table 979: DNZPDIS Technical data

Characteristics	Value
Operation accuracy	At the frequency $f = f_n$
	±3% of the set value or ±0.05 Ω (When $\|\angle Z_2 - \angle RCA\|$ is outside 80 to 100 degree)
Start time [1, 2, 3]	<75 ms
Operate time accuracy [3]	±1.0% of the set value or ±20 ms
Reset ratio	0.96
Reset time	Typically 30 ms

4.7.6 Power swing detection DSTRPSB (ANSI 68)

4.7.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Power swing detection	DSTRPSB	Zpsb	68

4.7.6.2 Function block

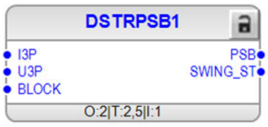


Figure 583: Function block

4.7.6.3 Functionality

The power swing detection function DSTRPSB detects power swing condition and can be used for blocking the distance protection function. The power swing detection function comprises an inner and an outer impedance characteristic. The supported zone characteristic shapes for inner and outer characteristic are quadrilateral and mho (circular). The power swing detection function is supervised by a load encroachment logic which ensures that the load impedance does not enter the characteristic of the power swing detection function during normal power system operation.

---

[1] Results based on statistical distribution of 1000 measurements
[2] Measured with static signal output (SSO)
[3] During fault, Z_2= 2.0 × *Ng Seq impedance Rv/Fw*

The function calculates the positive sequence impedance. Calculation is based on fundamental frequency components of positive sequence current and voltage. If the measured impedance stays between inner and outer characteristic longer than predetermined time and moves farther inside the inner characteristic, then a power swing condition is indicated.

4.7.6.4 Analog channel configuration

DSTRPSB has two analog group inputs which must be properly configured.

Table 980: Analog Inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

There are a few special conditions which must be noted with the configuration.

Table 981: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

4.7.6.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of DSTRPSB can be described by using a module diagram (see figure below). All the modules in the diagram are explained in the next sections.

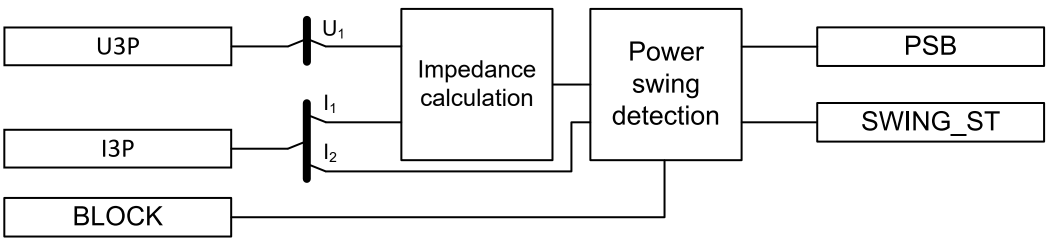


Figure 584: Function module diagram

Impedance calculation

This module receives positive sequence voltage which is calculated from fundamental frequency three phase voltages and positive sequence current calculated respectively from fundamental frequency three phase currents. For the module to calculate impedance it is required that the positive-sequence current is above 0.1xIn.

Operation is based on positive sequence impedance (Z_1) which is calculated using positive sequence voltage and current as follows:

$$\underline{Z}_1 = \frac{\underline{U}_1}{\underline{I}_1}$$

(Equation 281)

The calculated positive-sequence impedance amplitude Z1_AMPL and angle Z1_ANGLE are available in primary ohms and degrees, respectively, in the Monitored data view.

The calculated impedance is converted to ohms as the operating characteristics are defined with the ohm settings.

Power swing detection

Power swing detection function comprises an inner and outer quadrilateral /circular measurement characteristic. The positive sequence impedance is continuously monitored for detecting a power swing condition. During normal power system operation, the impedance is outside of outer characteristic. When the impedance enters outer characteristic, output SWING_ST is activated, and the power swing detection timer is triggered. The SWING_ST output will be deactivated if the impedance leaves the zone between inner and outer characteristic. If the impedance remains between the inner and outer characteristics longer than the time defined by the setting *Swing time* , and the impedance enters inner characteristic, output PSB is activated. The PSB output will be deactivated after the impedance leaves outer characteristic for the time defined by *Pulse time* setting.

When an unbalanced fault occurs during power swing, the PSB output should be deactivated to allow tripping. For the purpose module is monitoring negative sequence current which is calculated from fundamental frequency three phase currents. Negative sequence current level can be monitored if *Ng Seq current Spvn* is set to "Enable". When the negative sequence current is above the *Max Ng Seq current* setting longer than the time delay defined by the setting *Neg Seq current time*, the Power swing detection module is disabled. The module is disabled until negative sequence current drops below the setting value. The *Max Ng Seq current* setting should be set above the maximum negative sequence current which may appear during power swing.

Slow power swing can be used as criterion for disabling power swing detection. Monitoring is activated by setting *Slow swing Spvn* to "Enable". If the positive sequence impedance enters and remains inside outer characteristic longer than the time delay defined by the setting *Slow swing time*, the Power swing detection module is disabled. The module is disabled until the positive sequence impedance moves outside outer characteristics. The setting *Slow swing time* should be coordinated with network or cable current rating characteristics. Too long lasting large current may need to be cleared even if situation is classified as power swing.

In case of heavily loaded lines, the optional load encroachment logic can be enabled with the *Load discrimination* setting. The logic reserves an area for load impedance defined by the *Outer Fw Ld Ris Rch, Outer Rv Ld Ris Rch, Inner Fw Ld Ris Rch, Inner Rv Ld Ris Rch, Load angle1* and *Load angle2* settings.

Quadrilateral characteristic

If the *Pe Swg impedance Chr* is ‘Quadrilateral’, DSTRPSB has a double-polygon characteristic.

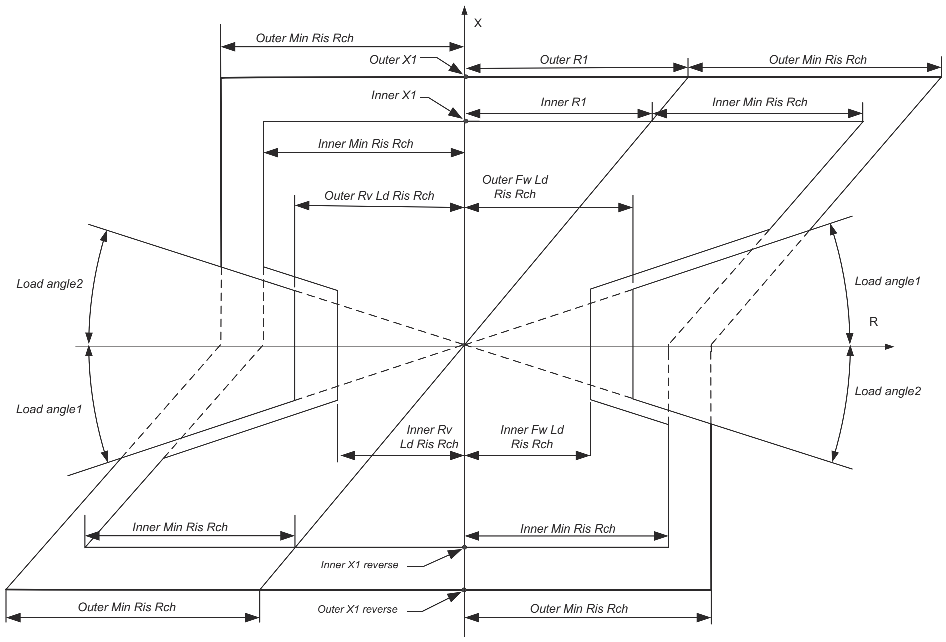


Figure 585: Quadrilateral operation characteristics

The reach of inner polygon in the reactive direction is defined by the line reach independently with the settings *Inner R1, Inner X1, Inner X1 reverse*. The resistive reach of inner polygon is defined at the minimum resistive reach with settings *Inner Min Ris Rch*. The reach of outer polygon in the reactive direction is defined by the line reach independently with the settings *Outer R1, Outer X1, Outer X1 reverse*. The resistive reach of outer polygon is defined at the minimum resistive reach with settings *Outer Min Ris Rch*.

Mho circular characteristics

When the *Pe Swg impedance Chr* is "Mho (circular)", the DSTRPSB has a double circular characteristic.

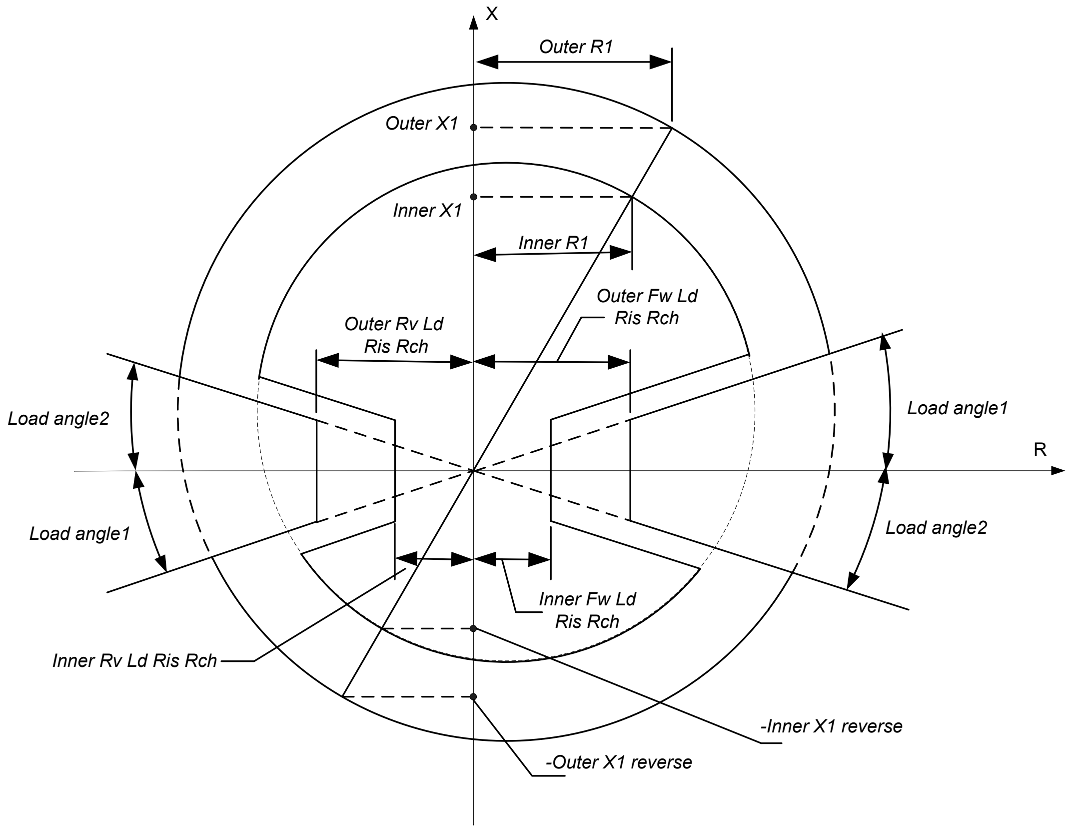


Figure 586: Mho operation characteristics

The reach of inner circle is defined by the settings *Inner R1, Inner X1, Inner X1 reverse*. Angle defined by settings *Inner R1* and *Inner X1* defines also reverse zone angle. The reach of outer circle is defined by the settings *Outer R1, Outer X1, Outer X1 reverse*. Angle defined by settings *Outer R1* and *Outer X1* defines also reserve zone angle.

The PSB and SWING_ST outputs can be blocked by activating BLOCK input. Blocking also resets internal timers and impedance calculation.

4.7.6.6 Application

Describe different application possibilities of the function. The application information answers one or more of the following questions:

- The problem of the application
- The purpose of the function
- Solution for the problem in general level
- Where can the function be used?
- When can the function be used?
- The application information shall NOT describe what the user should consider or should calculate, plan, dimension etc. to make the function work in the applications.

Power swing detection functions detect power swing conditions by using the fact that the voltage/current variation during a power swing is slow compared to the step change during a fault. Both faults and power swings may cause the positive sequence impedance to enter into the operating characteristic of a distance relay element. The apparent impedance moves from the pre-fault value to a fault value in a very short time, a few milliseconds, during a fault condition. However, the rate of change of the positive sequence impedance is much slower during a power swing condition than during a fault. It should be noted that the impedance measurement should not be used by itself to distinguish between a power swing condition from a phase fault. The fundamental method for discriminating between faults and power swings is to track the rate of change of the measured impedance.

The function measuring the rate of change of the positive sequence impedance comprises an inner and an outer impedance characteristic with a timer. If the positive sequence impedance remains between the inner and outer characteristics for a predetermined time and enters the inner characteristic, the function declares a power swing condition and asserts an output that can be used to block the distance protection. Figure below gives an example of power swing detection.

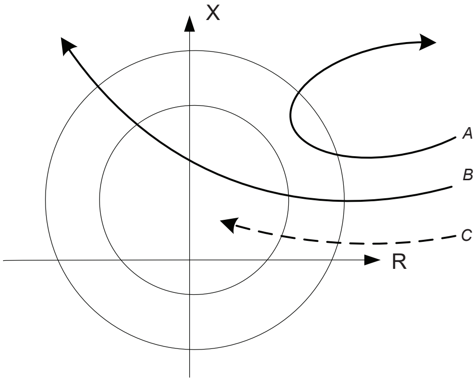


Figure 587: Example of power swing detection

In the above figure, the power swing detection characteristics and three typical positive sequence impedance trajectories are plotted. For trajectory A, the impedance moves into the power swing detection zone and leaves slowly, indicating the occurrence of a swing that quickly stabilizes. For trajectory C, impedance rapidly moves into, and remains in, the inner characteristic indicating an actual fault and not a power swing condition. For trajectory B, the impedance moves slowly into the power swing detection zone and exits the zone indicating that the network is becoming unstable. Only in this case power swing blocking functionality should be activated in order to avoid unwanted/unselective operation of distance protection.

The settings of outer impedance measurement characteristic of DSTRPSB should be set so that load impedance does not enter the outer characteristic during normal operation of the power system and covers the inner characteristic entirely. The settings of inner impedance measurement characteristic should be set to make the inner characteristic cover the distance protection zone entirely which will be blocked during power swing.

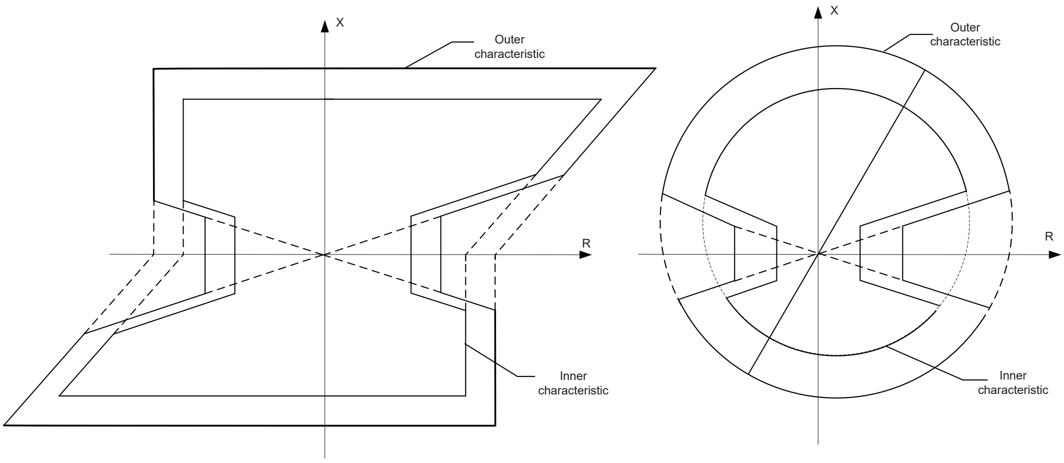


Figure 588: Relationship between inner and outer characteristic

4.7.6.7 Signals

DSTRPSB Input signals

Table 982: DSTRPSB Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

DSTRPSB Output signals

Table 983: DSTRPSB Output signals

Name	Type	Description
PSB	BOOLEAN	Power swing detected
SWING_ST	BOOLEAN	Impedance between inner and outer characteristic

4.7.6.8 Settings

DSTRPSB Settings

Table 984: DSTRPSB Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Inner R1	0.01...5999.99	ohm	0.01	30.00	Positive sequence resistive zone reach, inner border
Inner X1	0.01...5999.99	ohm	0.01	30.00	Positive sequence reactive zone reach, inner border
Inner X1 reverse	0.01...5999.99	ohm	0.01	30.00	Positive sequence reactive zone reach in reverse direction, inner border
Inner Min Ris Rch	0.01...5999.99	ohm	0.01	30.00	Minimum resistive reach, inner border
Outer R1	0.02...6000.00	ohm	0.01	40.00	Positive sequence resistive zone reach, outer border
Outer X1	0.02...6000.00	ohm	0.01	40.00	Positive sequence reactive zone reach, outer border
Outer X1 reverse	0.02...6000.00	ohm	0.01	40.00	Positive sequence reactive zone reach in reverse direction, outer border
Outer Min Ris Rch	0.02...6000.00	ohm	0.01	40.00	Minimum resistive reach, outer border
Swing time	20...300000	ms	10	40	Power swing detection timer for impedance stays between the inner characteristic and outer characteristic
Load discrimination	0=False 1=True			0=False	Enable load discrimination
Inner Fw Ld Ris Rch	0.01...6000.00	ohm	0.01	15.00	Resistive forward reach of inner characteristic for load discrimination
Inner Rv Ld Ris Rch	0.01...6000.00	ohm	0.01	15.00	Resistive reverse reach of inner characteristic for load discrimination
Outer Fw Ld Ris Rch	0.01...6000.00	ohm	0.01	25.00	Resistive forward reach of outer characteristic for load discrimination
Outer Rv Ld Ris Rch	0.01...6000.00	ohm	0.01	25.00	Resistive reverse reach of outer characteristic for load discrimination
Max impedance angle	5...85	deg	1	25	Maximum impedance angle, load discrimination
Min impedance angle	-85...-5	deg	1	-25	Minimum impedance angle, load discrimination

Table 985: DSTRPSB Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Pe Swg impedance Chr	1=Quadrilateral			1=Quadrilateral	Impedance characteristic

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Mho (circular)				

Table 986: DSTRPSB Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Ng Seq current Spvn	0=False 1=True			0=False	Negative sequence current supervision enabled
Max Ng Seq current	0.01...10.00	xIn	0.01	0.20	Maximum allowed negative sequence current for power swing detection
Ng Seq current time	20...1000	ms	10	20	Time for negative sequence current supervision blocking the function
Slow swing Spvn	0=False 1=True			0=False	Slow swing supervision enabled
Slow swing time	80...60000	ms	10	2000	Time for slow swing supervision blocking the function
Pulse time	20...60000	ms	10	500	Time for holding output PSB

4.7.6.9 Monitored data

DSTRPSB Monitored data

Table 987: DSTRPSB Monitored data

Name	Type	Values (Range)	Unit	Description
Z1_AMPL	FLOAT32	0.00...99999.00	ohm	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-180.00...180.00	deg	Positive sequence impedance phase angle
DSTRPSB	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.7.6.10 Technical data

Table 988: DSTRPSB Technical data

Characteristic	Value
Operation accuracy	At the frequency f = fn
	Current: ±1.5% of the set value or ±0.002 × I_n Impedance:

Table continues on the next page

Characteristic	Value
	±3% of the set value or ±0.05 Ω Phase angle: ±2°
Reset ratio	Typically 0.96/1.04
Operate time accuracy[1]	±1.0% of the set value or 20 ms

4.8 Power protection

4.8.1 Underpower protection DUPPDPR (ANSI 32U)

4.8.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Underpower protection	DUPPDPR	P<	32U

4.8.1.2 Function block

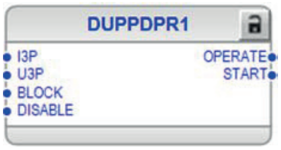


Figure 589: Function block

4.8.1.3 Functionality

The underpower protection function DUPPDPR is used for protecting generators and prime movers against the effects of very low power outputs or reverse power condition.

The function operates when the measured active power falls below the set value. The operating characteristics are according to definite time DT.

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself.

4.8.1.4 Analog channel configuration

DUPPDPR has two analog group inputs which must be properly configured.

[1] Measured with static power output (SPO)

Table 989: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 990: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with the corresponding one voltage channel connected if the measurement mode is set to "PhsAB", "PhsBC", "PhsCA", "PhsA", "PhsB" or "PhsC".
	The function requires that at least two (the third voltage will be derived) or all three voltage channels are connected for the other measurement modes.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.8.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of DUPPDPR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

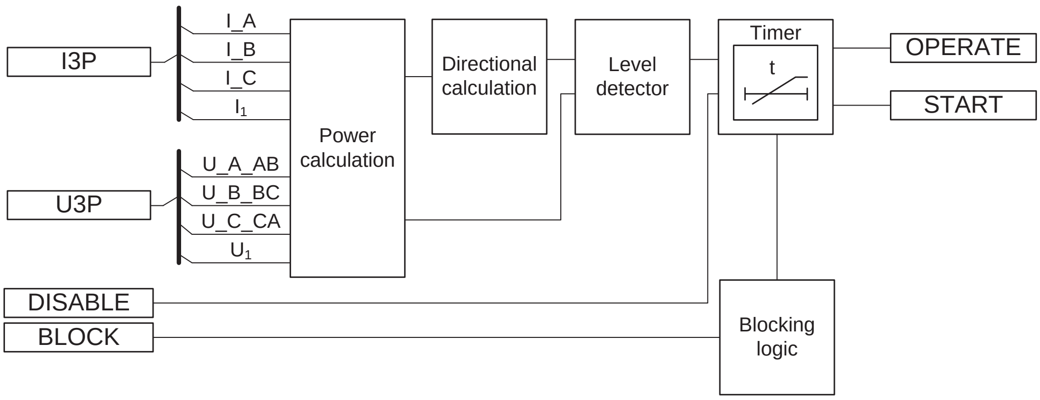


Figure 590: Functional module diagram

Power calculation

This module calculates the apparent power based on the selected voltage and current measurements as described in *Table 991*. The *Measurement mode* setting determines which voltage and current measurements are to be used.

It is also possible to use positive-sequence components for calculating apparent power, which makes the determination of power insensitive to the possible asymmetry in currents or voltages and corresponds to the real load of the prime mover of the generator. S‾ ‾‾s‾

Table 991: Power calculation

Measurement mode setting	Power calculation
PhsA, PhsB, PhsC	$\bar{S} = \bar{U}_a \cdot \bar{I}_a^* + \bar{U}_b \cdot \bar{I}_b^* + \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Arone	$\bar{S} = \bar{U}_{ab} \cdot \bar{I}_a^* - \bar{U}_{bc} \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Pos Seq	$\bar{S} = 3 \cdot \bar{U}_1 \cdot \bar{I}_1^*$ $P = Re(\bar{S})$
PhsAB	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ab} \cdot (\bar{I}_a^* - \bar{I}_b^*)$ $P = Re(\bar{S})$
PhsBC	$\bar{S} = \sqrt{3} \cdot \bar{U}_{bc} \cdot (\bar{I}_b^* - \bar{I}_c^*)$ $P = Re(\bar{S})$
PhsCA	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ca} \cdot (\bar{I}_c^* - \bar{I}_a^*)$ $P = Re(\bar{S})$
PhsA	$\bar{S} = 3 \cdot \bar{U}_a \cdot \bar{I}_a^*$ $P = Re(\bar{S})$
PhsB	$\bar{S} = 3 \cdot \bar{U}_b \cdot \bar{I}_b^*$

Table continues on the next page

Measurement mode setting	Power calculation
	$P = Re(\bar{S})$
PhsC	$\bar{S} = 3 \cdot \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended (default).

Depending on the set *Measurement mode*, the power calculation calculates active power, reactive power and apparent power values from the available set of measurements. The calculated powers S, P, Q and the power factor angle, PF_ANGL, are available in the Monitored data.

Directional calculation

Directional calculation determines the direction of the measured power. The measured power is considered to be in the forward direction if the active power is positive, else it is considered to be in the reverse direction.

A typical error is, for example, that the VT or CT poles are wrongly connected. This is seen as a power flow opposite to that of the intended direction. The *Pol Reversal* setting can be used to correct the situation. By setting the value to "True", the measured apparent power is turned 180 degrees.

Level detector

Level detector compares the calculated value of the active power with a set *Start value*. If the calculated value of the active power falls below *Start value* in the forward direction or if the measured power is in the reverse direction, Level detector enables the Timer module.

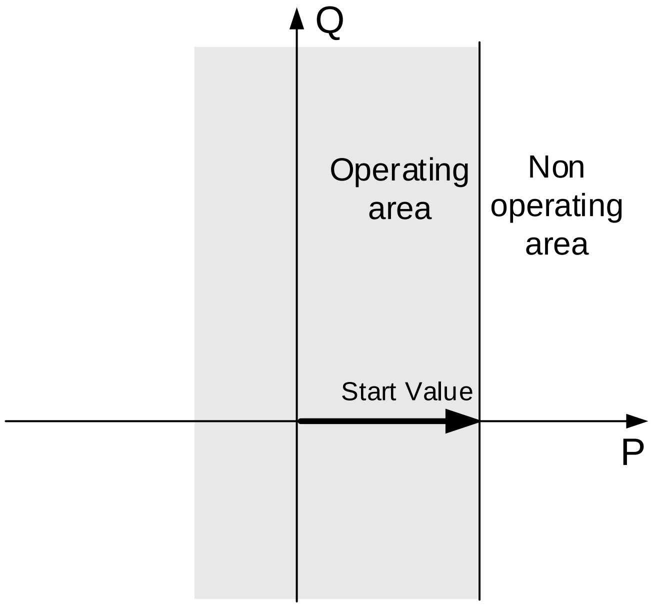


Figure 591: Operating characteristics of DUPPDPR with setting Start value

Timer

Once activated, the Timer activates the START output. The time characteristics are according to DT. When the operation timer has reached the value of *Operate delay time*, the OPERATE output is activated. In a drop-off situation, that is, if the underpower condition disappears before the operation delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The Timer calculates the START_DUR value which indicates the percentage of the time elapsed since the activation of the START output with respect to *Operate delay time*. The value is available in the Monitored data.

The DISABLE input can be used to coordinate the correct operation during the generator start-up situation. By activating the DISABLE signal, both the START and OPERATE outputs are blocked. Once the DISABLE signal is deactivated, the Timer remains blocked for an additional time duration as set through the setting *Disable time*.

Blocking logic

There are three operation modes in the blocking functionality. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.8.1.6 Application

The task of a generator in a power plant is to convert mechanical energy into electrical energy. Sometimes the mechanical power from the prime mover may decrease so much that it does not cover the internal losses. The task of an underpower protection is to protect the generator from very low power output conditions.

Steam turbines become easily overheated if the steam flow becomes too low or if the steam ceases to flow through the turbine. Hydro turbine of the Kaplan type may be damaged due to the fact that the turbine blade surfs on the water and sets up axial pressure on the bearing. Diesel engines may be damaged due to insufficient lubrication.

If the generator size is very large, it is uneconomical to continue running it with low generated power. In the reverse power condition, large generators draw a considerable amount of power from the rest of the system to feed their internal losses. Hence, it is desirable to disconnect the generator in such situations.

In case of the parallel-connected generators, for example, the load of one generator may be so low that it is better to disconnect it and let the remaining generators feed the network.

Where a low value of power setting is required, for example less than 2%, the correction parameters should be used to compensate for the measuring errors. The manufacturer of the measuring devices is to be contacted for information on the measuring errors.

If the measuring errors are not compensated for, the underpower setting should not be lower than the sum of the current-measuring and voltage-measuring errors.

For example, if the error of the current-measuring device is 2% and that of the voltage-measuring device is 1%, the minimum setting is (2 + 1)% = 3%.

4.8.1.7 Signals

DUPPDPR Input signals

Table 992: DUPPDPR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
DISABLE	BOOLEAN	0=False	Signal to block the function during generator startup

DUPPDPR Output signals

Table 993: DUPPDPR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.1.8 DUPPDPR Settings

Table 994: DUPPDPR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...2.00	xSn	0.01	0.10	Start value
Operate delay time	40...300000	ms	10	40	Operate delay time

Table 995: DUPPDPR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off

Table 996: DUPPDPR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB 9=PhsC			3=Pos Seq	Selection of power calculation method
Reset delay time	0...60000	ms	10	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Reverse the definition of the power direction
Disable time	0...60000	ms	1000	0	Additional wait time after CB closing

4.8.1.9 DUPPDPR Monitored data

Table 997: DUPPDPR Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
P	FLOAT32	-160.000...160.000	xSn	Active power
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
S	FLOAT32	0.000...160.000	xSn	Apparent power

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
PF_ANGLE	FLOAT32	-180.00...180.00	deg	Power factor angle
DUPPDPR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.1.10 Technical data

Table 998: DUPPDPR Technical data

Characteristic	Value
Operation accuracy [1]	Depending on the frequency of the measured current and voltage: f_n ±2 Hz
	Power measurement accuracy ±3% of the set value or ±0.002 × S_n Phase angle: ±2°
Start time [2, 3]	Typically 45 ms
Reset time	Typically 30 ms
Reset ratio	Typically 1.04
Operate time accuracy	±1.0% of the set value of ±20 ms
Suppression of harmonics	-50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.8.2 Reverse power-directional overpower protection DOPPDPR (ANSI 32R/32O)

4.8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Reverse power/directional overpower protection	DOPPDPR	P>/Q>	32R/32O

1 *Measurement mode* = “Pos Seq” (default)
2 U = U_n, f_n = 50 Hz, results based on statistical distribution of 1000 measurements
3 Includes the delay of the signal output contact

4.8.2.2 Function block

Figure 592: Function block

4.8.2.3 Functionality

The reverse power/directional overpower protection function DOPPDPR can be used for generator protection against delivering an excessive power beyond the generator's capacity to the grid, against the generator running like a motor, and against the motor running like a generator and for protecting a motor which consumes more reactive power due to loss of field. It can also be used in feeder protection for indicating overload on the distribution system, to indicate that a customer is supplying power into the grid and for protecting the transformer from delivering an excessive load.

The function starts and operates when the measured power exceeds the set limit and in a specified direction. The operate time characteristics are according to definite time (DT).

This function contains a blocking functionality. It is possible to block the function outputs, timer or the function itself.

4.8.2.4 Analog channel configuration

DOPPDPR has two analog group inputs which must be properly configured.

Table 999: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1000: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with the corresponding one voltage channel connected if the *Measurement mode* is set to "PhsAB", "PhsBC", "PhsCA", "PhsA", "PhsB" or "PhsC".
	The function requires that at least two (the third voltage will be derived) or all three voltage channels are connected for the other measurement modes.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.8.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DOPPDPR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

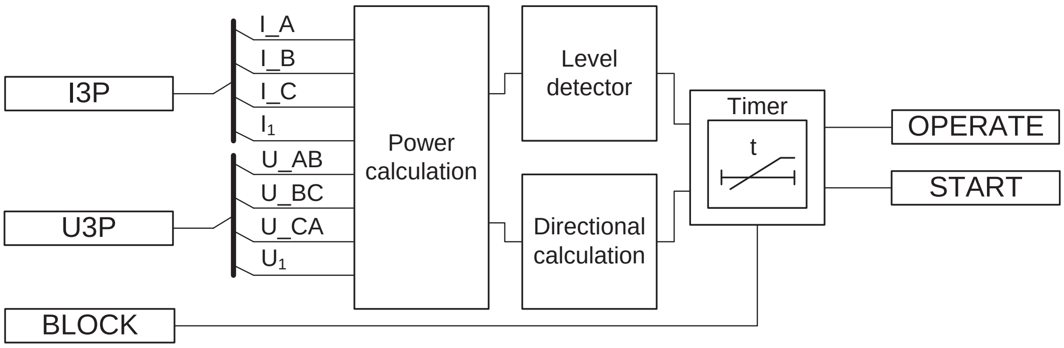


Figure 593: Functional module diagram

Power calculation

This module calculates the apparent power based on the selected voltages and currents. The *Measurement mode* setting determines which voltages and currents are used. It is also possible to use positive-sequence components for calculating the apparent power which makes the determination of power insensitive to a possible asymmetry in currents or voltages and corresponds to the real load on the prime mover of the generator.

Table 1001: Power calculation

Measurement mode setting	Power calculation
PhsA, PhsB, PhsC	$\bar{S} = \bar{U}_a \cdot \bar{I}_a^* + \bar{U}_b \cdot \bar{I}_b^* + \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$
Arone	$\bar{S} = \bar{U}_{ab} \cdot \bar{I}_a^* - \bar{U}_{bc} \cdot \bar{I}_c^*$ $P = Re(\bar{S})$

Table continues on the next page

Measurement mode setting	Power calculation
Pos Seq	$\bar{S} = 3 \cdot \bar{U}_1 \cdot \bar{I}_1^*$ $P = Re(\bar{S})$
PhsAB	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ab} \cdot (\bar{I}_a^* - \bar{I}_b^*)$ $P = Re(\bar{S})$
PhsBC	$\bar{S} = \sqrt{3} \cdot \bar{U}_{bc} \cdot (\bar{I}_b^* - \bar{I}_c^*)$ $P = Re(\bar{S})$
PhsCA	$\bar{S} = \sqrt{3} \cdot \bar{U}_{ca} \cdot (\bar{I}_c^* - \bar{I}_a^*)$ $P = Re(\bar{S})$
PhsA	$\bar{S} = 3 \cdot \bar{U}_a \cdot \bar{I}_a^*$ $P = Re(\bar{S})$
PhsB	$\bar{S} = 3 \cdot \bar{U}_b \cdot \bar{I}_b^*$ $P = Re(\bar{S})$
PhsC	$\bar{S} = 3 \cdot \bar{U}_c \cdot \bar{I}_c^*$ $P = Re(\bar{S})$

If all three phase voltages and phase currents are fed to the protection relay, the positive-sequence alternative is recommended.

The calculated powers S, P, Q and the power factor angle PF_ANGL are available in the Monitored data view.

Level detector

The Level detector compares the magnitude of the measured apparent power to the set *Start value*. If the measured value exceeds the set *Start value*, the Level detector sends an enabling signal to the Timer module.

Directional calculation

The Directional calculation module monitors the direction of the apparent power. When the apparent power flow is in the operating area, the module sends the enabling signal to the Timer module. The directional operation can be selected with the combination of the settings *Directional mode* and *Power angle*. The selectable options for the *Directional mode* setting are "Forward" and "Reverse". The *Power angle* setting can be used to set the power direction between the reactive and active power.

A typical error is, for example, that the VT or CT poles are wrongly connected. This is seen as a power flow opposite to that of the intended direction. The *Pol Reversal* setting can be used to correct the situation. By setting the value to "True", the measured apparent power is turned 180 degrees.

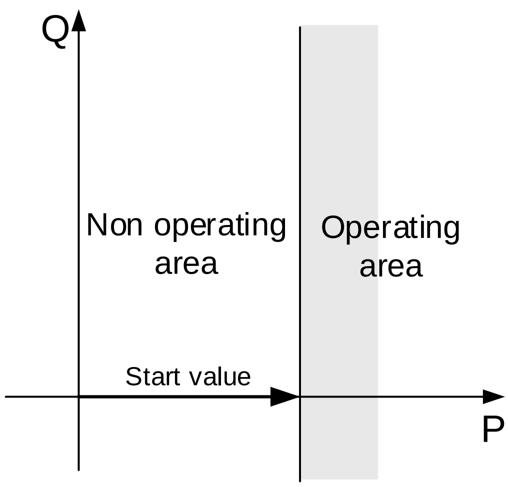


Figure 594: Operating characteristics with the Start Value setting, the Power angle setting being 0 and Directional mode "Forward"

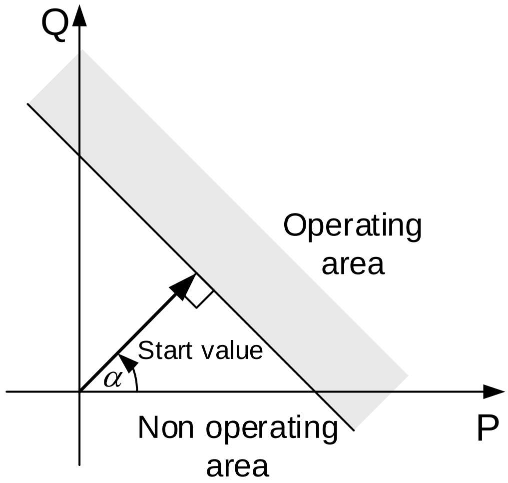


Figure 595: Operating characteristics with the Start Value setting, Power angle (α) being +45 and Directional mode "Forward"

Timer

Once activated, the Timer activates the START output. The time characteristics are according to DT. When the operation timer has reached the value of *Operate delay time*, the OPERATE output is activated. If a drop-off situation happens, that is, the value of power drops below *Start value* before the operate delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operate timer resets and the START output is deactivated.

The Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time (DT). The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode**, which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operate timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.8.2.6 Application

DOPPDPR is used to provide protection against an excessive power flow in the set operating direction. The main application is the protection of generators and turbines. It can also be used in feeder protection applications, for example, the ring network.

DOPPDPR in the forward direction can be used to protect the generators or motors from delivering or consuming excess power. For example, the generator overpower protection can be used to shed a noncritical feeder load or to start parallel generators. A synchronous motor may start consuming more reactive power in case of loss of excitation, in which case the forward overpower protection is used to detect such condition.

The DOPPDPR function has many applications when used as reverse power protection. A generator in a power plant converts mechanical energy to electrical energy. Sometimes the mechanical power from a prime mover may decrease to a limit that it does not cover the internal losses. The synchronous generator becomes a synchronous motor and starts importing power from the system. The effect of a generator acting as a motor implies no risk to the machine but can cause damage to the prime mover. The extent of the damage depends on the type of the prime mover.

Steam turbines become overheated easily if the steam flow drops too low or if the steam ceases to flow through the turbine. The break of a main steam pipe, damage to one or more blades in the steam turbine or an inadvertent closing of the main stop valves are typical causes for the low steam flow. The steam turbines of turbo generators can be protected during a low steam flow with the overpower protection operating in reverse direction. Hydroturbines tolerate reverse power much better than steam turbines do. There is a risk that the turbine runner moves axially and touches stationary parts. They are not always strong enough to withstand the associated stresses.

A hydroturbine that rotates in water with the closed wicket gates draws about 10 % of the rated power from the rest of the power system if the intake is blocked due to ice, snow, branches or leaves. A complete blockage of the intake may cause cavitations. If there is only air in the hydroturbine, the power demand drops to about 3 %. The risk of damages to the hydroturbines can justify the reverse operation of the overpower protection in unattended plants.

Whenever a low value of the reverse power setting is required, an underpower protection should also be used in conjunction with DOPPDPR. The limit depends on the CT and VT accuracy.

Diesel engines should have overpower protection in reverse direction. The generator takes about 15 % or more of its rated power from the system. A stiff engine may require 25 % of the rated power to motor it. A well run engine may need no more than 5 %. It is necessary to obtain information from the engine manufacturer and to measure the reverse power during commissioning.

Reverse overpower can also act as an alternative for an under excitation protection in case of small generators. If the field excitation is reduced, the generator may start importing the reactive power, making the generator run as an asynchronous generator. A synchronous generator is not designed to work asynchronously and may become damaged due to heating in the damper windings or heating in the rotor due to slip frequency current.

When operated in reverse power direction, DOPPDPR can be used as an alarm if the power flowing from the industry is feeding the grid, which may not be desired as per the rules and regulations of the utility owning the grid.

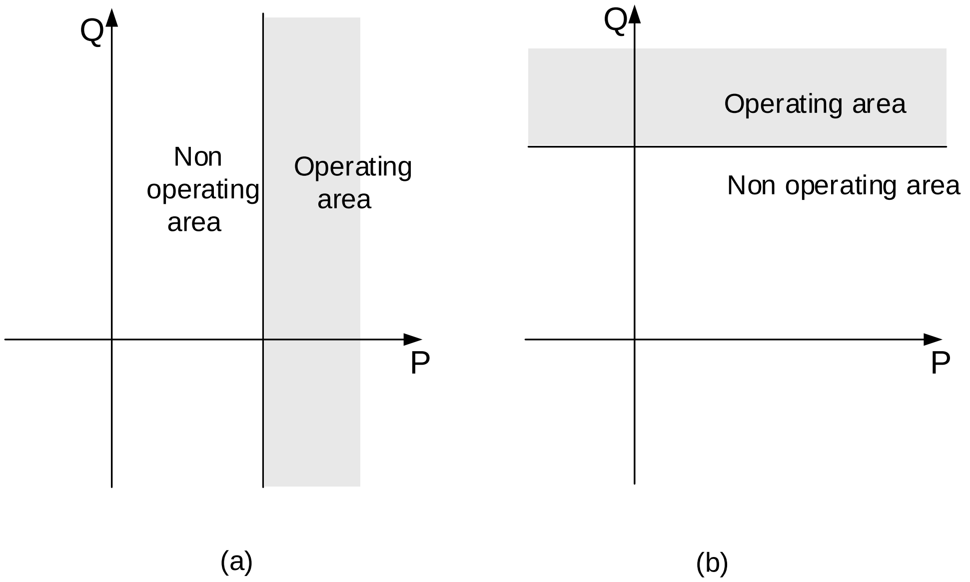


Figure 596: Forward active overpower characteristics (a) and forward reactive overpower characteristics (b)

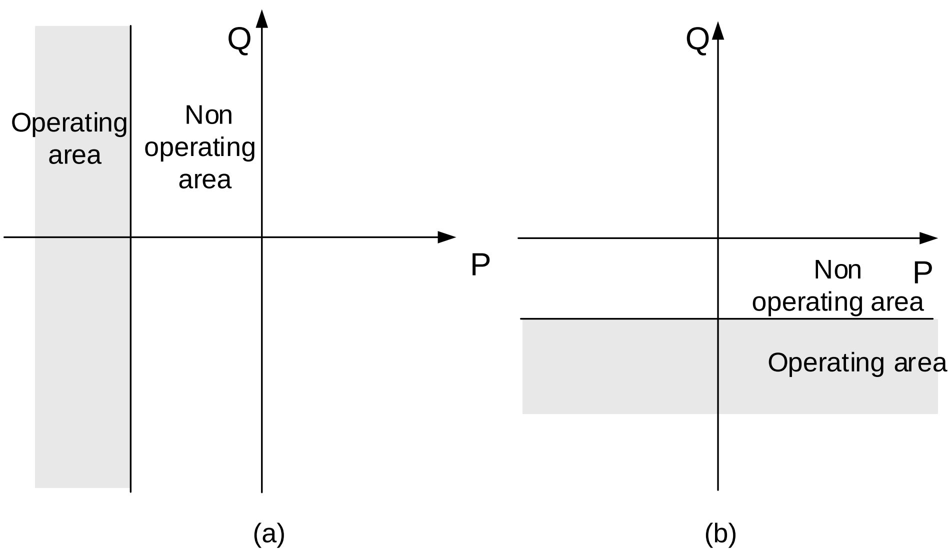


Figure 597: Reverse active overpower characteristics (a) and reverse reactive overpower characteristics (b)

4.8.2.7 Signals

DOPPDPR Input signals

Table 1002: DOPPDPR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

DOPPDPR Output signals

Table 1003: DOPPDPR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.2.8 DOPPDPR Settings

Table 1004: DOPPDPR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...2.00	xSn	0.01	1.00	Start value
Operate delay time	40...300000	ms	10	40	Operate delay time
Directional mode	2=Forward 3=Reverse			2=Forward	Directional mode
Power angle	-90...90	deg	1	0	Adjustable angle for power

Table 1005: DOPPDPR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB 9=PhsC			3=Pos Seq	Selection of power calculation method

Table 1006: DOPPDPR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Pol reversal	0=False 1=True			0=False	Reverse the definition of the power direction

4.8.2.9 DOPPDPR Monitored data

Table 1007: DOPPDPR Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
P	FLOAT32	-160.000...160.000	xSn	Active power
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
S	FLOAT32	0.000...160.000	xSn	Apparent power
PF_ANGLE	FLOAT32	-180.00...180.00	deg	Power factor angle
DOPPDPR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.2.10 Technical data

Table 1008: DOPPDPR Technical data

Characteristic	Value
Operation accuracy [1]	Depending on the frequency of the measured current and voltage: $f = f_n \pm 2$ Hz
	Power measurement accuracy ±3% of the set value or $\pm 0.002 \times S_n$ Phase angle: ±2°
Start time [2, 3]	Typically 45 ms
Reset time	Typically 30 ms
Reset ratio	Typically 0.94
Operate time accuracy	±1.0 % of the set value of ±20 ms
Suppression of harmonics	-50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

1 *Measurement mode* = “Pos Seq” (default)
2 $U = U_n$, f_n = 50 Hz, results based on statistical distribution of 1000 measurements
3 Includes the delay of the signal output contact

4.8.3 Directional reactive power undervoltage protection DQPTUV (ANSI 32Q,27)

4.8.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Directional reactive power undervoltage protection	DQPTUV	Q> ->,3U<	32Q,27

4.8.3.2 Function block

Figure 598: Function block

4.8.3.3 Functionality

The directional reactive power undervoltage protection function DQPTUV is used at the grid connection point of distributed power generating units as stipulated by various grid codes to prevent voltage collapse of the grid due to network faults. DQPTUV measures phase voltages and current at the grid connection point. The generating facility is disconnected from the network with a specific time delay if all phase voltages decrease and remain at or below the specified limit and if reactive power is simultaneously consumed (that is, under-excitation operation).

DQPTUV contains a blocking functionality to block function outputs, timer or the function itself.

4.8.3.4 Analog channel configuration

DQPTUV has two analog group inputs which must be properly configured.

Table 1009: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1010: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.8.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of DQPTUV can be described using a module diagram. All the modules in the diagram are explained in the next sections.

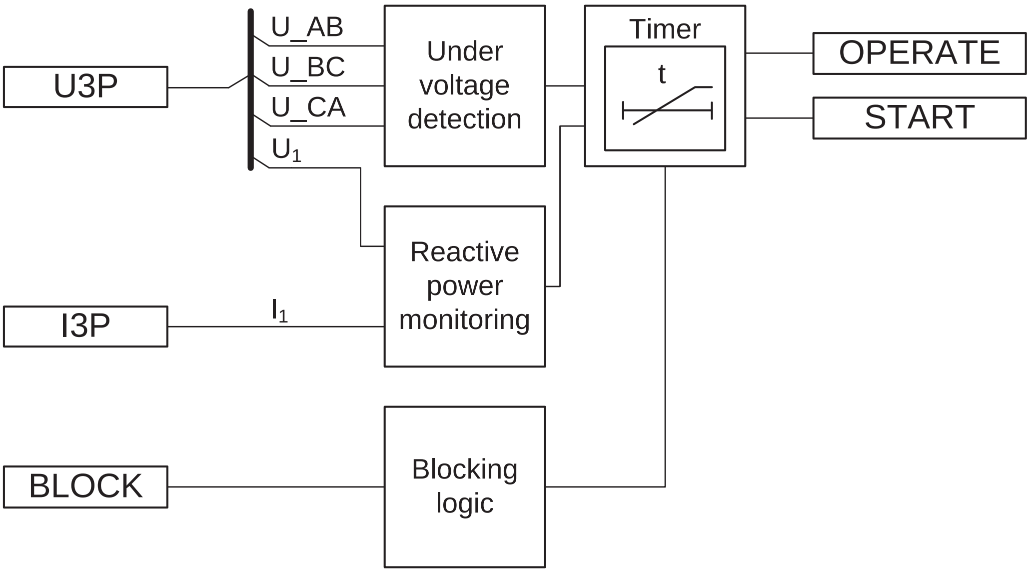


Figure 599: Functional module diagram

Under voltage detection

Under voltage detection compares the fundamental frequency component of all three phase-to-phase voltages with the set *Voltage start value*. When all three phase-to-phase voltages are lower than the set *Voltage start value*, the Under voltage detection module sends an enable signal to the Timer indicating an undervoltage condition at the grid connection point.

Reactive power monitoring

This module calculates and monitors the reactive power based on positive sequence current and voltage. The use of a positive sequence component makes the determination of power insensitive to a possible asymmetry in current and voltages.

When the reactive power exceeds *Min reactive power* and flows in the operating area, the module sends an enable signal to the Timer indicating that the reactive power is being consumed at the grid connection point. A slight tilt in the curve can be obtained by the setting *Pwr sector reduction*.

To avoid false tripping, reactive power calculation is blocked if the magnitude of positive sequence current is less than the set *Min Ps Seq current*.

The magnitude of calculated reactive power Q is available in the Monitored data view.

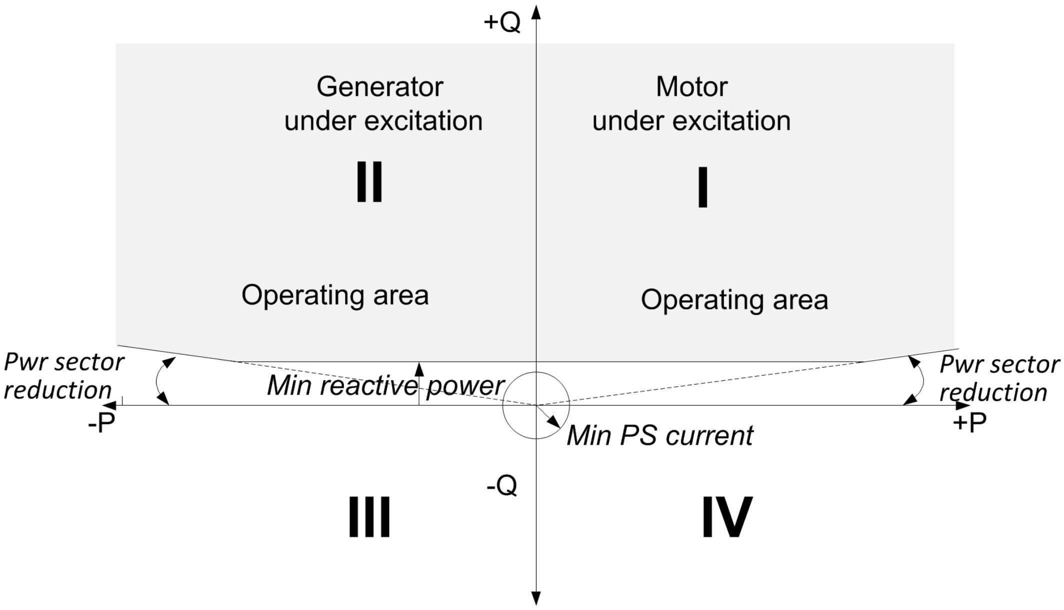


Figure 600: Operating area of DQPTUV function

Quadrant II	Generator produces active power, but draws reactive power (under-excited)
Quadrant III	Generator produces both active and reactive power

The power direction can be reversed by setting *Pol reversal* to “True”.

Timer

Once activated by both Under voltage detection and Reactive power monitoring module, the Timer activates the `START` output. The Timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the `OPERATE` output is activated. If the fault disappears before the module operates, the Timer is reset instantaneously.

The Timer calculates the start duration value "START_DUR" which indicates the percentage ratio of the start situation and the set operating time. The value is available through the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the `BLOCK` input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The `BLOCK` input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode setting* has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.8.3.6 Application

Use of distributed power generating units (PGU) is rapidly increasing due to liberalized markets (deregulation) and the global trend to use more renewable sources of energy. As the capacity of these generating units increase, they are connected directly to medium voltage networks. Until recent years it had been a practice by grid operators to disconnect the distributed power generator from the network in case of fault in the network.

If there is a considerable loss in the power generation, it may affect the system's ability to recover. To ensure power system stability, various grid codes have revised their requirements and therefore require that the distributed PGUs have to make a contribution to network support. In case of network faults, the distributed power generator should not be immediately disconnected from the network. Instead, as a matter of principle, generating plants connected to the medium-voltage network must be capable of participating in steady-state voltage control and dynamic network support. However, if the generators stay connected, it must be ensured that they do not take reactive power from the network because this may lead to collapse of the grid. DQPTUV is used for detecting such situations, that is, simultaneous undervoltage and reactive power (under excited generators) and trip the generators.

The protection function DQPTUV is developed considering various grid codes. For example, in the BDEW Technical Guideline "Generating Plants Connected to the Medium-Voltage Network" (June 2008 issue, Germany), it is stated that if all three phase-to-phase voltages at the grid connection point decrease and remain at and below a value of 85% of the rated and if reactive power is simultaneously consumed at the grid connection point (under-excited operation), the generating facility must be disconnected from the network with a time delay of 0.5 s.

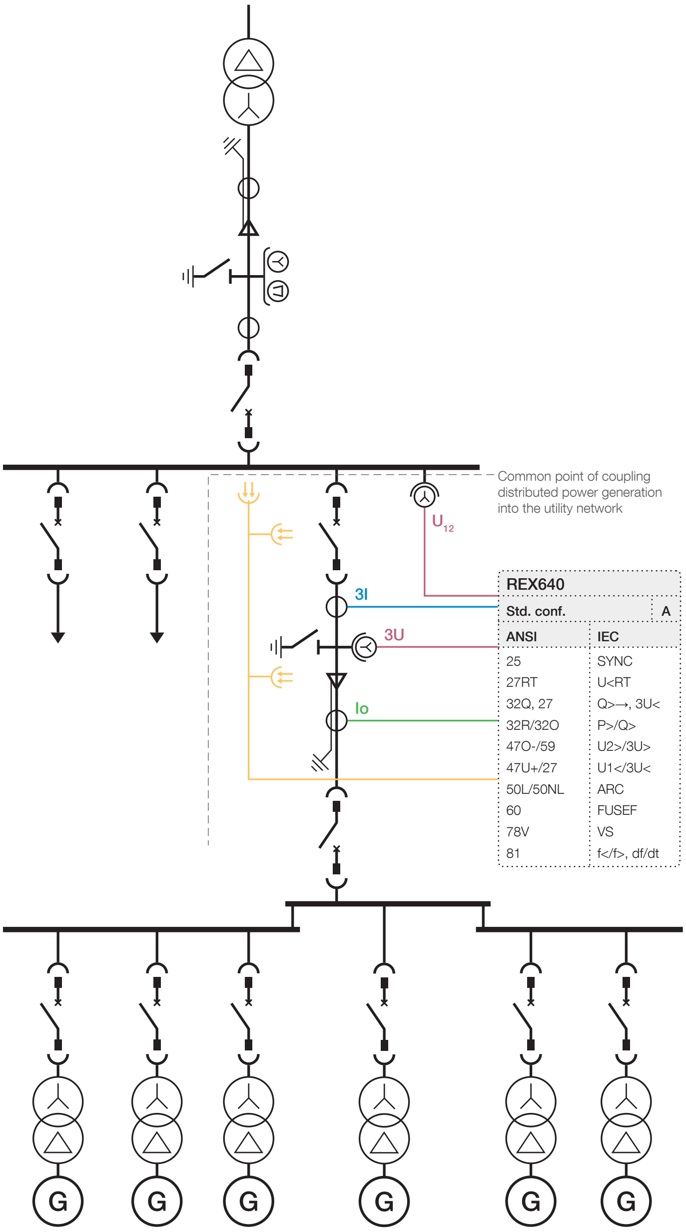


Figure 601: Application example of wind power plant as distributed power generation coupled into the utility network

4.8.3.7 Signals

DQPTUV Input signals

Table 1011: DQPTUV Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

DQPTUV Output signals

Table 1012: DQPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.8.3.8 DQPTUV Settings

Table 1013: DQPTUV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.20...1.20	xUn	0.01	0.85	Start value for under voltage detection
Operate delay time	100...300000	ms	10	500	Operate delay time

Table 1014: DQPTUV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off

Table 1015: DQPTUV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min reactive power	0.01...0.50	xSn	0.01	0.05	Minimum reactive power needed for function to operate
Min Ps Seq current	0.02...0.20	xIn	0.01	0.05	Minimum positive sequence current
Pwr sector reduction	0...10	deg	1	3	Power sector reduction
Pol reversal	0=False 1=True			0=False	Reverse the definition of the positive reactive power direction

4.8.3.9 DQPTUV Monitored data

Table 1016: DQPTUV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
Q	FLOAT32	-160.000...160.000	xSn	Reactive power
DQPTUV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.3.10 Technical data

Table 1017: DQPTUV Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current and voltage: f_n ±2 Hz Reactive power range |PF| <0.71
	Power: ±3.0 % or ±0.002 × Q_n Voltage: ±1.5 % of the set value or ±0.002 × U_n
Start time [1, 2]	Typically 46 ms
Reset time	<50 ms
Reset ratio	Typically 0.96
Operate time accuracy	±1.0 % of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

4.8.4 Underpower factor protection MPUPF (ANSI 55U)

4.8.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Underpower factor protection	MPUPF	PF<	55U

1 *Start value* = 0.05 × S_n, reactive power before fault = 0.8 × *Start value*, reactive power overshoot 2 times, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.8.4.2 Function block

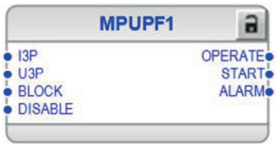


Figure 602: Function block

4.8.4.3 Functionality

The under power factor function MPUPF is used to provide out-of-step and loss of, or under excitation protection for small synchronous motors and generators. The function calculates the power factor and uses a threshold of under power factor as an indication of an out-of-step and/or loss of excitation condition.

In addition, the function can be applied as a power factor controller.

The function contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.8.4.4 Analog channel configuration

MPUPF has two analog group inputs which must be properly configured.

Table 1018: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1019: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that any two voltage channels are connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.8.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of MPUPF can be described using a module diagram. All the modules in the diagram are explained in the next sections.

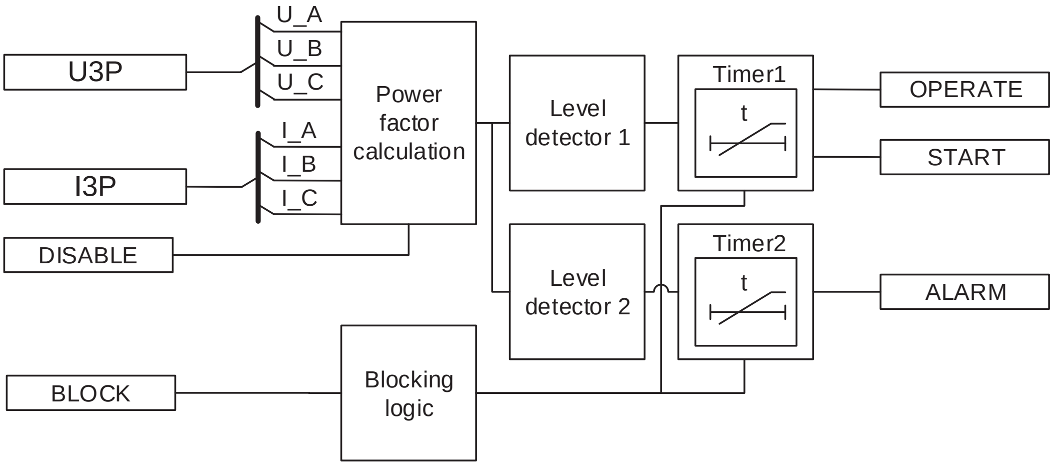


Figure 603: Functional module diagram

Power factor calculation

This module calculates three phase power factor using phase currents and voltages.

The three-phase power is calculated from the fundamental frequency components (DFT) of the phase-to-earth voltages and phase-to-earth currents.

$$\overline{S} = \overline{U}_A \cdot \overline{I}_A^* + \overline{U}_B \cdot \overline{I}_B^* + \overline{U}_C \cdot \overline{I}_C^*$$

Figure 604: Equation

$$P = \mathrm{Re}(\overline{S})$$

Figure 605: Equation

$$PF = \frac{P}{\left|\overline{S}\right|}$$

Figure 606: Equation

Figure 607 shows the resulting sign of the power factor. This should be consistent with the settings in the power and energy metering function of the relay.

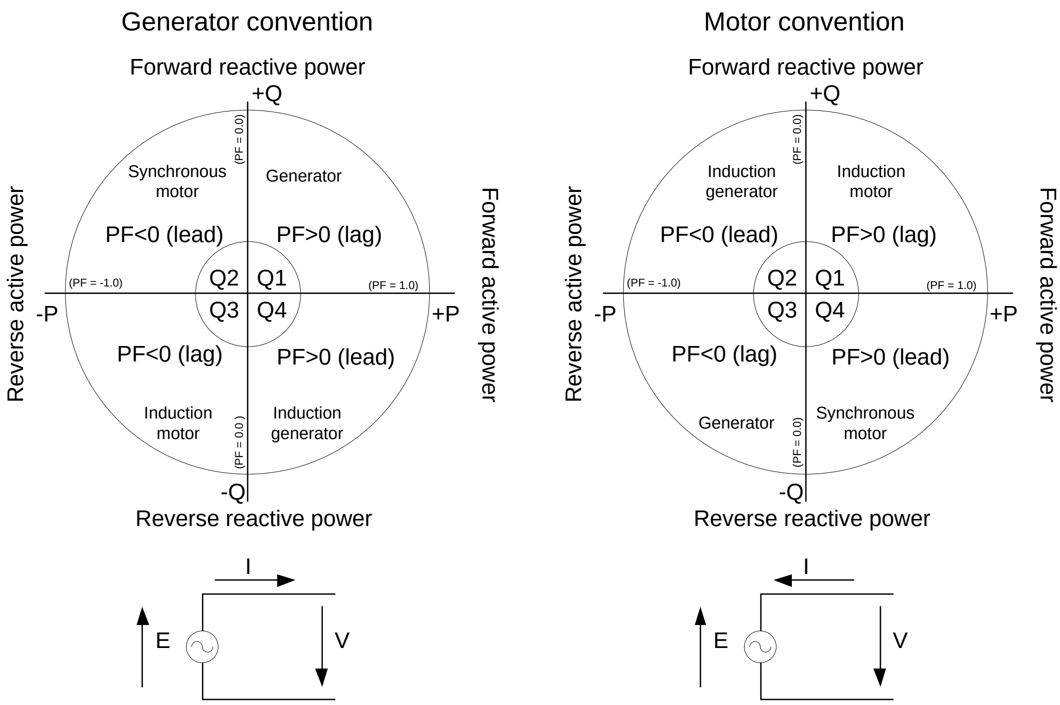


Figure 607: Power factor quadrant

If the polarity of the voltage signal is opposite to the normal polarity, the correction can be done by setting *Voltage reversal* to “Yes”, which rotates the power factor vector by 180 degrees.

If the magnitude of all three phase currents or voltages are respectively less than *Current block value* and *Voltage block value* settings, the power factor is set as unity that is 1.00 and the function is disabled internally.

The DISABLE input can be used to coordinate the correct operation during the startup situation. By activating the DISABLE signal, the power factor calculation is blocked. Once the DISABLE signal is deactivated, the function remains blocked for additional time duration as set through the setting *Disable time*.

Level detector 1

The Level detector 1 compares the calculated power factor to the set *Start value*. If the power factor value goes below the set *Start value* in the direction as defined by *Dir start value*, the Level detector sends an enabling signal to the Timer 1 module.

Level detector 2

The Level detector 2 compares the calculated power factor to the set *Alarm value*. If the power factor value goes below the set *Alarm value* in the direction as defined by *Dir alarm value*, the Level detector sends an enabling signal to the Timer 2 module.

Timer 1

Once activated, the Timer 1 activates the START output. The timer characteristic is according to DT. When the operate timer has reached the value set by *Start delay time* in the DT mode, the OPERATE output is activated. If a drop-off situation occurs, that is, a power factor improves and exceeds the *Start reset value* in the direction as defined by *Dir start reset value* before the operate delay is exceeded or either magnitude of all three phase current or voltages goes below *Current block value* and *Voltage block value* respectively, the timer reset state is activated. The reset timer depends on the *Reset delay time* setting.

The Timer 1 calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operating time. The value is available in the Monitored data view.

Timer 2

Once activated, the Timer 2 activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time* in the DT mode, the ALARM output is activated. If a drop-off situation occurs, that is, a power factor improves and exceeds the *Alarm reset value* in the direction as defined by *Dir alarm reset value* before the alarm delay is exceeded or either magnitude of all three phase current or voltages goes below *Current block value* and *Voltage block value* respectively, the timer reset state is activated. The reset timer depends on the *Reset delay time* setting.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.8.4.6 Application

The MPUPF function can be used to detect loss of excitation or for power factor correction. Synchronous motors are mostly operated at leading power factor and its operation as lagging power for extended period can be used an indication of an out-of-step condition possibly caused by under or loss of excitation. To detect such a situation, the relay is typically set to operate when the current into a motor lags more than 30 degrees, that is, a power factor goes below +0.87 lagging.

The function provides alarm facility which can be used as an early indication that the power factor is moving outside the allowable range; therefore the *Alarm value* setting should be set higher than the *Start value*. The delay time for alarm should also be set as low as possible, only long enough to prevent spurious activation of the output.

In a power factor correction application, the ALARM and START outputs can be used as controls to switch in capacitive loads when the *Alarm value* and *Start value* settings, respectively, are exceeded. The ALARM output is set for a higher value to add the first corrective load and the START output set for a second stage of corrective load, if needed. The *Start reset value* and *Alarm reset value* settings allow their respective outputs to remain activated to maintain the correction after power factor rises as a result, but to drop out after it reaches a level where corrective capacitive loading is no longer needed.

There are two general applications which can best utilize under power factor protection; power-factor control and loss of excitation.

When applying the function for power-factor control, both the start value and the start reset value should be the same sign (positive/negative) as well as the same direction (leading/lagging). Additionally, the absolute value of the start reset value should be greater than or equal to the absolute value of the start value. This allows the function to properly control any power factor controls within the system.

When applying the function for loss of excitation, both the start value and the start reset value should be the same sign (positive/negative), but the directions should be different (leading/lagging). This application is well-suited to protect against back-spinning. In this case the start reset value will only come into play once the system provides power in the opposite quadrant of the start value, for example, lagging PF turns to leading PF.

4.8.4.7 Signals

MPUPF Input signals

Table 1020: MPUPF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
DISABLE	BOOLEAN	0=False	Signal to block the function during machine startup

MPUPF Output signals

Table 1021: MPUPF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.8.4.8 MPUPF Settings

Table 1022: MPUPF Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value Dir	1=Lagging			1=Lagging	PF direction for start value

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Leading				
Start reset Val Dir	1=Lagging 2=Leading			1=Lagging	PF direction for start reset value
Alarm value Dir	1=Lagging 2=Leading			1=Lagging	PF direction for alarm value
Alarm reset Val Dir	1=Lagging 2=Leading			1=Lagging	PF direction for alarm reset value
Start value	-0.99...0.99		0.01	0.80	Start value
Start reset value	-0.99...0.99		0.01	0.85	Value at which start resets, drops out
Alarm value	-0.99...0.99		0.01	0.85	Alarm start value
Alarm reset value	-0.99...0.99		0.01	0.90	Value at which alarm resets, drops out
Operate delay time	100...300000	ms	1	500	Time delay for operation
Alarm delay time	100...300000	ms	1	500	Time delay for alarm

Table 1023: MPUPF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Min operate current	0.05...0.65	xIn	0.01	0.10	Minimum operating current
Min operate voltage	0.05...0.50	xUn	0.01	0.10	Minimum operating voltage
Disable time	0...60000	ms	1	5000	Additional wait time after CB closing
Voltage reversal	0=No 1=Yes			0=No	Rotates the PF by 180 degrees

Table 1024: MPUPF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.8.4.9 MPUPF Monitored data

Table 1025: MPUPF Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
PF	FLOAT32	-1.00...1.00		Calculated value of the 3-phase power factor
MPUPF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.8.4.10 Technical data

Table 1026: MPUPF Technical data

Characteristic	Value
Operation accuracy	Dependent on the frequency of the current measured: f_n ±2 Hz
	±0.018 for power factor
Operate time accuracy	±(1.0 % or 30 ms)
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5, 6, 7
Reset time	<40 ms

4.9 Arc protection ARCSARC (ANSI AFD)

4.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Arc protection	ARCSARC	ARC	AFD

4.9.2 Function block

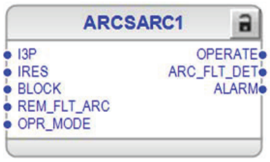


Figure 608: Function block

4.9.3 Functionality

The arc protection function ARCSARC detects arc situations in air-insulated metal-clad switchgears caused by, for example, human errors during maintenance or insulation breakdown during operation.

The function detects light from an arc either locally or via a remote light signal. The function also monitors phase and residual currents to be able to make accurate decisions on ongoing arcing situations.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

4.9.4 Analog channel configuration

ARCSARC has two analog group inputs which must be properly configured.

Table 1027: Analog inputs

Input	Description
I3P [1]	Three-phase currents, necessary when the operation mode "Light +current" is used
IRES [1]	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.9.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of ARCSARC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

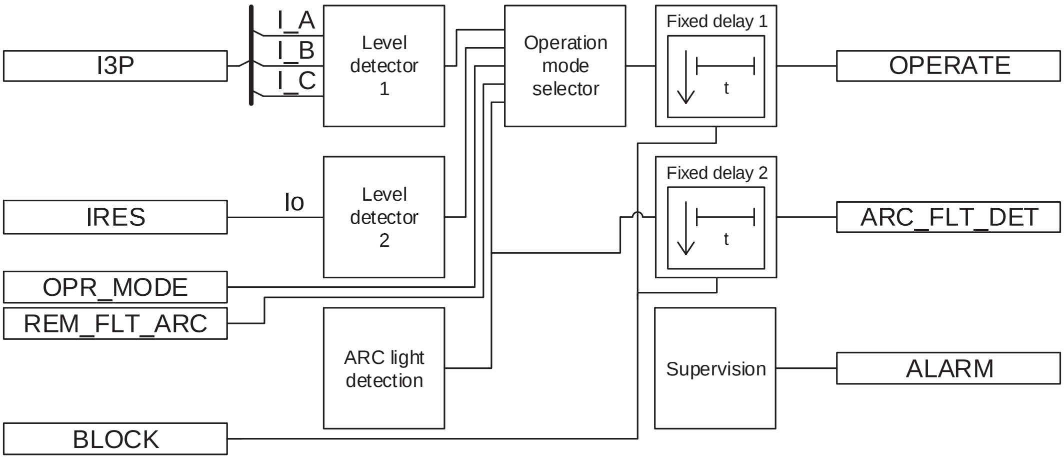


Figure 609: Functional module diagram

Level detector 1

The measured phase currents are compared phasewise to the set *Phase start value*. If the measured value exceeds the set *Phase start value*, the level detector reports the exceeding of the value to the operation mode selector.

[1] Can be connected to GRPOFF if "Light only" or "BI controlled" operation modes are used

Level detector 2

The measured residual currents are compared to the set *Ground start value*. If the measured value exceeds the set *Ground start value*, the level detector reports the exceeding of the value to the Operation mode selector.

ARC light detection

ARC detection information is received directly from the relay hardware input. The detected ARC fault is directly signalled to the Operation mode selector and Fixed delay 2 modules. There are four ARC detection inputs in the protection relay. Each input is connected to a dedicated ARCSARC function.

Table 1028: ARC detection inputs connected to ARCSARC

ARC input	ARC protection function
X11/ARC	ARCSARC1
X12/ARC	ARCSARC2
X13/ARC	ARCSARC3
X14/ARC	ARCSARC4

Operation mode selector

Depending on the *Operation mode* setting, Operation mode selector makes sure that all required criteria are fulfilled for a reliable decision of an arc fault situation. The operation is based on both current and light information in “Light+current” mode, on light information only in “Light only” mode or on remotely controlled information in “BI controlled” mode. When the "BI controlled" mode is in use and the OPR_MODE input is activated, the operation of the function is based on light information only. When the OPR_MODE input is deactivated, the operation of the function is based on both light and current information. When the required criteria are met, Fixed delay 1 timer is activated.

Fixed delay 1

Once this timer is activated, the OPERATE signal output is activated immediately. The output is kept active for minimum 25 ms or as long as the input is activated. The BLOCK signal can be used to block the OPERATE signal.

Fixed delay 2

Once this timer is activated, the ARC_FLT_DET output is activated immediately. The output is kept active for minimum 25 ms or as long as the input is activated. The BLOCK signal can be used to block the ARC light signal output ARC_FLT_DET.

Supervision

If a faulty arc sensor is internally detected or if the connection to the arc sensor is lost, ALARM output is activated if *Sensor supervision* is set to "on".

When *Sensor supervision* is set to "off", ALARM output stays false even though the arc sensor is faulty or unconnected.

4.9.6 Application

The arc protection can be realized as a stand-alone function in a single relay or as a station-wide arc protection, including several protection relays. If realized as a station-wide arc protection, different tripping schemes can be selected for the operation of the circuit breakers of the incoming and outgoing feeders. Consequently, the relays in the station can, for example, be set to trip the circuit breaker of either the incoming or the outgoing feeder, depending on the fault location in the switchgear. For maximum safety, the relays can be set to always trip both the circuit breaker of the incoming feeder and that of the outgoing feeder.

The arc protection consists of:

- Optional arc light detection hardware with automatic backlight compensation for lens type sensors
- Light signal output `ARC_FLT_DET` for routing indication of locally detected light signal to another relay
- Protection stage with phase- and earth-fault current measurement.

The function detects light from an arc either locally or via a remote light signal. Locally, the light is captured either by lens type point sensors or transparent fiber loop sensors connected to the light sensor input of the relay. This captured light is guided via optical fiber to the sensor input of the relay, where it is converted to electrical signal by means of a photo diode. The optical light sensors can be placed in the various compartments of the switchgear, for example, in the busbar compartment, the circuit breaker compartments, the bus riser and the outgoing feeder cable end compartments.

The light detected by the lens sensor inputs is compared to an automatically adjusted reference level. Each light sensor input has its own reference level. When the light exceeds the reference level of one of the inputs, the light is detected locally. When the light has been detected locally or remotely and, depending on the operation mode, if one or several phase currents exceed the set *Phase start value* limit, or the earth-fault current the set *Ground start value* limit, the arc protection stage generates an operation signal. The stage is reset in 30 ms, after all three-phase currents and the earth-fault current have fallen below the set current limits.

The light signal output from an arc protection stage `ARC_FLT_DET` is activated immediately in the detection of light in all situations. A station-wide arc protection is realized by routing the light signal output to an output contact connected to a binary input of another relay, or by routing the light signal output through the communication to an input of another relay.

It is possible to block the tripping and the light signal output of the arc protection stage with a binary input or a signal from another function block.

Arc protection with one protection relay

In installations, with limited possibilities to realize signaling between protection relays protecting incoming and outgoing feeders, or if only the protection relay for the incoming feeder is to be exchanged, an arc protection with a less selective level can be achieved with one protection relay. In arc detection, the arc protection stage trips the circuit breaker of the incoming feeder. The maximum recommended installation distance between the two lens sensors in the busbar area is six meters and the maximum distance from a lens sensor to the end of the busbar is three meters.

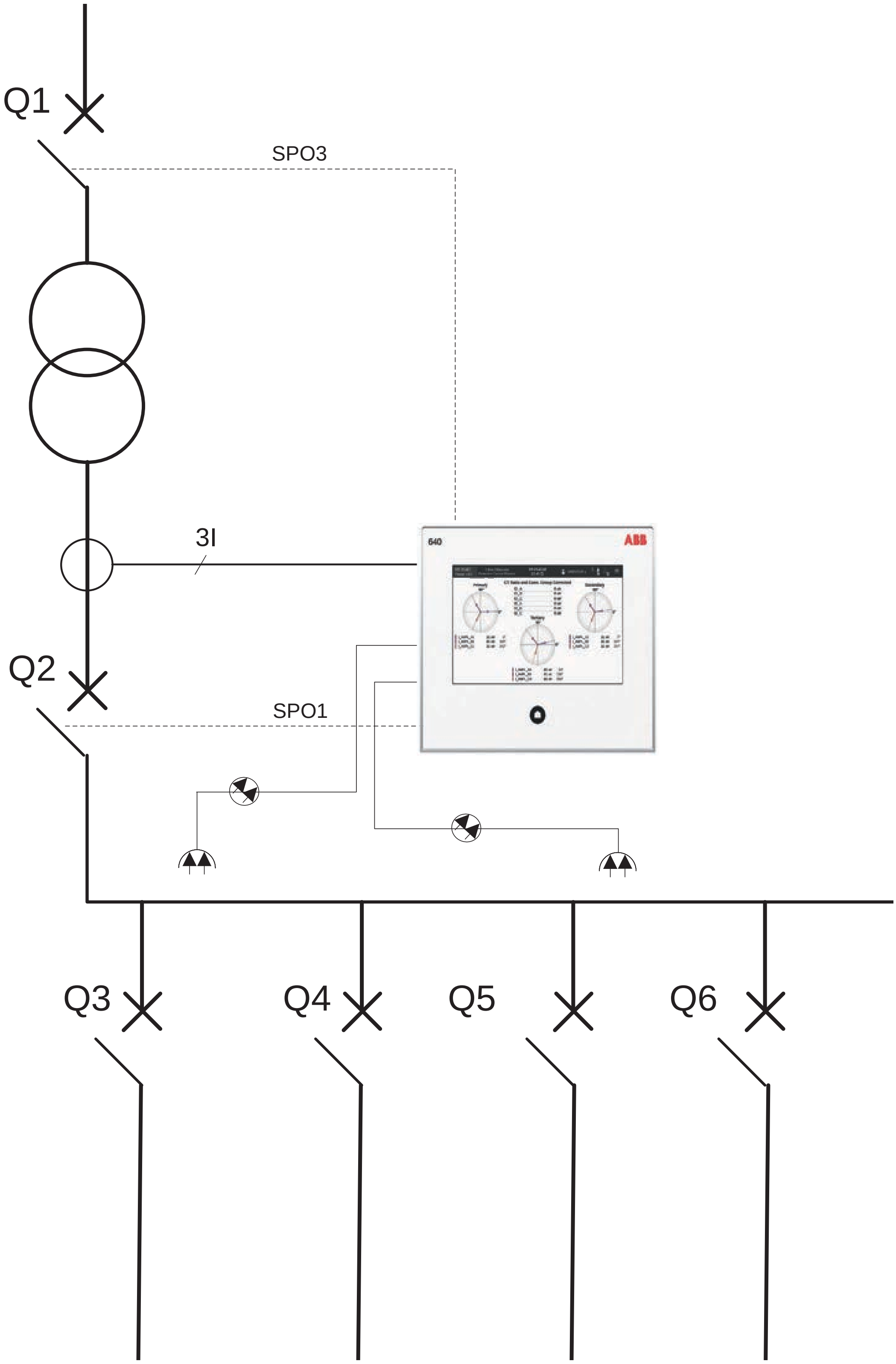


Figure 610: Arc protection with one protection relay

Arc protection with several protection relays

When using several protection relays, the protection relay protecting the outgoing feeder trips the circuit breaker of the outgoing feeder when detecting an arc at the cable terminations. If the protection relay protecting the outgoing feeder detects an arc on the busbar or in the breaker compartment via one of the other lens sensors, it generates a signal to the protection relay protecting the incoming feeder. When detecting the signal, the protection relay protecting the incoming feeder trips the circuit breaker of the incoming feeder and generates an external trip signal to all protection relays protecting the outgoing feeders, which in turn results in tripping of all circuit breakers of the outgoing feeders. For maximum safety, the protection relays can be configured to trip all the circuit breakers regardless of where the arc is detected.

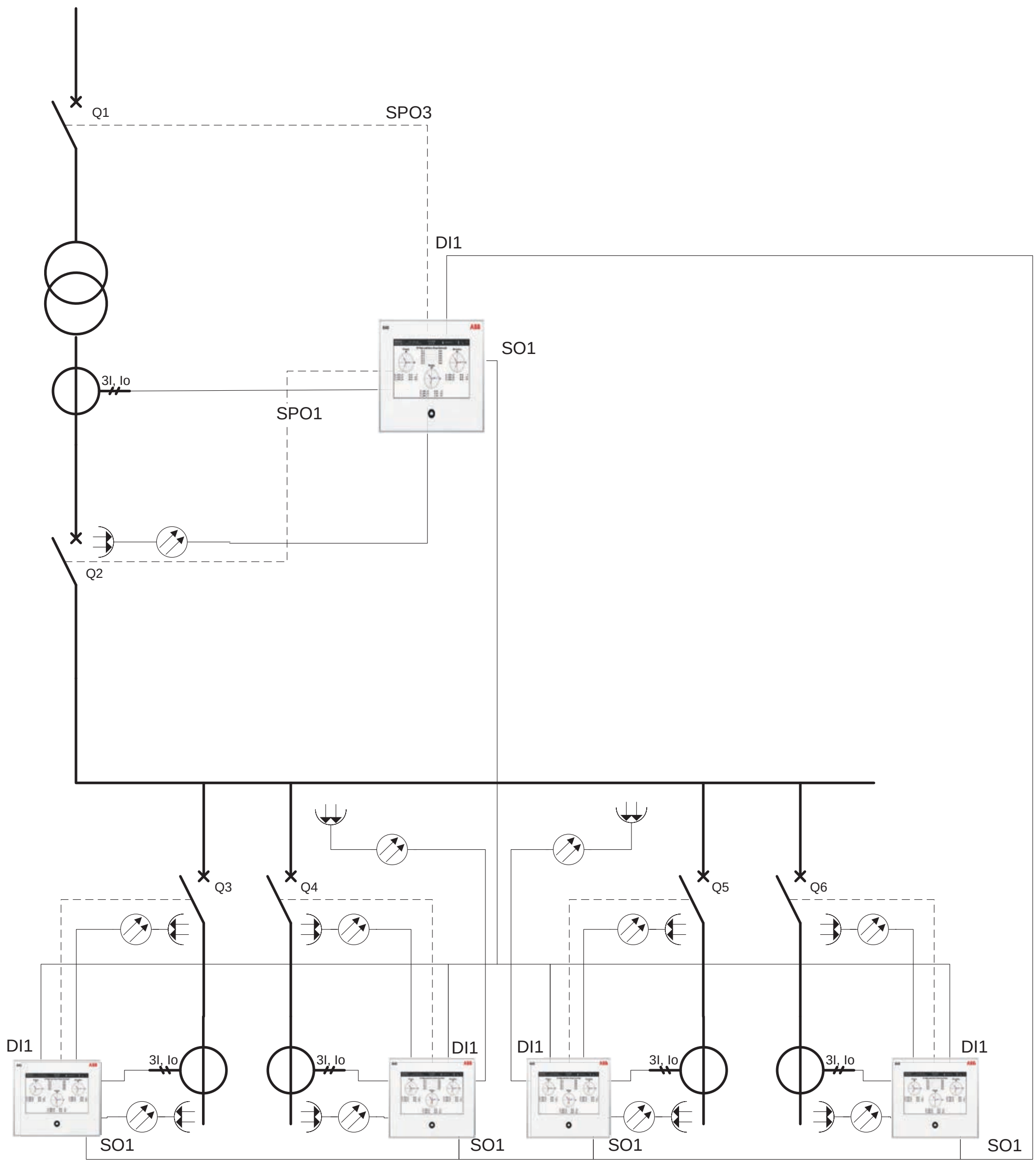


Figure 611: Arc protection with several protection relays and normal outputs

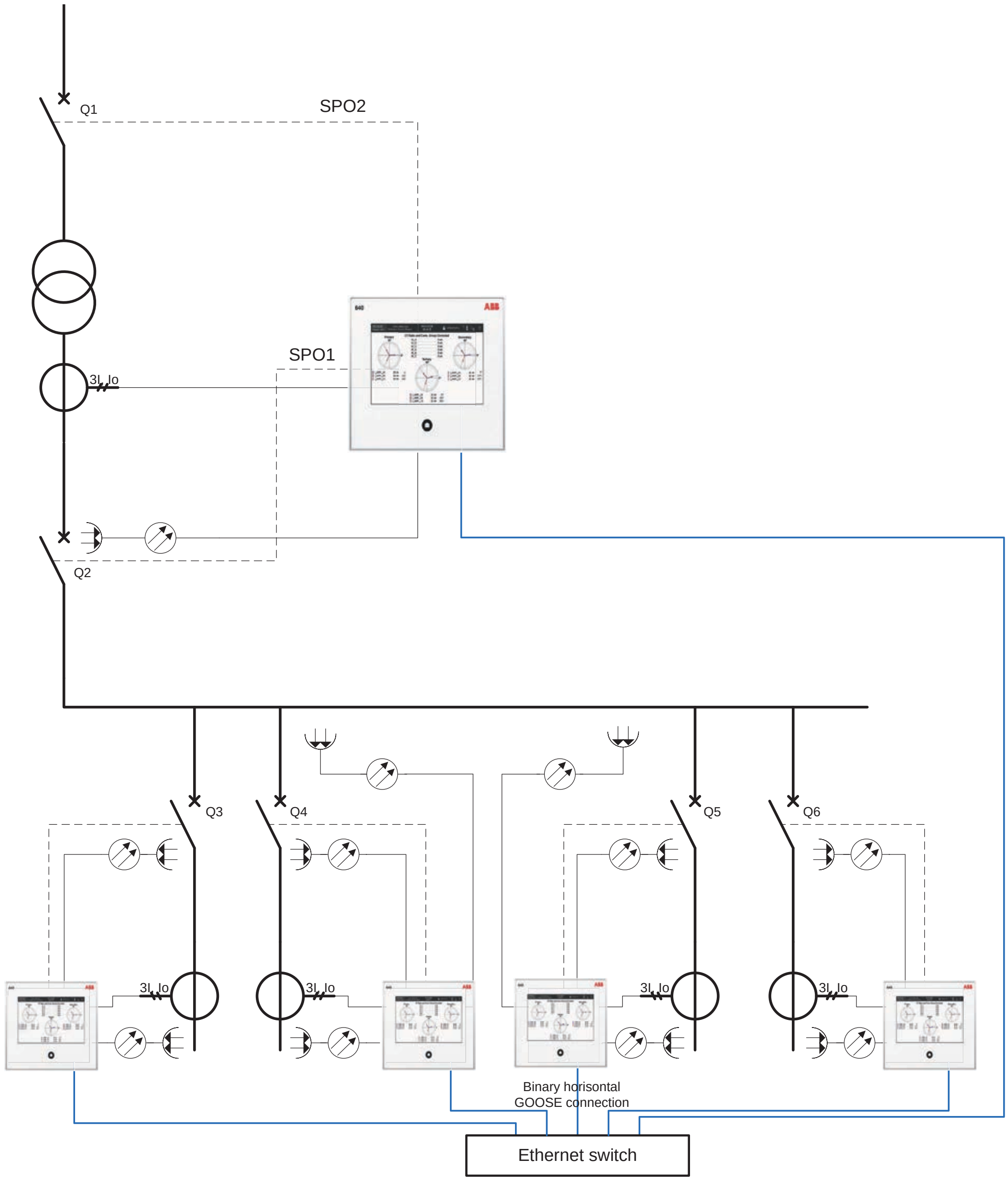


Figure 612: Arc protection with several protection relays and high-speed outputs and GOOSE

4.9.7 Signals

4.9.7.1 ARCSARC Input signals

Table 1029: ARCSARC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs
REM_FLT_ARC	BOOLEAN	0=False	Remote Fault arc detected
OPR_MODE	BOOLEAN	0=False	Operation mode input

4.9.7.2 ARCSARC Output signals

Table 1030: ARCSARC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
ARC_FLT_DET	BOOLEAN	Fault arc detected=light signal output
ALARM	BOOLEAN	Self supervision alarm

4.9.8 ARCSARC Settings

Table 1031: ARCSARC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase start value	0.50...40.00	xIn	0.01	2.50	Operating phase current
Ground start value	0.05...8.00	xIn	0.01	0.20	Operating residual current
Operation mode	1=Light+current 2=Light only 3=BI controlled			1=Light+current	Operation mode

Table 1032: ARCSARC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Sensor supervision	0=off 1=on			1=on	Sensor supervision selection

4.9.9 ARCSARC Monitored data

Table 1033: ARCSARC Monitored data

Name	Type	Values (Range)	Unit	Description
ARCSARC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.9.10 Technical data

Table 1034: ARCSARC Technical data

Characteristic		Value		
Operation accuracy		±3.0 % of the set value or ±0.01 × I_n		
Operate time		Minimum	Typical	Maximum
	Operation mode = "Light+current" [1, 2]	9 ms [2] 3 ms [3]	10 ms [2] 5 ms [3]	13 ms [2] 6 ms [3]
	Operation mode = "Light only" [2]	8 ms [2] 3 ms [3]	10 ms [2] 5 ms [3]	13 ms [2] 6 ms [3]
Reset time		Typically 50 ms		
Reset ratio		Typically 0.96		

4.10 Motor start-up supervision STTPMSU (ANSI 49,66,48,50TDLR)

4.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor start-up supervision	STTPMSU	Is2t n<	49,66,48,50TDLR

1 *Phase start value* = 1.0 × I_n, current before fault = 2.0 × set *Phase start value*, f_n = 50 Hz, fault with nominal frequency, results based on statistical distribution of 200 measurements
2 Includes the delay of the power output (PO) contact
3 Measured with static power output (SPO)

4.10.2 Function block

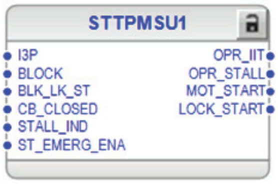


Figure 613: Function block

4.10.3 Functionality

The motor start-up supervision function STTPMSU is designed for protection against excessive starting time and locked rotor conditions of the motor during starting. For a good and reliable operation of the motor, the thermal stress during the motor starting is maintained within the allowed limits.

The starting of the motor is supervised by monitoring the TRMS magnitude of all the phase currents or by monitoring the status of the circuit breaker connected to the motor.

During the start-up period of the motor, STTPMSU calculates the integral of the I^2t value. If the calculated value exceeds the set value, the operate signal is activated.

STTPMSU has the provision to check the locked rotor condition of the motor using the speed switch, which means checking if the rotor is able to rotate or not. This feature operates after a predefined operating time.

STTPMSU also protects the motor from an excessive number of start-ups. Upon exceeding the specified number of start-ups within certain duration, STTPMSU blocks further starts. The restart of the motor is also inhibited after each start and continues to be inhibited for a set duration. When the lock of start of motor is enabled, STTPMSU gives the time remaining until the restart of the motor.

STTPMSU contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

4.10.4 Analog input configuration

STTPMSU has one analog group input which must be properly configured.

Table 1035: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing

blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.10.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of STTPMSU can be described with a module diagram. All the modules in the diagram are explained in the next sections.

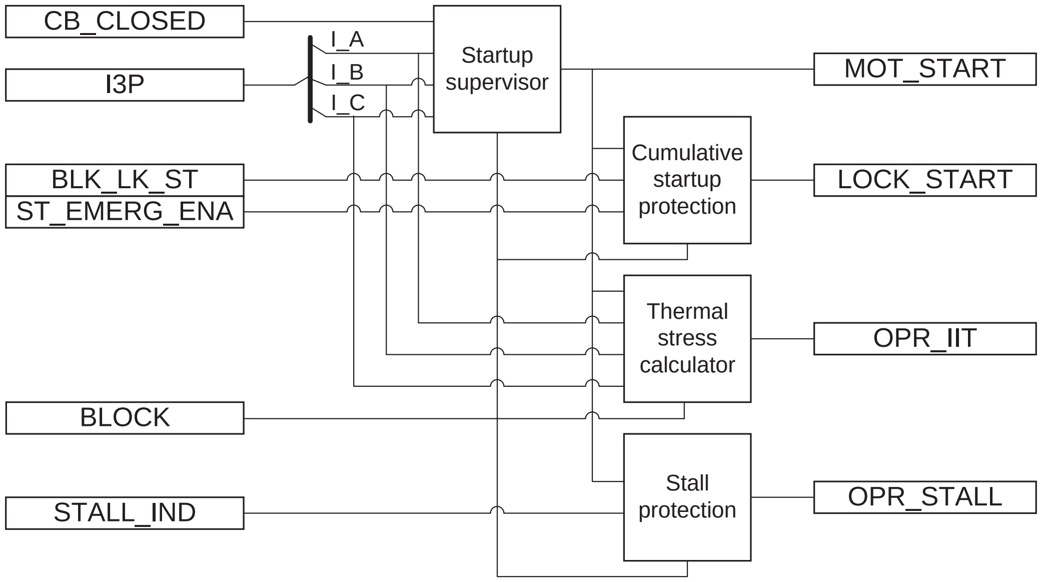


Figure 614: Functional module diagram

Startup supervisor

This module detects the starting of the motor. The starting and stalling motor conditions are detected in four different modes of operation. This is done through the *Operation mode* setting.

When the *Operation mode* setting is operated in the "IIt" mode, the function calculates the value of the thermal stress of the motor during the start-up condition. In this mode, the start-up condition is detected by monitoring the TRMS currents.

The *Operation mode* setting in the "IIt, CB" mode enables the function to calculate the value of the thermal stress when a start-up is monitored in addition to the `CB_CLOSED` input.

In the "IIt & stall" mode, the function calculates the thermal stress of the motor during the start-up condition. The start-up condition is detected by monitoring the TRMS currents.

In the "IIt & stall, CB" mode, the function calculates the thermal stress of the motor during the start-up condition but the start-up condition is detected by monitoring the TRMS current as well as the circuit breaker status.

In both the "IIt & stall" and "IIt & stall, CB" mode, the function also checks for motor stalling by monitoring the speed switch.

When the measured current value is used for start-up supervision in the "IIt" and "IIt & stall" modes, the module initially recognizes the de-energized condition of the motor when the values of all three phase currents are less than *Motor standstill A* for longer than 100 milliseconds. If any of the phase currents of the de-energized condition rises to a value equal to or greater than *Start detection A*, the MOT_START output signal is activated indicating that the motor start-up is in progress. The MOT_START output remains active until the values of all three phase currents drop below 90 percent of the set value of *Start detection A* and remain below that level for a time of *Str over delay time*, that is, until the start-up situation is over.

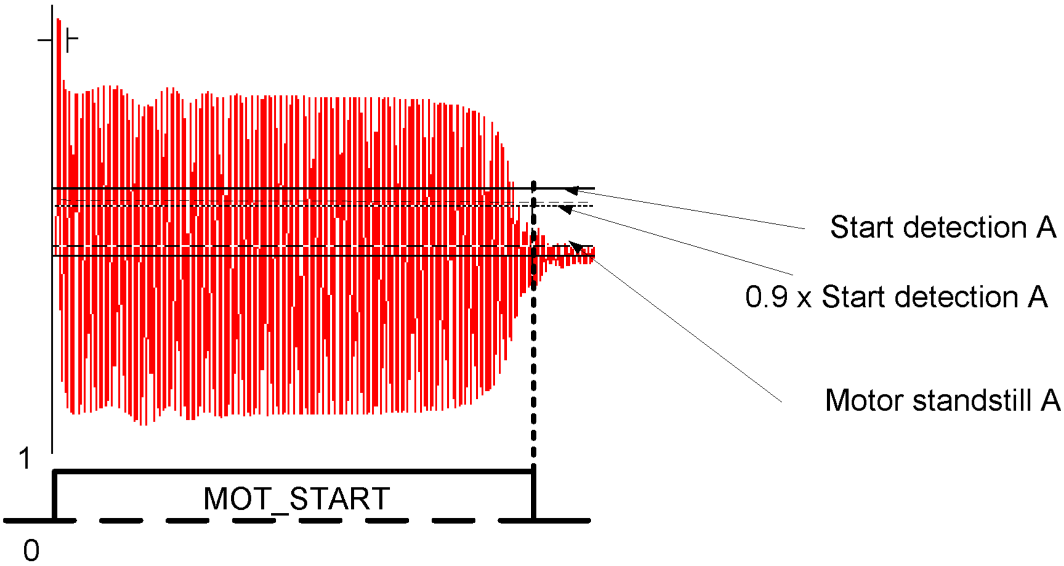


Figure 615: Functionality of start-up supervision in the "IIt and IIt&stall" mode

In case of the "IIt, CB" or "IIt & stall, CB" modes, the function initially recognizes the de-energized condition of the motor when the value of all three phase currents is below the value of the *Motor standstill A* setting for 100 milliseconds. The beginning of the motor start-up is recognized when CB is closed, that is, when the CB_CLOSED input is activated and at least one phase current value exceeds the *Motor standstill A* setting.

These two events do not take place at the same instant, that is, the CB main contact is closed first, in which case the phase current value rises above 0.1 pu and after some delay the CB auxiliary contact gives the information of the CB_CLOSED input. In some cases, the CB_CLOSED input can be active but the value of current may not be greater than the value of the *Motor standstill A* setting. To allow both possibilities, a time slot of 200 milliseconds is provided for current and the CB_CLOSED input. If both events occur during this time, the motor start-up is recognized.

The motor start-up ends either within the value of the *Str over delay time* setting from the beginning of the start-up or the opening of CB or when the CB_CLOSED input is deactivated. The operation of the MOT_START output signal in this operation mode is as illustrated in *Figure 616*.

This CB mode can be used in soft-started or slip ring motors for protection against a high starting current, that is, a problem in starting and so on.

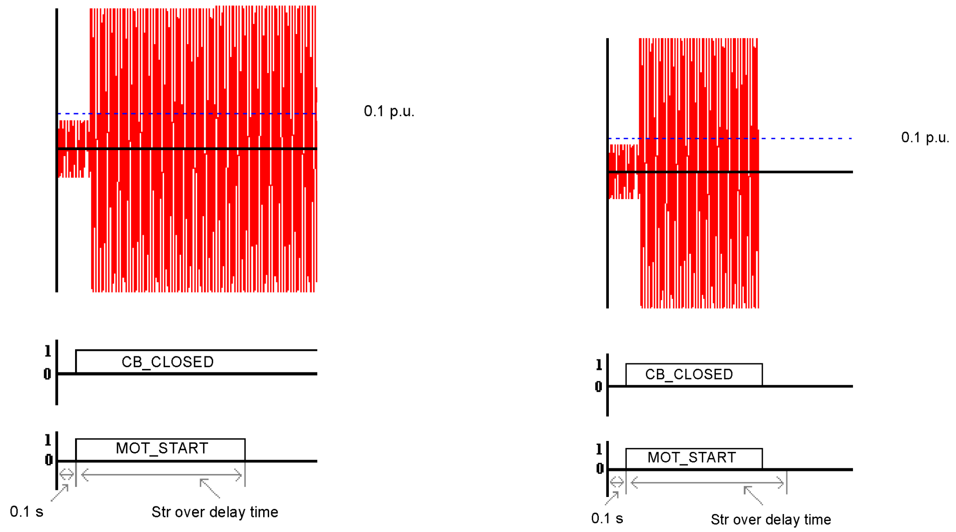


Figure 616: Functionality of start-up supervision in the "IIt, CB" mode and the "IIt and stall, CB" mode

The *Str over delay time* setting has different purposes in different modes of operation.

- In the “IIt” or “IIt & stall” modes, the aim of this setting is to check for the completion of the motor start-up period. The purpose of this time delay setting is to allow for short interruptions in the current without changing the state of the MOT_START output. In this mode of operation, the value of the setting is in the range of around 100 milliseconds.
- In the “IIt, CB” or “IIt & stall, CB” modes, the purpose of this setting is to check for the life of the protection scheme after the CB_CLOSED input has been activated. Based on the values of the phase currents, the completion of the start-up period cannot be judged. So in this mode of operation, the value of the time delay setting can even be as high as within the range of seconds, for example around 30 seconds.

The activation of the BLOCK input signal deactivates the MOT_START output.

Thermal stress calculator

Because of the high current surges during the start-up period, a thermal stress is imposed on the rotor. With less air circulation in the ventilation of the rotor before it reaches its full speed, the situation becomes even worse. Consequently, a long start-up causes a rapid heating of the rotor.

This module calculates the thermal stress developed in the motor during start-up. The heat developed during the starting can be calculated with the equation.

$$W = R_s \int_0^t i_s^2(t)\,dt$$

(Equation 282)

R_s	combined rotor and stator resistance
i_s	starting current of the motor
t	starting time of the motor

This equation is normally represented as the integral of I^2t. It is a commonly used method in protective protection relays to protect the motor from thermal stress during starting. The advantage of this method over the traditional definite time overcurrent protection is that when the motor is started with a reduced voltage as in the star-delta starting method, the starting current is lower. This allows more starting time for the motor since the module is monitoring the integral of I^2t.

The module calculates the accumulated heat continuously and compares it to the limiting value obtained from the product of the square of the values of the *Motor start-up A* and *Motor start-up time* settings. When the calculated value of the thermal stress exceeds this limit, the OPR_IIT output is activated.

The module also measures the time START_TIME required by the motor to attain the rated speed and the relative thermal stress IIT_RL. The values are available in the Monitored data view.

The activation of the BLOCK input signal resets the thermal stress calculator and deactivates the OPR_IIT output.

Stall protection

This module is activated only when the selected *Operation mode* setting value is "IIt & stall" or "IIt & stall, CB".

The start-up current is specific to each motor and depends on the start-up method used, such as direct online, autotransformer and rotor resistance insertion. The start-up time is dependent on the load connected to the motor.

Based on the motor characteristics supplied by the manufacturer, this module is required if the stalling time is shorter than or too close to the starting time. In such cases, a speed switch must be used to indicate whether a motor is accelerating during start-up or not.

At motor standstill, the STALL_IND input is active. It indicates that the rotor is not rotating. When the motor is started, at certain revolution the deactivation of the STALL_IND by the speed switch indicates that the rotor is rotating. If the input is not deactivated within *Lock rotor time*, the OPR_STALL output is activated.

The module calculates the duration of the motor in stalling condition, the STALL_RL output indicating the percent ratio of the start situation and the set value of *Lock rotor time*. The value is available in the Monitored data view.

The activation of the BLOCK input signal resets the operation time and deactivates the OPR_STALL output.

Cumulative start-up protection

This module protects the motor from an excessive number of start-ups.

Whenever the motor is started, the latest value of START_TIME is added to the existing value of T_ST_CNT and the updated cumulative start-up time is available at T_ST_CNT. If the value of T_ST_CNT is greater than the value of *Cumulative time Lim*, the LOCK_START output is activated and lockout condition for the restart of motor is enabled during the time the output is active. The LOCK_START output remains high until the T_ST_CNT value reduces to a value less than the value of

Cumulative time Lim. The start time counter reduces at the rate of the value of *Counter Red rate*.

The LOCK_START output becomes activated at the start of MOT_START. The output remains active for a period of *Restart inhibit time*.

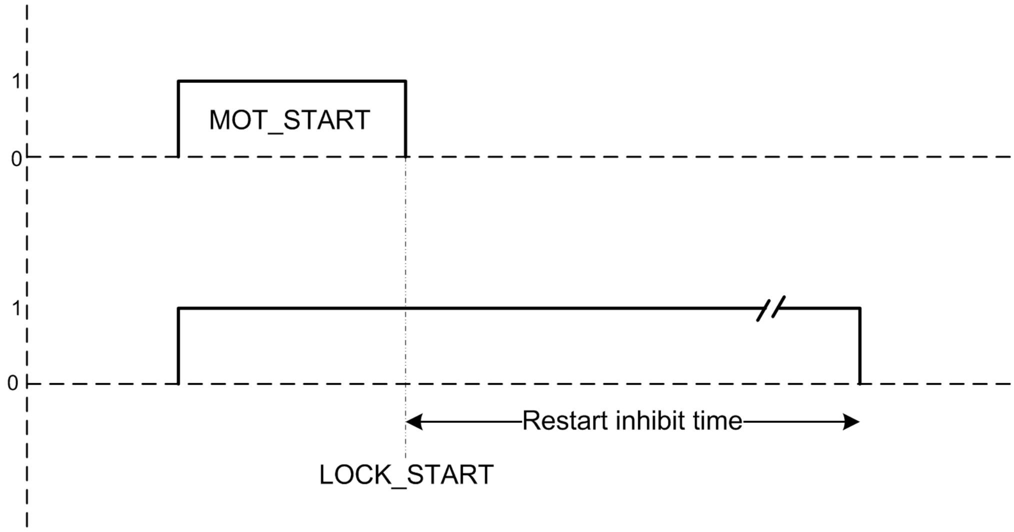


Figure 617: Time delay for cumulative start

This module also protects the motor from consecutive start-ups. When the LOCK_START output is active, T_RST_ENA shows the possible time for next restart. The value of T_RST_ENA is calculated by the difference of *Restart inhibit time* and the elapsed time from the instant LOCK_START is enabled.

When the ST_EMERG_ENA emergency start is set high, the value of the cumulative start-up time counter is set to *Cumulative time Lim* - 60s · *Emg start Red rate*. This disables LOCK_START and in turn makes the restart of the motor possible.

This module also calculates the total number of start-ups occurred, START_CNT. The value can be reset from the Clear menu.

The old *Number of motor start-ups occurred* counter value (START_CNT) can be taken into use by writing the value to the *Ini start up counter* parameter and resetting the value via the Clear menu from WHMI or LHMI.

The calculated values of T_RST_ENA, T_ST_CNT and START_CNT are available in the Monitored data view.

The activation of the BLK_LK_ST input signal deactivates the LOCK_START output. The activation of the BLOCK input signal resets the cumulative start-up counter module.

4.10.6 Application

When a motor is started, it draws a current well in excess of the motor's full-load rating throughout the period it takes for the motor to run up to the rated speed. The motor starting current decreases as the motor speed increases and the value of current remains close to the rotor-locked value for most of the acceleration period.

The full-voltage starting or the direct-on-line starting method is used out of the many methods used for starting the induction motor. If there is either an electrical or mechanical constraint, this starting method is not suitable. The full-voltage starting produces the highest starting torque. A high starting torque is generally required to start a high-inertia load to limit the acceleration time. In this method, full voltage is applied to the motor when the switch is in the "On" position. This method of starting results in a great initial current surge, which is typically four to eight times that of the full-load current drawn by the motor. If a star-delta starter is used, the value of the line current will only be about one-third of the direct-on-line starting current.

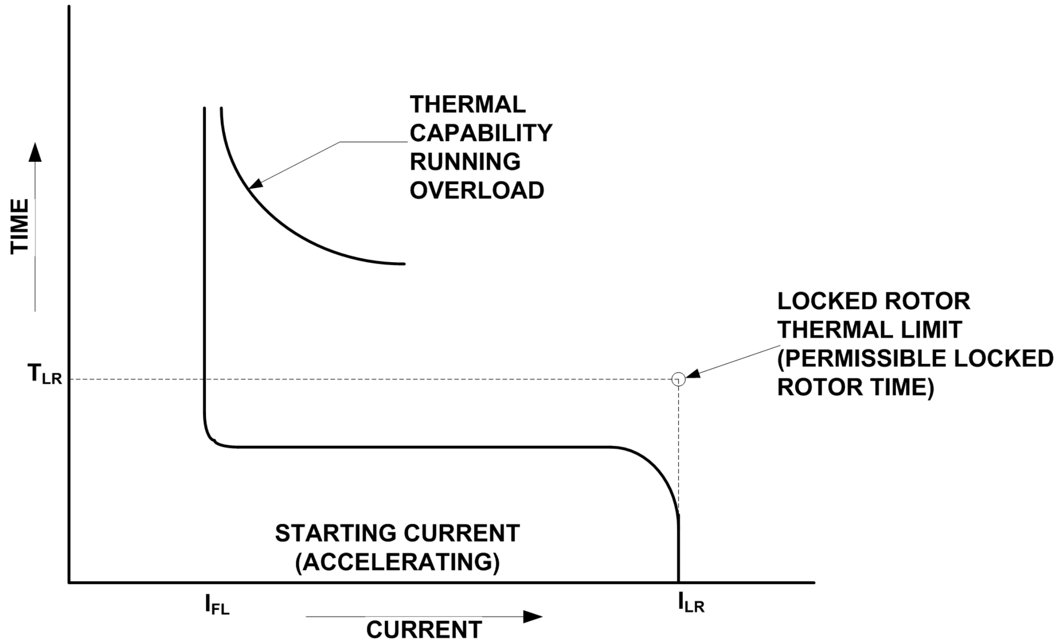


Figure 618: Typical motor starting and capability curves

The start-up supervision of a motor is an important function because of the higher thermal stress developed during starting. During the start-up, the current surge imposes a thermal strain on the rotor. This is exaggerated as the air flow for cooling is less because the fans do not rotate in their full speed. Moreover, the difference of speed between the rotating magnetic field and the rotor during the start-up time induces a high magnitude of slip current in the rotor at frequencies higher than when the motor is at full speed. The skin effect is stronger at higher frequencies and all these factors increase the losses and the generated heat. This is worse when the rotor is locked.

The starting current for slip-ring motors is less than the full load current and therefore it is advisable to use the circuit breaker in the closed position to indicate the starting for such type of motors.

The starting times vary depending on motor design and load torque characteristics. The time taken may vary from less than two seconds to more than 60 seconds. The starting time is determined for each application.

When the permissible stall time is less than the starting time of the motor, the stalling protection is used and the value of the time delay setting should be set slightly less than the permissible stall time. The speed switch on the motor shaft must be used for detecting whether the motor begins to accelerate or not. However, if the safe stall time is longer than the start-up time of the motor, the speed switch is not required.

The failure of a motor to accelerate or to reach its full nominal speed in an acceptable time when the stator is energized is caused by several types of abnormal conditions, including a mechanical failure of the motor or load bearings, low supply voltage, open circuit in one phase of a three-phase voltage supply or too high starting voltage. All these abnormal conditions result in overheating.

Repeated starts increase the temperature to a high value in the stator or rotor windings, or both, unless enough time is allowed for the heat to dissipate. To ensure a safe operation it is necessary to provide a fixed-time interval between starts or limit the number of starts within a period of time. This is why the motor manufacturers have restrictions on how many starts are allowed in a defined time interval. This function does not allow starting of the motor if the number of starts exceeds the set level in the register that calculates them. This insures that the thermal effects on the motor for consecutive starts stay within permissible levels.

For example, the motor manufacturer may state that three starts at the maximum are allowed within 4 hours and the start-up situation time is 60 seconds. By initiating three successive starts we reach the situation as illustrated. As a result, the value of the register adds up to a total of 180 seconds. Right after the third start has been initiated, the output lock of start of motor is activated and the fourth start will not be allowed, provided the time limit has been set to 121 seconds.

Furthermore, a maximum of three starts in 4 hours means that the value of the register should reach the set start time counter limit within 4 hours to allow a new start. Accordingly, the start time counter reduction should be 60 seconds in 4 hours and should thus be set to 60 s / 4 h = 15 s / h.

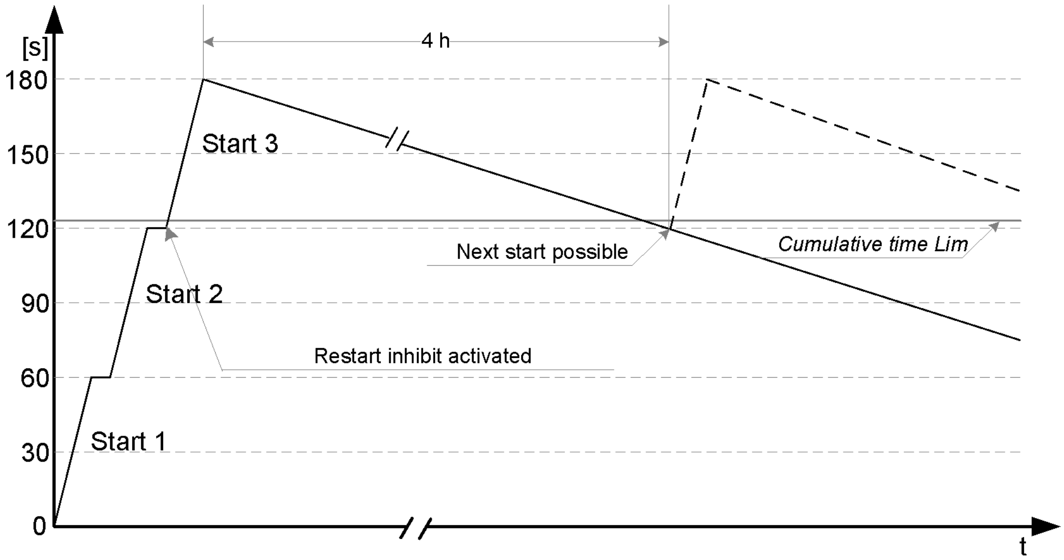


Figure 619: Typical motor-starting and capability curves

Setting of *Cumulative time Lim*

Cumulative time Lim is calculated by

$$\sum t_{si} = (n-1) \times t + margin$$

(Equation 283)

n	specified maximum allowed number of motor start-ups
t	start-up time of the motor (in seconds)
margin	safety margin (~10...20 percent)

Setting of *Counter Red rate*

Counter Red rate is calculated by

$$\Delta\sum t_s = \frac{t}{t_{reset}}$$

(Equation 284)

t	specified start time of the motor in seconds
t_{reset}	duration during which the maximum number of motor start-ups stated by the manufacturer can be made; time in hours

4.10.7 Signals

4.10.7.1 STTPMSU Input signals

Table 1036: STTPMSU Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block of function
BLK_LK_ST	BOOLEAN	0=False	Blocks lock out condition for restart of motor
CB_CLOSED	BOOLEAN	0=False	Input showing the status of motor circuit breaker
STALL_IND	BOOLEAN	0=False	Input signal for showing the motor is not stalling
ST_EMERG_ENA	BOOLEAN	0=False	Enable emergency start to disable lock of start of motor

4.10.7.2 STTPMSU Output signals

Table 1037: STTPMSU Output signals

Name	Type	Description
OPR_IIT	BOOLEAN	Operate/trip signal for thermal stress.
OPR_STALL	BOOLEAN	Operate/trip signal for stalling protection.
MOT_START	BOOLEAN	Signal to show that motor startup is in progress
LOCK_START	BOOLEAN	Lock out condition for restart of motor.

4.10.8 STTPMSU Settings

Table 1038: STTPMSU Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Motor start-up A	1.0...10.0	xIn	0.1	2.0	Motor starting current
Motor start-up time	1...80	s	1	5	Motor starting time
Lock rotor time	2...120	s	1	10	Permitted stalling time
Str over delay time	0...60000	ms	1	100	Time delay to check for completion of motor startup period

Table 1039: STTPMSU Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Start detection A	0.1...10.0	xIn	0.1	1.5	Current value for detecting starting of motor.

Table 1040: STTPMSU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=IIt 2=IIt, CB 3=IIt + stall 4=IIt + stall, CB			1=IIt	Motor start-up operation mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Counter Red rate	2.0...250.0	s/h	0.1	60.0	Start time counter reduction rate
Cumulative time Lim	1...500	s	1	10	Cumulative time based restart inhibit limit
Emg start Red rate	0.00...100.00	%	0.01	20.00	Start time reduction factor when emergency start is On
Restart inhibit time	0...250	min	1	30	Time delay between consecutive startups
Ini start up counter	0...999999		1	0	Initial value for the START_CNT

Table 1041: STTPMSU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Motor standstill A	0.01...0.20	xIn	0.01	0.12	Current limit to check for motor standstill condition

4.10.9 STTPMSU Monitored data

Table 1042: STTPMSU Monitored data

Name	Type	Values (Range)	Unit	Description
START_CNT	INT32	0...999999		Number of motor start-ups occurred
START_TIME	FLOAT32	0.0...999.9	s	Measured motor latest startup time in sec
T_ST_CNT	FLOAT32	0.0...99999.9	s	Cumulated start-up time in sec
T_RST_ENA	INT32	0...999	min	Time left for restart when lockstart is enabled in minutes
IIT_RL	FLOAT32	0.00...100.00	%	Thermal stress relative to set maximum thermal stress
STALL_RL	FLOAT32	0.00...100.00	%	Start time relative to the operate time for stall condition
STTPMSU	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.10.10 Technical data

Table 1043: STTPMSU Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the measured current: f_n ±2 Hz		
		±1.5 % of the set value or ±0.002 × I_n		
Start time [1, 2]		Minimum	Typical	Maximum
	I_{Fault} = 1.1 × set *Start detection A*	27 ms	30 ms	34 ms
Operate time accuracy		±1.0 % of the set value or ±20 ms		
Reset ratio		Typically 0.90		

4.10.11 Technical revision history

Table 1044: STTPMSU Technical revision history

Product connectivity level	Technical revision	Change
PCL4	E	Setting *Motor standstill A* minimum value changed from 0.05xIn to 0.01xIn.

4.11 Multipurpose protection MAPGAPC (ANSI MAP)

4.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multipurpose protection	MAPGAPC	MAP	MAP

[1] Current before = 0.0 × I_n, f_n = 50 Hz, overcurrent in one phase, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

4.11.2 Function block

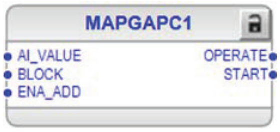


Figure 620: Function block

4.11.3 Functionality

The multipurpose protection function MAPGAPC is used as a general protection with many possible application areas as it has flexible measuring and setting facilities. The function can be used as an under- or overprotection with a settable absolute hysteresis limit. The function operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MAPGAPC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

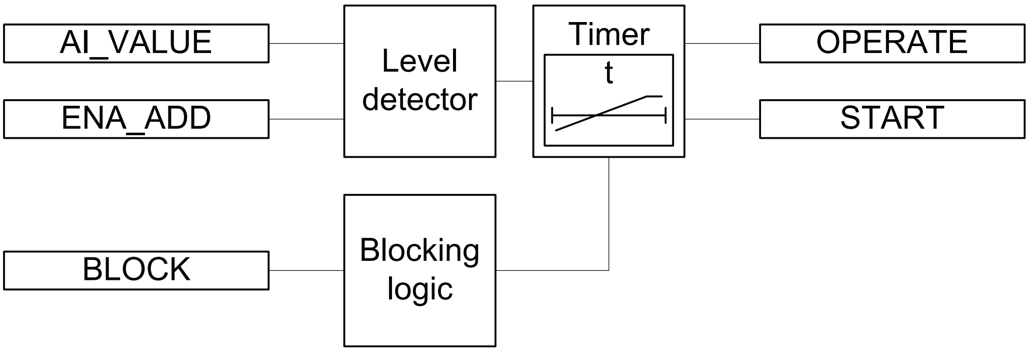


Figure 621: Functional module diagram

Level detector

The level detector compares `AI_VALUE` to the *Start value* setting. The *Operation mode* setting defines the direction of the level detector.

Table 1045: *Operation mode* types

Operation Mode	Description
"Under"	If the input signal AI_VALUE is lower than the set value of the "Start value" setting, the level detector enables the timer module.
"Over"	If the input signal AI_VALUE exceeds the set value of the *Start value* setting, the level detector enables the timer module.

The *Absolute hysteresis* setting can be used for preventing unnecessary oscillations if the input signal is slightly above or below the *Start value* setting. After leaving the hysteresis area, the start condition has to be fulfilled again and it is not sufficient for the signal to only return to the hysteresis area. If the ENA_ADD input is activated, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. The resulting threshold value for the comparator can be increased or decreased depending on the sign and value of the *Start value Add* setting.

Timer

Once activated, the timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated. If the starting condition disappears before the module operates, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

The timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, the function operates normally but the OPERATE output is not activated.

4.11.5 Application

The function block can be used for any general analog signal protection, either underprotection or overprotection. The setting range is wide, allowing various protection schemes for the function. Thus, the absolute hysteresis can be set to a value that suits the application.

The temperature protection using the RTD sensors can be done using the function block. The measured temperature can be fed from the RTD sensor to the function input that detects too high temperatures in the motor bearings or windings, for example. When the `ENA_ADD` input is enabled, the threshold value of the internal comparator is the sum of the *Start value Add* and *Start value* settings. This allows a temporal increase or decrease of the level detector depending on the sign and value of the *Start value Add* setting, for example, when the emergency start is activated. If, for example, *Start value* is 100, *Start value Add* is 20 and the `ENA_ADD` input is active, the input signal needs to rise above 120 before MAPGAPC operates.

4.11.6 Signals

4.11.6.1 MAPGAPC Input signals

Table 1046: MAPGAPC Input signals

Name	Type	Default	Description
AI_VALUE	FLOAT32	0.0	Analogue input value
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_ADD	BOOLEAN	0=False	Enable start added

4.11.6.2 MAPGAPC Output signals

Table 1047: MAPGAPC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.11.7 MAPGAPC Settings

Table 1048: MAPGAPC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	-10000.0...10000.0		0.1	0.0	Start value
Start value Add	-100.0...100.0		0.1	0.0	Start value Add
Operate delay time	0...200000	ms	100	0	Operate delay time

Table 1049: MAPGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Over 2=Under			1=Over	Operation mode

Table 1050: MAPGAPC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	100	0	Reset delay time
Absolute hysteresis	0.01...100.00		0.01	0.10	Absolute hysteresis for operation

4.11.8 MAPGAPC Monitored data

Table 1051: MAPGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
MAPGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.11.9 Technical data

Table 1052: MAPGAPC Technical data

Characteristic	Value
Operation accuracy	±1.0 % of the set value or ±20 ms

4.12 Capacitor bank protection

4.12.1 Three-phase overload protection for shunt capacitor banks COLPTOC (ANSI 51,37,86C)

4.12.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overload protection for shunt capacitor banks	COLPTOC	3I> 3I<	51,37,86C

4.12.1.2 Function block

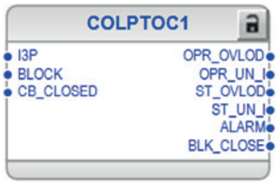


Figure 622: Function block symbol

4.12.1.3 Functionality

The three-phase overload protection for shunt capacitor banks function COLPTOC provides single-phase, two-phase and three-phase protection against overloads caused by harmonic currents and overvoltages in shunt capacitor banks. The operation of overload and alarm is based on the peak value of the integrated current which is proportional to the voltage across the capacitor.

The overload function operates with IDMT characteristic and an alarm function operates with DT characteristic.

COLPTOC provides undercurrent protection to detect disconnection of the capacitor. COLPTOC has breaker reclosing inhibit feature to enable complete capacitor discharging before breaker reclosing after it has operated.

COLPTOC contains blocking functionality. It is possible to block the function outputs, timers or the function itself.

4.12.1.4 Analog channel configuration

COLPTOC has one analog group input which must be properly configured.

Table 1053: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.12.1.5 Operation principle

The function can be enabled and disabled with the Operation setting. The corresponding parameter values are “On” and “Off”.

The operation of COLPTOC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

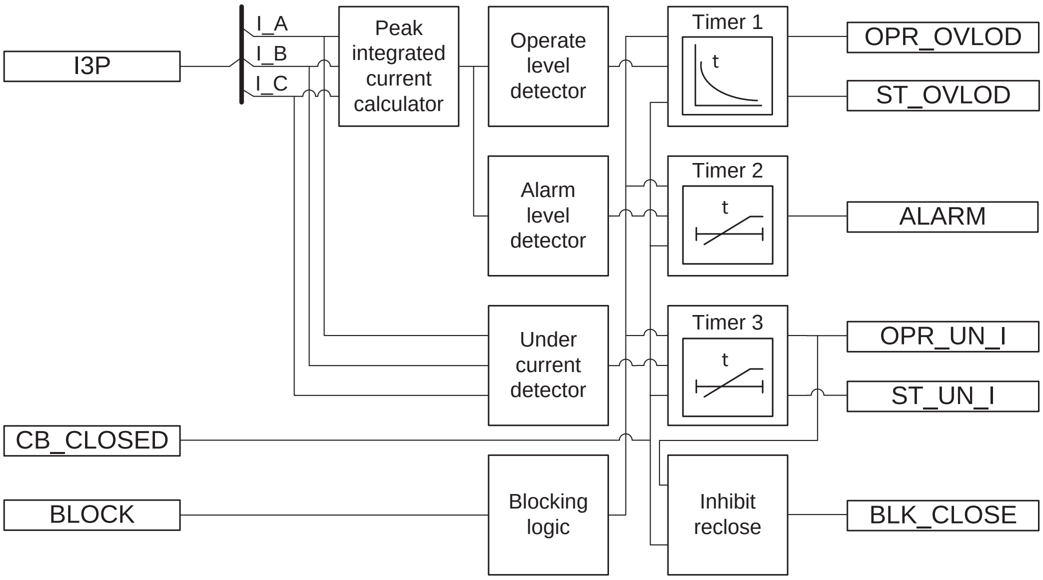


Figure 623: Functional module diagram

Peak integrated current calculator

The peak integrated current calculator calculates peak value of integrated current (I_PEAK_INT_A, I_PEAK_INT_B and I_PEAK_INT_C) which is proportional to the voltage over capacitor. The I_PEAK_INT_A, I_PEAK_INT_B and I_PEAK_INT_C values are available in monitored data view. The frequency response of the peak integrated current calculator can be seen in *Figure 624*.

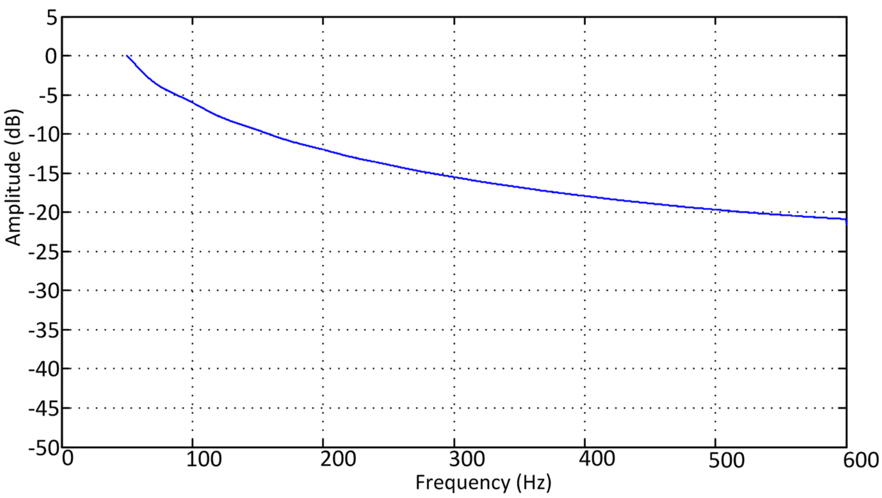


Figure 624: Frequency response of the peak integrated current calculator

Operate level detector

The Operate level detector compares I_PEAK_INT_x value to *Start value overload*. If the phase or phases in which I_PEAK_INT_x exceeds the setting matches the *Num of start phases* setting, the Operate level detector module activates the Timer 1 module.

Timer 1

Once activated, the Timer 1 module activates the ST_OVLOD output. The operation time depends on the overload level and *Time multiplier*. The operation time under standard characteristics is based on ANSI/IEEE 37.99 and IEC 60871-1 recommendations.

Table 1054: Standard Curve characteristics for IDMT Curve

Overload value	IED operate time(s) with k = 1	Standard
1.10	43200	IEC60871-1
1.15	1800	IEC60871-1
1.20	300	IEC60871-1
1.30	60	ANSI/IEEE37.99,IEC60871-1
1.40	15	ANSI/IEEE37.99
1.70	1	ANSI/IEEE37.99
2.20	0.120	ANSI/IEEE37.99

Operate time is based on maximum value of I_PEAK_INT_A, I_PEAK_INT_B and I_PEAK_INT_C. From maximum value calculated , operate time between any two consecutive points in the standard table is based on logarithmic interpolation.

The operate time can be scaled using the *Time multiplier* setting. The OPR_OVLOD output is activated if the overload situation lasts long enough to exceed the operation time.

The operate time for the operation overload stage is limited between 0.1 s to 43200 s (12 hours) if *Time multiplier* is used.

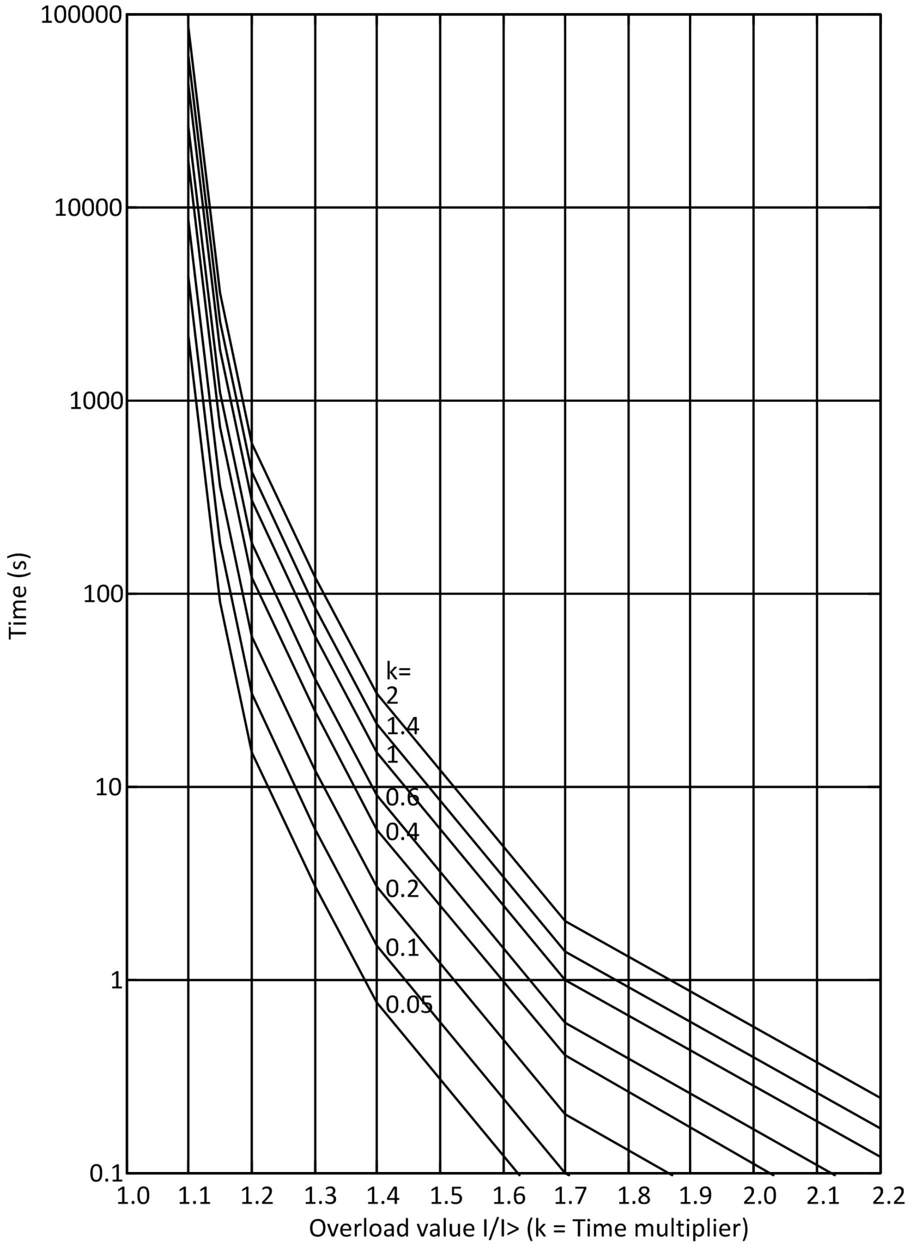


Figure 625: Inverse-time characteristic curves for overload stage

If the integrated current exceeds 1.1 times the setting *Start value overload* for a short period but does not operate as the current decreases within *Start value overload*, the output ST_OVLOD is kept active but the operation timer is frozen. However, if the integrated current exceeds 1.1 times the *Start value overload* setting value again, the operation timer continue from the freezing point. Thus, the operation timer is cumulative. If the integrated current exceeds 1.1 times the setting *Start value overload* only once and remains within the *Start value overload* area for 24 hours, the operation timer and the output ST_OVLOD are reset.

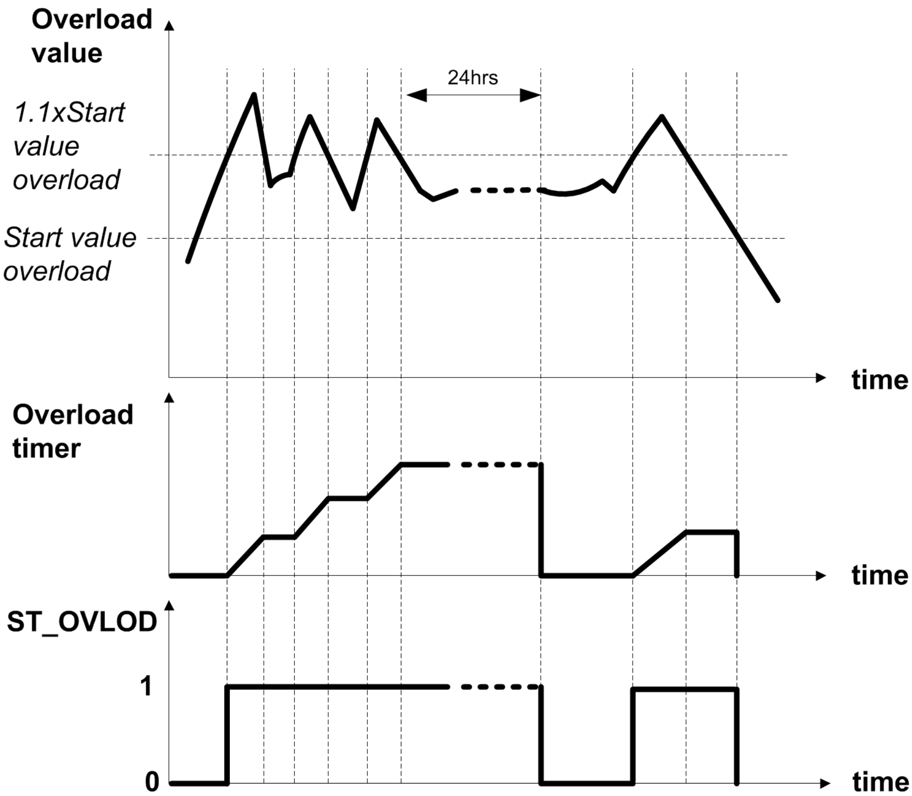


Figure 626: The behavior of the IDMT timer and the output ST_OVLOD

The ST_DUR_OVLOD output indicates the percentage ratio of the start situation and the operation time in the Timer 1 module and is available in the monitored data view.

The Timer 1 module is internally blocked for one second after the capacitor bank is connected by detecting the rising edge of the CB_CLOSED signal. The CB_CLOSED signal is True when the CB position is closed.

Alarm level detector

The Alarm level detector compares I_PEAK_INT_x value to *Alarm start value*. If the phase or phases in which I_PEAK_INT_x exceeds the setting matches the *Num of start phases* setting, the Alarm level detector module activates the Timer 2 module.

The *Num of start phases* setting is a common setting for both Operate level detector and Alarm level detector.

Timer 2

The Timer 2 characteristics are according to Definite Time (DT) .When the operation timer has reached the value of *Alarm delay time*, the ALARM output is activated.

If a drop-off situation happens, the timer is reset.

The Timer 2 module is internally blocked for one second after the capacitor bank is connected by detecting the rising edge of the

CB_CLOSED signal. The CB_CLOSED signal is True when the CB position is closed.

Under current detector

The Under current detector module can be enabled by setting *Enable under current* to “Enable” and disabled by setting it to “Disable”. The Under current detector module is also disabled when CB_CLOSED is FALSE, that is, when circuit breaker is open.

The fundamental frequency component of phase currents is compared to the setting *Start value Un Cur*. If all the three-phase currents are below the setting *Start value Un Cur*, the Under current detector module enables the Timer 3 module.

Timer 3

Once activated, the Timer 3 module activates the ST_UN_I output. The operation is based on DT characteristics. When the operation timer has reached the value of *Un Cur delay time*, the OPR_UN_I output is activated.

If the undercurrent situation disappears, the operation timer is reset. The ST_DUR_UN_I output indicates the percentage ratio of the undercurrent start situation and the set operation time in the Timer 3 module and is available in the monitored data view.

The OPR_UN_I output is of pulse type and remains TRUE for 150 ms. After that, ST_DUR_UN_I and OPR_UN_I are deactivated and ST_DUR_UN_I is reset.

If the circuit breaker closed status signal is not detected, the constant value TRUE has to be connected to CB_CLOSED input to enable the undercurrent detector.

If the circuit breaker status signal is not connected to CB_CLOSED input, the OPR_UN_I output is activated even if the circuit breaker is open and undercurrent is detected.

Inhibit reclose

When the output OPR_UN_I becomes active or when the CB_CLOSED state changes from TRUE to FALSE, that is, when circuit breaker opens, the reclosing inhibition module activates output BLK_CLOSE.

If *Enable under current* is set to “Disable”, the reclosing inhibition operation is based purely on the CB_CLOSED input.

When the relay powers up after a reboot or software reset, or if the Operation of COLPTOC function is switched from off to on, the BLK_CLOSE output is activated defined by the *Reclose inhibit time*, regardless the *Reclose inhibit mode*.

The behavior of the BLK_CLOSE output depends on *Reclose inhibit mode*. If *Reclose inhibit mode* is set to “Lockout”, the BLK_CLOSE output needs to be reset manually from the clearing menu parameter *COLPTOC inhibit recl*. If *Reclose inhibit mode* is set to “Non-latched”, the BLK_CLOSE output resets after the set *Reclose inhibit time* has elapsed.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** >

Blocking mode which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, COLPTOC is executed normally but the OPR_OVLOD and OPR_UN_I outputs are not allowed to activate.

The BLOCK input does not block the BLK_CLOSE signal.

4.12.1.6 Application

The application area for three-phase overload protection function of shunt capacitor bank is the protection of power capacitor banks intended for reactive power compensation and filtering of the harmonics. Shunt capacitor banks provide a low-impedance path to harmonic currents and hence attract harmonic currents flowing in the system. Increased harmonic currents result in excessive voltage stress across the capacitor bank. According to the standards, a high-voltage capacitor shall be able to withstand 10% overload. Loading beyond that can cause damage to the capacitor bank and in turn to the system. Hence, COLPTOC is specially designed for the protection against overloads produced by harmonic currents and overvoltage.

Undercurrent protection is used to disconnect the capacitor bank from the rest of the power system when the voltage at the capacitor bank terminals is too low for too long a period of time. To avoid an undercurrent trip operation when the capacitor bank is disconnected from the power system, the undercurrent functionality is blocked by using the capacitor bank circuit breaker status signal.

Furthermore, the reclosing inhibition feature provides protection against the reconnection of a charged capacitor to a live network. Whenever the capacitor bank circuit breaker is opened, the reclosing is inhibited for the duration of the discharge time of the capacitor. The reclosing inhibition functionality can be disabled manually or automatically. In the manual mode, the inhibition reclosing has to be manually reset and in automatic mode, the reclosing inhibitionl resets automatically after the set time.

4.12.1.7 Signals

COLPTOC Input signals

Table 1055: COLPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for acti-vating the blocking mode
CB_CLOSED	BOOLEAN	0=False	Input showing the status of capacitor circuit breaker

COLPTOC Output signals

Table 1056: COLPTOC Output signals

Name	Type	Description
OPR_OVLOD	BOOLEAN	Overload operated
OPR_UN_I	BOOLEAN	Operate under current
ST_OVLOD	BOOLEAN	Overload started
ST_UN_I	BOOLEAN	Under current started
ALARM	BOOLEAN	Alarm
BLK_CLOSE	BOOLEAN	Inhibit re-close of capacitor bank

4.12.1.8 COLPTOC Settings

Table 1057: COLPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value over-load	0.30...1.50	xIn	0.01	1.00	Start value for over-load stage
Alarm start value	80...120	%	1	105	Alarm start value (% of Start value overload)
Start value Un Cur	0.10...0.70	xIn	0.01	0.50	Start value for un-der current opera-tion
Time multiplier	0.05...2.00		0.01	1.00	Time multiplier for Capacitor Bank protection curves
Alarm delay time	500...6000000	ms	100	300000	Alarm delay time
Un Cur delay time	100...120000	ms	100	1000	Delay time for un-der current opera-tion

Table 1058: COLPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reclose inhibit time	1...6000	s	1	1	Reclose inhibit time

Table 1059: COLPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reclose inhibit mode	1=Non-latched 3=Lockout			1=Non-latched	Reclose inhibit mode
Num of start phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required for operate activation

Table 1060: COLPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Enable under current	0=Disable 1=Enable			1=Enable	Enable under current functionality

4.12.1.9 COLPTOC Monitored data

Table 1061: COLPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
ST_DUR_OVLOD	FLOAT32	0.00...100.00	%	Start duration for overload stage
ST_DUR_UN_I	FLOAT32	0.00...100.00	%	Start duration for under current operation
I_PEAK_INT_A	FLOAT32	0.00...40.00		Phase A peak value of the integrated current of the capacitor
I_PEAK_INT_B	FLOAT32	0.00...40.00		Phase B peak value of the integrated current of the capacitor
I_PEAK_INT_C	FLOAT32	0.00...40.00		Phase C peak value of the integrated current of the capacitor
COLPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.12.1.10 Technical data

Table 1062: COLPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz, and no harmonics
	5 % of the set value or 0.002 × I_n
Start time for overload stage [1, 2]	Typically 75 ms

Table continues on the next page

Characteristic	Value
Start time for under current stage [2,3]	Typically 26 ms
Reset time for overload and alarm stage	Typically 60 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	1 % of the set value or ±20 ms
Operate time accuracy in inverse time mode	10 % of the theoretical value or ±20 ms
Suppression of harmonics for under current stage	DFT: -50 dB at f = n × fn, where n = 2,3,4,5,..

4.12.2 Current unbalance protection for capacitor banks CUBPTOC (ANSI 60N)

4.12.2.1 Identification

Table 1063: Function identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current unbalance protection for shunt capacitor banks	CUBPTOC	dI>C	60N

4.12.2.2 Function block

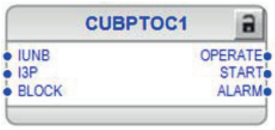


Figure 627: Function block symbol

4.12.2.3 Functionality

The current unbalance protection for shunt capacitor banks function CUBPTOC is used to protect the double-Y-connected capacitor banks from internal faults. CUBPTOC is suitable for the protection of internally fused, externally fused and fuseless applications.

CUBPTOC has two stages of operation, that is, operation stage and alarm stage. In the operating stage, CUBPTOC starts when the measured unbalance current

[1] Harmonics current before fault = 0.5 × I_n, harmonics fault current 1.5 × *Start value*, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact
[3] Harmonics current before fault = 1.2 × I_n, harmonics fault current 0.8 × *Start value*, results based on statistical distribution of 1000 measurements

exceeds the set limit. The operation time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). The operation under alarm stage is either based on the DT characteristics or the faulty element counter of a capacitor bank.

CUBPTOC has a blocking functionality. It is possible to block the function outputs, timers or the function itself.

4.12.2.4 Analog channel configuration

CUBPTOC has two analog group inputs which must be properly configured.

Table 1064: Analog inputs

Input	Description
IUNB	Unbalance current (measured)
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1065: Special conditions

Condition	Description
IUNB measurement	The function requires that the unbalance current measurement is connected via the RESTCTR function block.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.12.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”. The current unbalance protection for shunt capacitor banks operates on the DFT measurement mode.

The operation of CUBPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

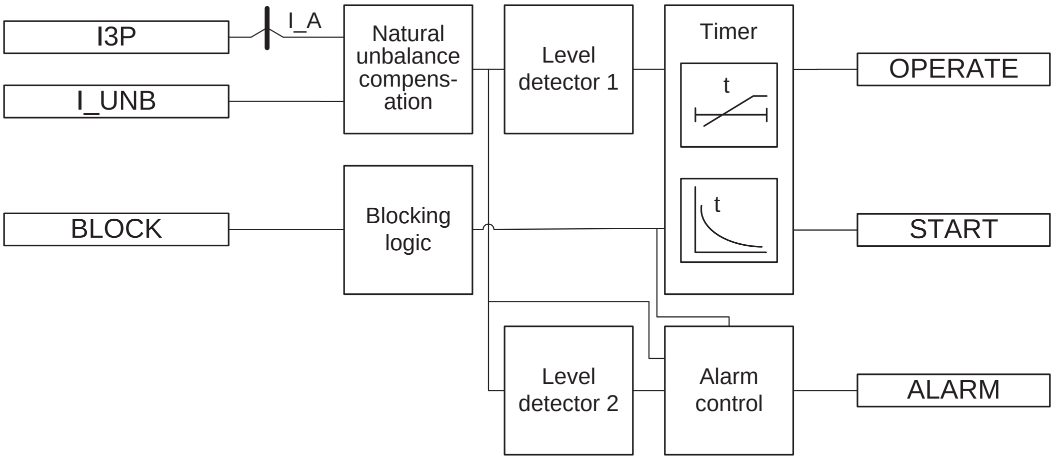


Figure 628: Functional module diagram

Natural unbalance Compensation

A standard double-Y-connected shunt capacitor bank configuration is shown in *Figure 629*. The fundamental frequency component of an unbalance current is measured on the common neutral connecting the two balanced parts of a shunt capacitor bank, that is, between star point 1 and star point 2.

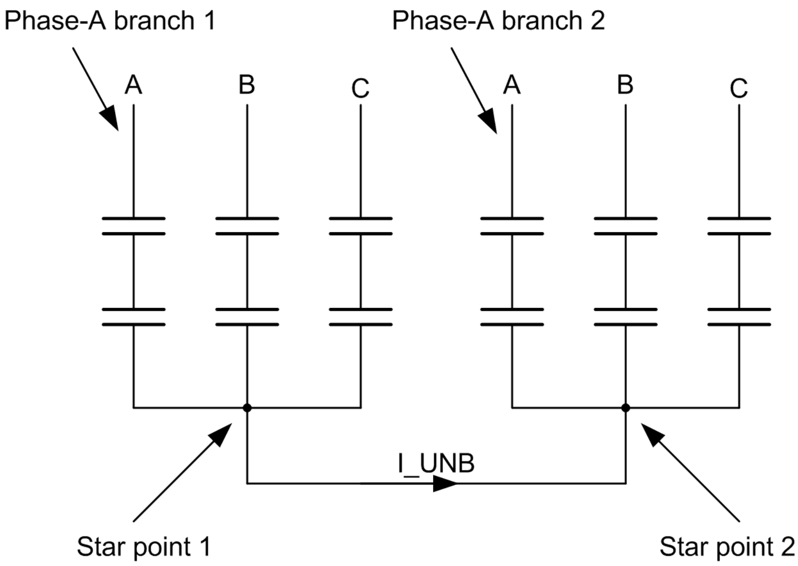


Figure 629: Double-Y-connected capacitor bank

The phase angle of the measured fundamental frequency component of the unbalance current I_UNB is synchronized by using the phase current I_A as a reference.

$$\angle \overline{I_{unb}} = \angle \overline{I\_UNB} - \angle \overline{I\_A}$$

(Equation 285)

In a three-phase star-connected capacitor bank circuit, there may be some amount of natural unbalance current flowing through the neutral, which is primarily due to capacitor manufacturing tolerances. The natural unbalance current must be compensated for before using the measured unbalance current for the function operation. The natural unbalance current needs to be recorded when there is no fault in the capacitor banks, and it is initiated through the command *Record unbalance*, available under menu path **Control** > **CUBPTOC**. By selecting *Record unbalance* with value "Record", the measured unbalance current $\overline{I}_{Unb}$ is considered as the natural unbalance current $\overline{I}_{NatUnb}$ and is stored as a reference. The amplitude and angle of the recorded natural unbalance current I_AMPL_NAT and I_ANGL_NAT are available in the monitored data view.

Once the natural unbalance current is recorded during further executions of the function, the natural unbalance current is subtracted from the measured unbalance current $\overline{I}_{Unb}$ to obtain the compensated unbalance current $\overline{I}_{CompUnb}$ as shown in *Figure 630*.

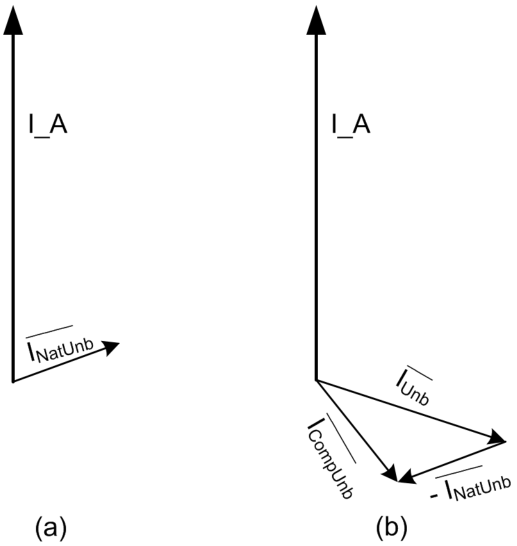


Figure 630: Natural unbalance compensation. (a) Healthy condition when the natural unbalance is recorded (b) Unbalance compensation during faulty conditions

The natural unbalance current compensation is enabled using the setting *Natural Comp Enable*. If *Natural Comp Enable* is set to "FALSE", the unbalance current is not compensated. If *Natural Comp Enable* is set to "TRUE", the compensated unbalance current is calculated based on the equation.

$$\overline{I}_{CompUnb} = \overline{I}_{Unb} - \overline{I}_{NatUnb}$$

(Equation 286)

The amplitude I_AMPL_COMP and the angle I_ANGL_COMP of the compensated unbalance current $\overline{I}_{CompUnb}$ are available in the monitored data view.

Level detector 1

The calculated compensated unbalance current I_AMPL_COMP is compared to the set "Start value". If I_AMPL_COMP exceeds the set "Start value", the Level detector 1 sends an enabling signal to the Timer 1 module.

Timer 1

Once activated, the Timer 1 module activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated. When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C* and *Curve parameter E*.

In a drop-off situation, that is when a fault suddenly disappears before the operate delay is exceeded, the Timer 1 reset state is activated. The functionality of the Timer 1 in the reset state depends on the combination of the Operating curve type and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, an immediate reset occurs. The START output is deactivated when the reset timer has elapsed.

The setting *Time multiplier* is used for scaling the IDMT operation and reset times.

The setting parameter *Minimum operate time* defines the minimum desired operation time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve but always at least the value of the *Minimum operate time* setting.

The Timer 1 module calculates the start duration value START_DUR, which indicates the percentile ratio of the start situation and the set operation time. The value is available in the monitored data view.

In a typical double-Y-connected configuration (Figure 629), there are two branches in every phase and hence six individual counters COUNT_BR1_A, COUNT_BR2_A, COUNT_BR1_B, COUNT_BR2_B, COUNT_BR1_C and COUNT_BR2_C are maintained. Based on the phase angle of the compensated unbalance current I_ANGL_COMP, the phase and the branch of the element failure location is detected. However, the element failure location also depends on the type of capacitor banks, that is, whether internal or external fuses are used. The setting *Fuse location* is used to set the capacitor bank type as “External” or “Internal”.

For an external fuse capacitor bank, the element failure location and corresponding counters to be incremented are determined based on the phase angle of the compensated unbalance current.

Table 1066: Element failure location and counters to be incremented for external fuse case

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
-15...+15	Phase-A branch 1	COUNT_BR1_A
-15...-45	Phase-A branch 1 Phase-C branch 2	COUNT_BR1_A COUNT_BR2_C
-45...-75	Phase-C branch 2	COUNT_BR2_C
-75...-105	Phase-B branch 1 Phase-C branch 2	COUNT_BR1_B COUNT_BR2_C
-105...-135	Phase-B branch 1	COUNT_BR1_B
-135...-165	Phase-B branch 1 Phase-A branch 2	COUNT_BR1_B COUNT_BR2_A
-165...-180	Phase-A branch 2	COUNT_BR2_A
+165...+180	Phase-A branch2	COUNT_BR2_A
+135...+165	Phase-C branch 1 Phase-A branch 2	COUNT_BR1_C COUNT_BR2_A
+105...+135	Phase-C branch 1	COUNT_BR1_C
+75...+105	Phase-C branch1 Phase-B branch2	COUNT_BR1_C COUNT_BR2_B
+45...+75	Phase-B branch2	COUNT_BR2_B
+15...+45	Phase-A branch1 Phase-B branch2	COUNT_BR1_A COUNT_BR2_B

If the capacitor bank is fuseless, then the setting *Fuse location* should be set to “External” and *Table 1066* can be used to determine the element failure location.

If the compensated unbalance current I_AMPL_COMP is greater than three times the set *Alarm value*, it is considered to be a case of blown external fuse. For the internal fuse and blown fuse cases, the element failure location and corresponding counters to be incremented are determined based on the phase angle of the compensated unbalance current.

Table 1067: Element failure location and counters to be incremented for internal fuse and blown fuse case

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
-15...+15	Phase-A branch 2	COUNT_BR2_A
-15... -45	Phase-A branch 2	COUNT_BR2_A

Table continues on the next page

Phase angle of the compensated unbalance current (degrees)	Phase and branch of the element failure	Counters to be incremented
	Phase-C branch 1	COUNT_BR1_C
-45...-75	Phase-C branch 1	COUNT_BR1_C
-75...-105	Phase-B branch 2 Phase-C branch 1	COUNT_BR2_B COUNT_BR1_C
-105...-135	Phase-B branch 2	COUNT_BR2_B
-135...-165	Phase-B branch 2 Phase-A branch 1	COUNT_BR2_B COUNT_BR1_A
-165...-180	Phase-A branch 1	COUNT_BR1_A
+165...+180	Phase-A branch 1	COUNT_BR1_A
+135...+165	Phase-C branch 2 Phase-A branch 1	COUNT_BR2_C COUNT_BR1_A
+105...+135	Phase-C branch 2	COUNT_BR2_C
+75...+105	Phase-C branch 2 Phase-B branch 1	COUNT_BR2_C COUNT_BR1_B
+45...+75	Phase-B branch 1	COUNT_BR1_B
+15...+45	Phase-A branch 2 Phase-B branch 1	COUNT_BR2_A COUNT_BR1_B

After *Alarm delay time* has elapsed, the corresponding counter value is incremented based on the magnitude of the unbalance current. If I_AMPL_COMP is less than 1.5 times the set *Alarm value*, the counter is incremented by one. Furthermore, if I_AMPL_COMP is between 1.5 and 2.5 times the set *Alarm value*, the counter is incremented by two and so on.

Normally, the setting *Alarm value* is about 0.1 percent lower than the value of the unbalance current which is caused by one faulty element. This setting value has to be chosen carefully because a slightly lower value may lead to a situation where the counters show more failures than the actual. Too high setting leads to a situation where a fault is not detected.

The counter values COUNT_BR1_A, COUNT_BR2_A, COUNT_BR1_B, COUNT_BR2_B, COUNT_BR1_C and COUNT_BR2_C are available in the monitoring data view. The total number of element failures in double-Y-connected capacitor banks, FAIL_COUNT, is available in the monitored data view.

The `ALARM` output is activated, when the value of FAIL_COUNT exceeds the setting *Element failure limit*.

The counter values can be reset via *CUBPTOC counters* which is located under the Clear menu.

Level detector 2

The calculated compensated unbalance current I_AMPL_COMP is compared to the set *Alarm start value*. If the I_AMPL_COMP exceeds the set *Alarm value* the Level detector 2 sends enabling signal to the Alarm control module.

Alarm control

Depending on the *Alarm mode* setting, the alarm stage operation is according to “Normal mode” or “Element counter mode”.

In the “Normal mode” the time characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the ALARM output is activated. If the fault disappears before the alarm activates, the alarm timer is reset immediately.

The “Element counter mode” is used to detect faulty elements of the capacitor bank and count the number of element failures in each branch and line. On activation, this module increments the corresponding element failure counters after the set *Alarm delay time* has elapsed.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode**, which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the "Freeze timers" mode, the operation timer is frozen to the prevailing value. In the "Block all" mode, the whole function is blocked and the timers are reset. In the "Block OPERATE output" mode, CUBPTOC operates normally but the OPERATE output is not activated.

4.12.2.6 Application

CUBPTOC is designed for the protection against internal faults in double-Y-connected capacitor banks. This unbalance protection detects an asymmetry in the capacitor bank caused by blown fuses or short circuits across bushings or between capacitor units and the racks in which they are mounted.

Normally, the capacitor units are designed to withstand 110 percent of the nominal voltage continuously. When an element inside a capacitor bank fails, the remaining healthier elements experience an increase in voltage across them. If the voltage exceeds the 110 percent value of the nominal voltage, it can lead to a failure of the healthier elements of the bank and in turn fail the entire capacitor bank. Since the capacitor unbalance current is directly proportional to the element failures, unbalance protection is an effective way of detecting capacitor element failures. The current unbalance protection function is usually used with the three-phase capacitor bank overload protection function to increase the sensitivity of protection for capacitor banks.

Due to the two-stage (operation and alarm stage) unbalance protection and the natural unbalance compensation facility, the protection of capacitor banks with internal fuses can be implemented with a very high degree of sensitivity.

Furthermore, CUBPTOC provides a sophisticated method of detecting the number of faulty elements in each phase by calculating the differential unbalance current.

The unbalance protection function can be used for internally fused, externally fused and fuseless shunt capacitor banks. Since a fuseless capacitor bank lacks the individual capacitor unit fuses, current unbalance protection becomes even more critical for fuseless applications.

When an individual element fails, it causes unbalance current. With an increasing number of element failures, the unbalance current increases and CUBPTOC gives an alarm. The alarm level is normally set to 50 percent of the maximum permitted level. The capacitor bank needs to be taken out of service to replace the faulty units. If this is not done, the capacitor bank is tripped when the maximum allowed unbalance current level is exceeded.

If two simultaneous faults occur in the same phase but in different branches, there is no change in the unbalance current and CUBPTOC does not detect this type of faults.

If two simultaneous faults occur in the same branch but in different phases, it may cause a phase angle equal to a situation where there is only one fault in the branch. Therefore, the element failure counters show only one fault instead of two.

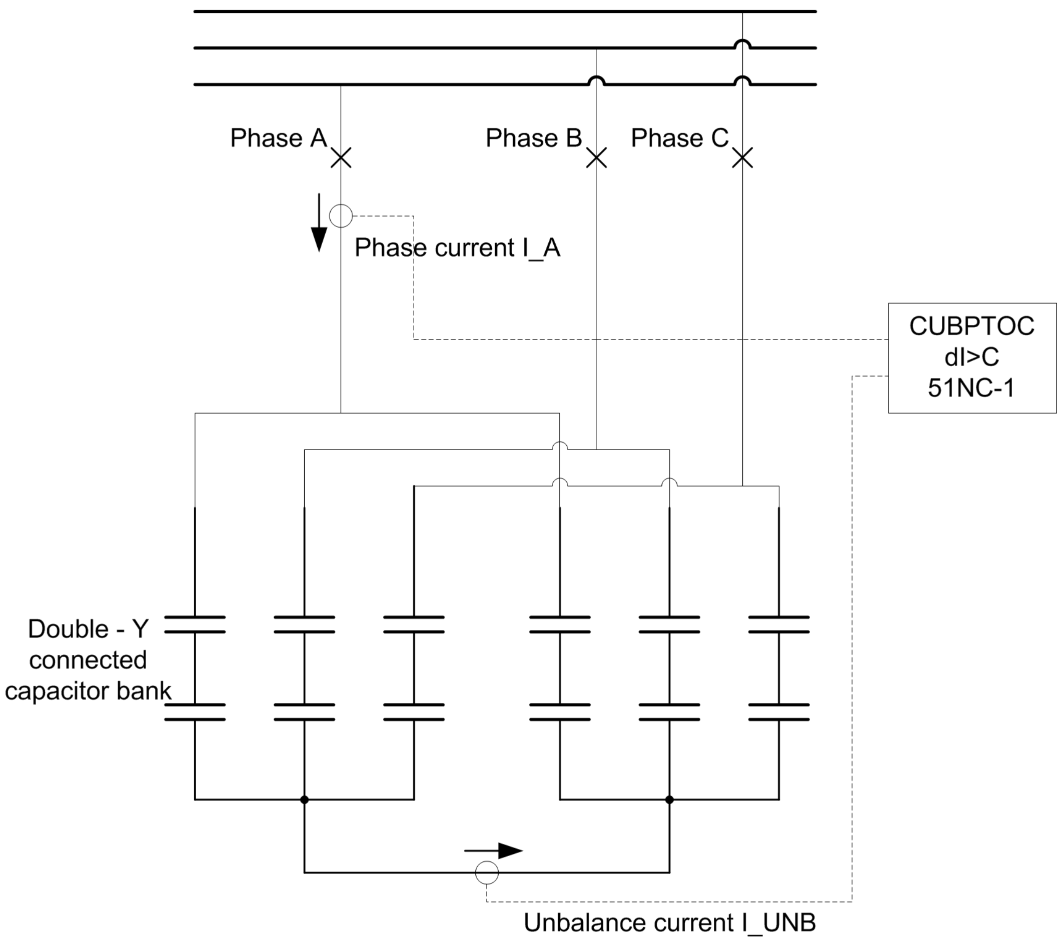


Figure 631: Example of double-Y-connected shunt capacitor bank unbalance protection

Connect the phase current analog input I_A and unbalance current I_UNB to the protection relay for the CUBPTOC function to start working.

Steps to measure natural unbalance current

1. The setting *Natural Comp Enable* must be set to “TRUE”.
2. The capacitor bank must be energized.
3. The capacitor bank compensated unbalance current I_COM_AMPL is observed from Monitored data.
4. The command *Record unbalance* must be activated by selecting the value “Record” which stores the unbalance reference for future unbalance calculations.
5. The compensated unbalance current (I_COM_AMPL) is re-checked to be approximately zero.

The natural unbalance recording should be made only during the steady-state condition and when all the capacitor bank elements are assumed to be in service.

4.12.2.7 Signals

CUBPTOC Input signals

Table 1068: CUBPTOC Input signals

Name	Type	Default	Description
IUNB	SIGNAL	-	Analog input
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

CUBPTOC Output signals

Table 1069: CUBPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.12.2.8 CUBPTOC Settings

Table 1070: CUBPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm mode	1=Normal			1=Normal	Mode of operation for Alarm stage

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Element counter				
Start value	0.01...1.00	xIn	0.01	0.10	Start value
Alarm start value	0.01...1.00	xIn	0.01	0.05	Alarm start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type 19=RD type			15=IEC Def. Time	Selection of time delay curve type
Operate delay time	50...200000	ms	10	5000	Operate delay time
Alarm delay time	50...200000	ms	10	200000	Alarm delay time

Table 1071: CUBPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Fuse location	1=Internal 2=External			1=Internal	Location of capacitor fuse
Element fail limit	1...100		1	3	Element failure limit above which alarm is active
Natural Comp enable	0=False 1=True			0=False	Enable natural unbalance compensation

Table 1072: CUBPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.00860...120.00000		0.00001	28.20000	Parameter A for customer programmable curve
Curve parameter B	0.00000...0.71200		0.00001	0.12170	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 1073: CUBPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves

4.12.2.9 CUBPTOC Monitored data

Table 1074: CUBPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
I_NAT_AMPL	FLOAT32	0.00...5.00	xIn	Recorded natural unbalance current amplitude
I_NAT_ANGL	FLOAT32	-179.00...179.00	deg	Recorded natural unbalance current angle
I_COM_AMPL	FLOAT32	0.00...5.00	xIn	Compensated unbalance current amplitude
I_COM_ANGL	FLOAT32	-179.00...179.00	deg	Compensated unbalance current angle
COUNT_BR1_A	INT32	0...2147483647		Number of element failures in branch1 phase-A
COUNT_BR2_A	INT32	0...2147483647		Number of element failures in branch2 phase-A
COUNT_BR1_B	INT32	0...2147483647		Number of element failures in branch1 phase-B
COUNT_BR2_B	INT32	0...2147483647		Number of element failures in branch2 phase-B
COUNT_BR1_C	INT32	0...2147483647		Number of element failures in branch1 phase-C
COUNT_BR2_C	INT32	0...2147483647		Number of element failures in branch2 phase-C
FAIL_COUNT	INT32	0...2147483647		Total number of element failures
CUBPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
I-unb-xIn:1	FLOAT32	0.00...5.00	xIn	Measured neutral unbalance current amplitude

4.12.2.10 Technical data

Table 1075: CUBPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	1.5 % of the set value or 0.002 × I_n
Start time [1, 2]	Typically 26 ms

Table continues on the next page

Characteristic	Value
Reset time	Typically 40 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	1 % of the theoretical value or ±20 ms
Operate time accuracy in inverse definite minimum time mode	5 % of the theoretical value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2,3,4,5,..

4.12.3 Three-phase current unbalance protection for shunt capacitor banks HCUBPTOC (ANSI 60P)

4.12.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase current unbalance protection for shunt capacitor banks	HCUBPTOC	3dI>C	60P

4.12.3.2 Function block

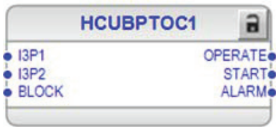


Figure 632: Function block symbol

4.12.3.3 Functionality

The three-phase current unbalance protection function for shunt capacitor banks HCUBPTOC is used to protect the H-bridge capacitor banks against internal faults. HCUBPTOC is suitable for protection of internally fused, externally fused and fuse-less capacitor bank applications.

HCUBPTOC has two stages of operation, the operation stage and alarm stage. In the operation stage, HCUBPTOC starts when the measured unbalance current exceeds the set limit. The operating time characteristics can be selected to be either definite time (DT) or inverse definite minimum time (IDMT). In the alarm stage, the alarm starts when the measured unbalance current exceeds the set alarm limit. The alarm time characteristics are based on DT.

HCUBPTOC contains blocking functionality. It is possible to block the function outputs, timers or the function itself.

1 Fundamental frequency current = 1.0 × I_n, current before fault = 0.0 × I_n, fault current = 2.0 × *Start value*, results based on statistical distribution of 1000 measurements
2 Includes the delay of the signal output contact

4.12.3.4 Analog channel configuration

HCUBPTOC has two analog group inputs which must be properly configured.

Table 1076: Analog inputs

Input	Description
I3P1	Three-phase currents
I3P2	Three-phase unbalance currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.12.3.5 Operation principle

The function can be enabled and disabled with the Operation setting. The corresponding parameter values are “On” and “Off”.

The three-phase current unbalance protection for shunt capacitor banks operates on the DFT measurement mode. The operation of HCUBPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

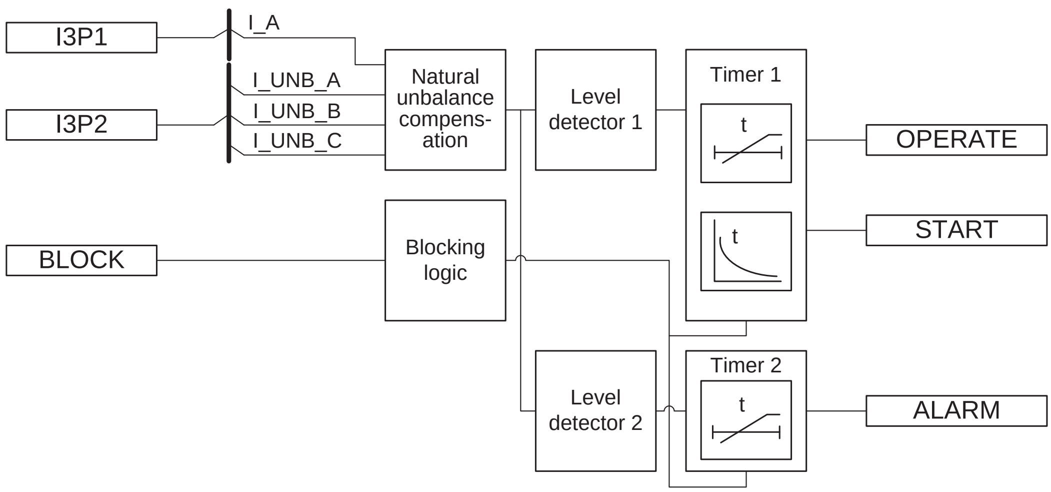


Figure 633: Function module diagram

Natural unbalance compensation

In the three-phase H-bridge-connected shunt capacitor bank configuration, the unbalance currents `I_UNB_A`, `I_UNB_B` and `I_UNB_C` are measured at the common points of the H-bridge.

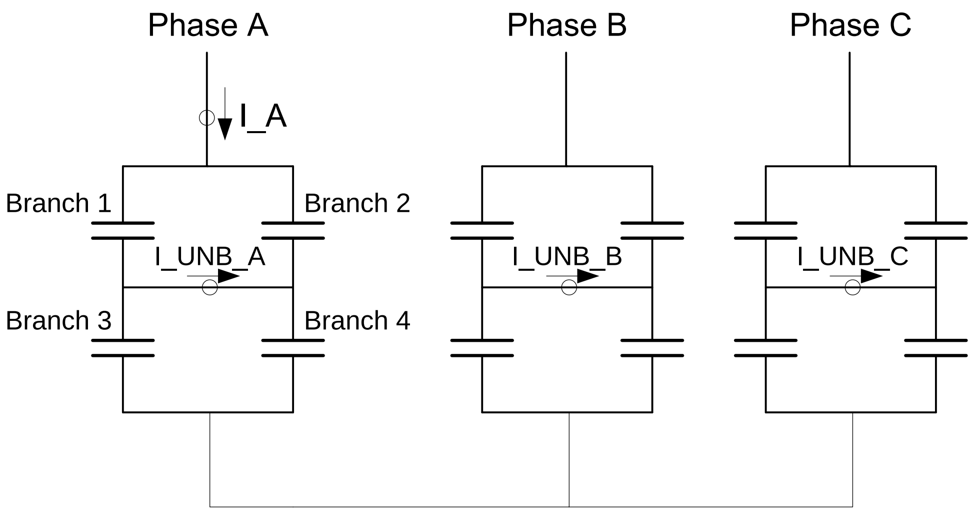


Figure 634: H-Bridge-connected capacitor bank

The phase angles of three-phase measured unbalance currents are synchronized using the phase current I_A as reference. The phase-A unbalance current phase angle can be calculated with the equation.

$$\angle\overline{I_{Unb\_A}} = \angle\overline{I\_UNB\_A} - \angle\overline{I\_A}$$

(Equation 287)

A three-phase H-bridge-connected capacitor bank circuit may have some amount of natural unbalance current flowing through the common points of H-bridge, which may primarily be due to capacitor manufacturing tolerances. Therefore, the natural unbalance current must be compensated for before using the measured unbalance current for function operation.

The natural unbalance current needs to be recorded when there is no fault in the capacitor banks, and it is initiated through the command *Record unbalance* available under menu path **Control** > **HCUBPTOC**. The natural unbalance currents are recorded for all the phases at the same time by setting command *Record unbalance* to “Record all phases” or each natural unbalance current can be recorded separately for individual phases by setting command *Record unbalance* to “Record phase A” or “Record phase B” or “Record phase C”. By selecting *Record unbalance* with value “Record”, the measured three-phase unbalance currents ($\overline{I_{Unb\_A}}, \overline{I_{Unb\_B}}, \overline{I_{Unb\_C}},$) are considered the natural unbalance currents for each phase respectively and stored as a reference. The amplitude and angle of the phasewise-recorded natural unbalance currents I_NAT_AMPL_A, I_NAT_ANGL_A, I_NAT_AMPL_B, I_NAT_ANGL_B, I_NAT_AMPL_C and I_NAT_ANGL_C are available in the monitored data view.

Once a natural unbalance current is recorded, the phasewise natural unbalance current is subtracted from the corresponding phase-measured unbalance current ($\overline{I_{Unb}}$) during further executions of the function to obtain the compensated unbalance current ($\overline{I_{CompUnb}}$) .

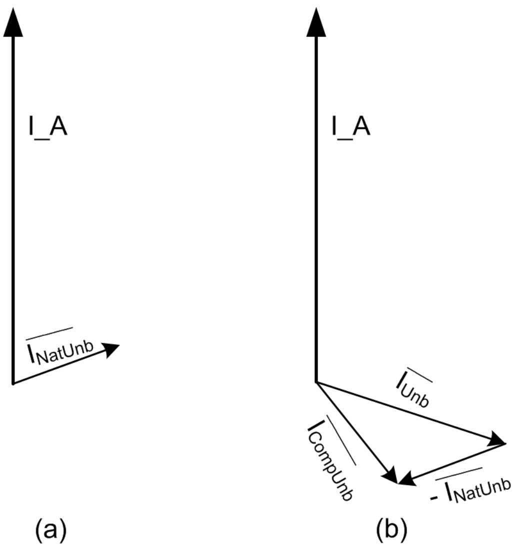


Figure 635: Natural unbalance compensation. (a) Healthy condition when the natural unbalance is recorded (b) Unbalance compensation during faulty conditions

The natural unbalance compensation for each phase is enabled based on the settings *Natural Comp Ena PhA*, *Natural Comp Ena PhB* and *Natural Comp Ena PhC* respectively. For example, if *Natural Comp Ena PhA* is set to “FALSE”, the unbalance current is not compensated. If *Natural Comp Ena PhA* is set to “TRUE”, the compensated unbalance current for phase A is calculated based on the equation.

$$\overline{I_{CompUnb\_A}} = \overline{I_{Unb\_A}} - \overline{I_{NatUnb\_A}}$$

(Equation 288)

$I_{CompUnb\_A}$	Phase A-compensated unbalance current
I_{Urb_A}	Phase A-measured unbalance current
I_{NatUnb_A}	Phase A-recorded natural unbalance current

The phasewise-compensated unbalance current amplitudes and angles `I_COM_AMPL_A`, `I_COM_ANGL_A`, `I_COM_AMPL_B`, `I_COM_ANGL_B`, `I_COM_AMPL_C` and `I_COM_ANGL_C` are available in the monitored data view.

The phase angles of the unbalance currents indicate the branch of a faulty element in a capacitor bank. For an internal fuse capacitor bank, the element failure branch location is determined based on the phase angle of the compensated unbalance current.

Table 1077: Detection of element failure location for internal fuse capacitor bank

Name of the phase angle	Phase angle of unbalance current	Element failure branch location *Figure 634*
I_COM_ANGL_A	~+180°	Phase A - Branch 1 or Phase A - Branch 4
I_COM_ANGL_A	~0°	Phase A - Branch 2 or Phase A - Branch 3

Table continues on the next page

I_COM_ANGL_B	~+60°	Phase B - Branch 1 or Phase B - Branch 4
I_COM_ANGL_B	~–120°	Phase B - Branch 2 or Phase B - Branch 3
I_COM_ANGL_C	~–60°	Phase C - Branch 1 or Phase C - Branch 4
I_COM_ANGL_C	~+120°	Phase C - Branch 2 or Phase C - Branch 3

If external fuses are used, the direction of an unbalance current is opposite to that of the bank where internal fuses are in use.

Table 1078: Detection of element failure location for external fuse capacitor bank

Name of the phase angle	Phase angle of unbalance current	Element failure branch location *Figure 634*
I_COM_ANGL_A	~0°	Phase A - Branch 1 or Phase A - Branch 4
I_COM_ANGL_A	~+180°	Phase A - Branch 2 or Phase A - Branch 3
I_COM_ANGL_B	~–120°	Phase B - Branch 1 or Phase B - Branch 4
I_COM_ANGL_B	~+60°	Phase B - Branch 2 or Phase B - Branch 3
I_COM_ANGL_C	~+120°	Phase C - Branch 1 or Phase C - Branch 4
I_COM_ANGL_C	~–60°	Phase C - Branch 2 or Phase C - Branch 3

Level detector 1

The phasewise-compensated unbalance currents I_COM_AMPL_A, I_COM_AMPL_B and I_COM_AMPL_C are compared to the set *Start value*. If the compensated unbalance current in one or more phases exceeds the set *Start value*, the Level detector 1 module sends the enabling signal to the Timer 1 module.

Timer 1

Once activated, the Timer 1 module activates the START output. Depending on the value of the *Operating curve type* setting, the time characteristics are according to DT or IDMT. When the operation timer has reached the value of *Operate delay time* in the DT mode or the maximum value defined by the inverse time curve, the OPERATE output is activated.

When the user-programmable IDMT curve is selected, the operation time characteristics are defined by the parameters *Curve parameter A*, *Curve parameter B*, *Curve parameter C* and *Curve parameter E*.

In a drop-off situation, that is, when a fault suddenly disappears before the operation delay is exceeded, the Timer 1 reset state is activated. The functionality of Timer 1 in the reset state depends on the combination of the *Operating curve type* and *Reset delay time* settings. When the DT characteristic is selected, the reset timer runs until the set *Reset delay time* value is exceeded. When the IDMT curves are selected, an immediate reset occurs. The START output is deactivated when the reset timer has elapsed.

The setting *Time multiplier* is used for scaling the IDMT operation times.

The setting parameter *Minimum operate time* defines the minimum desired operation time for IDMT. The setting is applicable only when the IDMT curves are used.

The *Minimum operate time* setting should be used with great care because the operation time is according to the IDMT curve, but always at least the value of the *Minimum operate time* setting.

Timer 1 calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the monitored data view.

Level detector 2

The phasewise-compensated unbalance currents I_COM_AMPL_A, I_COM_AMPL_B and I_COM_AMPL_C are compared to the set *Alarm start value*. If the compensated unbalance current in one or more phases exceeds the set *Alarm start value*, the Level detector 2 module sends the enabling signal to the Timer 2 module.

Timer 2

Once activated, the timer activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the ALARM output is activated.

If the fault disappears before the alarm activates, the alarm timer is reset immediately.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, HCUBPTOC operates normally but the OPERATE output is not activated.

4.12.3.6 Application

Shunt capacitor banks (SCBs) are widely used in transmission and distribution networks to produce reactive power support. Located in relevant places such as in the vicinity of load centers, SCBs have beneficial effects on power system performance: increased power factor, reduced losses, improved system capacity and better voltage level at load points.

The capacitor bank terminology ‘Bank’, ‘Unit’ and ‘Element’ is shown in *Figure 636*.

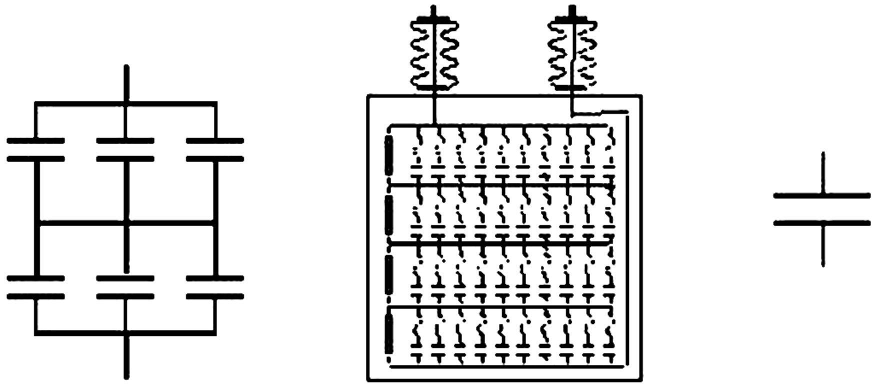


Figure 636: Bank, unit and element of a capacitor bank

HCUBPTOC is designed for the protection against internal faults in H-bridge-connected capacitor banks. This unbalance protection detects an asymmetry in the capacitor bank, caused by blown fuses or short-circuits across bushings, or between capacitor units and the racks in which they are mounted.

Normally, the capacitor units are designed to withstand 110% of the nominal voltage continuously. When an element inside a capacitor bank fails, the remaining healthy elements experience an increase in voltage across them. If the voltage exceeds 110% of the nominal voltage, it can lead to a failure of the healthy elements of the bank and in turn fail the entire capacitor bank. Since the capacitor unbalance current is directly proportional to element failures, unbalance protection is an effective way of detecting capacitor element failures. The current unbalance protection function is usually used along with the three-phase capacitor bank overload protection function to increase the sensitivity of protection for capacitor banks.

Due to the two-stage (operation and alarm stage) unbalance protection and the natural unbalance compensation facility, the protection of capacitor banks with internal fuses can be implemented with a very high degree of sensitivity.

The unbalance protection function can be used for internally fused, externally fused and fuseless shunt capacitor banks. Since a fuseless capacitor bank lacks the individual capacitor unit fuses, current unbalance protection becomes even more critical for fuseless applications.

When an individual element fails, it creates current unbalance. With an increasing number of element failures, the unbalance current increases and HCUBPTOC gives an alarm. The alarm level is normally set to 50% of the maximum permitted level. The capacitor bank then should be taken out of service to replace the faulty units. If not, the capacitor bank is tripped when the maximum allowed unbalance current level is exceeded.

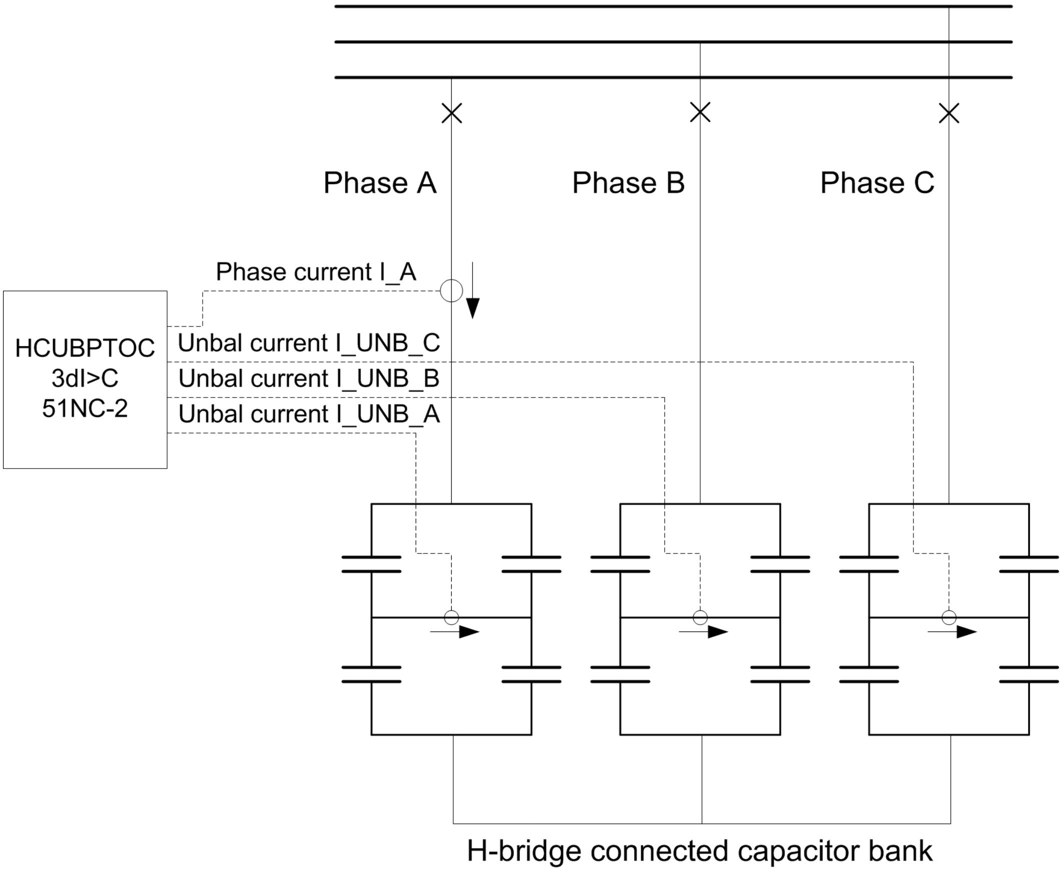


Figure 637: Application example of capacitor bank unbalance protection

The phase current analog input I_A and at least one unbalance current must be connected to the protection relay for the HCUBPTOC function to start working.

Steps to measure natural unbalance current

1. The setting *Natural Comp Enable* must be set to “TRUE”.
2. The capacitor bank must be energized.
3. The capacitor bank compensated unbalance current `I_COM_AMPL` is observed from Monitored data.
4. The command *Record unbalance* must be activated by selecting the value “Record” which stores the unbalance reference for future unbalance calculations.
5. The compensated unbalance current (`I_COM_AMPL`) is re-checked to be approximately zero.

The natural unbalance recording should be made only during the steady-state condition and when all the capacitor bank elements are assumed to be in service.

4.12.3.7 Signals

HCUBPTOC Input signals

Table 1079: HCUBPTOC Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

HCUBPTOC Output signals

Table 1080: HCUBPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
ALARM	BOOLEAN	Alarm

4.12.3.8 HCUBPTOC Settings

Table 1081: HCUBPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...1.00	xIn	0.01	0.10	Start value
Alarm start value	0.01...1.00	xIn	0.01	0.05	Alarm start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operating curve type	1=ANSI Ext. inv. 2=ANSI Very inv. 3=ANSI Norm. inv. 4=ANSI Mod. inv. 5=ANSI Def. Time 6=L.T.E. inv. 7=L.T.V. inv. 8=L.T. inv. 9=IEC Norm. inv. 10=IEC Very inv. 11=IEC inv. 12=IEC Ext. inv. 13=IEC S.T. inv. 14=IEC L.T. inv. 15=IEC Def. Time 17=Programmable 18=RI type			15=IEC Def. Time	Selection of time delay curve type

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	19=RD type				
Operate delay time	40...200000	ms	10	5000	Operate delay time
Alarm delay time	40...200000	ms	10	200000	Alarm delay time

Table 1082: HCUBPTOC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Natural Comp Ena PhA	0=False 1=True			0=False	Enable natural unbalance compensation PhA
Natural Comp Ena PhB	0=False 1=True			0=False	Enable natural unbalance compensation PhB
Natural Comp Ena PhC	0=False 1=True			0=False	Enable natural unbalance compensation PhC

Table 1083: HCUBPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Curve parameter A	0.00860...120.00000		0.00001	28.20000	Parameter A for customer programmable curve
Curve parameter B	0.00000...0.71200		0.00001	0.12170	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00		0.01	2.00	Parameter C for customer programmable curve
Curve parameter E	0.0...1.0		0.1	1.0	Parameter E for customer programmable curve

Table 1084: HCUBPTOC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	20...60000	ms	1	20	Minimum operate time for IDMT curves

4.12.3.9 HCUBPTOC Monitored data

Table 1085: HCUBPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
I_NAT_AMPL_A	FLOAT32	0.00...5.00	xIn	Recorded natural unbalance current amplitude phase A
I_NAT_ANGL_A	FLOAT32	-179.00...179.00	deg	Recorded natural unbalance current angle phase A
I_NAT_AMPL_B	FLOAT32	0.00...5.00	xIn	Recorded natural unbalance current amplitude phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_NAT_ANGL_B	FLOAT32	-179.00...179.00	deg	Recorded natural unbalance current angle phase B
I_NAT_AMPL_C	FLOAT32	0.00...5.00	xIn	Recorded natural unbalance current amplitude phase C
I_NAT_ANGL_C	FLOAT32	-179.00...179.00	deg	Recorded natural unbalance current angle phase C
I_COM_AMPL_A	FLOAT32	0.00...5.00	xIn	Compensated unbalance current amplitude phase A
I_COM_ANGL_A	FLOAT32	-179.00...179.00	deg	Compensated unbalance current angle phase A
I_COM_AMPL_B	FLOAT32	0.00...5.00	xIn	Compensated unbalance current amplitude phase B
I_COM_ANGL_B	FLOAT32	-179.00...179.00	deg	Compensated unbalance current angle phase B
I_COM_AMPL_C	FLOAT32	0.00...5.00	xIn	Compensated unbalance current amplitude phase C
I_COM_ANGL_C	FLOAT32	-179.00...179.00	deg	Compensated unbalance current angle phase C
HCUBPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
IL1-unb:1	FLOAT32	0.00...5.00	xIn	Measured unbalance current amplitude phase A
IL2-unb:1	FLOAT32	0.00...5.00	xIn	Measured unbalance current amplitude phase B
IL3-unb:1	FLOAT32	0.00...5.00	xIn	Measured unbalance current amplitude phase C

4.12.3.10 Technical data

Table 1086: HCUBPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	1.5 % of the set value or 0.002 × I_n
Start time [1, 2]	Typically 26 ms
Reset time	Typically 40 ms
Reset ratio	Typically 0.96

Table continues on the next page

[1] Fundamental frequency current = 1.0 × I_n, current before fault = 0.0 × I_n, fault current = 2.0 × *Start value*, results based on statistical distribution of 1000 measurements

[2] Includes the delay of the signal output contact

Characteristic	Value
Operate time accuracy in definite time mode	1 % of the theoretical value or ±20 ms
Operate time accuracy in IDMT mode	5 % of the theoretical value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2,3,4,5,..

4.12.4 Shunt capacitor bank switching resonance protection, current based, SRCPTOC (ANSI 55ITHD)

4.12.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Shunt capacitor bank switching resonance protection, current based	SRCPTOC	TD>	55ITHD

4.12.4.2 Function block

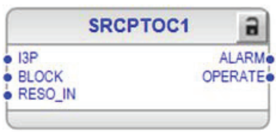


Figure 638: Function block symbol

4.12.4.3 Functionality

The shunt capacitor bank switching resonance protection, current based, function SRCPTOC is used for detecting three-phase resonance caused by capacitor switching or topology changes in the network. The operating characteristic is a definite time (DT).

SRCPTOC contains a blocking functionality. It is possible to block function outputs, timers or the function itself.

4.12.4.4 Analog input configuration

SRCPTOC has one analog group input which must be properly configured.

Table 1087: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.12.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of SRCPTOC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

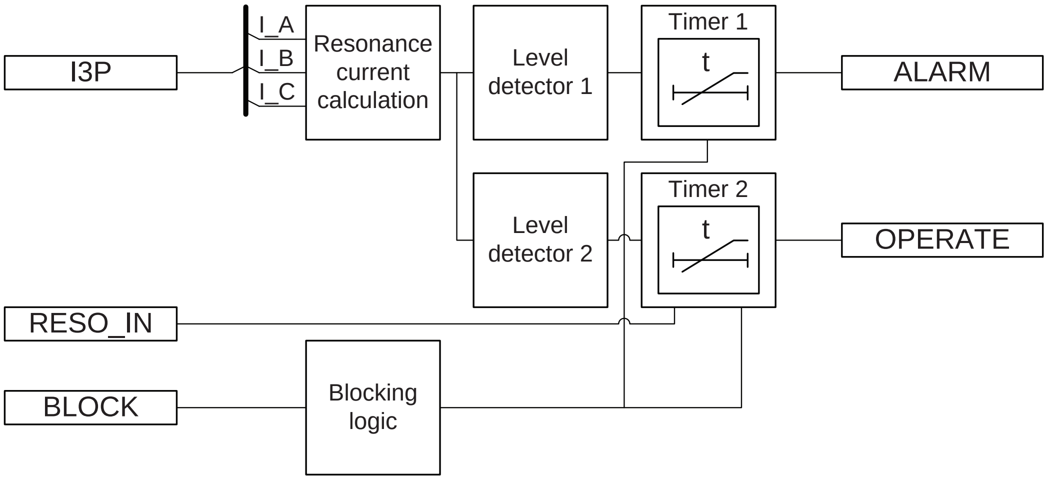


Figure 639: Functional module diagram

Resonance current calculation

This module calculates the resonance current per phase set as per setting *Tuning harmonic Num*. The resonance current for phase A is calculated with the equation.

$$I\_RESO\_A = \sqrt{I_{RMS\_A}^2 - I_{1\_A}^2 - I_{DC\_A}^2 - I_{K\_A}^2}$$

(Equation 289)

I_{RMS_A}	RMS value of current in phase A (contains up to 11 th harmonic)
I_{DC_A}	DC-component in phase A current
$_{I\_A}$	Fundamental component in phase A current
I_{K_A}	K th harmonic component in phase A current, K is defined by setting *Tuning harmonic Num*
I_RESO_A	Calculated resonance current for phase A

The resonance current is calculated through the filter implementation. The DC and fundamental components are removed by passing the total RMS current through the High pass filter. The K th harmonic component is removed by passing the High pass filter output through the K th harmonic Band stop filter. The magnitude response of the High pass filter and all the harmonic Band stop filters are shown in *Figure 640*.

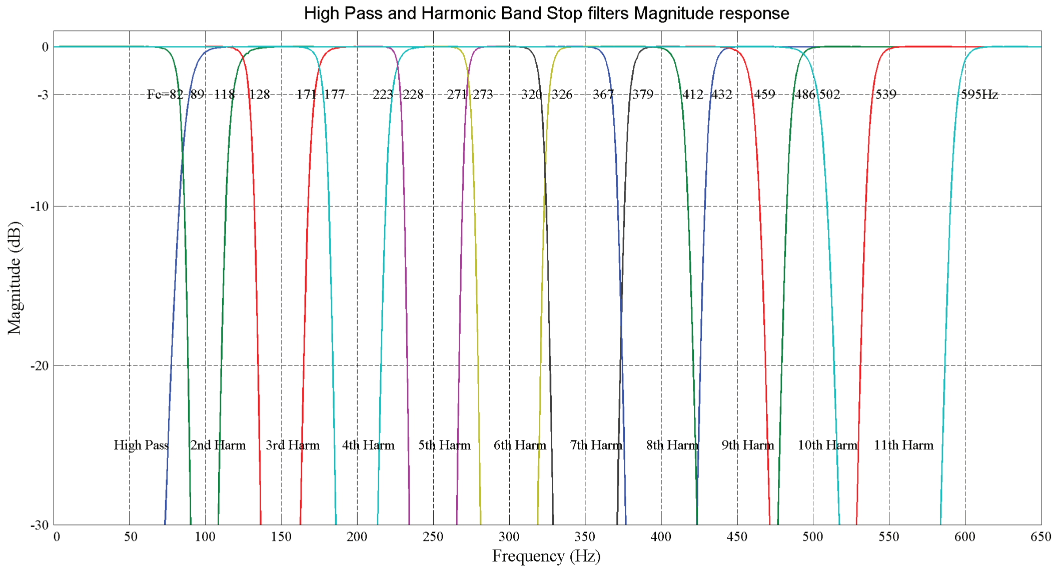


Figure 640: Magnitude response of High pass and all the harmonic Band stop filters

Similarly resonance current is calculated in the same way for phase B and phase C. Resonance currents I_RESO_A, I_RESO_B and I_RESO_C are available in the monitored data view.

The maximum of the three calculated resonance currents is further considered for calculation.

$$I\_RESONANCE = Max(I\_RESO\_A, I\_RESO\_B, I\_RESO\_C)$$

(Equation 290)

If a capacitor bank is used only for reactive power compensation and there is no series reactor in a filter branch, the resonance protection is very important. In this case, the setting *Tuning harmonic Num* should be set to 1 because the capacitor branch is not tuned for a special frequency as in tuned filter applications. Even though *Tuning harmonic Num* is set to 1, the fundamental component is subtracted only once from I_{RMS}.

Level detector 1

The maximum calculated resonance current is compared to the set *Alarm start value*. If the calculated I_RESONANCE exceeds the set *Alarm start value*, the module sends the enabling signal to the Timer 1 module.

Level detector 2

The maximum calculated resonance current is compared to the set *Start value*. If the calculated I_RESONANCE exceeds the set *Start value*, this module sends the enabling signal to the Timer 2 module.

Timer 1

Once activated, the timer activates the alarm timer. The timer characteristic is according to DT. When the alarm timer has reached the value set by *Alarm delay time*, the ALARM output is activated.

If the fault disappears before the alarm activates, the alarm timer is reset immediately.

Timer 2

Once activated, the timer activates the operation timer. The timer characteristic is according to DT. When the operation timer has reached the value set by *Operate delay time*, the OPERATE output is activated.

If the fault disappears before the operate activates, the operation timer is reset immediately.

If the input RESO_IN becomes active, the OPERATE output is activated immediately. If the resonance protection at a higher-order filter branch has already operated, the function in lower-order filter branches can be tripped immediately using this feature.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the IED program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, SRCPTOC operates normally but the OPERATE output is not activated.

4.12.4.6 Application

Switched shunt capacitor banks are widely used by utilities and customers in industrial distribution systems to provide voltage support and to improve the power factor of a load. Capacitor steps may be switched in and out of circuits routinely as the demand for capacitive VAR compensation of a load fluctuates. Normally, automatic power factor controllers are employed which automatically switch on or off the capacitors of the capacitor bank, depending upon the prevalent reactive power requirement in the system.

One potential problem for the application of automatic power factor controllers is that it may cause harmonic resonance under certain system conditions. Capacitor switching changes the parameters of the system, which may cause the resonance frequency of the circuit to be equal to one of the frequencies of the harmonic sources prevalent in the system. Harmonic resonance, when it occurs, may result in severe voltage and current distortions, which increases losses and causes overheating of other equipment in the circuit.

A traditional way of solving the problem is to conduct a detailed system study for each individual installation and use the results to properly size the capacitors and determine the right operating range of capacitors to avoid harmonic resonance with other system components. However, this method is not economical but more time-consuming.

The capacitor switching-resonance protection function can be used as a solution to the above mentioned problem. The basis for the harmonic resonance protection is the detection of a current harmonic resonance condition caused by capacitor switching. A prolonged increase of the harmonic distortion level after a switching operation is a clear indication of such condition. When a resonant condition caused by capacitor switching occurs in a circuit, SRCPTOC detunes the circuit by taking the reverse action, that is, switching the capacitor bank off if switching it on causes resonance. If the resonance situation has been detected and SRCPTOC has switched off a capacitor bank, power factor controller should not try to switch on the capacitor bank until the switching resonance function reset.

The capacitor switching-resonance protection function can also be used to protect harmonic filters. In harmonic filter bank applications, the SRCPTOC function can be tuned to harmonic frequency for which the harmonic filter is designed to ensure that the function does not include thr tuned harmonic frequency current into the calculation of the resonance current. If there is more than one harmonic filter bank involved, each SRCPTOC tunes to the harmonic frequency of its corresponding filter bank. The interlinking between the functions can be done in such a way that if resonance occurs in a higher harmonic frequency filter bank, all the lower harmonic frequency filter banks can be tripped immediately by activating the function input `RESO_IN`.

The settings *Alarm start value* and *Start value* determine the portion of the total harmonic current (excluding the harmonic defined by the setting *Tuning harmonic Num*) in relation to the CT nominal value required for SRCPTOC to give alarm and operate respectively.

For power factor correction application

- *Tuning harmonic Num* must be set to 1.
- *Alarm start value* and *Start value* must be set according to the standard IEEE519 -1992.

For harmonic filter application

- *Tuning harmonic Num* must be set to the filter design tuning frequency.
- *Alarm start value* and *Start value* must be set according to the standard IEEE519 -1992.

Settings *Alarm start value* and *Start value* should be selected as such that in normal operation SRCPTOC should not operate.

4.12.4.7 Signals

SRCPTOC Input signals

Table 1088: SRCPTOC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RESO_IN	BOOLEAN	0=False	Input signal from higher frequency resonance branch

SRCPTOC Output signals

Table 1089: SRCPTOC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm
OPERATE	BOOLEAN	Operate signal

4.12.4.8 SRCPTOC Settings

Table 1090: SRCPTOC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm start value	0.03...0.50	xIn	0.01	0.03	Alarm limit for filtered harmonic currents
Start value	0.03...0.50	xIn	0.01	0.03	Tripping limit for filtered harmonic currents indicating resonance condition
Tuning harmonic Num	1...11		1	11	Tuning frequency harmonic number of the filter branch
Operate delay time	120...360000	ms	1	200	Operate delay time for resonance
Alarm delay time	120...360000	ms	1	200	Alarm delay time for resonance alarm

Table 1091: SRCPTOC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

4.12.4.9 SRCPTOC Monitored data

Table 1092: SRCPTOC Monitored data

Name	Type	Values (Range)	Unit	Description
I_RESO_A	FLOAT32	0.00...40.00	xIn	Resonance current for phase A
I_RESO_B	FLOAT32	0.00...40.00	xIn	Resonance current for phase B
I_RESO_C	FLOAT32	0.00...40.00	xIn	Resonance current for phase C
SRCPTOC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.12.4.10 Technical data

Table 1093: SRCPTOC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	Operate value accuracy: ±3 % of the set value or ±0.002 × I_n (for 2nd order Harmonics) ±1.5 % of the set value or ±0.002 × I_n (for 3rd order < Harmonics < 10th order) ±6 % of the set value or ±0.004 × I_n (for Harmonics >= 10th order)
Reset time	Typically 45 ms or maximum 50 ms
Retardation time	Typically 0.96
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0 % of the set value or ±20 ms
Suppression of harmonics	-50 dB at f = f_n

4.12.5 Compensated neutral unbalance voltage protection CNUPTOV (ANSI 59NU)

4.12.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Compensated neutral unbalance voltage protection	CNUPTOV	CNU>	59NU

4.12.5.2 Function block

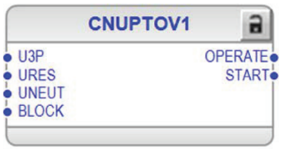


Figure 641: Function block

4.12.5.3 Functionality

The compensated neutral unbalance voltage protection function CNUPTOV detects overvoltage at the neutral point of the shunt capacitor. A blown fuse or a shortcircuited capacitor element results in unbalance in the shunt capacitor bank causing increase in neutral point voltage. With CNUPTOV, an inherent capacitor bank unbalance which results in non-zero neutral point voltage can be compensated automatically on a continuous basis.

The function starts when the fundamental (DFT) component of the compensated neutral unbalance voltage exceeds the set limit. CNUPTOV operates with the definite time (DT) characteristics.

The function contains a blocking functionality. It is possible to block function outputs, the definite timer or the function itself.

4.12.5.4 Analog channel configuration

CNUPTOV has three analog group inputs which must be properly configured.

Table 1094: Analog inputs

Input	Description
U3P	Three phase voltages
URES	Residual voltage (measured or calculated)
UNEUT	Measured neutral voltage

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1095: Special conditions

Condition	Description
U3P connected real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.
URES calculated	The function requires that all three voltage channels from terminal side are connected to calculate residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. Check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

4.12.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of CNUPTOV can be described with a module diagram. All the modules in the diagram are explained in the next sections.

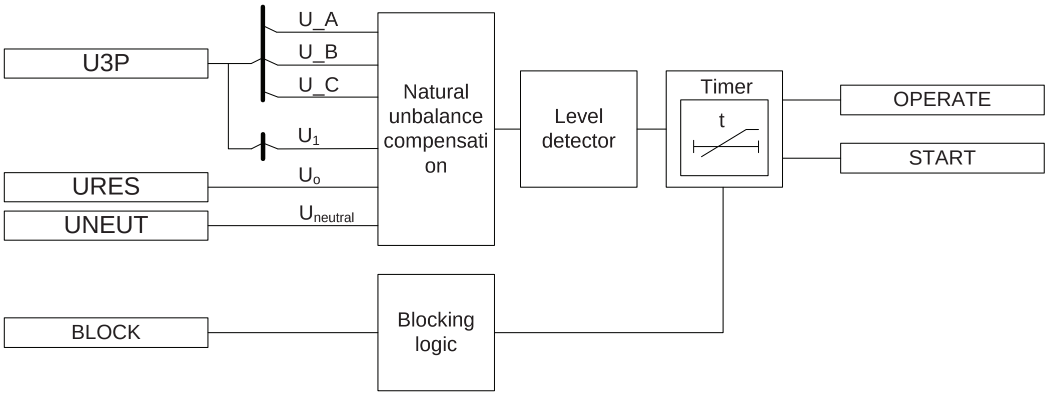


Figure 642: Functional module diagram

Natural unbalance compensation

This module calculates the natural unbalance compensation. Calculation for compensation is initiated through the command Record unbalance, available under the menu path **Control** > **CNUPTOV**. The function equates the operating signal to zero and calculates $\overline{U_{unb}}$ from the available known quantities. $\overline{U_{unb}}$ is memorized as $\overline{U_{unb}}(m)$. This memorized value is then used when calculating the operating quantity. For more information, see the *Chapter 4.12.5.6 Operating quantity* section in this manual.

If the positive-sequence voltage is available at the time of memorizing the $\overline{U_{unb}}(m)$ value, the positive-sequence voltage is also memorized as $\overline{U_1}(m)$. The function then applies the revised compensation voltage to account for change in bus voltages between the moment of memorizing the compensation voltage and the time of applying it.

$$\overline{U_{unb}} = \overline{U_{unb}}(m) \cdot \frac{\overline{U_1}}{\overline{U_1}(m)}$$

Figure 643: Equation

Level detect

The operating signal is compared to the set *Start value*. If the operating signal exceeds the set *Start value*, Level detector sends an enabling signal to the Timer module.

Timer

Once activated, Timer activates the START output. The time characteristic is according to DT. When the operation timer has reached the value set by *Operate delay* time, the OPERATE output is activated if the operating signal persists. If a drop-off situation happens, that is, the fault disappears before the operate delay is exceeded, the timer reset state is activated. If the reset timer reaches the value set by *Reset delay time*, the operation timer resets and the START output is deactivated.

Timer calculates the start duration value START_DUR, which indicates the percentage ratio of the start situation and the set operation time. The value is available in the Monitored data view.

Blocking logic

There are three operation modes in the blocking function. The operation modes are controlled by the BLOCK input and the global setting in **Configuration** > **System** > **Blocking mode** which selects the blocking mode. The BLOCK input can be controlled by a binary input, a horizontal communication input or an internal signal of the protection relay's program. The influence of the BLOCK signal activation is preselected with the global setting *Blocking mode*.

The *Blocking mode* setting has three blocking methods. In the “Freeze timers” mode, the operation timer is frozen to the prevailing value, but the OPERATE output is not deactivated when blocking is activated. In the “Block all” mode, the whole function is blocked and the timers are reset. In the “Block OPERATE output” mode, the function operates normally but the OPERATE output is not activated.

4.12.5.6 Operating quantity

Operating quantity in ungrounded SCB

Consider a case of a standard ungrounded shunt capacitor bank as shown in *Figure 644*.

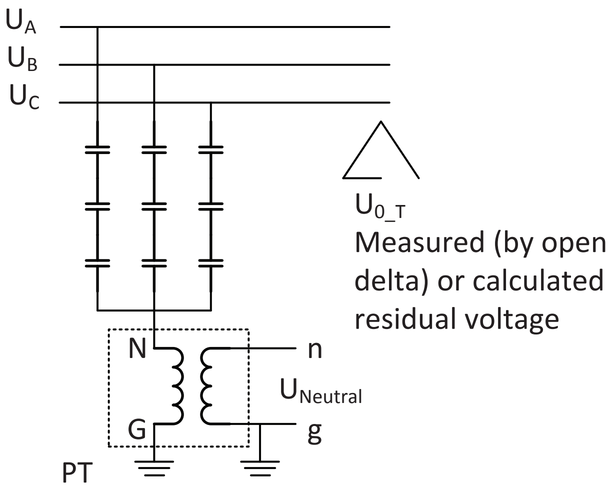


Figure 644: Ungrounded SCB

The operating signal for the compensated neutral voltage unbalance in per unit with reference to the neutral side of an ungrounded SCB is as indicated in *Figure 645*.

$$\text{Operating signal} = \left| \frac{\overline{U}_{Neutral}}{U_{N\_sr}} - \frac{n_{Uo}}{U_{N\_pr}} \cdot \overline{U}_o - \overline{U}_{unb} \right|$$

Figure 645: Equation

$U_{Neutral}$	Measured shunt capacitor neutral voltage
U_o	Measured open delta voltage
U_{unb}	Natural unbalance compensation component
n_{Uo}	Voltage ratio of open delta VT
U_{N_sr}	Rated secondary voltage of neutral connected VT
U_{N_pr}	Rated primary voltage of neutral connected VT

The rated *Primary voltage* and *Secondary voltage* for the neutral voltage channel $U_{Neutral}$, and for U_{N_pr} and U_{N_sr} are set in the global setting under **Configuration** > **Analog inputs** > **Voltage (Uo,VT)**.

The operating signal setting is given as multiple of the neutral VT rated voltage.

In monitored data, xUn refers to neutral VT rated voltage.

4.12.5.7 Application

Shunt capacitor banks are provided with an unbalance protection function which is mainly used to detect problems within capacitor units using the presumed symmetry in the impedances of the protected bank. The unbalance protection responds to unbalances in the measured signals caused by changes in the impedance of the capacitor bank.

In compensating unbalance protection, the operating signal compensates both the inherent capacitor bank unbalance and the system unbalance. The method involves measuring the residual voltage at the capacitor terminal side and at the neutral side. The terminal side's residual voltage component is obtained directly by VTs connected in open delta or by deriving open delta voltage using all three terminal side phase voltages. The neutral side's residual voltage is measured directly by connecting a VT between the neutral point and earth. It is advisable to block the function with the fuse failure function.

Example 1, ungrounded SCB

Figure 646 illustrates how much the neutral voltage changes in case of failure of some phase elements of the ungrounded SCB.

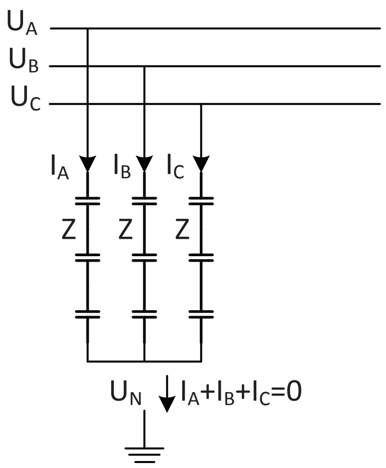


Figure 646: Ungrounded SCB

In a healthy ungrounded capacitor bank, the sum of the phase currents is

$$\bar{I}_A + \bar{I}_B + \bar{I}_C = 0$$

Figure 647: Equation

If the capacitor bank is symmetrical, that is, there is equal impedance in each phase, the equation can be

$$\left(\frac{\bar{U}_A - \bar{U}_N}{Z}\right) + \left(\frac{\bar{U}_B - \bar{U}_N}{Z}\right) + \left(\frac{\bar{U}_C - \bar{U}_N}{Z}\right) = 0$$

Figure 648: Equation

If the fault in the capacitor bank changes the phase A impedance to kZ

$$\left(\frac{\bar{U}_A - \bar{U}_N}{kZ}\right) + \left(\frac{\bar{U}_B - \bar{U}_N}{Z}\right) + \left(\frac{\bar{U}_C - \bar{U}_N}{Z}\right) = 0$$

Figure 649: Equation

$$\frac{\bar{U}_A}{kZ} + \frac{\bar{U}_B}{Z} + \frac{\bar{U}_C}{Z} = \bar{U}_N \cdot \left(\frac{1}{kZ} + \frac{2}{Z}\right)$$

Figure 650: Equation

$$\overline{U}_A + k \cdot \left(\overline{U}_B + \overline{U}_C\right) = \overline{U}_N \cdot (1 + 2 \cdot k)$$

Figure 651: Equation

If the system is symmetrical, that is, the system is healthy without any fault

$$\overline{U}_A + \overline{U}_B + \overline{U}_C = 0$$

Figure 652: Equation

Combining *Figure 651* and *Figure 652* results in

$$\overline{U}_A + k \cdot \left(-\overline{U}_A\right) = \overline{U}_N \cdot (1 + 2 \cdot k)$$

Figure 653: Equation

$$\overline{U}_N = \overline{U}_A \cdot \frac{(1-k)}{(1+2 \cdot k)}$$

Figure 654: Equation

Considering the neutral VT ratio, per unit voltage referred to the neutral side is given by

$$\overline{U}_N = \frac{\overline{U}_A \cdot \frac{(1-k)}{(1+2 \cdot k)}}{U_{N\_pr}}$$

Figure 655: Equation

For example, if the impedance of the 20 kV system (U_A = 11.547 kV) capacitance drops by 5 percent, that is, k = 0.95, the neutral voltage is around 200 V according to *Figure 654*. If the voltage rating of a neutral VT is 20 kV/100 V, then in per unit terms refer to neutral side, the neutral voltage is around 0.01 · Un, that is, *Start value* should be set around 0.01.

In addition, assume that residual voltage (terminal side) is measured directly using an open-delta VT having ratio of $\frac{20kV}{\sqrt{3}} / \frac{100V}{\sqrt{3}} / \frac{100V}{3}$. Also, the *Primary voltage* and *Secondary voltage* settings under **Configuration** > **Analog inputs** > **Voltage (UoB,VT)** in a grounded system are set as 11.547 kV and 100 V, respectively. Similarly, if the VT connected at the neutral point has a ratio of $\frac{20kV}{\sqrt{3}} / \frac{100V}{\sqrt{3}}$, the *Primary voltage* and *Secondary voltage* settings under **Configuration** > **Analog inputs** > **Voltage (UoB,VT)** must be set as 20 kV and 100 V, respectively.

4.12.5.8 Signals

CNUPTOV Input signals

Table 1096: CNUPTOV Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
UNEUT	SIGNAL	-	Analog input
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

CNUPTOV Output signals

Table 1097: CNUPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.12.5.9 CNUPTOV Settings

Table 1098: CNUPTOV Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.01...1.00	xUn	0.01	0.01	Start value
Operate delay time	100...300000	ms	100	100	Operate delay time

Table 1099: CNUPTOV Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 1100: CNUPTOV Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

4.12.5.10 CNUPTOV Monitored data

Table 1101: CNUPTOV Monitored data

Name	Type	Values (Range)	Unit	Description
START_DUR	FLOAT32	0.00...100.00	%	Ratio of start time / operate time
U_AMPL_RES	FLOAT32	0.00...5.00	xUn	Magnitude of capacitor terminal open delta voltage (either calculated or derived)

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
U_ANGL_RES	FLOAT32	-180.00...180.00	deg	Angle of capacitor terminal open delta voltage (either calculated or derived)
U_AMPL_N	FLOAT32	0.00...5.00	xUn	Magnitude of capacitor neutral zero sequence voltage
U_ANGL_N	FLOAT32	-180.00...180.00	deg	Angle of capacitor neutral zero sequence voltage
U_UNB_AMPL	FLOAT32	0.00...5.00	xUn	Magnitude of recorded natural unbalance compensation component voltage
U_UNB_ANGL	FLOAT32	-180.00...180.00	deg	Angle of recorded natural unbalance compensation component voltage
U_OPR	FLOAT32	0.00...5.00	xUn	Calculated operating voltage
CNUPTOV	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.12.5.11 Technical data

Table 1102: CNUPTOV Technical data

Characteristic		Value
Operation accuracy		Depending on the frequency of the measured voltage: f_n ±2 Hz
		±1.5 % of the set value or ±0.002 × U_n
Start time [1, 2]	U_{Fault} = 1.1 × set *Start value*	Typically 75 ms
Reset time		Typically 40 ms
Reset ratio		Typically 0.96
Retardation time		<35 ms
Operate time accuracy		±1.0 % of the set value or ±20 ms
Suppression of harmonics		DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

1 *Start value* = 0.1 × U_n, Voltage before fault = 0.9 × U_n, f_n = 50 Hz, overvoltage in one phase-to-earth with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements
2 Measured with static signal output (SSO)

5 Protection related functions

5.1 Three-phase inrush detector INRPHAR (ANSI 68HB)

5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase inrush detector	INRPHAR	3I2f>	68HB

5.1.2 Function block

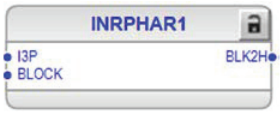


Figure 656: Function block

5.1.3 Functionality

The three-phase inrush detector function INRPHAR is used to detect transformer inrush situations in distribution networks.

Transformer inrush detection is based on the following principle: the output signal `BLK2H` is activated once the numerically derived ratio of second harmonic current I_2H and the fundamental frequency current I_1H exceeds the set value.

The operate time characteristic for the function is of definite time (DT) type.

The function contains a blocking functionality. Blocking deactivates all outputs and resets timers.

5.1.4 Analog channel configuration

INRPHAR has one analog group input which must be properly configured.

Table 1103: Analog signals

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of INRPHAR can be described using a module diagram. All the modules in the diagram are explained in the next sections.

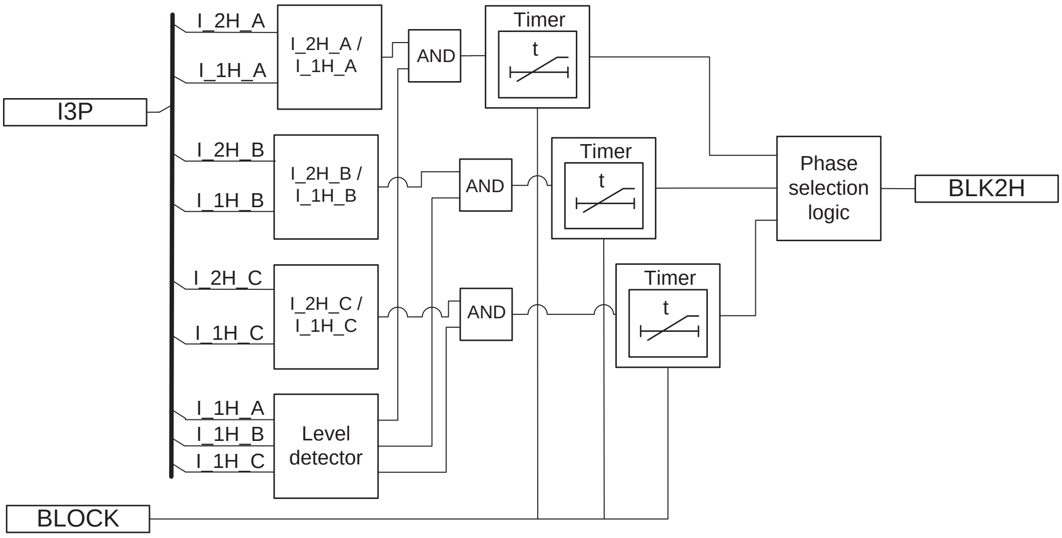


Figure 657: Functional module diagram

I_2H/I_1H

These modules calculate the ratio of the second harmonic (I_2H) and fundamental frequency (I_1H) of the phase currents. The calculated value is compared to the set *Start value*. If the calculated value exceeds the set *Start value*, the module output is activated.

Level detector

The output of the phase-specific level detector is activated when the fundamental frequency current I_1H exceeds the set *Min operate current* of the nominal current.

Timer

Once activated, Timer runs until the set *Operate delay time* value is exceeded. The time characteristics is according to DT. When the operation timer has reached the *Operate delay time* value, the Timer module output is activated. If the timer has elapsed and the inrush situation still exists, the Timer module output remains active until the I_2H/I_1H ratio drops below the set *Start value* , that is, until the inrush situation is over. If the drop-off situation occurs within the operate time up counting, the reset timer is activated. If the drop-off time exceeds *Reset delay time* , the operate timer is reset.

The `BLOCK` input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the `BLOCK` input prevents the `BLK2H` output from being activated.

Phase selection logic

This module determines the number of phases used for activating the `BLK2H` output. If Num of start phases = "1 out of 3", an inrush on any of the phases activates output `BLK2H`. If the set value equals "2 out of 3", an inrush or at least two phases are required to activate output `BLK2H`.

5.1.6 Application

Transformer protections require high stability to avoid tripping during magnetizing inrush conditions. A typical example of an inrush detector application is doubling the start value of an overcurrent protection during inrush detection.

The inrush detection function can be used to selectively block overcurrent and earth-fault function stages when the ratio of the second harmonic component to the fundamental component exceeds the set value.

Other applications of this function include the detection of inrush in lines connected to a transformer.

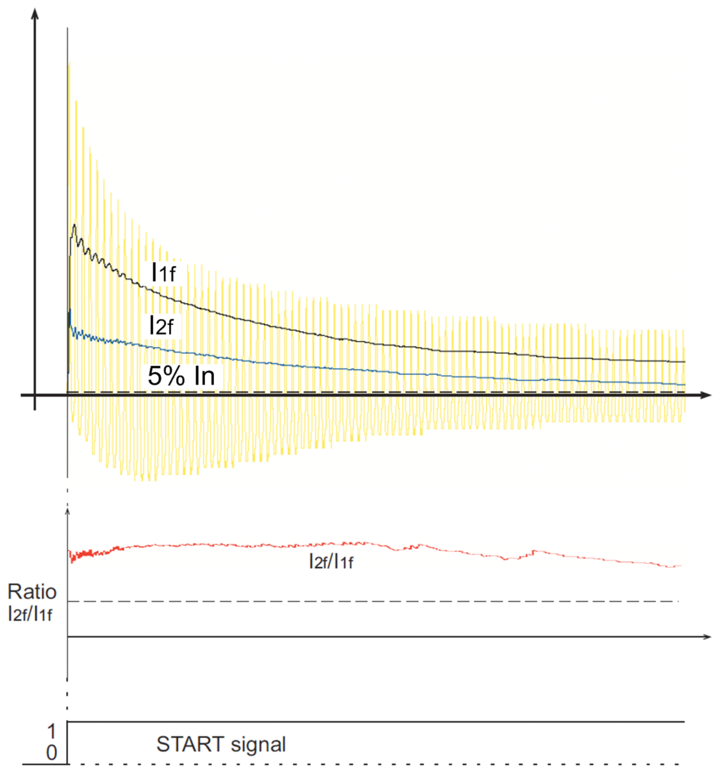


Figure 658: Inrush current in transformer

It is recommended to use the second harmonic and the waveform based inrush blocking from the transformer differential protection function TR2PTDF, if available.

5.1.7 Signals

5.1.7.1 INRPHAR Input signals

Table 1104: INRPHAR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block input status

5.1.7.2 INRPHAR Output signals

Table 1105: INRPHAR Output signals

Name	Type	Description
BLK2H	BOOLEAN	Second harmonic based block

5.1.8 INRPHAR Settings

Table 1106: INRPHAR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	5...100	%	1	20	Ratio of the 2. to the 1. harmonic leading to restraint
Operate delay time	20...60000	ms	1	20	Operate delay time

Table 1107: INRPHAR Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min operate current	5...500	%In	1	5	Minimum fundamental component of phase current for activation

Table 1108: INRPHAR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 1109: INRPHAR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Num of start phases	1=1 out of 3 2=2 out of 3			1=1 out of 3	Number of phases required for operate activation
Reset delay time	0...60000	ms	1	20	Reset delay time

5.1.9 INRPHAR Monitored data

Table 1110: INRPHAR Monitored data

Name	Type	Values (Range)	Unit	Description
INRPHAR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.1.10 Technical data

Table 1111: INRPHAR Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	Current measurement:

Table continues on the next page

Characteristic	Value
	±1.5 % of the set value or ±0.002 × I_n Ratio I2f/I1f measurement: ±5.0 % of the set value
Reset time	+35 ms / -0 ms
Reset ratio	Typically 0.96
Operate time accuracy	+35 ms / -0 ms

5.2 Circuit breaker failure protection CCBRBRF (ANSI 50BF)

5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker failure protection	CCBRBRF	3I>/Io>BF	50BF

5.2.2 Function block

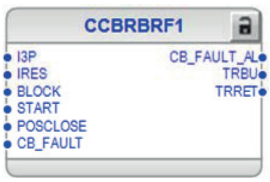


Figure 659: Function block

5.2.3 Functionality

The circuit breaker failure protection function CCBRBRF is activated by trip commands from the protection functions. The commands are either internal commands to the terminal or external commands through binary inputs. The start command is always a default for three-phase operation. CCBRBRF includes a three-phase conditional or unconditional retrip function, and also a three-phase conditional back-up trip function.

CCBRBRF uses the same levels of current detection for both retrip and back-up trip. The operating values of the current measuring elements can be set within a predefined setting range. The function has two independent timers for trip purposes: a retrip timer for the repeated tripping of its own breaker and a back-up timer for the trip logic operation for upstream breakers. A minimum trip pulse length can be set independently for the trip output.

The function contains a blocking functionality which can be used to block the function outputs.

5.2.4 Analog channel configuration

CCBRBRF has two analog group inputs which must be properly configured.

Table 1112: Analog inputs

Input	Description
I3P [1]	Three-phase currents, necessary when *CB failure mode* is set other than "Breaker status"
IRES [1]	Residual current (measured or calculated), necessary when *CB failure mode* is set other than "Breaker status"

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CCBRBRF can be described using a module diagram. All the modules in the diagram are explained in the next sections. Also further information on the retrip and backup trip logics is given in sub-module diagrams.

[1] Can be connected to GRPOFF if *CB failure mode* is set to "Breaker status" and *CB fail retrip mode* is not set to "Current check".

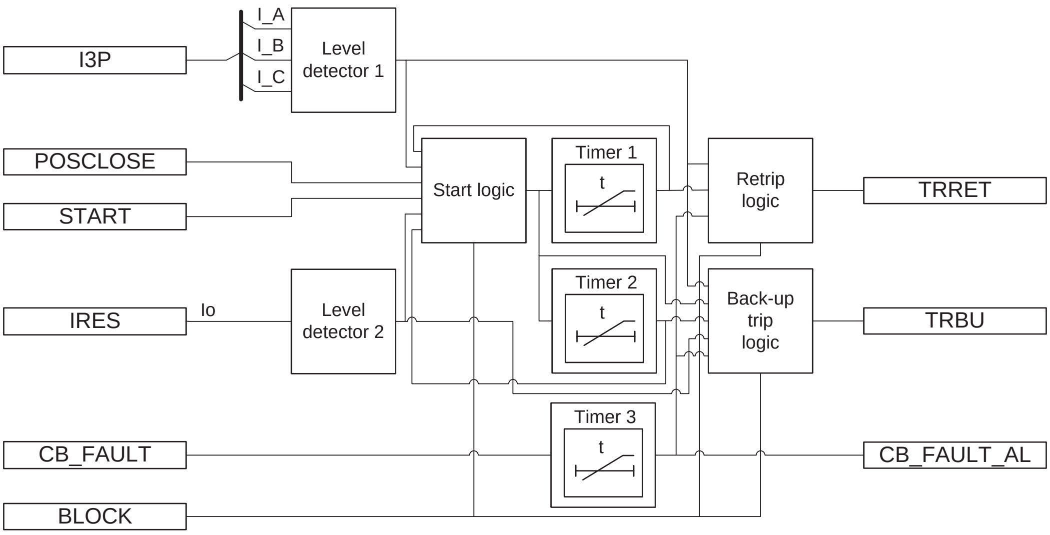


Figure 660: Functional module diagram

Level detector 1

The measured phase currents are compared phasewise to the set *Current value*. If the measured value exceeds the set *Current value*, the level detector reports the exceeding of the value to the start, retrip and backup trip logics. The parameter should be set low enough so that breaker failure situations with small fault current or high load current can be detected. The setting can be chosen in accordance with the most sensitive protection function to start the breaker failure protection.

Level detector 2

The measured residual current is compared to the set *Current value Res*. If the measured value exceeds the set *Current value Res*, the level detector reports the exceeding of the value to the start and backup trip logics. In high-impedance earthed systems, the residual current at phase-to-earth faults is normally much smaller than the short circuit currents. To detect a breaker failure at single-phase earth faults in these systems, it is necessary to measure the residual current separately. In effectively earthed systems, also the setting of the earth-fault current protection can be chosen at a relatively low current level. The current setting should be chosen in accordance with the setting of the sensitive earth-fault protection.

Start logic

Start logic is used to manage the starting of Timer 1 and Timer 2. It also resets the function after the circuit breaker failure is handled. On the rising edge of the `START` input, the enabling signal is sent to Timer 1 and Timer 2. Typically, the `START` input is activated when any protection function operates and trips the circuit breaker.

The Start logic module is reset depending on the settings *CB failure mode* and *CB failure trip mode* as shown in *Table 1113*. In all cases in *Table 1113*, however, the resetting is possible only after 150 ms from the activation of Start logic. This time is for ensuring correct operation in case of oscillation in the starting signal.

Table 1113: Start logic operation

Value of setting CB failure mode	Value of setting CB failure trip mode	Start logic reset condition
Current	1 out of 3	All phase currents drop below *Current value* setting.
	1 out of 4	All phase currents drop below *Current value* setting and the residual current drops below *Current value Res* setting.
	2 out of 4	Either of the following is true: • All phase currents drop below *Current value* setting. • The residual current drops below *Current value Res* setting and (at least) two phases are below *Current value* setting.
Breaker status	1 out of 3 1 out of 4 2 out of 4	CB is in open position.
Both(AND)	1 out of 3	Either of the following is true: • CB is in open position. • All phase currents drop below *Current value* setting.
	1 out of 4	Either of the following is true: • CB is in open position. • All phase currents drop below *Current value* setting and the residual current drops below *Current value Res* setting.
	2 out of 4	One of the following is true: • CB is in open position. • All phase currents drop below *Current value* setting. • The residual current drops below *Current value Res* setting and (at least) two phases are below *Current value* setting.
Both(OR)	1 out of 3	CB is in open position and all phase currents drop below *Current value* setting.
	1 out of 4	CB is in open position and all phase currents drop below *Current value* setting and the residual current drops below *Current value Res* setting.
	2 out of 4	CB is in open position and either of the following is true: • All phase currents drop below *Current value* setting.

Value of setting CB failure mode	Value of setting CB failure trip mode	Start logic reset condition
		• The residual current drops below *Current value Res* setting and (at least) two phases are below *Current value* setting.

In addition, the function is immediately reset if:

- *Start latching mode* is set to "Level sensitive", and the START signal is deactivated. The recommended setting value is "Rising edge".
- The BLOCK input is activated.

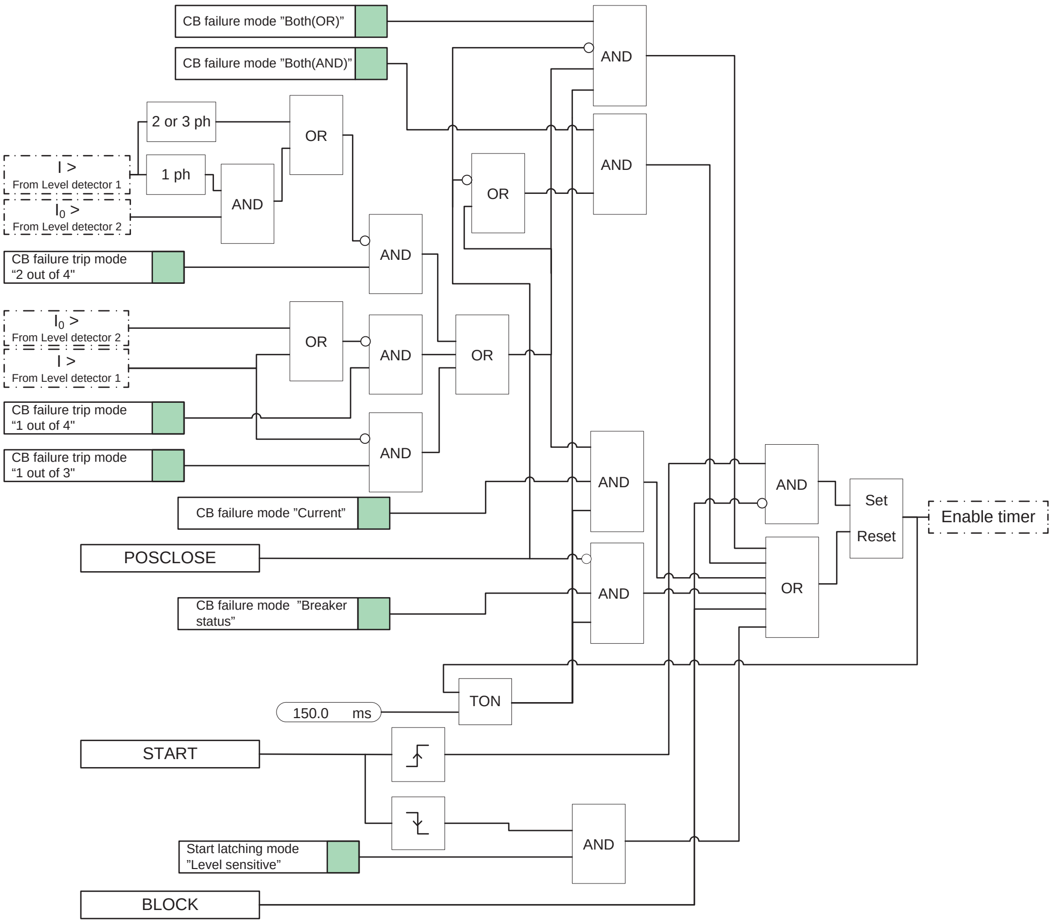


Figure 661: Start logic

Timer 1

Once activated, the timer runs until the set *Retrip time* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the value set with *Retrip time*, the retrip logic is activated. A typical setting is 0...50 ms.

Timer 2

Once activated, the timer runs until the set *CB failure delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the set maximum time value *CB failure delay*, the backup trip logic is activated. The value of this setting is made as low as possible at the same time as any unwanted operation is avoided. A typical setting is 90 - 150 ms, which is also dependent on the retrip timer.

The minimum time delay for the CB failure delay can be estimated as:

$$CBfailuredelay \geq Retriptime + t_{cbopen} + t_{BFP\_reset} + t_{margin}$$

(Equation 291)

t_{cbopen}	Maximum opening time for the circuit breaker
t_{BFP_reset}	Maximum time for the breaker failure protection to detect the correct breaker function (the current criteria reset)
t_{margin}	Safety margin

It is often required that the total fault clearance time is less than the given critical time. This time often depends on the ability to maintain transient stability in case of a fault close to a power plant.

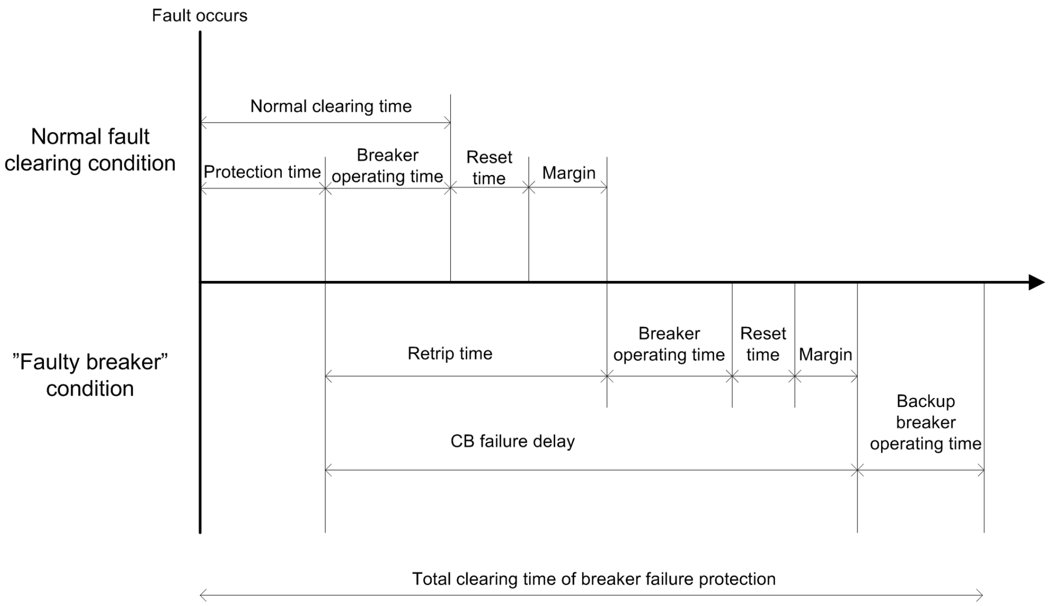


Figure 662: Timeline of the breaker failure protection

Timer 3

This module is activated by the `CB_FAULT` signal. Once activated, the timer runs until the set *CB fault delay* value has elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value *CB fault delay*, the `CB_FAULT_AL` output is activated. After the set time, an alarm is given so that the circuit breaker can be repaired. A typical value is 5 s.

Retrip logic

Timer 1 activates Retrip logic, which can be used to give a retrip signal `TRRET` for the main circuit breaker. The operation of Retrip logic depends on the settings *CB failure mode* and *CB fail retrip mode* as shown in Table 1114.

Table 1114: Retrip logic operation

Value of setting CB fail retrip mode	Value of setting CB failure mode	Retrip functionality
Off	Current Breaker status Both(AND) Both(OR	Retrip functionality switched off. TRRET is not activated.
Without Check	Current Breaker status Both(AND) Both(OR	TRRET is activated after Timer 1 elapses.
Current check	Current	TRRET is activated after Timer 1 elapses and any phase current exceeds *Current value* setting.
	Breaker status	TRRET is activated after Timer 1 elapses and CB is in closed position.
	Both(AND)	TRRET is activated after Timer 1 elapses and CB is in closed position and any phase current exceeds *Current value* setting.
	Both(OR)	TRRET is activated after Timer 1 elapses and either of the following is true: • CB is in closed position. • Any phase current exceeds *Current value* setting.

TRRET activation is blocked if either CB_FAULT_AL output (from Timer 3) is active or the BLOCK input is activated.

Once activated, TRRET remains active for the set *Trip pulse time* or until the reasons for activation are reset. TRRET is also reset if CB_FAULT_AL or BLOCK is activated.

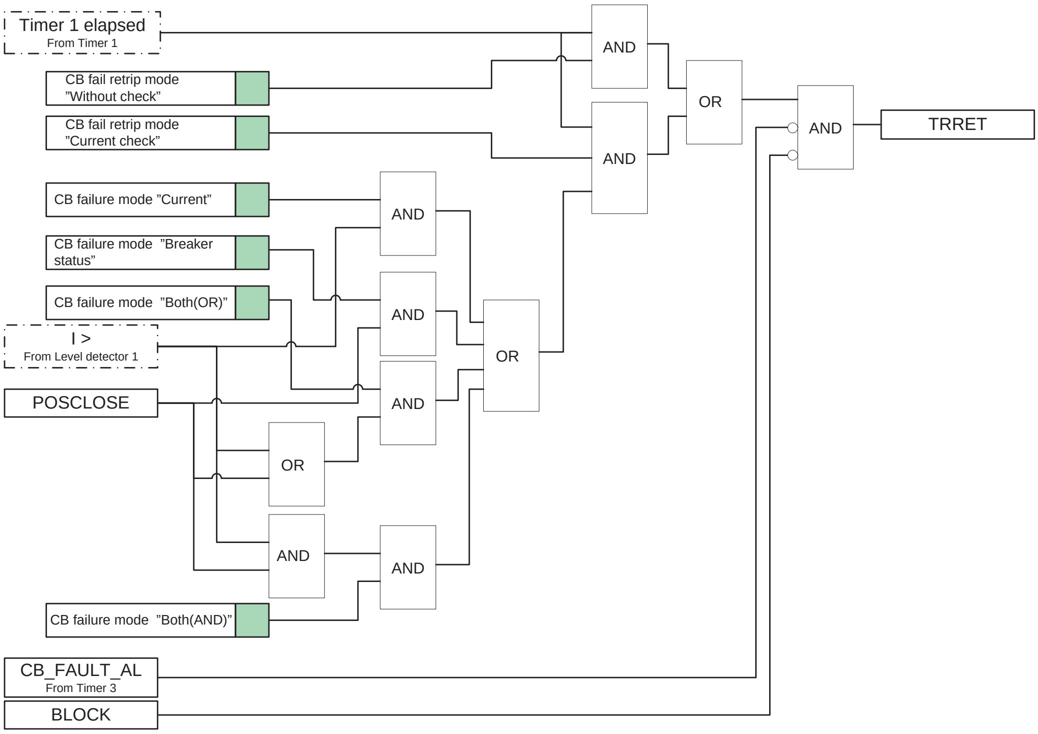


Figure 663: Retrip logic

Backup trip logic

Timer 2 activates Backup trip logic, which gives a backup trip `TRBU` for the upstream circuit breaker if the main circuit breaker fails to clear the fault. Backup trip logic is also activated if the timer-enabling signal from the Start logic module (rising edge of the `START` input detected) and `CB_FAULT_AL` are both active.

The operation of Backup trip logic depends on the settings *CB failure mode* and *CB failure trip* mode as shown in *Table 1115*.

Table 1115: Backup trip logic operation

Value of setting CB failure mode	Value of setting CB failure trip mode	Conditions for activating Backup trip logic
Current	1 out of 3	Any phase current exceeds *Current value* setting.
	1 out of 4	Either of the following is true: • Any phase current exceeds *Current value* setting. • The residual current exceeds *Current value Res* setting.
	2 out of 4	Either of the following is true: • Any phase current exceeds *Current value* setting and the residual current exceeds *Current value Res* setting.

Table continues on the next page

Value of setting CB failure mode	Value of setting CB failure trip mode	Conditions for activating Backup trip logic
		• Two or three phase currents exceed *Current value* setting.
Breaker status	1 out of 3 1 out of 4 2 out of 4	CB is in closed position.
Both(AND)	1 out of 3	CB is in closed position and any phase current exceeds *Current value* setting.
	1 out of 4	CB is in closed position and either of the following is true: • Any phase current exceeds *Current value* setting. • The residual current exceeds *Current value Res* setting.
	2 out of 4	CB is in closed position and either of the following is true: • Any phase current exceeds *Current value* setting and the residual current exceeds *Current value Res* setting. • Two or three phase currents exceed *Current value* setting.
Both(OR)	1 out of 3	Either of the following is true: • CB is in closed position. • Any phase current exceeds *Current value* setting.
	1 out of 4	One of the following is true: • CB is in closed position. • Any phase current exceeds *Current value* setting. • The residual current exceeds *Current value Res* setting.
	2 out of 4	One of the following is true: • CB is in closed position. • Any phase current exceeds *Current value* setting and the residual current exceeds *Current value Res* setting. • Two or three phase currents exceed *Current value* setting.

Once activated, TRBU remains active until the set *Trip pulse time* or until the reasons for activation are reset. TRRET is also reset if BLOCK is activated.

In most applications, "1 out of 3" is sufficient.

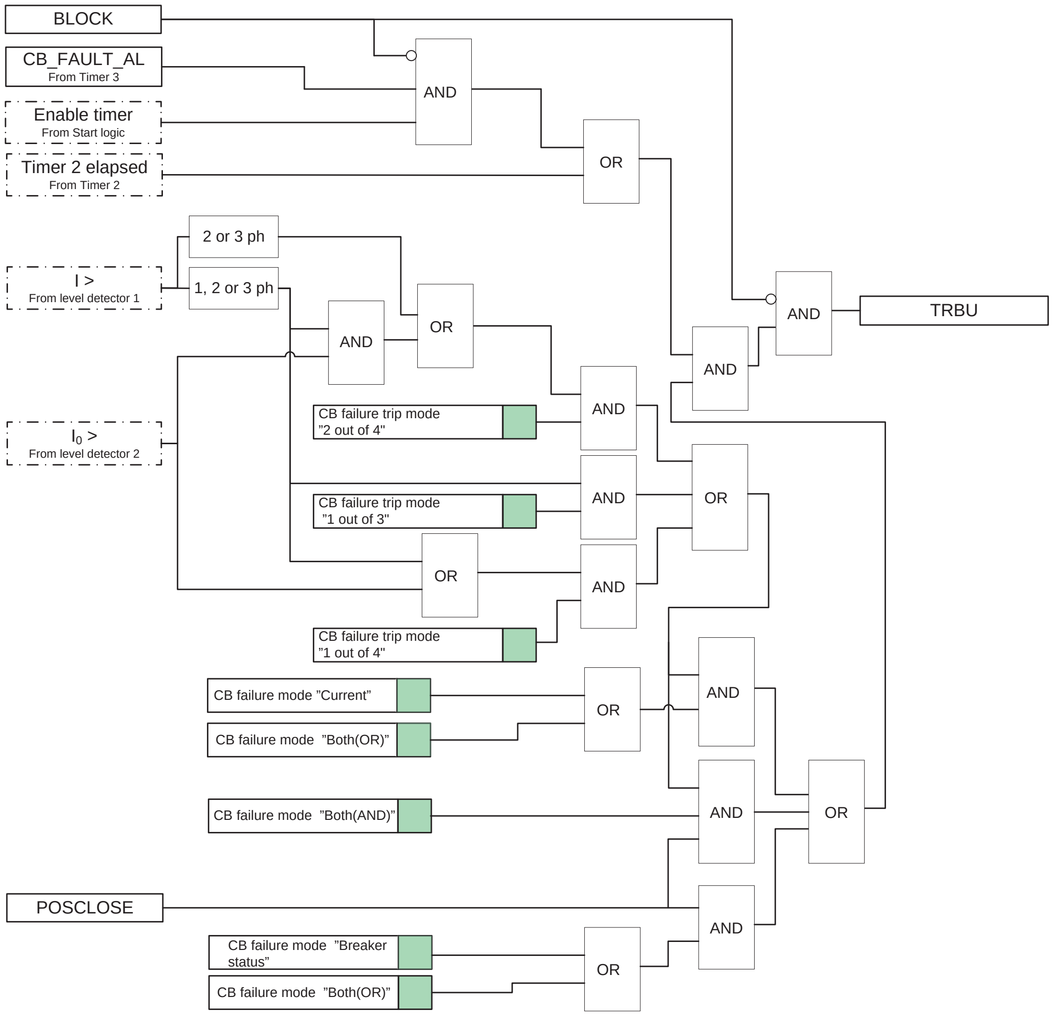


Figure 664: Backup trip logic

5.2.6 Application

The n-1 criterion is often used in the design of a fault clearance system. This means that the fault is cleared even if some component in the fault clearance system is faulty. A circuit breaker is a necessary component in the fault clearance system. For practical and economical reasons, it is not feasible to duplicate the circuit breaker for the protected component, but breaker failure protection is used instead.

The breaker failure function issues a backup trip command to up-stream circuit breakers in case the original circuit breaker fails to trip for the protected component. The detection of a failure to break the current through the breaker is made by measuring the current or by detecting the remaining trip signal (unconditional).

CCBRBRF can also retrip. This means that a second trip signal is sent to the protected circuit breaker. The retrip function is used to increase the operational reliability of the breaker. The function can also be used to avoid backup tripping of several breakers in case mistakes occur during protection relay maintenance and tests.

CCBRBRF is initiated by operating different protection functions or digital logics inside the protection relay. It is also possible to initiate the function externally through a binary input.

CCBRBRF can be blocked by using an internally assigned signal or an external signal from a binary input. This signal blocks the function of the breaker failure protection even when the timers have started or the timers are reset.

The retrip timer is initiated after the start input is set to true. When the pre-defined time setting is exceeded, CCBRBRF issues the retrip and sends a trip command, for example, to the circuit breaker's second trip coil. Both a retrip with current check and an unconditional retrip are available. When a retrip with current check is chosen, the retrip is performed only if there is a current flow through the circuit breaker.

The backup trip timer is also initiated at the same time as the retrip timer. If CCBRBRF detects a failure in tripping the fault within the set backup delay time, which is longer than the retrip time, it sends a backup trip signal to the chosen backup breakers. The circuit breakers are normally upstream breakers which feed fault current to a faulty feeder.

The backup trip always includes a current check criterion. This means that the criterion for a breaker failure is that there is a current flow through the circuit breaker after the set backup delay time.

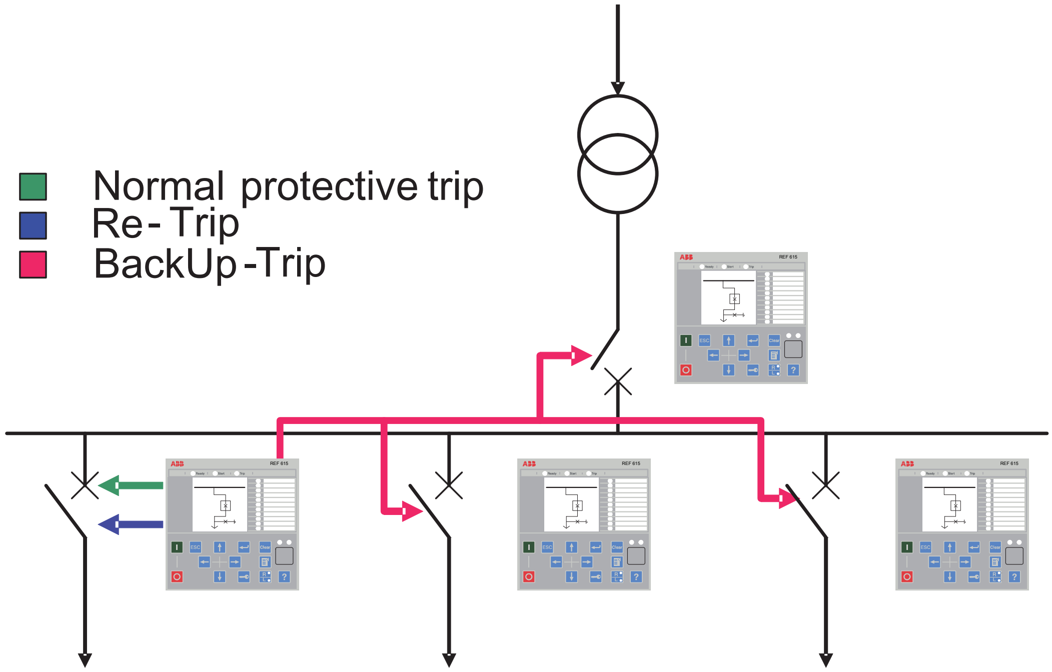


Figure 665: Typical breaker failure protection scheme in distribution substations

5.2.7 Signals

5.2.7.1 CCBRBRF Input signals

Table 1116: CCBRBRF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block CBFP operation
START	BOOLEAN	0=False	CBFP start command
POSCLOSE	BOOLEAN	0=False	CB in closed position
CB_FAULT	BOOLEAN	0=False	CB faulty and unable to trip

5.2.7.2 CCBRBRF Output signals

Table 1117: CCBRBRF Output signals

Name	Type	Description
CB_FAULT_AL	BOOLEAN	Delayed CB failure alarm
TRBU	BOOLEAN	Backup trip
TRRET	BOOLEAN	Retrip

5.2.8 CCBRBRF Settings

Table 1118: CCBRBRF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Current value	0.05...2.00	xIn	0.01	0.30	Operating phase current
Current value Res	0.05...2.00	xIn	0.01	0.30	Operating residual current
CB failure trip mode	1=2 out of 4 2=1 out of 3 3=1 out of 4			2=1 out of 3	Backup trip current check mode
CB failure mode	1=Current 2=Breaker status 3=Both (AND) -1=Both (OR)			1=Current	Operating mode of function
CB fail retrip mode	1=Off 2=Without Check 3=Current check			1=Off	Operating mode of retrip logic
Retrip time	0...60000	ms	10	120	Delay timer for retrip
CB failure delay	0...60000	ms	10	240	Delay timer for backup trip

Table 1119: CCBRBRF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
CB fault delay	0...60000	ms	10	5000	Circuit breaker faulty delay
Measurement mode	2=DFT 3=Peak-to-Peak			3=Peak-to-Peak	Phase current measurement mode of function
Trip pulse time	0...60000	ms	10	200	Pulse length of retrip and backup trip outputs
Start latching mode	1=Rising edge 2=Level sensitive			1=Rising edge	Start reset delayed or immediately

5.2.9 CCBRBRF Monitored data

Table 1120: CCBRBRF Monitored data

Name	Type	Values (Range)	Unit	Description
CCBRBRF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.2.10 Technical data

Table 1121: CCBRBRF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±1.5 % of the set value or ±0.002 × I_n
Operate time accuracy	±1.0 % of the set value or ±20 ms
Reset time	<20 ms
Retardation time	<20 ms

5.2.11 Technical revision history

Table 1122: CCBRBRF Technical revision history

Technical revision	Change
B	Default trip pulse time changed to 150 ms
C	Added new setting parameter *Start latching mode*. Maximum value changed to 2.00 xIn for the *Current value* setting.

Table continues on the next page

Technical revision	Change
D	Internal improvement.
E	Maximum value for *Current value* and *Current value Res* changed from “1.00 x In” to “2.00 x In”.

5.3 Master trip TRPPTRC (ANSI 94/86)

5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Master trip	TRPPTRC	Master Trip	94/86

5.3.2 Function block

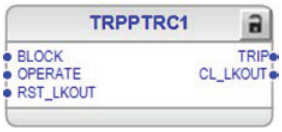


Figure 666: Function block

5.3.3 Functionality

The master trip function TRPPTRC is used as a trip command collector and handler after the protection functions. The features of this function influence the trip signal behavior of the circuit breaker. The minimum trip pulse length can be set when the non-latched mode is selected. It is also possible to select the latched or lockout mode for the trip signal.

5.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

When the TRPPTRC function is disabled, all trip outputs intended to go through the function to the circuit breaker trip coil are blocked.

The operation of TRPPTRC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

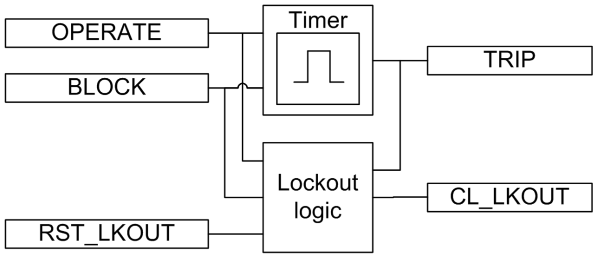


Figure 667: Functional module diagram

Timer

The duration of the TRIP output signal from TRPPTRC can be adjusted with the *Trip pulse time* setting when the "Non-latched" operation mode is used. The pulse length should be long enough to secure the opening of the breaker. For three-pole tripping, TRPPTRC has a single input OPERATE, through which all trip output signals are routed from the protection functions within the protection relay, or from external protection functions via one or more of the protection relay's binary inputs. The function has a single trip output TRIP for connecting the function to one or more of the protection relay's binary outputs, and also to other functions within the protection relay requiring this signal.

The BLOCK input blocks the TRIP output and resets the timer.

Lockout logic

TRPPTRC is provided with possibilities to activate a lockout. When activated, the lockout can be manually reset after checking the primary fault by activating the RST_LKOUT input or from the LHMI clear menu parameter. When using the "Latched" mode, the resetting of the TRIP output can be done similarly as when using the "Lockout" mode. It is also possible to reset the "Latched" mode remotely through a separate communication parameter.

The minimum pulse trip function is not active when using the "Lockout" or "Latched" modes but only when the "Non-latched" mode is selected.

The CL_LKOUT and TRIP outputs can be blocked with the BLOCK input.

Table 1123: Operation modes for the TRPPTRC trip output

Mode	Operation
Non-latched	The *Trip pulse length* parameter gives the minimum pulse length for TRIP
Latched	TRIP is latched ; both local and remote clear-ing is possible.
Lockout	TRIP is locked and can be cleared only locally via menu or the RST_LKOUT input.

5.3.5 Application

All trip signals from different protection functions are routed through the trip logic. The most simplified application of the logic function is linking the trip signal and ensuring that the signal is long enough.

The tripping logic in the protection relay is intended to be used in the three-phase tripping for all fault types (3ph operating). To prevent the closing of a circuit breaker after a trip, TRPPTRC can block the CBXCBR closing.

TRPPTRC is intended to be connected to one trip coil of the corresponding circuit breaker. If tripping is needed for another trip coil or another circuit breaker which needs, for example, different trip pulse time, another trip logic function can be used. The two instances of the PTRC function are identical, only the names of the functions, TRPPTRC1 and TRPPTRC2, are different. Therefore, even if all references are made only to TRPPTRC1, they also apply to TRPPTRC2.

The inputs from the protection functions are connected to the `OPERATE` input. Usually, a logic block OR is required to combine the different function outputs to this input. The `TRIP` output is connected to the binary outputs on the IO board. This signal can also be used for other purposes within the protection relay, for example when starting the breaker failure protection.

TRPPTRC is used for simple three-phase tripping applications.

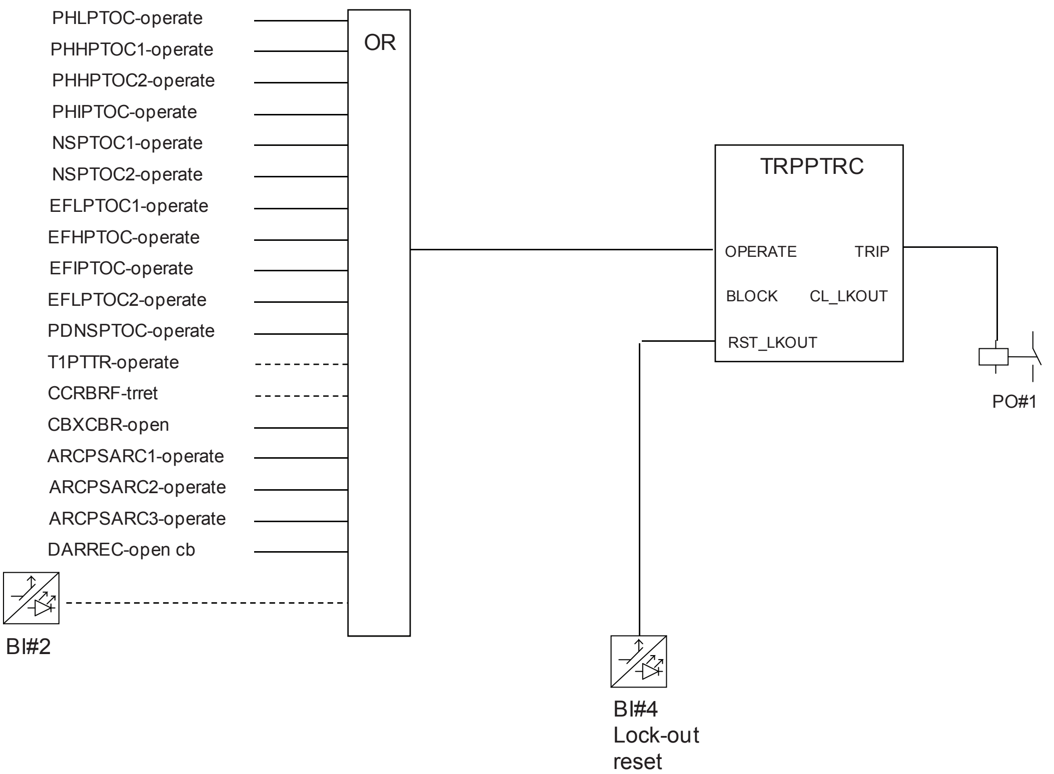


Figure 668: Typical TRPPTRC connection

5.3.6 Signals

5.3.6.1 TRPPTRC Input signals

Table 1124: TRPPTRC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block of function
OPERATE	BOOLEAN	0=False	Operate
RST_LKOUT	BOOLEAN	0=False	Input for resetting the circuit breaker lockout function

5.3.6.2 TRPPTRC Output signals

Table 1125: TRPPTRC Output signals

Name	Type	Description
TRIP	BOOLEAN	General trip output signal
CL_LKOUT	BOOLEAN	Circuit breaker lockout output (set until reset)

5.3.7 TRPPTRC Settings

Table 1126: TRPPTRC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Trip pulse time	20...60000	ms	1	250	Minimum duration of trip output signal
Trip output mode	1=Non-latched 2=Latched 3=Lockout			1=Non-latched	Select the operation mode for trip output

5.3.8 TRPPTRC Monitored data

Table 1127: TRPPTRC Monitored data

Name	Type	Values (Range)	Unit	Description
TRPPTRC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.4 High-impedance fault detection PHIZ (ANSI HIZ)

5.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
High-impedance fault detection	PHIZ	HIF	HIZ

5.4.2 Function block

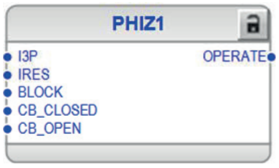


Figure 669: Function block

5.4.3 Functionality

A small percentage of earth faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high-impedance faults do not pose imminent danger to power system equipment. However, they are a substantial threat to humans and properties; people can touch or get close to conductors carrying large amounts of energy.

ABB has developed a patented technology (US Patent 7,069,116 B2 June 27, 2006, US Patent 7,085,659 B2 August 1, 2006) to detect a high-impedance fault.

The high-impedance fault detection function PHIZ also contains a blocking functionality. It is possible to block function outputs, if desired.

5.4.4 Analog channel configuration

PHIZ has two analog group inputs which must be properly configured.

Table 1128: Analog inputs

Input	Description
I3P	Three-phase currents
IRES	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

PHIZ uses a multi-algorithm approach. Each algorithm uses various features of earth currents to detect a high-impedance fault.

Although the PHIZ algorithm is very sophisticated, the setting required to operate the function is simple. The *Security Level* setting, with the setting range of 1 to 10, is set to strike a balance between the extremes of security and dependability which together constitute the reliability of any system. The setting value “10” is more secure than “1”.

The higher the *Security Level* setting, the lower the probability of false detection, but the system might miss out some genuine fault. On the other hand, a lower setting would make the system operate more dependably for high-impedance faults in the line, but the operation is more likely for other transients in the system. There are events in electrical networks which can cause similar current waveforms like high-impedance faults. These events could then be detected by the PHIZ algorithm causing unnecessary detections. Normally, electrical network operator does not know the existence of these events well and those can also be happening very randomly. The effect is also always dependent on event location compared to protection relay measurement location. All these facts make the PHIZ algorithm operation in certain electrical networks quite hard to measure and forecast beforehand. There is not any direct formula which can calculate the exact right setting based on known electrical network parameters.

It is hence recommended to set the value midway to “5” initially. Based on experience and confidence gained in a particular application, the setting can be moved either side. In many cases, it would be a good practice to use PHIZ as an indicative function during a piloting phase, until enough experience has been gathered and a suitable setting found.

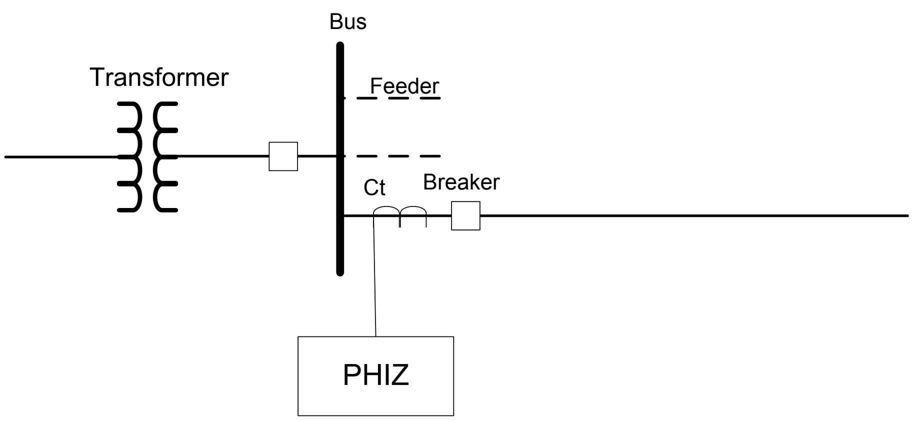


Figure 670: Electrical power system equipped with PHIZ

Power system signals are acquired, filtered and then processed by individual high-impedance fault detection algorithm. The results of these individual algorithms are further processed by a decision logic to provide the detection decision. The decision logic can be modified depending on the application requirement.

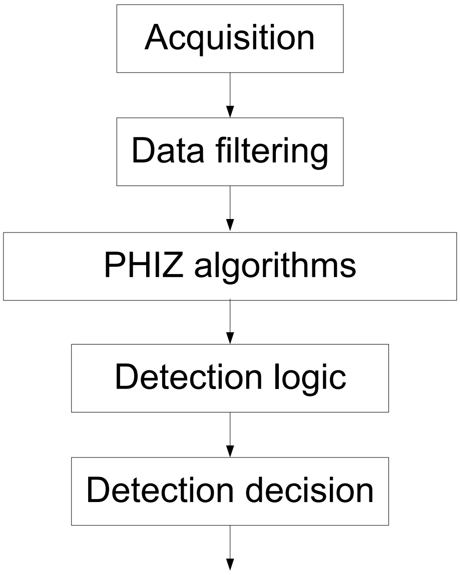


Figure 671: Block diagram of PHIZ

PHIZ is based on algorithms that use earth current signatures which are considered non-stationary, temporally volatile and of various burst duration. All harmonic and non-harmonic components within the available data window can play a vital role in the high-impedance fault detection. A major challenge is to develop a data model that acknowledges that high-impedance faults could take place at any time within the observation window of the signal and could be delayed randomly and attenuated substantially. The model is motivated by extensive research, actual experimental observations in the laboratory, field testing and what traditionally represents an accurate depiction of a non-stationary signal with a time-dependent spectrum.

Figure 672: Validation of PHIZ on gravel

Figure 673: Validation of PHIZ on concrete

Figure 674: Validation of PHIZ on sand

Figure 675: Validation of PHIZ on grass

5.4.6 Application

PHIZ is used to detect a downed conductor dropping to a very resistive ground, causing an earth fault which is very difficult to detect by a conventional protection relay functionality. PHIZ is then targeted to be used with overhead lines. PHIZ must be used in electrical networks with efficiently grounded or isolated neutral.

Electric power lines experience faults for many reasons. In most cases, electrical faults manifest in mechanical damage, which must be repaired before returning the line to service.

Most of the electrical network faults are earth faults. Conventional protection systems based on overcurrent, impedance or other principles are suitable for detecting relatively low-impedance faults which have a relatively high fault current.

However, a small percentage of the earth faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high-impedance faults do not pose imminent danger to power system equipment. However, they are a considerable threat to people and property. The IEEE Power System Relay Committee working group on High Impedance Fault Detection Technology defines High Impedance Faults as those that 'do not produce enough fault current to be detectable by conventional overcurrent relays or fuses.

PHIZ always needs sensitive Io measurement.

High-impedance fault (PHIZ) detection requires a different approach than that for conventional low-impedance faults. Reliable detection of PHIZ provides safety to humans and animals. ABB has developed innovative technology for highimpedance fault detection with over ten years of research resulting in many successful field tests.

5.4.7 Signals

5.4.7.1 PHIZ Input signals

Table 1129: PHIZ Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
CB_CLOSED	BOOLEAN	0=False	Circuit Breaker Closed input
CB_OPEN	BOOLEAN	0=False	Circuit Breaker Open input

5.4.7.2 PHIZ Output signals

Table 1130: PHIZ Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

5.4.8 PHIZ Settings

Table 1131: PHIZ Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Security Level	1...10		1	5	Security Level

Table 1132: PHIZ Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
System type	1=Grounded 2=Ungrounded			1=Grounded	System Type

5.4.9 PHIZ Monitored data

Table 1133: PHIZ Monitored data

Name	Type	Values (Range)	Unit	Description
Position	Dbpos	0=intermediate		Position

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=open 2=closed 3=faulty		
PHIZ	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.5 Binary signal transfer BSTGAPC (ANSI BST)

5.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Binary signal transfer	BSTGAPC	BST	BST

5.5.2 Function block

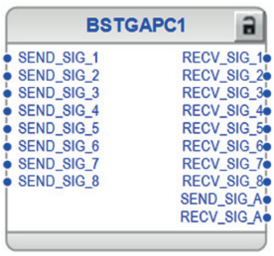


Figure 676: Function block

5.5.3 Functionality

The binary signal transfer function BSTGAPC is used for transferring binary signals between the local and remote end line differential protection relays. The function includes eight binary signals that are transferred in the protection communication telegram and can be freely configured and used for any purpose in the line differential application.

BSTGAPC transfers binary data continuously over the protection communication channel between the terminals. Each of the eight signals are bidirectional and the binary data sent locally is available remotely as a received signal.

BSTGAPC includes a minimum pulse time functionality for the received binary signals. Each received signal has its own minimum pulse time setting parameter.

BSTGAPC includes two alarm output signals. The SEND_SIG_A output signal is updated according to the status of the sent binary signals. The RECV_SIG_A output signal is updated according to the status of the received binary signals. Each signal can be separately included or excluded from the alarm logic with a setting parameter.

5.5.4 Operation principle

The *Signal 1...8 mode* setting can be used for changing the operation of the bidirectional signal channel. The signal channel can be disabled by setting the corresponding parameter value to “Not in use”. When the signal channel is disabled locally or remotely, the corresponding RECV_SIG_1...8 signal status is always false on both ends.

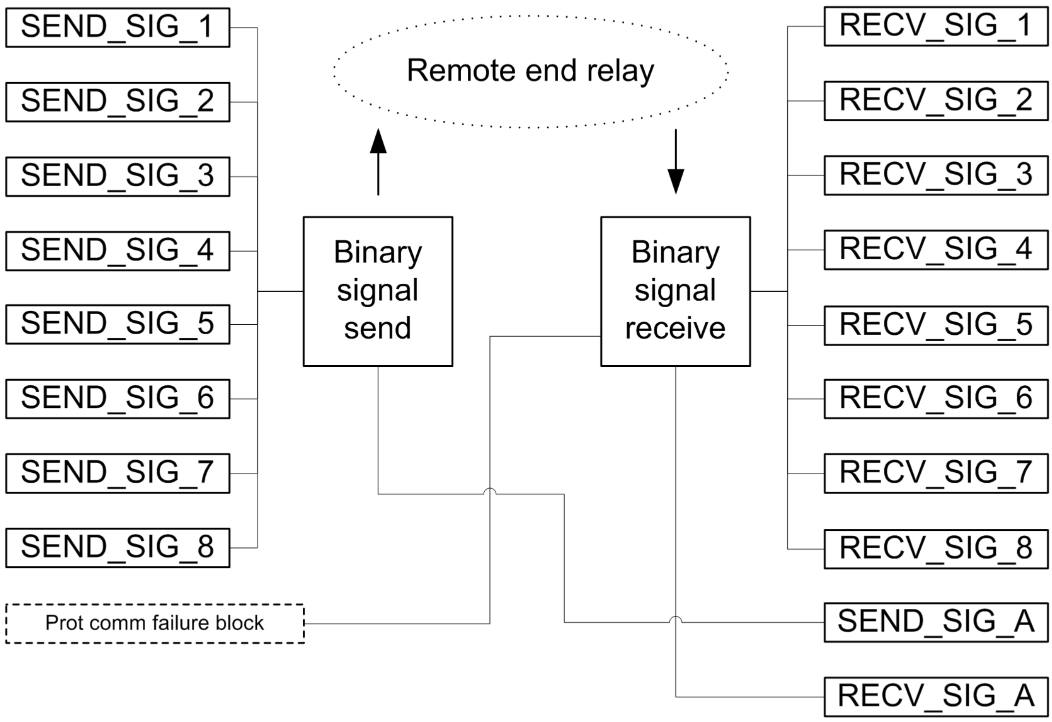


Figure 677: Functional module diagram

Binary signal send

The status of the inputs is continuously sent in the line differential protection telegrams. SEND_SIG_A can be used for alarming based on the status of SEND_SIG_1...8. By selecting the signal mode as "In use, alarm sel.", the sending status of the corresponding signal affects also the activation criteria of SEND_SIG_A. Further, in case more than one signal channels are selected into the alarm logic, the activation criteria can be defined according to "Any of selected" (OR) or "All of selected" (AND).

Binary signal receive

The function receives continuous binary data within the protection telegrams from the remote end protection relay. This received binary data status is then available as the RECV_SIG_1...8 outputs on the local end protection relay. RECV_SIG_A can be used for alarming based on the status of RECV_SIG_1...8. By selecting the signal mode as "In use, alarm sel.", the received status of the corresponding signal affects the activation criteria of RECV_SIG_A. Further, in case more than one signal channels are selected into the alarm logic, the activation criteria can be defined according to "Any of selected" (OR) or "All of selected" (AND). Each signal has also the *Pulse time 1...8* setting that defines the minimum pulse length for RECV_SIG_1...8. Also, in case the protection communication supervision detects a failure in the communication, the RECV_SIG_1...8 outputs are not set to false sooner than the minimum pulse length defined is first ensured for each signal.

5.5.5 Application

Among with the analog data, the binary data can also be exchanged with the line differential protection relays. The usage of the binary data is application specific and can vary in each separate case. The demands for the speed of the binary signals vary depending on the usage of the data. When the binary data is used as blocking signals for the line differential protection, the transfer response is extremely high. Binary signal interchange can be used in applications such as:

- Remote position indications
- Inter-tripping of the circuit breakers on both line ends
- Blocking of the line differential protection during transformer inrush or current circuit supervision failure
- Protection schemes; blocking or permissive
- Remote alarming

The figure shows the overall chain to transfer binary data in an example application. The position indication of the local circuit breaker is connected to the protection relay's input interface and is then available for the relay configuration. The circuit breaker position indication is connected to the first input of BSTGAPC which is used to send information to the remote end via communication. In the remote end, this information is handled as a remote circuit breaker open position and it is available from the first output of BSTGAPC. This way the information can be exchanged.

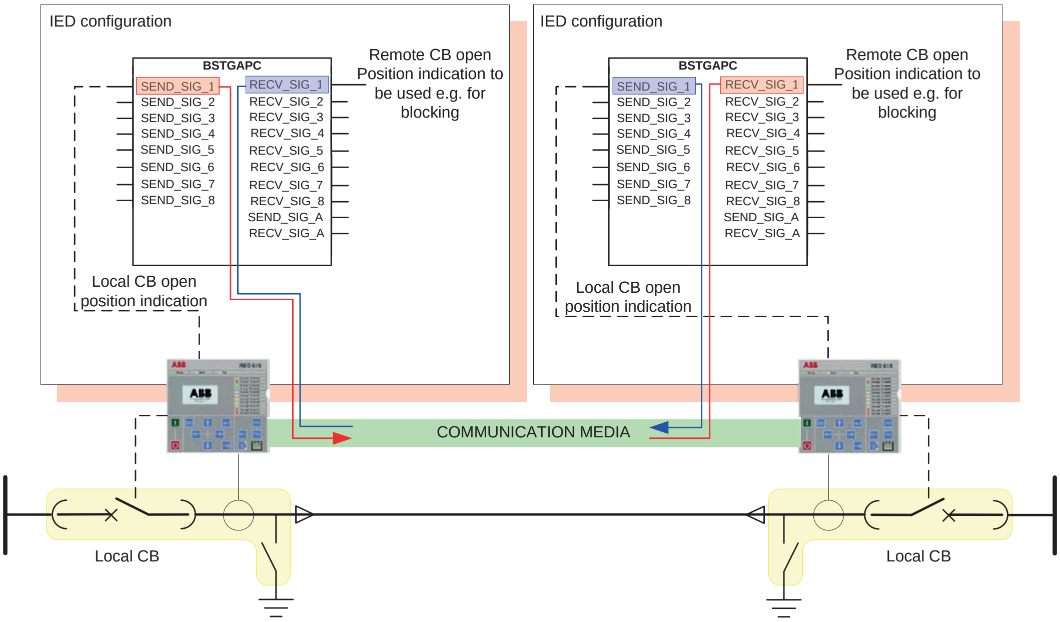


Figure 678: Example of usage of binary signal transfer for position indication change

Additional dedicated channel can be used to transfer binary signal infor-mation quickly without the need to configure GOOSE. This minimizes the configuration effort since configuration templates can be directly used when signal transfer is required only for point to point instead of multipoint.

In addition to X6 Ethernet port which is tied to PCSITPC1 and BSTGAPC1-2, X3 Ethernet port can be configured to dedicated channel mode. It also requires PCSITPC2 block for supervision and one of the BSTGAPC3-4 for signal connections. Analog signals are not available for this channel.

Dedicated channel	Functions	Description
Ethernet Port X6	BSTGAPC1-2, PCSITPC1, LNPLDF1	Includes analog data and can be used for line differen-tial application as well as for binary signal transfer.
Ethernet Port X3	BSTGAPC3-4, PCSITPC2	Analog data cannot be either send or received. Only used for binary signal transfer. Ethernet port must be set to dedicated channel mode.

Relay pairs exchanging only binary signals can be connected to either port. However, one must verify that connector types match especially when X3 is connected to X6 (SFP module).

5.5.6 Signals

Table 1134: BSTGAPC Input signals

Name	Type	Default	Description
SEND_SIG_1	BOOLEAN	0=False	Send signal 1 state
SEND_SIG_2	BOOLEAN	0=False	Send signal 2 state
SEND_SIG_3	BOOLEAN	0=False	Send signal 3 state
SEND_SIG_4	BOOLEAN	0=False	Send signal 4 state
SEND_SIG_5	BOOLEAN	0=False	Send signal 5 state
SEND_SIG_6	BOOLEAN	0=False	Send signal 6 state
SEND_SIG_7	BOOLEAN	0=False	Send signal 7 state
SEND_SIG_8	BOOLEAN	0=False	Send signal 8 state

Table 1135: BSTGAPC Output signals

Name	Type	Description
RECV_SIG_1	BOOLEAN	Receive signal 1 state
RECV_SIG_2	BOOLEAN	Receive signal 2 state
RECV_SIG_3	BOOLEAN	Receive signal 3 state
RECV_SIG_4	BOOLEAN	Receive signal 4 state
RECV_SIG_5	BOOLEAN	Receive signal 5 state
RECV_SIG_6	BOOLEAN	Receive signal 6 state
RECV_SIG_7	BOOLEAN	Receive signal 7 state
RECV_SIG_8	BOOLEAN	Receive signal 8 state
SEND_SIG_A	BOOLEAN	Binary signal transfer sending alarm state
RECV_SIG_A	BOOLEAN	Binary signal transfer receive alarm state

5.5.7 Settings

Table 1136: BSTGAPC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Signal 1 mode	1=In use 2=In use, alarm sel. 3=Not in use			2=In use, alarm sel.	Operation mode for signal 1
Signal 2 mode	1=In use 2=In use, alarm sel. 3=Not in use			2=In use, alarm sel.	Operation mode for signal 2
Signal 3 mode	1=In use 2=In use, alarm sel. 3=Not in use			1=In use	Operation mode for signal 3
Signal 4 mode	1=In use 2=In use, alarm sel.			1=In use	Operation mode for signal 4

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Not in use				
Signal 5 mode	1=In use 2=In use, alarm sel. 3=Not in use			1=In use	Operation mode for signal 5
Signal 6 mode	1=In use 2=In use, alarm sel. 3=Not in use			1=In use	Operation mode for signal 6
Signal 7 mode	1=In use 2=In use, alarm sel. 3=Not in use			1=In use	Operation mode for signal 7
Signal 8 mode	1=In use 2=In use, alarm sel. 3=Not in use			1=In use	Operation mode for signal 8
Pulse time 1	0...60000	ms	1	0	Minimum pulse time for received signal 1
Pulse time 2	0...60000	ms	1	0	Minimum pulse time for received signal 2
Pulse time 3	0...60000	ms	1	0	Minimum pulse time for received signal 3
Pulse time 4	0...60000	ms	1	0	Minimum pulse time for received signal 4
Pulse time 5	0...60000	ms	1	0	Minimum pulse time for received signal 6
Pulse time 6	0...60000	ms	1	0	Minimum pulse time for received signal 6
Pulse time 7	0...60000	ms	1	0	Minimum pulse time for received signal 7
Pulse time 8	0...60000	ms	1	0	Minimum pulse time for received signal 8

Table 1137: BSTGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm mode	1=Any of selected 2=All of selected			1=Any of selected	Selects the used alarm logic mode for activating SEND_SIG_A and RECV_SIG_A

5.5.8 Technical data

Table 1138: BSTGAPC Technical data

Characteristic		Value
Signalling delay	Fiber optic link	<5 ms
	Galvanic pilot wire link	<10 ms

5.6 Emergency start-up ESMGAPC (ANSI EST,62)

5.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Emergency start-up	ESMGAPC	ESTART	EST,62

5.6.2 Function block

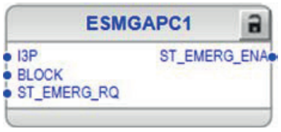


Figure 679: Function block

5.6.3 Functionality

An emergency condition can arise in cases where the motor needs to be started despite knowing that this can increase the temperature above limits or cause a thermal overload that can damage the motor. The emergency start-up function ESMGAPC allows motor start-ups during such emergency conditions. ESMGAPC is only to force the protection relay to allow the restarting of the motor. After the emergency start input is activated, the motor can be started normally. ESMGAPC itself does not actually restart the motor.

The function contains a blocking functionality. It is possible to block function outputs, timer or the function itself.

5.6.4 Analog channel configuration

ESMGAPC has one analog group input which must be properly configured.

Table 1139: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing

blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.6.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of ESMGAPC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

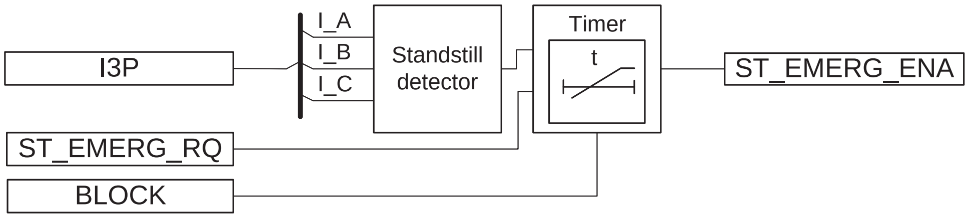


Figure 680: Functional module diagram

Standstill detector

The module detects if the motor is in a standstill condition. The standstill condition can be detected based on the phase current values. If all three phase currents are below the set value of *Motor standstill A*, the motor is considered to be in a standstill condition.

Timer

The timer is a fixed 10-minute timer that is activated when the ST_EMERG_RQ input is activated and motor standstill condition is fulfilled. Thus, the activation of the ST_EMERG_RQ input activates the ST_EMERG_ENA output, provided that the motor is in a standstill condition. The ST_EMERG_ENA output remains active for 10 minutes or as long as the ST_EMERG_RQ input is high, whichever takes longer.

The activation of the BLOCK input blocks and also resets the timer.

The function also provides the ST_EMERG_ENA output change date and time, T_ST_EMERG. The information is available in the monitored data view.

5.6.6 Application

If the motor needs to be started in an emergency condition at the risk of damaging the motor, all the external restart inhibits are ignored, allowing the motor to be restarted. Furthermore, if the calculated thermal level is higher than the restart inhibit level at an emergency start condition, the calculated thermal level is set slightly below the restart inhibit level. Also, if the register value of the cumulative start-up time counter exceeds the restart inhibit level, the value is set slightly below the restart disable value to allow at least one motor start-up.

The activation of the ST_EMERG_RQ digital input allows to perform emergency start. The protection relay is forced to a state which allows the restart of motor, and the operator can now restart the motor. A new emergency start cannot be made until the 10 minute time-out has passed or until the emergency start is released, whichever takes longer.

The last change of the emergency start output signal is recorded.

5.6.7 Signals

5.6.7.1 ESMGAPC Input signals

Table 1140: ESMGAPC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ST_EMERG_RQ	BOOLEAN	0=False	Emergency start input

5.6.7.2 ESMGAPC Output signals

Table 1141: ESMGAPC Output signals

Name	Type	Description
ST_EMERG_ENA	BOOLEAN	Emergency start

5.6.8 ESMGAPC Settings

Table 1142: ESMGAPC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Motor standstill A	0.01...0.20	xIn	0.01	0.12	Current limit to check for motor standstill condition

Table 1143: ESMGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

5.6.9 ESMGAPC Monitored data

Table 1144: ESMGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
T_ST_EMERG	Timestamp			Emergency start activation timestamp
ESMGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.6.10 Technical data

Table 1145: ESMGAPC Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5 % of the set value or ±0.002 × U_n

5.6.11 Technical revision history

Table 1146: ESMGAPC Technical revision history

Product connectivity level	Technical revision	Change
PCL4	E	Setting *Motor standstill A* minimum value changed from 0.05xIn to 0.01xIn.

5.7 Fault locator SCEFRFLO (ANSI FLOC)

5.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fault locator	SCEFRFLO	FLOC	FLOC

5.7.2 Function block

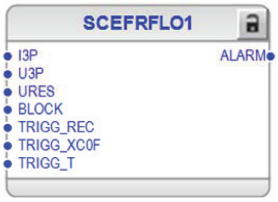


Figure 681: Function block

5.7.3 Functionality

The fault locator function SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems, and it can locate short circuits in all kinds of distribution networks. Earth faults can be located in effectively earthed and in low-resistance or low-reactance earthed networks. With certain limitations, SCEFRFLO can also be used for locating an earth fault in unearthed distribution networks. Moreover, SCEFRFLO can be applied to compensated (resonant earthed) networks where an earth-fault current raising resistor is connected in parallel with the arc suppression coil. The location of the continuous low-ohmic earth fault can be determined by using the switching of the parallel resistor of the coil during an earth fault.

The fault distance calculation is based on the locally measured fundamental frequency current and voltage phasors. The full operation of SCEFRFLO requires all phase currents and phase-to-earth voltages to be measured.

The fault distance estimate is obtained when SCEFRFLO is externally or internally triggered.

5.7.4 Analog channel configuration

SCEFRFLO has three analog group inputs which must be properly configured.

Table 1147: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages
URES [1]	Residual voltage (measured), necessary when the phase-to-phase voltages are measured and Phase voltage Meas is set to "Accurate"

See the preprocessing function blocks in this document for the possible signal sources. The `GRPOFF` signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

[1] Can be connected to `GRPOFF` if *Phase voltage Meas* is set to "Ph-to-ph without Uo"

Table 1148: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.7.5 Operation principle

The function can be enabled or disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of SCEFRFLO can be described with a module diagram. All the modules in the diagram are explained in the next sections.

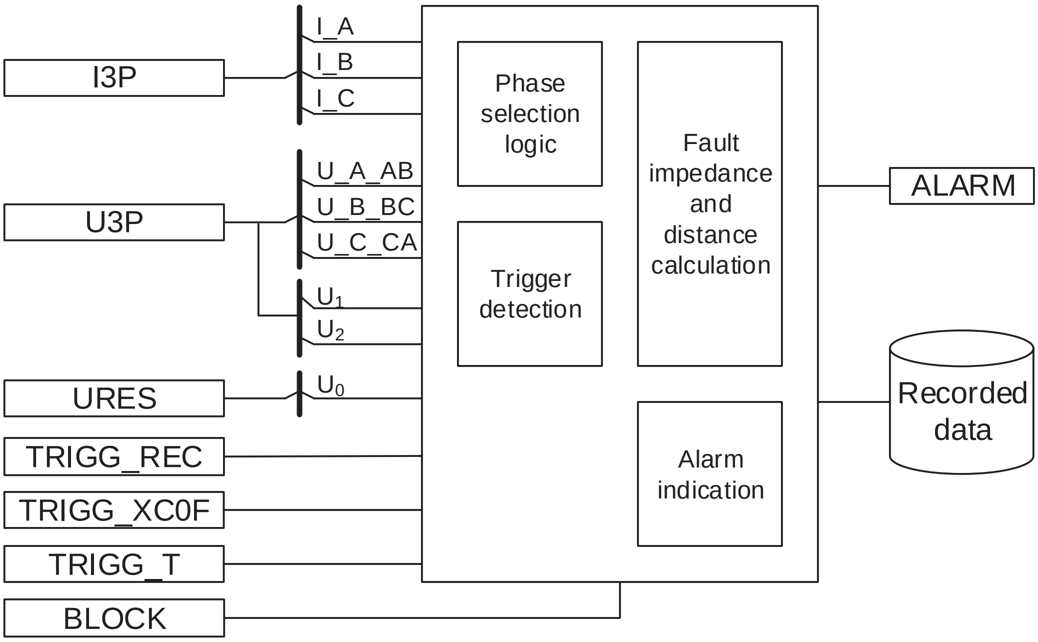


Figure 682: Functional module diagram

The fault distance calculation is done in two steps. First, the fault type is determined with the in-built Phase selection logic (PSL). Second, based on the selected impedance measuring element (fault loop) the fault distance from the measuring point to the fault location is calculated.

The phase current magnitude's minimum threshold value is 1 % xIn.

5.7.5.1 Phase selection logic

Phase selection logic identifies the faulty phases based on a combined impedance and current criterion. Phase selection logic is virtually setting-free and has only one parameter, *Z Max phase load*, for discriminating a heavy symmetrical load from a three-phase fault. The setting *Z Max phase load* can be calculated using the equation

$$Z\ Max\ phase\ load = 0.8 \cdot \frac{U_{xy}^2}{S_{\max}}$$

(Equation 292)

U_{xy}	Nominal phase-to-phase voltage
S_{max}	Maximum three-phase load

For example, if U_{xy} = 20 kV and S_{max} = 1 MVA, then *Z Max phase load* = 320.0 Ω.

The identification of the faulty phases is compulsory for the correct operation of SCEFRFLO. This is because only one of the impedance-measuring elements (fault loops) provides the correct result for a specific fault type. A three-phase fault is an exception and theoretically it can be calculated with any of the fault loops. The fault loop used in the fault distance calculation is indicated in the recorded data Flt loop as specified in *Table 1149*.

Table 1149: Fault types and corresponding fault loops

Fault type	Description	Flt loop
-	No fault	No fault
A-E	Phase A-to-earth fault	AG Fault
B-E	Phase B-to-earth fault	BG Fault
C-E	Phase C-to-earth fault	CG Fault
A-B	Phase A-to-B short circuit fault	AB Fault
B-C	Phase B-to-C short circuit fault	BC Fault
C-A	Phase C-to-A short circuit fault	AC Fault
A-B-C-(E)	Three-phase short circuit	ABC Fault

In case of two-phase-to-earth-faults (A-B-E, B-C-E or C-A-E), the selected fault loop depends on the location of the earth faults. When the faults are located at the same feeder, the corresponding phase-to-phase loop (“AB Fault”, “BC Fault” or “CA Fault”) is used for calculation. When the faults are located at different feeders, the phase-to-earth loop (“AG Fault”, “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder is used for calculation.

5.7.5.2 Fault impedance and distance calculation

As soon as a fault condition is recognized by Phase selection logic, the fault distance calculation is started with one of the seven impedance-measuring elements, that is, the fault loops. SCEFRFLO uses independent algorithms for each fault type to achieve optimal performance.

The inherent result from the fault distance calculation is the ohmic fault loop impedance value.

Table 1150: The calculated impedance values available in the recorded data

Impedance valule	Description
Flt phase reactance	Estimated positive sequence reactance from the substation to the fault location in primary ohms.
Flt point resistance	Fault resistance value in the fault spot in primary ohms. The composition of this term depends on the fault loop as described in the following subsections.
Flt loop resistance	The total fault loop resistance from the substation to the fault location in primary ohms. Fault point resistance is included in this value. The composition of this term is different for short-circuit and earth-fault loops as described in the following subsections.
Flt loop reactance	The total fault loop reactance from the substation to the fault location in primary ohms. The composition of this term is different for short-circuit and earth-faults loops as described in the following subsections.

These impedance values can be used as such or they can be further processed in system-level fault location applications, such as distribution management system (DMS).

5.7.5.3 Fault loops “AG Fault” or “BG Fault” or “CG Fault”

Fault loops “AG Fault”, “BG Fault” and “CG Fault” are used for single-phase-toearth faults. When the earth faults are located at different feeders, they are also applied in the case of two-phase-to-earth faults. In this case, the phase-to-earth loop (“AG Fault”, “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder is used for calculation. *Figure 683* shows the phase-to-earth fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = R_{fault}$$

(Equation 293)

$$Flt\ loop\ resistance = R_1 + R_N + R_{fault}$$

(Equation 294)

$$Flt\ loop\ reactance = X_1 + X_N$$

(Equation 295)

$$Flt\ phase\ reactance = X_1$$

(Equation 296)

R_1	Estimated positive-sequence resistance from the substation to the fault location
X_1	Estimated positive-sequence reactance from the substation to the fault location
R_0	Estimated zero-sequence resistance from the substation to the fault location
X_0	Estimated zero-sequence reactance from the substation to the fault location
R_N	Estimated the earth return path resistance (= (R0 – R1)/3) from the substation to the fault location
X_N	Estimated is the earth return path reactance (= (X0 – X1)/3) from the substation to the fault
R_{fault}	Estimated fault resistance at the fault location

The recorded data Flt phase reactance provides the estimated positive-sequence reactance from the substation to the fault location.

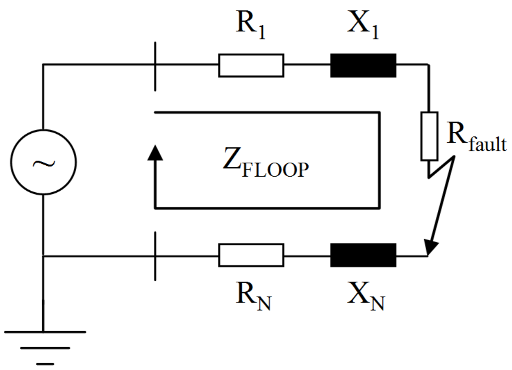


Figure 683: Fault loop impedance for phase-to-earth fault loops “AG Fault”, “BG Fault” or “CG Fault”

Setting *Flt Loc Det mode* is used for selecting between different algorithms for the calculation of the earth-fault distance. In case of compensated (resonant earthed) networks where an earth-fault current raising resistor is used, setting *Flt Loc Det mode* = "Comp, switched R" should be selected. In all other cases of system neutral point earthing (effectively earthed, low-resistance, low-reactance or unearthed networks), setting "Non-comp" should be selected.

Earth-fault distance calculation in case of non-compensated networks

In case of non-compensated networks (effectively earthed, low-resistance, lowreactance or unearthed networks), the setting *Flt Loc Det mode* is equal to "Noncomp". Furthermore, the earth-fault distance calculation algorithm is selected with setting *EF algorithm Sel*. Options for the selection are "Load compensation" and "Load modelling". For the correct operation of both algorithms, there should not be any zero-sequence current sources, for example, earthing transformers, in front of the protection relay.

The “Load compensation” algorithm uses symmetrical components to compensate for the effect of load on the measured voltages and currents. In case of radial feeders, this algorithm should be selected with low-impedance/effectively earthed systems where the fault current is fed from one side only and there are no in-feeds along the protected line.

The “Load modelling” algorithm takes into account the effect of the load in the measured currents and voltages by considering it in the fault loop model. In case of radial feeders, this algorithm can be applied with low-impedance/effectively earthed systems where the fault current is fed from one side only. The “Load modelling” algorithm has been especially designed for unearthed systems.

The “Load modelling” algorithm requires the *Equivalent load Dis* setting, that is, an equivalent load distance, as an additional parameter. The derivation and meaning of this parameter is illustrated in *Figure 684*, where the load is assumed to be evenly distributed along the feeder, resulting in the actual voltage drop curve as seen in the middle part of *Figure 684*.

In case of evenly distributed load, *Equivalent load Dis* ~ 0.5. When the load is tapped at the end of the feeder, *Equivalent load Dis* = 1.0. If the load distribution is unknown, a default value of 0.5 can be used for *Equivalent load Dis*.

The maximum value of the voltage drop, denoted as U_{drop}(real), appears at the end of the feeder. The *Equivalent load Dis* setting is the distance at which a single load tap corresponding to the total load of the feeder results in a voltage drop equal to U_{drop}(real). The dashed curve shows the voltage drop profile in this case.

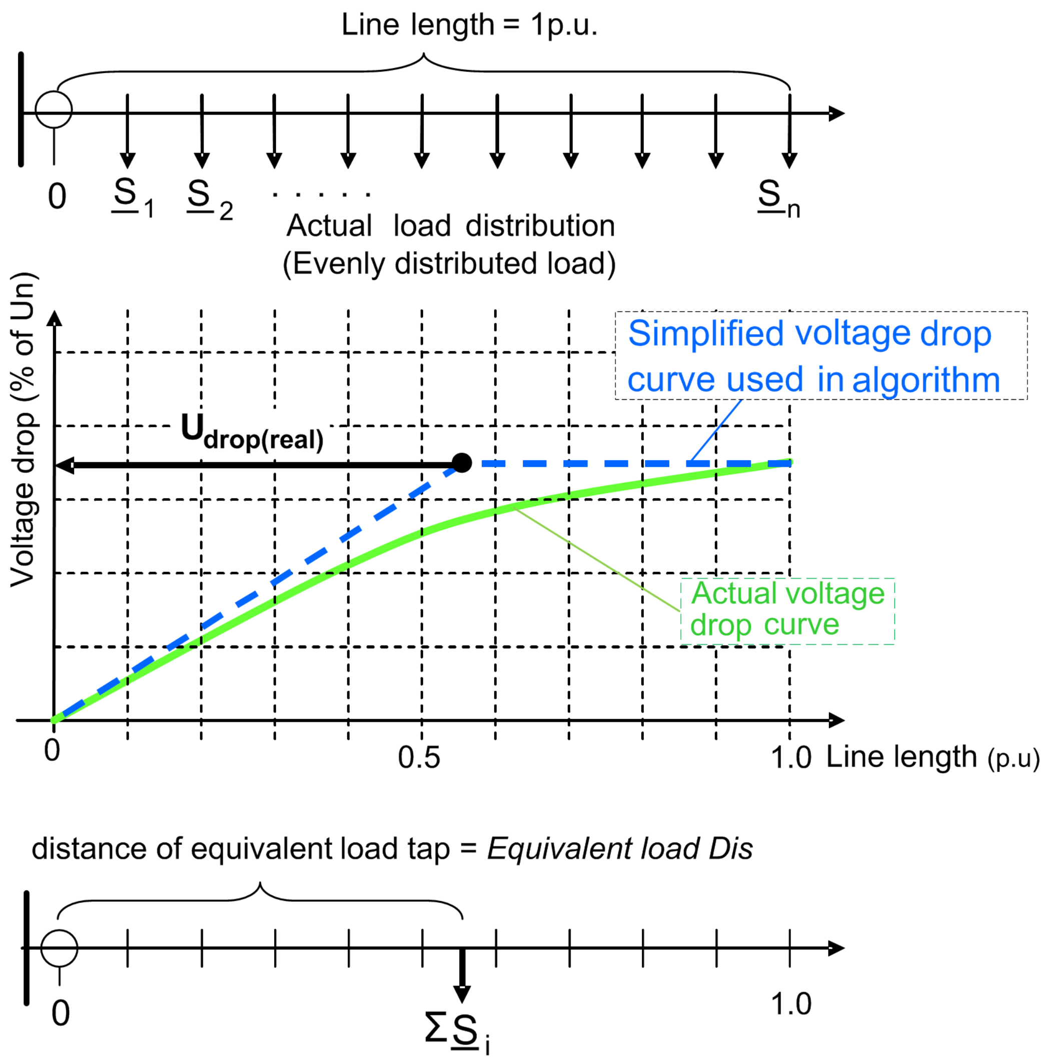


Figure 684: Description of the equivalent load distance

The exact value for *Equivalent load Dis* can be calculated based on the load flow and voltage drop calculations using data from DMS-system and the following equation.

$$Equivalent\ load\ Dis = \frac{U_{d(real)}}{U_{d(tap,d=1)}}$$

(Equation 297)

$U_{d(real)}$	The actual maximum voltage drop of the feeder
$U_{d(tap,d=1)}$	The fictional voltage drop, if the entire load would be tapped at the end (d=1) of the feeder (not drawn in *Figure 684*). The calculation of this value requires data from the DMS system.

Alternatively, the setting *Equivalent load Dis* can be determined by conducting a single-phase earth-fault test (R_{fault} = 0 Ω) at that point of the feeder where the maximum actual voltage drop takes place. This point is typically located at the end of the main line. As a result, the calculated value is stored in the recorded data Equivalent load Dis.

In addition, when the setting *EF algorithm Sel* is equal to "Load modelling", the *EF algorithm Cur Sel* setting determines whether the used algorithm is based on zero-sequence "Io based" or negative-sequence "I2 based" current. The difference between "Io based" and "I2 based" methods is that "I2 based" does not require the *Ph capacitive React* and *Ph leakage Ris* settings. In case of "Io based", these settings are needed to compensate for the influence of the line-charging capacitances of the protected feeder. This improves the accuracy of the fault location estimate when fault resistance is involved in the fault.

With certain restrictions, the “Load modelling” algorithm can also be applied to unearthed networks. In this case the *EF algorithm Cur Sel* setting should be set to “Io based” and thus *Ph capacitive React* and *Ph leakage Ris* settings must be determined.

The prerequisite for the operation of SCEFRFLO in earth faults in unearthed networks is that the earth-fault current of the network corresponding to a solid fault exceeds the pre-fault load current; that is the *Equation 298* is valid.

$$Flt\ to\ Lod\ Cur\ ratio = \frac{\left|I_{ef(Rfault=0)}\right|}{\left|I_{Load}\right|} \geq 1$$

(Equation 298)

This ratio is estimated by SCEFRFLO and stored in the recorded data Flt to Lod Cur ratio together with the fault distance estimate.

In case of an unearthed network, sufficient fault current magnitude resulting in Flt to Lod Cur ratio >1 can be achieved, for example, with proper switching operations in the background network, if possible, which increase the fault current. If the faulty feeder is re-energized after the switching operation, a new estimate for the fault distance can be obtained. Fault resistance decreases the fault location accuracy so the resistance should not be higher than a few hundred ohms. Also, a low value of Flt to Lod Cur ratio causes inaccuracy and affects the quality of the fault distance estimate. The inaccuracies affecting the calculated fault distance estimate are reported in the recorded result quality indicator value Flt Dist quality in *Table 93*.

Earth-fault distance calculation in case of compensated (resonant earthed) networks where an earth-fault current raising resistor is used

In case of compensated (resonant earthed) networks where an earth-fault current raising resistor is used, the setting *Flt Loc Det mode* is equal to "Comp, switched R". The algorithm for calculation of earth-fault distance requires a measurable change in the measured phase currents and phase-to-earth voltages during an earth fault. Such a change can be accomplished by switching on the resistor of the PAW winding (Power Auxiliary Winding) of the compensation coil during the fault.

The algorithm requires three independent time instances, which are assumed to be known by the algorithm:

- t_0 = time instance before the fault
- t_1 = time instance before the change during the earth fault
- t_2 = time instance after the change during the earth fault

The effect of loads is considered by applying “Load modelling” algorithm.

The required settings of the algorithm are:

- R1 = Positive-sequence resistance of the protected feeder [ohm, prim]
- X1 = Positive-sequence reactance of the protected feeder [ohm, prim]
- R0 = Zero-sequence resistance of the protected feeder [ohm, prim]
- X0 = Zero-sequence reactance of the protected feeder [ohm, prim]
- s = Equivalent load distance [pu]

Determining timings of changes: determination of earth fault occurrence and time instance t0

Timing t_0 is needed to store the current and voltage phasors right before the occurrence of the earth fault. Timing t_0 is common to both triggering types (*Calculation Trg mode* either “Internal” or “External”). Pre-fault (indicating healthy network) phasors are continuously updated and stored at intervals of 300 ms until the earth fault is indicated. When the earth fault is detected (internal detection), the pre-fault phasor is stored at least 300 ms before the detection of the earth fault. This time instance before the earth fault is noted as t_0 (see *Figure 685*).

Determining timings of changes: determination of changes during an earth fault due to parallel resistor switching, time instances t1 and t2

- Time instance t_1 equals the time during earth fault, right before the switching of the parallel resistor of the coil (see *Figure 685*)
- Time instance t_2 equals the time during earth fault, just after the switching of the parallel resistor of the coil (see *Figure 685*)

In case of external triggering, time instances t_1 and t_2 are determined using input `TRIGG_T` and delay setting *Time delay*. `TRIGG_T` input should be activated when the parallel resistor is switched ON. Time instance t_1 is taken at least one fundamental cycle before `TRIGG_T` rising edge. Time instance t_2 is taken according to the set *Time delay* after the rising edge of `TRIGG_T` signal. Setting *Time delay* should be few hundreds of ms and it is needed due to oscillations in currents and voltages after the switching of the parallel resistor.

`TRIGG_T` activation must be given after the initial earth-fault ignition transients. Only one activation of `TRIGG_T` is allowed during an earth fault. However, further activations are internally disabled.

Activation of input TRIGG_REC is required in case of external triggering to record the calculated estimates for fault distance. TRIGG_REC should be activated during the earth fault after the switching of the parallel resistor.

In case of internal triggering, time instances t_1 and t_2 are determined by monitoring the change of the resistive component of Io current using admittance calculation during the earth fault and comparing the magnitude of change to setting *Zero Ris Curr change*. Time instance t_1 is taken at least one fundamental cycle before and t_2 at least one fundamental cycle after the change in the resistive component of Io exceeding the start value (setting *Zero Ris Curr change*). The value for setting Zero Ris Curr change should be chosen based on the rated current value of the parallel resistor with proper margin:

Zero Ris Curr change < Ipar_rated [A] · q

where q = 0.5–0.7

For example, if the rated current value of the parallel resistor is 10A@20kV and In = 100 A for Io channel, then

Zero Ris Curr change < 0.05–0.07xIn

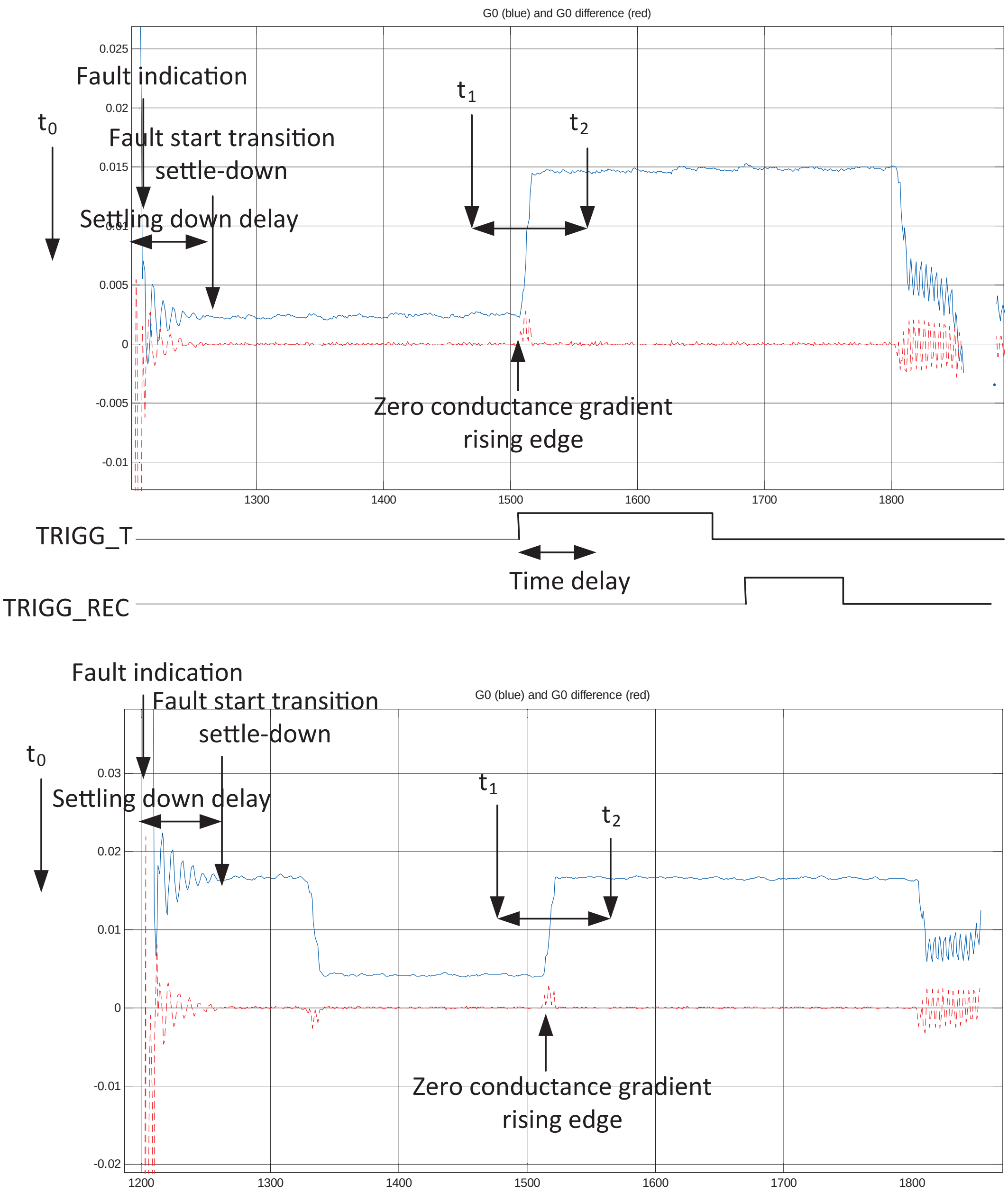


Figure 685: Fault distance estimate triggering moment definitions

Fault loops “AB Fault”, “BC Fault” or “CA Fault”

Fault loops “AB Fault”, “BC Fault” or “CA Fault” are used for phase-to-phase short circuit faults as well as in the case of a two-phase-to-earth fault if the individual earth faults are located at the same feeder. *Figure 686* shows the phase-to-phase fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = \frac{R_{fault}}{2}$$

(Equation 299)

$$Flt\ loop\ resistance = R_1 + \frac{R_{fault}}{2}$$

(Equation 300)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 301)

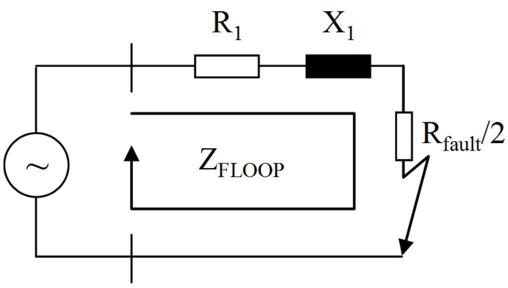


Figure 686: Fault loop impedance for phase-to-phase fault loops (either “AB Fault”, “BC Fault” or “CA Fault”)

The fault distance calculation algorithm for the phase-to-phase fault loops is defined by using settings *Load Com PP loops* and *Enable simple model*. Options for the selection are "Disabled" or "Enabled".

Load compensation can be enabled or disabled with setting *Load Com PP loops*. Load compensation should be disabled only if the ratio between the fault current and load current is high or when the value of the fault distance estimate for the short circuit fault is required from each shot of an autoreclosing sequence.

The fault distance calculation is most accurate when calculated with the fault loop model. This model requires positive-sequence impedances of the protected feeder to be given as settings. If these settings are not available, valid impedance values can be calculated also without the fault loop model with setting *Enable simple model* = "Enabled". However, a valid distance estimate, that is, the conversion of measured impedance (“electrical fault distance”) into a physical fault distance requires accurate positive-sequence impedance settings.

Fault loop “ABC Fault”

Fault loop “ABC Fault” is used exclusively for the three-phase short circuit fault. *Figure 687* shows the three-phase fault loop model. The following impedances are measured and stored in the recorded data of SCEFRFLO.

$$Flt\ point\ resistance = R_{fault}$$

(Equation 302)

$$Flt\ loop\ resistance = R_1 + R_{fault}$$

(Equation 303)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 304)

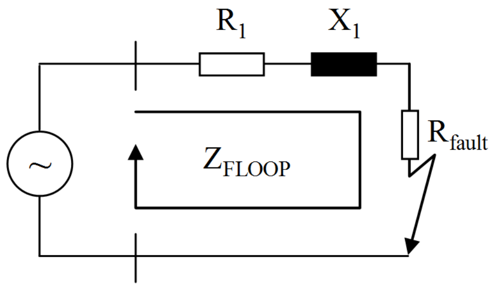


Figure 687: Fault loop impedance for a three-phase fault loop ("ABC Fault")

The three-phase fault distance is calculated with a special measuring element using positive-sequence quantities. This is advantageous especially in case of non-transposed (asymmetric) lines, as the influence of line parameter asymmetry is reduced. If the line is non-transposed, all the phase-to-phase loops have different fault loop reactances. The use of positive-sequence quantities results in the average value of phase-to-phase loop reactances, that is, the most representative estimate in case of three-phase faults.

The fault distance calculation algorithm for the three-phase fault loop is defined with settings *Load Com PP loops* and *Enable simple model*. Options for the selection are "Disabled" or "Enabled".

Load compensation can be enabled or disabled with setting *Load Com PP loops*. The load compensation should be disabled only if the ratio between the fault current and load current is high or when the value of the fault distance estimate for the short circuit fault is required from each shot of an autoreclosing sequence.

The fault distance calculation is most accurate when the calculation is made with the fault loop model. This model requires positive sequence impedances of the protected feeder to be given as settings. If these settings are not available, valid impedance values can be calculated also without the fault loop model with setting *Enable simple model* = "Enabled". However, a valid distance estimate, that is, the conversion of measured impedance ("electrical fault distance") into a physical fault distance requires accurate positive-sequence impedance settings.

Estimation of fault resistance in different fault loops

The fault point resistance value provided by the impedance calculation is available in recorded data Flt point resistance and it depends on the applied fault loop as shown in *Figure 688*. In case of earth faults, the estimated fault point resistance includes the total fault point resistance between the faulty phase and earth, for example, the arc and earthing resistances. In case of phase-to-phase faults, the estimated fault point resistance is half of the total fault point resistance between the phases. In case of a three-phase fault, the estimated fault point resistance equals the total fault point resistance per phase, for example, the arc resistance per phase.

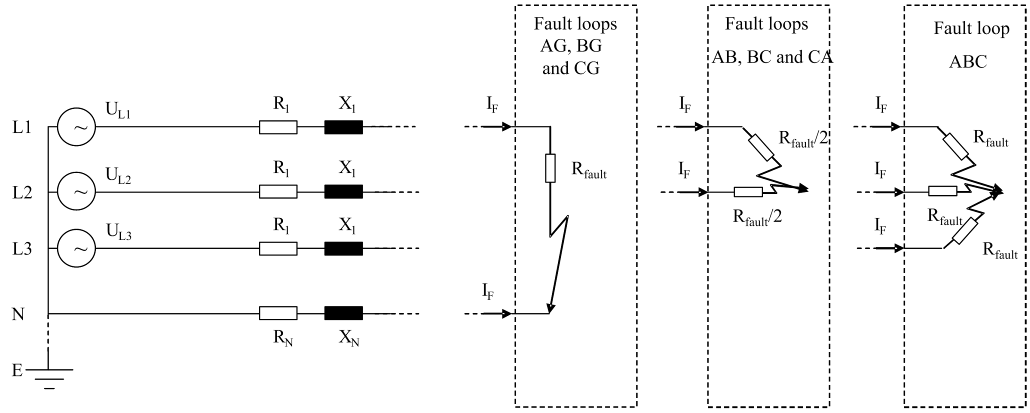


Figure 688: Definition of a physical fault point resistance in different fault loops

Steady-state asymmetry and load compensation

Power systems are never perfectly symmetrical. The asymmetry produces steady-state quantities in the form of zero-sequence and negative-sequence voltages and currents. If not compensated, these are error sources for fault distance calculation especially in case of earth faults. All earth-fault distance calculation algorithms of SCEFRFLO use the delta quantities which mitigate the effects of the steady-state asymmetry.

The load current is another error source for fault distance calculation. Its influence increases with higher fault resistance values. SCEFRFLO employs independent load compensation methods for each fault type to achieve optimal performance. The purpose of load compensation is to improve the accuracy of the fault distance calculation models by estimating the actual fault current in the fault location. Delta-quantities are used for this to mitigate the effect of load current on fault distance estimation.

For earth faults, the load compensation is done automatically inside the fault distance calculation algorithm. For short circuit faults, load compensation is enabled with setting *Load Com PP loops*. The default value is "Enabled". The parameter should be set to "Disabled" only if the ratio between the expected fault current and load current is high or when the fault distance estimate for the short circuit fault is required for each shot of an autoreclosing sequence.

The delta quantity describes the change in measured signal due to the fault.

$$\Delta x = x_{fault} + x_{pre\text{-}fault}$$

(Equation 305)

x_{fault}	Signal value during fault
$x_{pre\text{-}fault}$	Signal value during healthy state just before fault

Result quality indicator

The quality of the estimated fault distance is judged and reported in recorded data as the Flt Dist quality together with the fault distance estimate. The Flt Dist quality is a bit vector indicating detected sources of inaccuracy in the fault distance estimate. If Flt Dist quality equals 1, the result is not affected by error sources. This results in good quality for the fault distance estimate. If factors affecting negatively the fault distance estimation are detected, the Flt Dist quality is according to *Table 93*. In this case, the estimated fault distance (Flt distance) value is given on the HMI in parentheses.

Table 1151: Fault distance quality indicator Flt Dist quality

Value	Corresponding inaccuracy description
2	Estimation stability criterion has not been reached
4	Fault point resistance exceeds 500 Ω
8	Fault point resistance exceeds 5 × X_{loop}
16	Fault point resistance exceeds 20 × X_{loop}[1]
32	Flt to Lod Cur ratio is below 1.00
64	Fault distance estimate outside tolerances (<-0.1 pu or >1.1 pu)
128	Distance estimate calculation is not done due to too low magnitudes of I or U
256	Distance estimate calculation cannot be performed (for example avoiding internal division by zero)

For example, if fault point resistance exceeds 500 Ω and Flt to Lod Cur ratio is below 1.0, Flt Dist quality is “36”. As another example, if no error sources are found, but stability criterion is not met, the value of Flt Dist quality is “2”.

Impedance settings

The fault distance calculation in SCEFRFLO is based on the fault loop impedance modeling. The fault loop is parametrized with the impedance settings and these can be set at maximum for three line sections (A, B and C). Each section is enabled by entering a section length, which ranges from zero to settings *Line Len section A*, *Line Len section B* or *Line Len section C* in the order section A-> section B-> section C.

The earth-fault loops require both positive-sequence and zero-sequence impedances, for example, *R1 line section A* and *X1 line section A*, *R0 line section A* and *X0 line section A*. For the short circuit loops, only positive-sequence impedances are needed, but they can be omitted if the setting *Enable simple model* equals "Enabled".

If the impedance settings are in use, it is important that the settings closely match the impedances of used conductor types. The impedance settings are given in primary ohms [ohm/pu] and the line section lengths in per unit [pu]. Thus, impedances can be either given in ohm/km and section length in km, or ohm/mile and section length in miles. The resulting Flt distance matches the units entered for the line section lengths.

Positive-sequence impedance values

Fault location requires accurate setting values for line impedances. Positive-sequence impedances are required both for location of short circuits and earth faults. As data sheet impedance per unit values are generally valid only for a certain tower configuration, the values should be adjusted according to the

[1] Xloop is the total loop reactance according to settings

actual installation configuration. This minimizes the fault location errors caused by inaccurate settings.

The positive-sequence reactance per unit and per phase can be calculated with a following approximation equation which applies to symmetrically transposed three-phase aluminium overhead lines without ground wires.

$$X_1 \approx \omega_n \cdot 10^{-4} \left(2 \cdot \ln \frac{a_{en}}{r} + 0.5 \right) [\Omega / km]$$

(Equation 306)

ω_n	$2 \times \pi \times f_n$, where f_n = fundamental frequency [Hz]
a_{en}	$\sqrt[3]{(a_{12} \cdot a_{23} \cdot a_{31})}$
	the geometric average of phase distances [m]
a_{xy}	distance [m] between phases x and y
r	radius [m] for single conductor

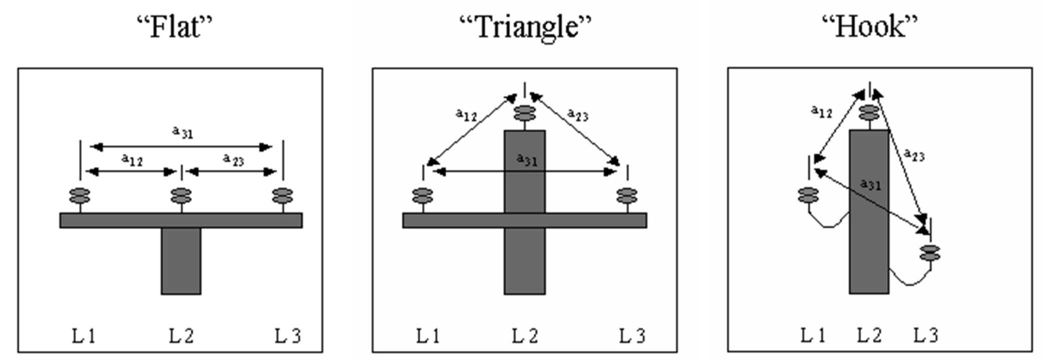


Figure 689: Typical distribution line tower configurations

Example values of positive-sequence impedances for typical medium voltage overhead-lines are given in the following tables.

Table 1152: Positive-sequence impedance values for typical 11 kV conductors, "Flat" tower configuration

Name	R1 [Ω/km]	X1 [Ω/km]
ACSR 50 SQ.mm	0.532	0.373
ACSR 500 SQ.mm	0.0725	0.270

Table 1153: Positive-sequence impedance values for typical 10/20 kV conductors, "Flat" tower configuration

Name	R1 [Ω/km]	X1 [Ω/km]
Al/Fe 36/6 Sparrow	0.915	0.383
Al/Fe 54/9 Raven	0.578	0.368
Al/Fe 85/14 Pigeon	0.364	0.354

Table continues on the next page

Name	R1 [Ω/km]	X1 [Ω/km]
Al/Fe 93/39 Imatra	0.335	0.344
Al/Fe 108/23 Vaasa	0.287	0.344
Al/Fe 305/39 Duck	0.103	0.314

Table 1154: Positive-sequence impedance values for typical 33 kV conductors, “Flat” tower configuration

Name	R1 [Ω/km]	X1 [Ω/km]
ACSR 50 sq.mm	0.529	0.444
ACSR 100 sq.mm	0.394	0.434
ACSR 500 sq.mm	0.0548	0.346

Zero-sequence impedance values

Location of earth faults requires both positive-sequence and zero-sequence impedances. For short circuit faults, zero-sequence impedances are not required.

The positive-sequence impedance per unit values for the lines are typically known or can easily be obtained from data sheets. The zero-sequence values are generally not as easy to obtain as they depend on the actual installation conditions and configurations. Sufficient accuracy can, however, be obtained with rather simple calculations using the following equations, which apply per phase for symmetrically transposed three-phase aluminium overhead lines without ground wires.

$$R_0[50Hz] \approx R1 + 0.14804[\Omega / km]$$

(Equation 307)

$$R_0[60Hz] \approx R1 + 0.17765[\Omega / km]$$

(Equation 308)

$$X_0 \approx 2 \cdot \omega_n \cdot 10^{-4}\left(3 \cdot \ln \frac{W}{r_{en}} + 0.25\right)[\Omega / km]$$

(Equation 309)

R_1	conductor AC resistance [Ω/km]
W	$658\sqrt{\frac{\rho_{earth}}{f_n}}$ the equivalent depth [m] of the earth return path
ρ_{earth}	earth resistivity [Ωm]

Table continues on the next page

r_{en}	$\sqrt[3]{r \cdot \sqrt[3]{a_{12}^2 \cdot a_{23}^2 \cdot a_{31}^2}}$ the equivalent radius [m] for conductor bundle
r	radius [m] for single conductor
a_{xy}	distance [m] between phases x and y

Ph leakage Ris and *Ph capacitive React* settings

The *Ph leakage Ris* and *Ph capacitive React* settings are used for improving fault distance estimation accuracy for earth faults. They are critical for an accurate fault location in unearthed networks. In other types of networks they are less critical. The *Ph leakage Ris* setting represents the leakage losses of the protected feeder in terms of resistance per phase. The *Ph capacitive React* setting represents the total phase-to-earth capacitive reactance of the protected feeder per phase. Based on experience, a proper estimate for *Ph leakage Ris* should be about 20…40 × *Ph capacitive React*.

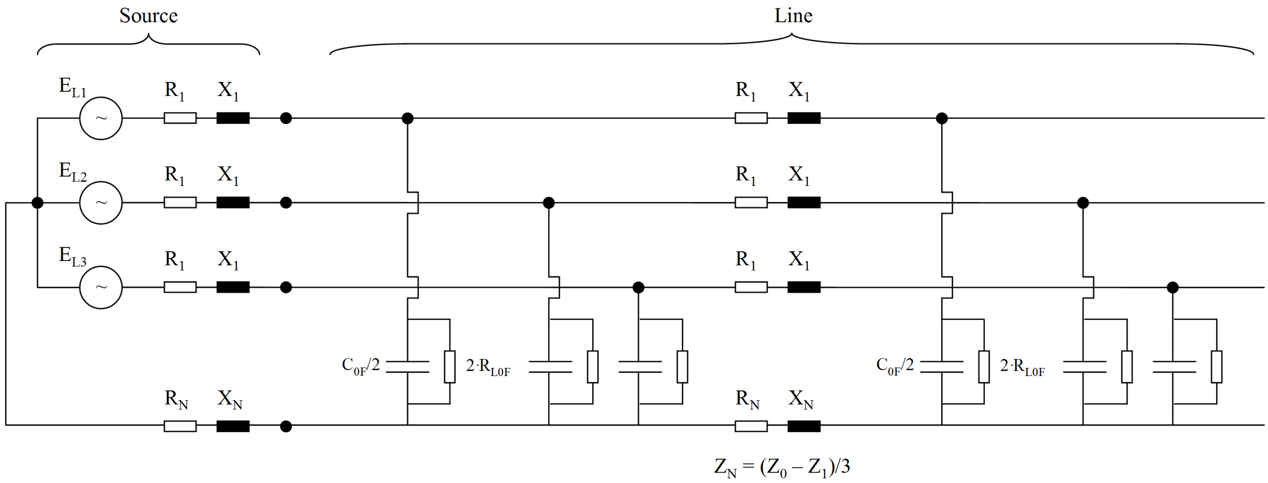


Figure 690: Equivalent diagram of the protected feeder. R L0F = Ph leakage Ris.

The determination of the *Ph capacitive React* setting can be based either on network data or measurement.

If the total phase-to-earth capacitance (including all branches) per phase C_{0F} of the protected feeder is known, the setting value can be calculated.

$$Ph\ capacitive\,React = \frac{1}{(\omega_n \cdot C_{0F})}$$

(Equation 310)

In case of unearthed network, if the earth-fault current produced by the protected feeder I_{ef} is known, the setting value can be calculated.

$$Ph\ capacitive\ React = \frac{\sqrt{3} \cdot U_{xy}}{I_{ef}}$$

(Equation 311)

U_{xy} Phase-to-earth voltage

SCEFRFLO can also determine the value for the *Ph capacitive React* setting by measurements. The calculation of *Ph capacitive React* is triggered by the binary signal connected to the TRIGG_XC0F input when an earth-fault test is conducted outside the protected feeder during commissioning, for example, at the substation busbar. The *Calculation Trg mode* has to be “External”. After the activation of the TRIGG_XC0F triggering input, the calculated value for setting *Ph capacitive React* is obtained from recorded data as parameter *XC0F Calc*. This value has to be manually entered for the *Ph capacitive React* setting. The calculated value matches the current switching state of the feeder so if the switching state of the protected feeder changes, the value should be updated.

Figure 691 shows an example configuration, which enables the measurement of setting *Ph capacitive React*.

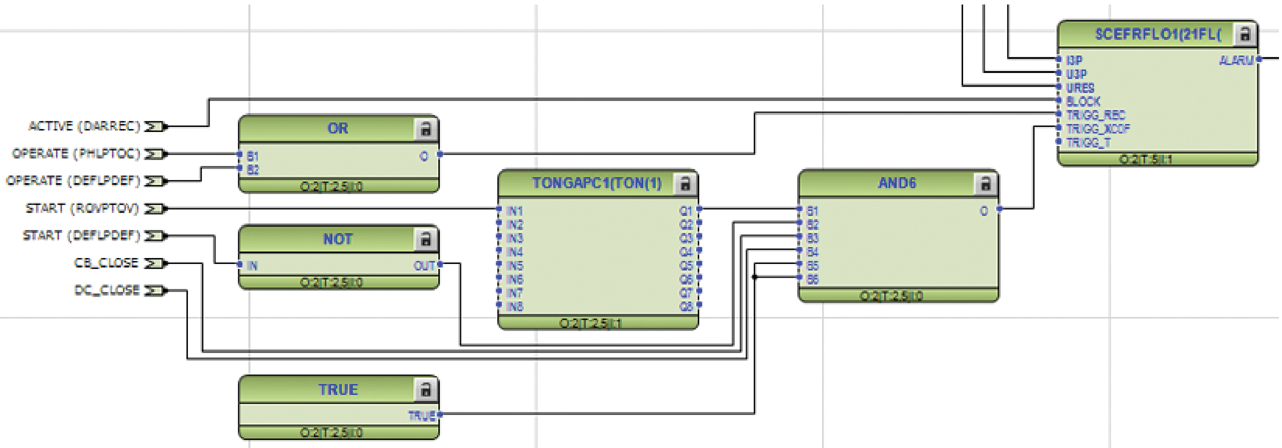


Figure 691: An example configuration, which enables the measurement of setting Ph capacitive React

If the earth fault is detected by the residual overvoltage function (START of ROVPTOV), but not seen by the forward-looking earth-fault protection function (START of DEFLPDEF), the fault is located outside the protected feeder. This is mandatory for valid measurement of setting *Ph capacitive React*. After a set delay (TONGAPC), the input TRIGG_XC0F is activated and the parameter *XC0F Calc* in the recorded data is updated. The delay (TONGAPC) must be set longer than the start delay of the directional earth-fault function DEFLPDEF, but shorter than the minimum operating time of the directional earth-fault functions in any of the feeders. For example, if the start delay is 100 ms and the shortest operating time 300 ms, a value of 300 ms can be used. Circuit breaker and disconnector status is used to verify that the entire feeder is measured.

Modeling a non-homogeneous line

A typical distribution feeder is built with several different types of overhead lines and cables. This means that the feeder is electrically non-homogeneous. SCEFRFLO allows the modeling of the line impedance variation in protection relay with three line sections with independent impedance settings. This improves the accuracy of physical fault distance conversion done in the protection relay, especially in cases where the line impedance non-homogeneity is severe. Each section is enabled by entering a section length, which differs from zero, to settings *Line Len section A*, *Line Len section B* or *Line Len section C* in the order section A-> section B-> section C.

The impedance model with one line section is enabled by setting *Line Len section A* to differ from zero. In this case the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A* and *X0 line section A* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used only in the case of a homogeneous line, that is, when the protected feeder consists of only one conductor type.

The impedance model with two line sections is enabled by setting both *Line Len section A* and *Line Len section B* to differ from zero. In this case the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A*, *X0 line section A*, *R1 line section B*, *X1 line section B*, *R0 line section B* and *X0 line section B* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used in the case of a non-homogeneous line when the protected feeder consists of two types of conductors.

The impedance model with three line sections is enabled by setting *Line Len section A*, *Line Len section B* and *Line Len section C* to differ from zero. In this case, the impedance settings *R1 line section A*, *X1 line section A*, *R0 line section A*, *X0 line section A*, R1 line section B, *X1 line section B*, *R0 line section B*, *X0 line section B*, *R1 line section C*, *X1 line section C*, *R0 line section C* and *X0 line section C* are used for the fault distance calculation and for conversion from reactance to physical fault distance. This option should be used in the case of a non-homogeneous line when the protected feeder consists of more than two types of conductors.

The effect of line impedance non-homogeneity on the conversion of fault loop reactance into physical fault distance is demonstrated in the example shown in *Figure 692* with a 10-km-long feeder with three line types. The total line impedance for the 10 km line is R1 = 6.602 Ω (0.660 Ω/km) and X1 = 3.405 Ω (0.341 Ω/km), consisting of the following sections and impedance values.

- 4 km of PAS 150 (R1 = 0.236 Ω/km, X1 = 0.276 Ω/km)
- 3 km of Al/Fe 54/9 Raven (R1 = 0.536 Ω/km, X1 = 0.369 Ω/km)
- 3 km of Al/Fe 21/4 Swan (R1 = 1.350 Ω/km, X1 = 0.398 Ω/km)

The non-homogeneity of feeder impedance can be illustrated by drawing the protected feeder in RX-diagram (in the impedance plane), as shown in *Figure 692*.

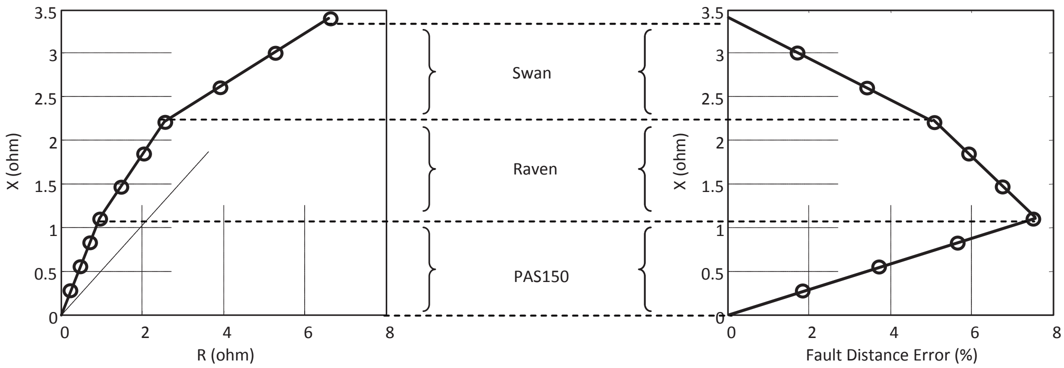


Figure 692: Example impedance diagram of an electrically non-homogeneous feeder (left), and the resulting error in fault distance if the measured fault loop reactance is converted into physical fault distance by using only one line section parameters (right).

In *Figure 692* the feeder is modelled either with one or three line sections with parameters given in *Table 1155*.

Table 1155: Impedance settings

Parameter	Impedance model with one section	Impedance model with three sections
R1 line section A	0.660 Ω/pu	0.236 Ω/pu
X1 line section A	0.341 Ω/pu	0.276 Ω/pu
Line Len section A	10.000 pu	4.000 pu
R1 line section B	N/A	0.536 Ω/pu
X1 line section B	N/A	0.369 Ω/pu
Line Len section B	0.000 pu	3.000 pu
R1 line section C	N/A	1.350 Ω/pu
X1 line section C	N/A	0.398 Ω/pu
Line Len section C	0.000 pu	3.000 pu

Figure 692 illustrates the error when converting the measured fault loop reactance into physical fault distance. The fault location is varied from 1 km to 10 km in 1 km steps (marked with circles). An error of nearly eight per cent at maximum is created by the conversion procedure when modeling a non-homogenous line with only one section. By using impedance model with three line sections, there is no error in the conversion.

The previous example assumed a short circuit fault and thus, only positive-sequence impedance settings were used. The results, however, also apply for earth faults.

Taps or spurs in the feeder

If the protected feeder consists of taps or spurs, the measured fault impedance corresponds to several physical fault locations (For example, A or B in *Figure 693*). The actual fault location must be identified using additional information, for example, short circuit current indicators placed on tapping points.

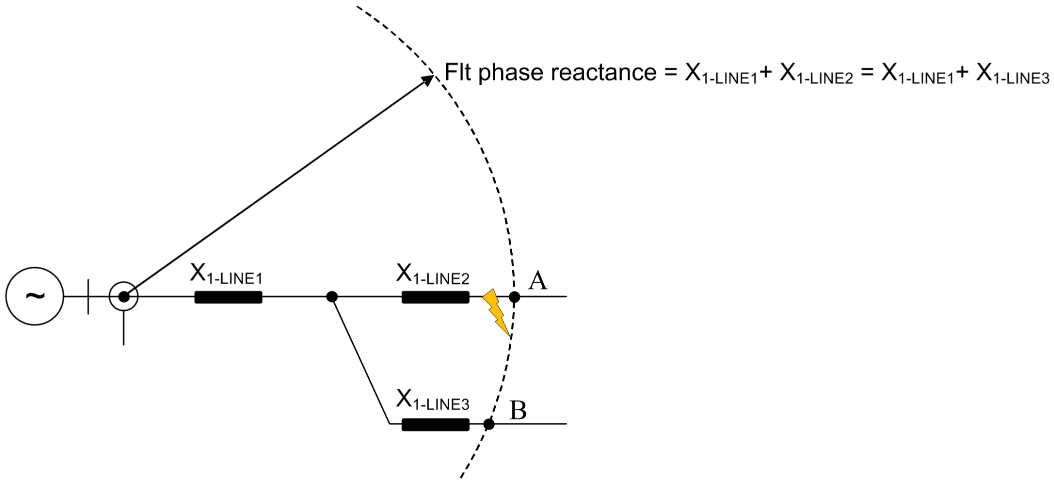


Figure 693: Fault on a distribution line with spurs

5.7.5.4 Trigger detection

The fault distance estimate is obtained when SCEFRFLO is triggered. The triggering method is defined with setting *Calculation Trg mode*. The options for selection are "External" or "Internal", where the default value is "External". The TRIGG_OUT event indicates the fault distance value recording moment. The fault distance estimate, Flt distance, together with the time stamp of actual triggering are saved in the recorded data of SCEFRFLO.

- In case of external triggering, an external trigger signal should be connected to the `TRIGG_REC` input. The triggering signal is typically a trip signal from a protective function. At triggering moment the fault distance is stored into recorded data. It is important that triggering be timed suitably to provide sufficient time for the distance estimation calculation before tripping of the feeder circuit breaker.
- In case of internal triggering, the `TRIGG_REC` input is not used for triggering. Instead, the trigger signal is created internally so that the estimation is started when Phase selection logic detects a fault and the estimate is triggered when its value has stabilized sufficiently. This is judged by maximum variation in fault distance estimate and defined with setting *Distance estimate Va* (in the same unit as the fault distance estimate). When successive estimates during one fundamental cycle are within “final value ± *Distance estimate Va*”, the fault distance estimate (mean of successive estimates) is recorded. If the stabilization criterion has not been fulfilled, the fault distance estimate is given right before the fault ends. Phase selection logic is a non-directional function so internal triggering should not be used when directionality is required.

Generally, SCEFRFLO requires a minimum of two fundamental cycles of measuring time after the fault occurrence. *Figure 694* illustrates typical behavior of fault distance estimate of SCEFRFLO as a function of time.

- Immediately after the fault occurrence, the estimate is affected by initial fault transients in voltages and currents.
- Approximately one fundamental cycle after the fault occurrence, the fault distance estimate starts to approach the final value.
- Approximately two fundamental cycles after the fault occurrence, the stability criterion for fault distance estimate is fulfilled and the TRIGG_OUT event is sent. The recorded data values are stored at this moment.

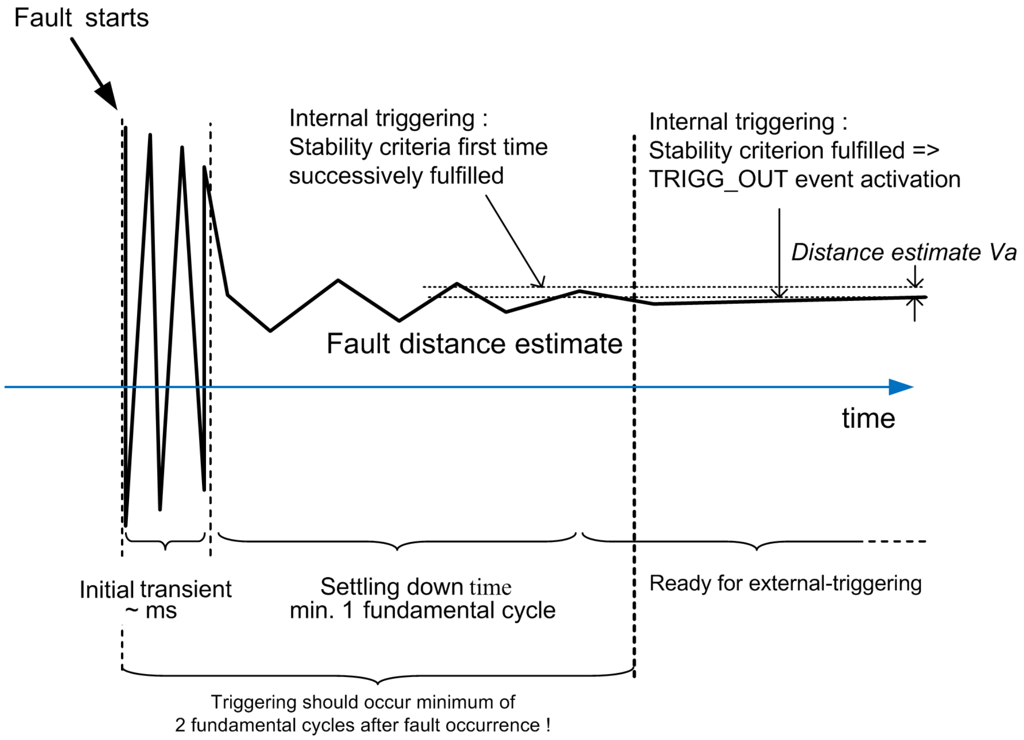


Figure 694: The behavior of fault distance estimate in time

5.7.5.5 Alarm indication

SCEFRFLO contains an alarm output for the calculated fault distance. If the calculated fault distance FLT_DISTANCE is between the settings *Low alarm Dis limit* and *High alarm Dis limit*, the ALARM output is activated. If setting *High alarm Dis limit* has been set below *Low alarm Dis limit*, the ALARM operation is inverted: the ALARM output is activated if *High alarm Dis limit* is undershot or *Low alarm Dis limit* is exceeded. The default value for both is zero so that no distance estimate activates ALARM.

The ALARM output can be utilized, for example, in regions with waterways or other places where knowledge of certain fault locations is of high importance.

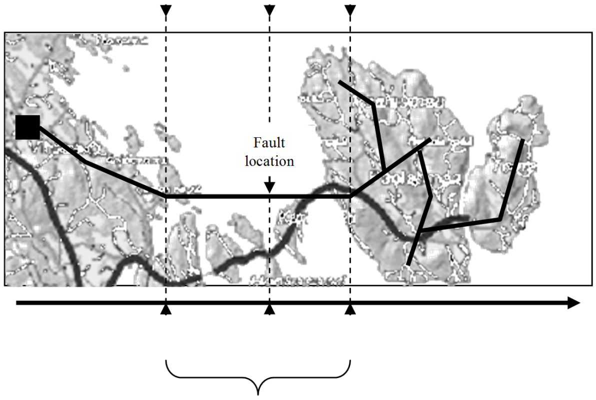


Figure 695: An example of the ALARM output use

5.7.5.6 Recorded data

All the information required for a later fault analysis is recorded to SCEFRFLO recorded data. In the protection relay, recorded data is found in **Monitoring** > **Recorded data** > **Other protection** > **SCEFRFLO**.

SCEFRFLO has also monitored data values which are used for the read-out of continuous calculation values. *Table 1156* shows which of the recorded data values are available as continuous monitoring values during a fault.

Table 1156: Cross reference table for recorded and monitored data values

Recorded data	Monitored data
Flt loop	FAULT_LOOP
Flt distance	FLT_DISTANCE
Flt Dist quality	FLT_DIST_Q
Flt loop resistance	RFLOOP
Flt loop reactance	XFLOOP
Flt phase reactance	XFPHASE
Flt point resistance	RF
Flt to Lod Cur ratio	IFLT_PER_ILD
Equivalent load Dis	S_CALC
XC0F Calc	XC0F_CALC

5.7.6 Measurement modes

The full operation of SCEFRFLO requires that all three phase-to-earth voltages are measured. The voltages can be measured with conventional voltage transformers or voltage dividers connected between the phase and earth (*VT connection* is set to “Wye”). Another alternative is to measure phase-to-phase voltages (*VT connection* is set to “Delta”) and residual voltage (Uo). Both alternatives are covered by setting the configuration parameter *Phase voltage Meas* to "Accurate".

The function can operate correctly with only two phase-to-earth voltages if the residual voltage is also measured and connected to the source UTVTR which provides the phase-to-earth voltages to the function. In this case, the missing phase-to-earth voltage is correctly calculated internally in the relay. If the measured residual voltage is connected to SCEFRFLO input URES, *Phase voltage Meas* can be set to "Accurate".

When the *Phase voltage Meas* setting is set to "Ph-to-ph without Uo" and only phase-to-phase voltages are available (but not Uo), only short-circuit measuring loops (fault loops “AB Fault”, “BC Fault”, “CA Fault” or “ABC Fault”) can be measured accurately. In this case, the earth-fault loops (fault loops “AG Fault”, “BG Fault” or “CG Fault”) cannot provide correct fault distance estimates and the triggering of the function in case of an earth fault is automatically disabled. The situation is similar if only two phase-to-earth voltages are measured and the measured residual voltage is not connected to SCEFRFLO.

5.7.7 Application

The main objective of the feeder terminals is a fast, selective and reliable operation in faults inside the protected feeder. In addition, information on the distance to the fault point is very important for those involved in operation and maintenance. Reliable information on the fault location greatly decreases the downtime of the protected feeders and increases the total availability of a power system.

SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems and is applicable for locating short circuits in all kinds of distribution networks. Earth faults can be located in effectively earthed and low-resistance/low-reactance earthed networks. With certain limitations, SCEFRFLO can also be used for locating an earth fault in unearthed distribution networks.

Configuration example

A typical configuration example for SCEFRFLO triggering is illustrated in *Figure 691* where external triggering is applied, that is, *Calculation Trg mode* is set to “External”. The OPERATE signal from non-directional overcurrent function PHLPTOC is used to provide an indication of a short circuit fault. The OPERATE signal from the directional earth-fault function DEFLPDEF is used to provide an indication of an earth fault at the protected feeder.

SCEFRFLO with the autoreclosing function

When SCEFRFLO is used with the autoreclosing sequence, the distance estimate from the first trip is typically the most accurate one. The fault distance estimates from successive trips are possible but accuracy can be decreased due to inaccurate load compensation. During the dead time of an autoreclosing sequence, the load condition of the feeder is uncertain.

The triggering of SCEFRFLO can also be inhibited during the autoreclosing sequence. This is achieved by connecting the signal ACTIVE from the autoreclosing function DARREC, which indicates that the autoreclosing sequence is in progress, to the BLOCK input of SCEFRFLO. Blocking of the SCEFRFLO triggering is indicated during the autoreclosing sequence when the load compensation or steady-state asymmetry elimination is based on the delta quantities. This applies to the short circuit faults when *Load Com PP loops* is set to "Enabled" or, to earth faults, when *EF algorithm Sel* is set to "Load compensation" or "Load modelling".

5.7.8 Signals

5.7.8.1 SCEFRFLO Input signals

Table 1157: SCEFRFLO Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Signal for blocking the triggering
TRIGG_REC	BOOLEAN	0=False	Distance calculation triggering signal
TRIGG_XC0F	BOOLEAN	0=False	XC0F calculation triggering signal
TRIGG_T	BOOLEAN	0=False	Start calculation sequence for compensation network

5.7.8.2 SCEFRFLO Output signals

Table 1158: SCEFRFLO Output signals

Name	Type	Description
ALARM	BOOLEAN	Fault location alarm signal

5.7.9 SCEFRFLO Settings

Table 1159: SCEFRFLO Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Flt Loc Det mode	2=Non-comp 1=Comp, switched R			2=Non-comp	Fault location detection mode
Z Max phase load	1.0...10000.0	ohm	0.1	80.0	Impedance per phase of max. load, overcurr./under-imp., PSL
Ph leakage Ris	20...1000000	ohm	1	210000	Line PhE leakage resistance in primary ohms
Ph capacitive React	10...1000000	ohm	1	7000	Line PhE capacitive reactance in primary ohms
R1 line section A	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section A

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
X1 line section A	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line reactance, line section A
R0 line section A	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line resistance, line section A
X0 line section A	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line reactance, line section A
Line Len section A	0.000...1000.000	pu	0.001	0.000	Line length, section A

Table 1160: SCEFRFLO Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
High alarm Dis limit	0.000...1.000	pu	0.001	0.000	High alarm limit for calculated distance
Low alarm Dis limit	0.000...1.000	pu	0.001	0.000	Low alarm limit for calculated distance
Equivalent load Dis	0.00...1.00		0.01	0.50	Equivalent load distance when EF algorithm equals to load modelling
R1 line section B	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section B
X1 line section B	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line reactance, line section B
R0 line section B	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line resistance, line section B
X0 line section B	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line reactance, line section B
Line Len section B	0.000...1000.000	pu	0.001	0.000	Line length, section B
R1 line section C	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section C
X1 line section C	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line reactance, line section C
R0 line section C	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line resistance, line section C
X0 line section C	0.000...1000.000	ohm / pu	0.001	4.000	Zero sequence line reactance, line section C
Line Len section C	0.000...1000.000	pu	0.001	0.000	Line length, section C

Table 1161: SCEFRFLO Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Phase voltage Meas	1=Accurate 2=Ph-to-ph without Uo			1=Accurate	Phase voltage measurement principle
Calculation Trg mode	1=Internal 2=External			2=External	Trigger mode for distance calculation

Table 1162: SCEFRFLO Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
EF algorithm Sel	1=Load compensation 2=Load modelling			1=Load compensation	Selection for PhE-loop calculation algorithm
EF algorithm Cur Sel	1=Io based 2=I2 based			1=Io based	Selection for earth-fault current model
Load Com PP loops	0=Disabled 1=Enabled			1=Enabled	Enable load compensation for PP/3P-loops
Enable simple model	0=Disabled 1=Enabled			0=Disabled	Enable calc. without impedance settings for PP/3P-loops
Time delay	0...3000	ms	10	100	Time delay to start calculation in compensated networks
Zero Ris Curr change	0.005...1.000	xIn	0.001	0.010	Change in measured resistive component current due to fault
Distance estimate Va	0.001...0.300		0.001	0.015	Allowed variation of short circuit distance estimate

5.7.10 SCEFRFLO Monitored data

Table 1163: SCEFRFLO Monitored data

Name	Type	Values (Range)	Unit	Description
RF	FLOAT32	0.00...3000.00	ohm	Fault point resistance in primary ohms
FAULT_LOOP	Enum	1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault -5=No fault		Fault impedance loop
FLT_DISTANCE	FLOAT32	0.00...3000.00	pu	Fault distance in units selected by the user
FLT_DIST_Q	INT32	0...511		Fault distance quality
RFLOOP	FLOAT32	0.00...3000.00	ohm	Fault loop resistance in primary ohms
XFLOOP	FLOAT32	0.00...3000.00	ohm	Fault loop reactance in primary ohms
XFPHASE	FLOAT32	0.00...3000.00	ohm	Positive sequence fault reactance in primary ohms
IFLT_PER_ILD	FLOAT32	0.00...60000.00		Fault to load current ratio
S_CALC	FLOAT32	0.00...1.00		Estimated equivalent load distance
XC0F_CALC	FLOAT32	0.00...3000.00	ohm	Estimated PhE capacitive reactance of line
SCEFRFLO	Enum	1=on		Status

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		2=blocked 3=test 4=test/blocked 5=off		
Triggering time	Timestamp			Estimate triggering time
Flt loop	Enum	1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault -5=No fault		Fault loop
Flt distance	FLOAT32	0.00...3000.00	pu	Fault distance
Flt Dist quality	INT32	0...511		Fault distance quality
Flt loop resistance	FLOAT32	0.00...3000.00	ohm	Fault loop resistance
Flt loop reactance	FLOAT32	0.00...3000.00	ohm	Fault loop reactance
Flt phase reactance	FLOAT32	0.00...3000.00	ohm	Fault phase reactance
Flt point resistance	FLOAT32	0.00...3000.00	ohm	Fault resistance
Flt to Lod Cur ratio	FLOAT32	0.00...60000.00		Fault to load current ratio
Equivalent load Dis	FLOAT32	0.00...1.00		Estimated equivalent load distance
XC0F Calc	FLOAT32	0.00...3000.00	ohm	Estimated PhE capacitive reactance of the line
Pre fault time	Timestamp			Pre-fault time
A Pre Flt Phs A Magn	FLOAT32	0.00...40.00	xIn	Pre-fault current phase A, magnitude
A Pre Flt Phs A Angl	FLOAT32	-180.00...180.00	deg	Pre-fault current phase A, angle
A Pre Flt Phs B Magn	FLOAT32	0.00...40.00	xIn	Pre-fault current phase B, magnitude
A Pre Flt Phs B Angl	FLOAT32	-180.00...180.00	deg	Pre-fault current phase B, angle
A Pre Flt Phs C Magn	FLOAT32	0.00...40.00	xIn	Pre-fault current phase C, magnitude
A Pre Flt Phs C Angl	FLOAT32	-180.00...180.00	deg	Pre-fault current phase C, angle
V Pre Flt Phs A Magn	FLOAT32	0.00...40.00	xUn	Pre-fault voltage phase A, magnitude
V Pre Flt Phs A Angl	FLOAT32	-180.00...180.00	deg	Pre-fault voltage phase A, angle
V Pre Flt Phs B Magn	FLOAT32	0.00...40.00	xUn	Pre-fault voltage phase B, magnitude
V Pre Flt Phs B Angl	FLOAT32	-180.00...180.00	deg	Pre-fault voltage phase B, angle
V Pre Flt Phs C Magn	FLOAT32	0.00...40.00	xUn	Pre-fault voltage phase C, magnitude
V Pre Flt Phs C Angl	FLOAT32	-180.00...180.00	deg	Pre-fault voltage phase C, angle
A Flt Phs A Magn	FLOAT32	0.00...40.00	xIn	Fault current phase A, magnitude
A Flt Phs A angle	FLOAT32	-180.00...180.00	deg	Fault current phase A, angle

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
A Flt Phs B Magn	FLOAT32	0.00...40.00	xIn	Fault current phase B, magnitude
A Flt Phs B angle	FLOAT32	-180.00...180.00	deg	Fault current phase B, angle
A Flt Phs C Magn	FLOAT32	0.00...40.00	xIn	Fault current phase C, magnitude
A Flt Phs C angle	FLOAT32	-180.00...180.00	deg	Fault current phase C, angle
V Flt Phs A Magn	FLOAT32	0.00...40.00	xUn	Fault voltage phase A, magnitude
V Flt Phs A angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase A, angle
V Flt Phs B Magn	FLOAT32	0.00...40.00	xUn	Fault voltage phase B, magnitude
V Flt Phs B angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase B, angle
V Flt Phs C Magn	FLOAT32	0.00...40.00	xUn	Fault voltage phase C, magnitude
V Flt Phs C angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase C, angle

5.7.11 Technical data

Table 1164: SCEFRFLO Technical data

Characteristic	Value
Measurement accuracy	At the frequency $f = f_n$ Impedance: ±2.5 % or ±0.25 Ω Distance: ±2.5 % or ±0.16 km/0.1 mile XC0F_CALC: ±2.5 % or ±50 Ω IFLT_PER_ILD: ±5 % or ±0.05

5.8 Switch-onto-fault protection CVPSOF (ANSI SOTF)

5.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Switch-onto-fault protection	CVPSOF	CVPSOF	SOTF

5.8.2 Function block

Figure 696: Function block

5.8.3 Functionality

The switch-onto-fault function CVPSOF is a complementary function, especially to the distance protection function (DSTPDIS), but it can also be used to complement the non-directional or directional overcurrent protection functions (PHxPTOC, DPHxPDOC).

CVPSOF accelerates the operation of the protection ensuring a fast trip when the breaker is closed onto faulted feeder or bus. Without CVPSOF the measured voltages may be too small for the impedance zones or the directional overcurrent stages to operate reliably. This condition exists when the voltage transformers are located in the feeder or the bus side to be energized and therefore the voltage memory required for a correct directional measurement is not available.

5.8.4 Analog channel configuration

CVPSOF has two analog group inputs which must be properly configured.

Table 1165: Analog inputs

Input	Description
I3P [1]	Three-phase currents, necessary when Operation mode is other than "Start"
U3P [2]	Three-phase voltages, necessary when Operation mode is other than "Start

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

1 Can be connected to GRPOFF if *Operation mode* is set to "Start" and *Automatic SOTF Ini* is set to "DLD disabled" or "Voltage"

2 Can be connected to GRPOFF if *Operation mode* is set to "Start" and *Automatic SOTF Ini* is set to "DLD disabled" or "Current"

Table 1166: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.8.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CVPSOF can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

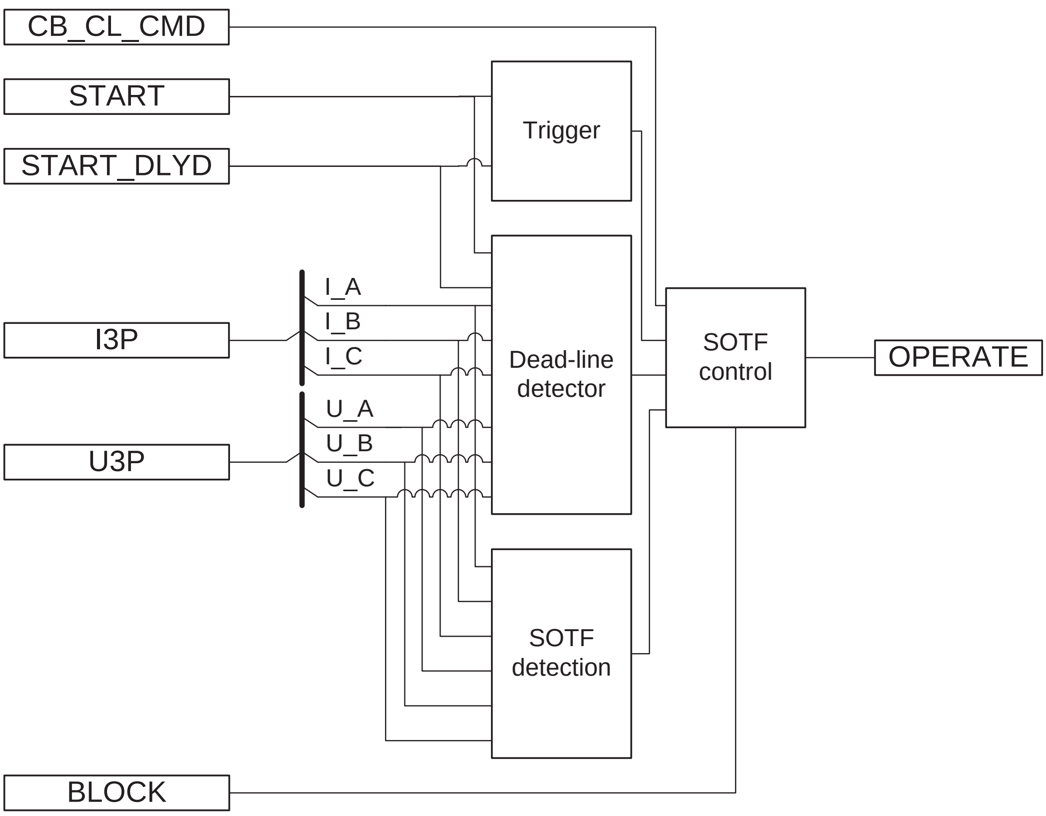


Figure 697: Functional module diagram

Trigger

This module is used for detecting a possible fault immediately after circuit breaker closing. The use of external protection function, typically the start signal from a non-directional distance zone or overcurrent stage, is required for fault indication. The START and START_DLYD inputs are available for the purpose.

- The START input has no delay. Thus, a switch-onto-fault situation is immediately signalled to SOTF control.
- START_DLYD is used when an additional delay is required to start the signal. The switch-onto-fault situation is signalled to the SOTF control after the set *Operate delay time*.

Dead-line detector

The dead line detection should be used only when the voltage transformers are located on the line side of the circuit breaker.

The *Automatic SOTF Ini* setting is used to configure the internal dead line detection function.

Table 1167: Options for dead line detection

Automatic SOTF Ini	Description
DLD disabled	The dead line detection function is disabled. This operation mode must be applied when voltage transformers are located on the bus side of the circuit breaker.
Voltage	The dead line detection function is enabled and based solely on the undervoltage condition. A dead line condition is declared, if all the phase voltages are below the *Voltage dead Lin Val* setting. The dead line is detected if the dead line condition is declared and simultaneously no fault is detected by the START and START_DLYD inputs . The dead line condition is signalled to the SOTF control after the delay defined with the *Dead line time* setting.
Current	The dead line detection function is enabled and based solely on the undercurrent condition. A dead line condition is declared, if all the phase currents are below the *Current dead Lin Val* setting. The dead line is detected if the dead line condition is declared and simultaneously no fault is detected by the START and START_DLYD inputs. The dead line condition is signalled to the SOTF control after delay defined with the *Dead line time* setting.
Current & Voltage	The dead line detection function is enabled and based on undercurrent and undervoltage condition. A dead line condition is declared, if all the phase currents are below the *Current dead Lin Val* setting and simultaneously all phase voltages are below the *Voltage dead Lin Val* setting. The dead line is detected if the dead line condition is declared and simultaneously no fault is detected by the START and START_DLYD inputs. The dead line condition is signalled to the SOTF control after delay defined with the *Dead line time* setting.

SOTF detection

The purpose of this module is to detect the switch onto fault situation based on the current and voltage measurements. If the voltage, in any of the phases, is below the *Voltage dead Lin Val* setting and simultaneously the current in the same phase exceeds the *Current dead Lin Val* setting, the SOTF situation is signalled to SOTF control module after the set *Cur voltage Det time*.

SOTF control

The SOTF control module needs to be activated before the operation is possible in the switch-onto-fault situation. There are two ways to activate the SOTF control module.

- By CB_CL_CMD (circuit breaker closing command).
- By the dead line condition received from the dead line detection module.

Dead line detection should be used only when the voltage transformers are located on the line side of the circuit breaker.

When the CB_CL_CMD input is activated or the dead line condition is detected, the SOTF control module becomes active. The reset timer is started when CB_CL_CMD is inactivated or the dead line condition disappears. Thus, the module becomes inactive after the set *SOTF reset time* is exceeded.

When the SOTF control module is active, the *Operation mode* setting defines the operation criteria for the detection of a switch-onto-fault condition. The detection can be based on the external start signals from the distance or overcurrent functions, on the measured internal voltage and current levels, or on both.

Table 1168: Options for SOTF detection

Operation mode	Description
Start	The OPERATE output is activated immediately after a signal from the trigger module. This indicates that the breaker is closed onto fault.
Current & Voltage	The OPERATE output is activated immediately after a signal from the SOTF detection module. This indicates that the breaker is closed onto fault. This operation mode can be used, for example, if the non-directional distance zone is not available.
Both	The OPERATE output is activated immediately after a signal from the trigger or SOTF detection modules. This indicates that the breaker is closed onto fault.

The OPERATE output can be blocked by activating the BLOCK input.

5.8.6 Application

The operation of CVPSOF is generally based on the non-directional distance zone or the non-directional overcurrent stage. When the feeder-side voltage transformers are used for providing the polarization quantity for the distance or directional overcurrent protection, the use of non-directional impedance or current based protection for starting CVPSOF secures a fast switch-onto-fault tripping in the close-in three-phase short circuits. The non-directional protection provides a fast fault clearance when the protection is used for energizing a bus from the feeder with a short circuit fault in it. Other protection functions, like time delayed zero-sequence overcurrent functions, can be connected to CVPSOF to increase the dependability of the scheme. The other main advantage of using CVPSOF is that it typically accelerates the tripping in case of energizing a feeder onto a fault. Without CVPSOF, this tripping is normally performed by the normal time-graded protection or alternatively by the time-delayed local backup protection, for which operating times are considerably longer than with CVPSOF tripping.

An internal dead line detection check is provided to activate the function when the voltage transformers are located on the feeder side. An initiation by the dead line detection is highly recommended for the busbar configurations where more than one circuit breaker at one feeder end can energize the protected feeder or the feeder can also be energized from the other end.

Setting guidelines

Input `START`: If a distance zone is used for starting the switch-onto-fault function, the zone has to be set to cover the entire protected feeder with a safety margin of minimum 20 percent. If the non-directional zone is not available, the internal *Current & Voltage* criterion or the start signal from the GFC function can be used instead. If a non-directional overcurrent is used for starting, the current setting must not be higher than what is required for the non-delayed and dependable tripping for a close-in three-phase fault during minimum source conditions. If the short-circuit current along the feeder is considerably higher than the maximum load currents, it is possible that the whole feeder length is covered by CVPSOF tripping. If it is required to delay the tripping, for example, due to high inrush currents, the starting signal can be connected to the `START_DLYD` input instead.

The *Current dead Lin Val* setting parameter is set to 20 percent of the base current by default. The parameter must be set with a sufficient margin of 15...20 percent under the minimum expected load current. The setting must still exceed the maximum charging current of a feeder.

The *Voltage dead Lin Val* setting parameter is set to 70 percent of the base voltage by default. This is a suitable setting in most cases, but it is recommended to check the suitability in the actual application.

The *Cur voltage Det time* setting parameter is set to 0.02 seconds by default. This is suitable in most applications. This delay can be coordinated, for example, with the dead time settings of the AR shots to prevent the release of CVPSOF by the dead line detection function when the high-speed autoreclosing is in progress.

The *Dead line time* setting parameter is set to 0.2 seconds by default. This is suitable in most applications. The delay must not be set too short to avoid unwanted activations during the transients in the system.

The *SOTF reset time* setting parameter is set to 1 second by default. This is suitable for most applications.

5.8.7 Signals

5.8.7.1 CVPSOF Input signals

Table 1169: CVPSOF Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
CB_CL_CMD	BOOLEAN	0=False	External enabling of SOTF by CB close command
START	BOOLEAN	0=False	Start from function to be accelerated by SOTF
START_DLYD	BOOLEAN	0=False	Start from function to be accelerated with delay by SOTF

5.8.7.2 CVPSOF Output signals

Table 1170: CVPSOF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate

5.8.8 CVPSOF Settings

Table 1171: CVPSOF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 1172: CVPSOF Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Start 2=Current&voltage 3=Both			3=Both	Mode of operation of SOTF Function
SOTF initialization	1=SwitchCommand -2=Voltage or SwitchCmd -3=Current or SwitchCmd -4=Cur&Vol or SwitchCmd			-2=Voltage or SwitchCmd	Switch onto fault initialization

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Current dead Lin Val	0.01...1.00	xIn	0.01	0.20	Dead line value, current. Used also in auto activation logic
Voltage dead Lin Val	0.01...0.58	xUn	0.01	0.40	Dead line value, voltage. Used also in auto activation logic
Cur voltage Det time	0...60000	ms	10	20	Time delay for voltage and current based detection
Operate time delay	0...120000	ms	10	20	Delay for the delayed start input
SOTF reset time	0...60000	ms	10	1000	SOTF detection period after initialization
Dead line time	0...60000	ms	10	200	Delay time for activation of dead line detection

5.8.9 CVPSOF Monitored data

Table 1173: CVPSOF Monitored data

Name	Type	Values (Range)	Unit	Description
CVPSOF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.8.10 Technical data

Table 1174: CVPSOF Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2Hz
	Current: ±1.5 % of the set value or ±0.002 × I_n Voltage: ±1.5 % of the set value or ±0.002 × U_n
Operate time accuracy	±1.0 % of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

5.9 Local acceleration logic DSTPLAL (ANSI 21LAL)

5.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Local acceleration logic	DSTPLAL	LAL	21LAL

5.9.2 Function block

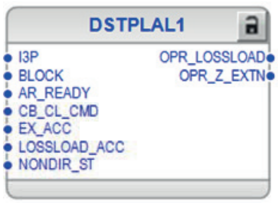


Figure 698: Function block

5.9.3 Functionality

The local acceleration logic function DSTPLAL is a complementary function to the distance protection function DSTPDIS. DSTPLAL is not intended for a stand-alone use.

The main purpose of DSTPLAL is to achieve a fast fault clearing which is independent of the fault location on the protected feeder when no communication channel is available between the local and remote terminals. DSTPLAL enables a fast fault clearing during certain conditions, but the function cannot completely replace the communication scheme logic.

DSTPLAL can be controlled either by the autorecloser (zone extension logic) or by monitoring the loss of load currents (the loss of load logic). Both operation modes are enabled independently.

5.9.4 Analog channel configuration

DSTPLAL has one analog group input which must be properly configured.

Table 1175: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.9.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of DSTPLAL can be described with a module diagram. All the modules in the diagram are explained in the next sections.

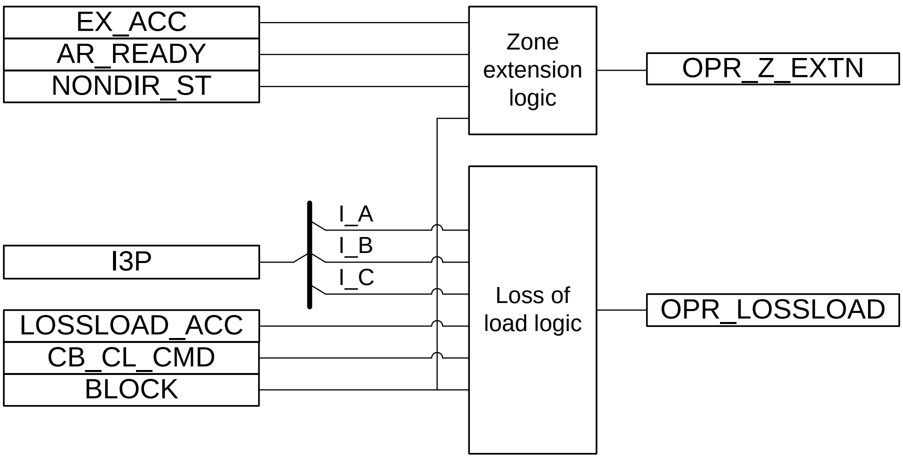


Figure 699: Functional module diagram

Zone extension logic

Zone extension logic is enabled with *Operation mode* = "Zone extension".

When the zone extension operation mode is enabled, the autoreclosing function DARREC enables a fast fault clearance that covers the entire length of the protected feeder. This is achieved by allowing a time-delayed overreaching zone to trip instantaneously when a fault occurs. For this purpose, one of the DSTPDIS zones can be configured with an independently set reach.

After the overreaching zone instantaneously trips, the autoreclosing sequence starts. If the fault is transient, the system may get restored in the first shot of AR. However, in case of a persistent fault only the first trip of the AR sequence is accelerated by Zone extension logic. During the rest of the sequence, Zone extension logic is blocked and AR initiation is performed selectively by the time-graded distance zones.

If the fault is located on the adjacent feeder or bus within the reach of the overreaching zone, tripping and AR initiation take place in an external fault.

Zone extension logic can be described using a module diagram.

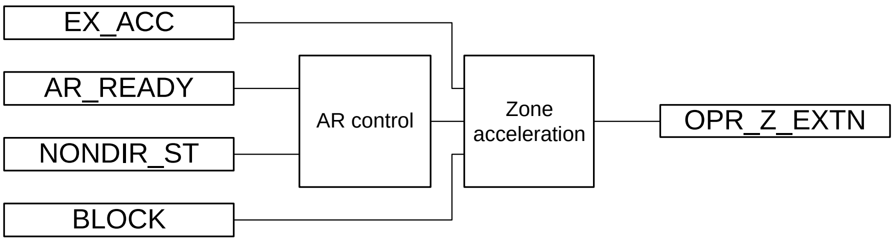


Figure 700: Functional module diagram of Zone extension logic

AR control

The AR control module supervises the zone acceleration by monitoring the status of the AR_READY and NONDIR_ST input signals. The READY output signal from the autorecloser (AR) function, which indicates the status of the autoreclosing, is connected to the AR_READY input. The start signal from the non-directional zone is connected to the NONDIR_ST input. If the non-directional zone is not available for this, then the start output from the overreaching zone with the biggest reach or GFC can be used instead.

The permission for zone acceleration is given if AR_READY = TRUE, that is, the AR function is ready to start a new AR sequence. If the set reclaim time of the AR function expires before the fault is cleared, the NONDIR_ST input signal is used to block the activation of the zone acceleration. This ensures that the accelerated trip followed by the AR initiation is not repeated for the same fault regardless of the reclaim time setting and the reach of the overreaching zone connected to the EX_ACC input. Otherwise, this could lead to pumping of the circuit breaker, that is, the repetition of the first shot without being able to complete the desired AR sequence.

The AR control module blocks the Zone acceleration module after the initiation of the first shot until the AR sequence has been completed, that is, until the AR_READY input signal changes its state back from FALSE to TRUE.

Zone acceleration

The start signal from the overreaching zone whose operation is to be accelerated is connected to the EX_ACC input. When the EX_ACC input is activated and, simultaneously, the AR control module gives permission for acceleration, the operate signal from Zone extension logic is obtained from the OPR_Z_EXTN output, which is used to trip the circuit breaker and initiate the autoreclosing (the AR shot).

The activation of the BLOCK input blocks the OPR_Z_EXTN output.

Loss of load logic

Loss of load logic is enabled with *Operation mode* = "Loss of load".

When the loss of load operation mode is enabled, a time-delayed overreaching zone is allowed to trip instantaneously if the loss of load current condition is detected.

The loss of load function does not operate in case of a three-phase fault as all the phases are faulty. Therefore, none of the current values drops below the *Minimum current* setting, meaning that the loss of load current condition cannot be detected.

Loss of load logic can be described using a module diagram.

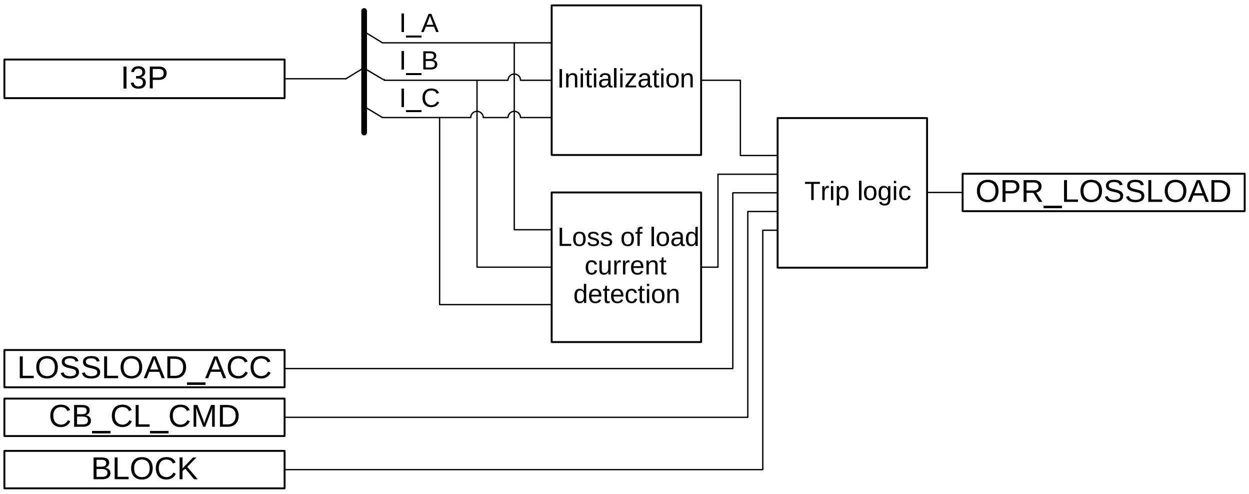


Figure 701: Functional module diagram of Loss of load logic

Initialization

The Initialization module gives an enabling signal to the Trip logic module when the values of all three phase currents are above the set value of *Load current value* for more than the time set with *Load release on time*. The enabling signal has a drop-off delay defined with the *Load release off Tm* setting.

Loss of load current detection

The Loss of load current detection module gives an enabling signal to the Trip logic module if any of the phase current values drops below the *Minimum current* setting due to a remote end breaker opening and, simultaneously, the value of at least one phase current exceeds the value of the *Load current value* setting due to a fault. Such a condition has to be valid for longer than the *Minimum current time* setting.

Trip logic

The operate signal is obtained from the OPR_LOSSLOAD output if the enable signal is received from both Initialization and Loss of load current detection modules and, simultaneously, a fault is seen by the overreaching zone connected to the LOSSLOAD_ACC input.

The activation of the `BLOCK` input blocks the `OPR_LOSSLOAD` output. Temporary blocking is achieved using the circuit breaker's close command pulse connected to the `CB_CL_CMD` input. It is used to prevent an unwanted operation due to initial transients after the breaker is closed, for example, in case of inrush currents.

5.9.6 Application

DSTPLAL is used in those applications where the conventional communication scheme logic cannot be applied (when no communication channel is available), but the user still requires a fast clearance for the faults on the entire feeder.

DSTPLAL enables a fast fault clearing during certain conditions, but it is unable to replace the communication scheme logic due to a possible lack of selectivity during the first trip and AR initiation and also as the loss of load logic cannot operate for three-phase faults. DSTPLAL is controlled either by the autoreclosing (Zone extension logic) or by monitoring the loss of load current (Loss of load logic).

Zone extension logic

The zone extension operation mode can be applied when the autoreclosing function DARREC is in operation. When the zone extension is enabled, DARREC is used to enable the fast fault clearance independent of the fault location on the protected feeder. This is achieved by allowing a time-delayed overreaching zone to trip instantly when a fault occurs. Also, if there are tapped loads on the protected feeder, it is required to set a dedicated zone to initiate one or two shots as fast as possible before the protection devices of these taps clear. If the fault is still present after these shots, further tripping is delayed in accordance with the other zones so that the operation becomes slower than the protection of the load taps, enabling it to clear. The final tripping that ends the sequence is always performed selectively according to the time grading of the zones.

If the fault is located on the adjacent feeder or bus within the reach of the overreaching zone, the tripping and the AR initiation take place during an external fault.

Setting guidelines

The *Load current value* setting must be set below the minimum three-phase load current during the healthy state. A security factor of 0.5 is used:

Load current value = $0.5 \cdot I_{minload}$

$I_{minload}$ minimum load current during normal operation conditions

The loss of load function is released after *Load release on time* is elapsed and the load current in all three phases is above the *Load current value* setting. If the current values drop below the *Load current value* setting, the release condition stays activated until the drop-out delay time has expired (the *Load release off Tm* setting). The value of *Load release off Tm* is by default set to "0.3 s". The *Load release on time* setting is used to increase the security of the loss of load function, for example, in the case of transient inrush currents during the energizing of a power transformer. When there is no need for delaying the release, the *Load release on time* is set to zero in applications.

The *Minimum current* setting is used to detect the loss of load condition in healthy phases during the fault. The *Minimum current* setting is set to a value higher than the maximum current flowing in the healthy phases during the fault when the breaker at the remote end has been opened and the load flowing through has therefore been disconnected. This current can be, for example, due to the charging current of the phases or the load current of the tapped loads. The *Minimum current* setting value is set below the *Load current value* setting. By default, the *Minimum current* setting value is set to "0.05 pu".

The *Minimum current time* setting is used to provide the start delay for the loss of load current detection to avoid an unwanted release of the function. The value of *Minimum current time* is by default set to "0.2 s".

5.9.7 Signals

5.9.7.1 DSTPLAL Input signals

Table 1176: DSTPLAL Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
AR_READY	BOOLEAN	0=False	Autoreclosure ready, releases function used for fast trip
CB_CL_CMD	BOOLEAN	0=False	CB close command
EX_ACC	BOOLEAN	0=False	Connected to function used for tripping at zone extension
LOSSLOAD_ACC	BOOLEAN	0=False	Connected to function used for tripping at loss of load
NONDIR_ST	BOOLEAN	0=False	Non directional criteria used to prevent instantaneous trip

5.9.7.2 DSTPLAL Output signals

Table 1177: DSTPLAL Output signals

Name	Type	Description
OPR_LOSSLOAD	BOOLEAN	Operate by loss of load
OPR_Z_EXTN	BOOLEAN	Operate by zone extension

5.9.8 DSTPLAL Settings

Table 1178: DSTPLAL Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Load current value	0.01...1.00	xIn	0.01	0.10	Load current before disturbance
Minimum current	0.01...1.00	xIn	0.01	0.05	Level taken as current loss due to remote CB trip
Load release off Tm	0...60000	ms	10	300	Time delay on drop off for load current release
Minimum current time	0...60000	ms	10	200	Time delay on pick-up for Minimum current value
Operation mode	1=Zone extension 2=Loss of load 3=Both			3=Both	Operation mode
Load release on time	0...60000	ms	10	0	Time delay on pick-up for load current release

5.9.9 DSTPLAL Monitored data

Table 1179: DSTPLAL Monitored data

Name	Type	Values (Range)	Unit	Description
DSTPLAL	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.9.10 Technical data

Table 1180: DSTPLAL Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±1.5 % of the set value or $\pm 0.002 \times I_n$
Operate time accuracy	±1.0 % of the set value or ±20 ms
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,…

5.10 Scheme communication logic DSOCPSCH (ANSI 85 21SCHLGC)

5.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Scheme communication logic	DSOCPSCH	CL	85 21SCHLGC

5.10.2 Function block

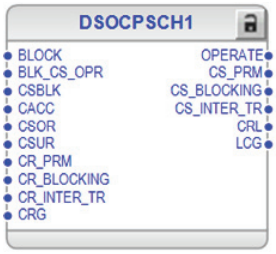


Figure 702: Function block

5.10.3 Functionality

The scheme communication logic function DSOCPSCH is used to achieve instantaneous fault clearing independent of the fault location on the protected feeder. Several communication scheme types are available.

- Direct underreaching transfer trip DUTT
- Permissive underreaching transfer trip PUTT
- Permissive overreaching transfer trip POTT
- Directional comparison blocking scheme DCB

The directional comparison unblocking scheme DCUB can also be implemented by complementing the permissive schemes with an additional logic called the unblocking function, which is also included in DSOCPSCH.

If the permissive overreach scheme is used, some of the power system conditions require additional special logic circuits, such as the current reversal and weak-end infeed logic function CRWPSCH.

5.10.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of DSOCPSCH can be described with a module diagram. All the modules in the diagram are explained in the next sections.

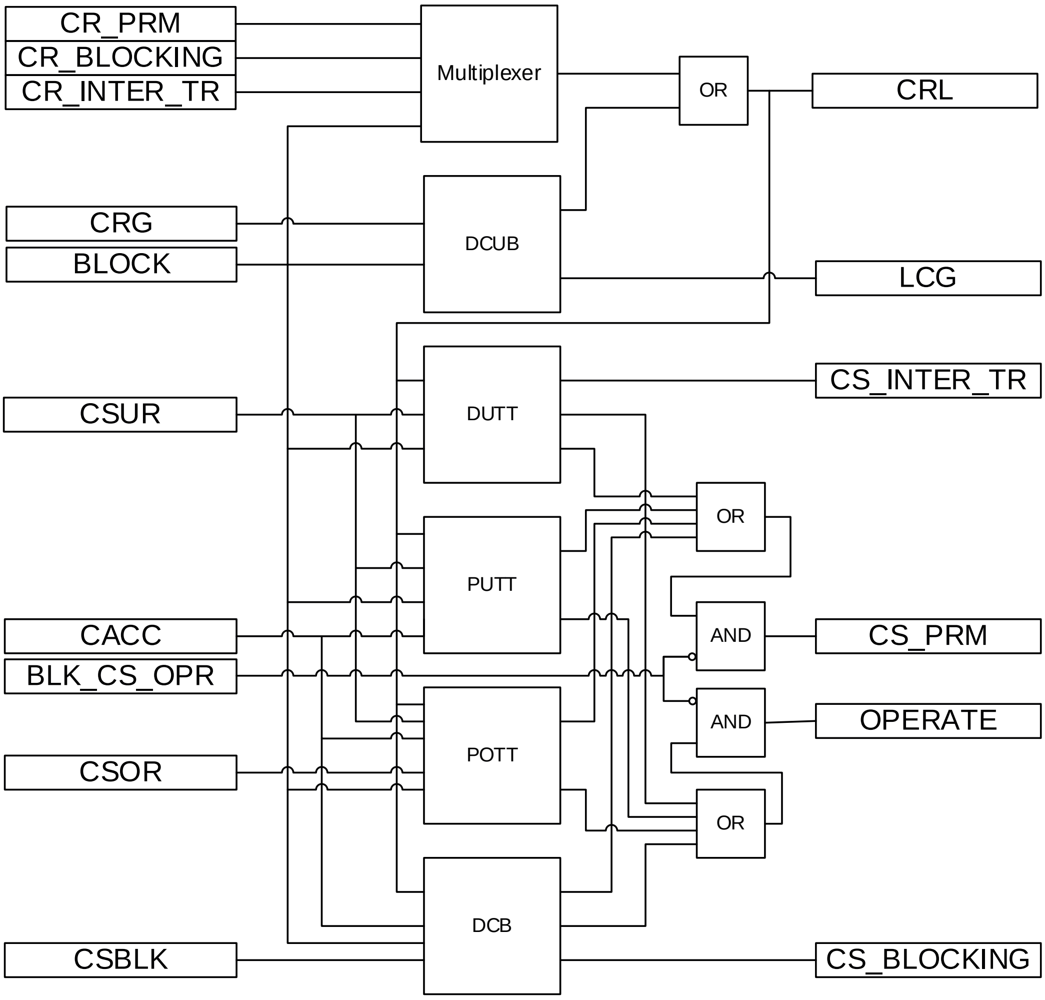


Figure 703: Functional module diagram

The applied communication scheme logic in DSOCPSCH is selected with the *Scheme type* setting.

Table 1181: Communication scheme based on the Scheme type value

Scheme type **value**	**Communication scheme**
"Intertrip"	DUTT
"Permissive Underreach"	PUTT
"Permissive Overreach"	POTT
"Blocking"	DCB

The unblocking scheme (DCUB) is enabled with the *Unblock Mode* setting.

Multiplexer

The multiplexer connects an input signal to an output based on the value of the *Scheme type* setting.

Table 1182: Connected inputs based on the Scheme type value

Scheme type value	Inputs connected to an output
"Intertrip"	CR_INTER_TR
"Permissive Underreach" or "Permissive Over-reach"	CR_PRM
"Blocking"	CR_BLOCKING

Direct underreaching transfer trip scheme DUTT

The direct intertrip scheme is enabled with *Scheme type* = "Intertrip".

In the direct intertrip scheme, the start signal from the underreaching zone Z1 is connected to the CSUR input to create a carrier send CS_INTER_TR signal. The duration of the CSUR input signal is prolonged by the *Carrier Min Dur* setting to ensure a sufficient duration for the CS_INTER_TR signal.

The local circuit breaker is directly tripped (activation of the OPERATE output) with the carrier received CS_INTER_TR signal after a settable pick-up delay *Coordination Time* has elapsed without further local criteria.

The unblocking function (*Unblock Mode* = "Permanent" and *Unblock Mode* = "Time window") must not be enabled with the DUTT scheme, as the lost guard signal results in an immediate trip of the local circuit breaker.

The activation of the BLOCK input totally blocks the direct intertrip scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

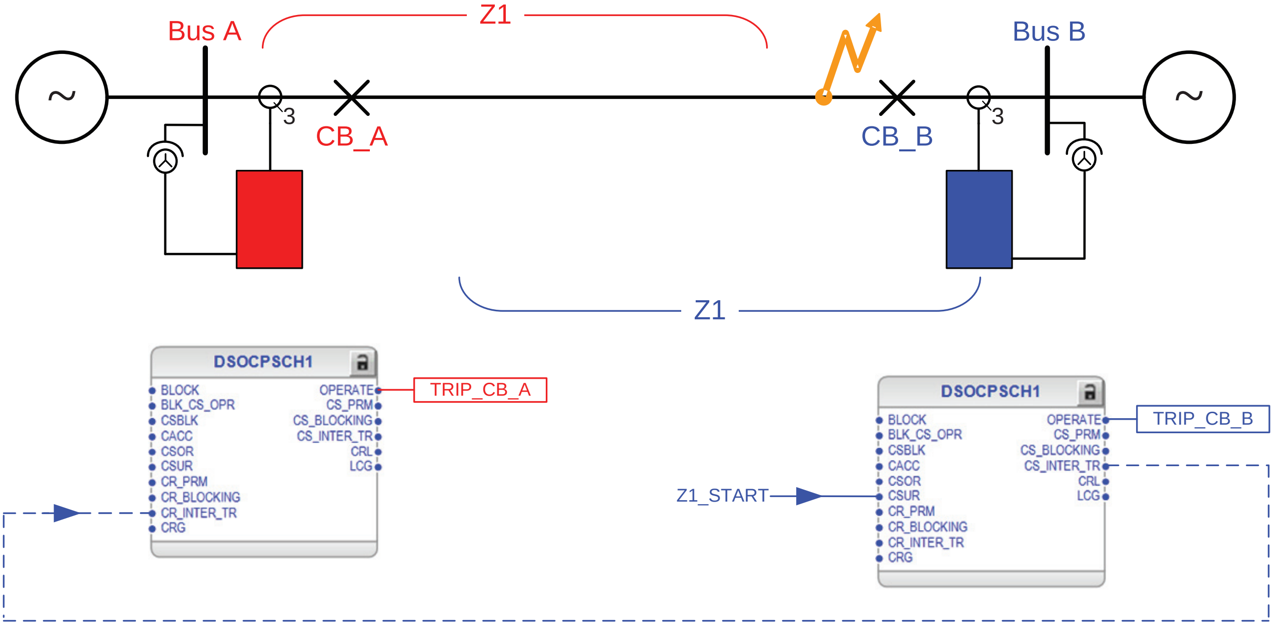


Figure 704: Simplified functional diagram of the direct intertrip scheme

Permissive underreaching transfer trip scheme PUTT

The permissive underreach scheme is enabled with *Scheme type* = "Permissive Underreach".

In the permissive underreach scheme, the start signal from the underreaching zone Z1 is connected to the CSUR input to create a CS_PRM signal. The duration of the CSUR input signal can be prolonged by the *Carrier Min Dur* setting to ensure a sufficient duration of the CS_PRM signal.

In the permissive underreach scheme, the CS_PRM signal, or the CRL signal if the unblocking function is enabled, is used to allow the overreaching zone Z2 to trip (activation of the OPERATE output) after the pick-up delay *Coordination Time*. The start signal from the overreaching zone Z2 is connected to the CACC input.

Activating the BLOCK input totally blocks the permissive underreach scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

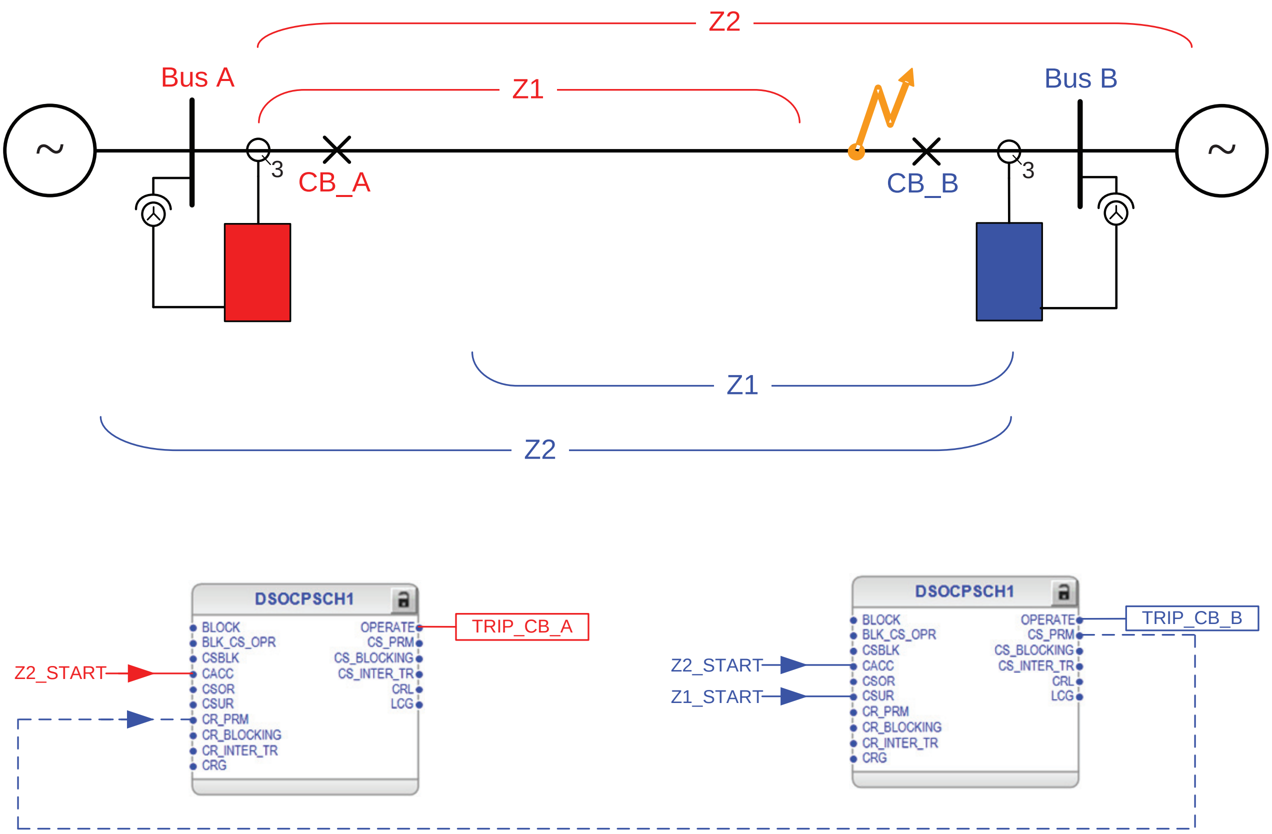


Figure 705: Simplified functional diagram of the permissive underreach scheme

Permissive overrreaching transfer trip scheme POTT

The permissive overreach scheme is enabled with *Scheme type* = "Permissive Overreach".

In this scheme, the start signal from the overreaching zone Z2 is connected to the CSOR input to create a CS_PRM signal. The CS_PRM signal can also be issued simultaneously from the underreaching zone Z1. In this case, the start signal from the underreaching zone Z1 is connected to the CSUR input. The duration of the CSUR input signal is prolonged by the *Carrier Min Dur* setting to ensure a sufficient duration of the CS_PRM signal.

In case of parallel feeders, and when the external current reversal logic (CRWPSCH) is enabled, the CS_PRM signal is not prolonged and the value of *Carrier Min Dur* is set to zero to secure correct operation.

In the permissive overreach scheme, the received signal CR_PRM, or CRL if the unblocking function is enabled, is used to allow the overreaching zone Z2 to trip (activation of the OPERATE output) after the settable pick-up delay *Coordination Time*. The start signal from the overreaching zone is connected to the CACC input.

Activating the BLOCK input totally blocks the permissive overreach scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

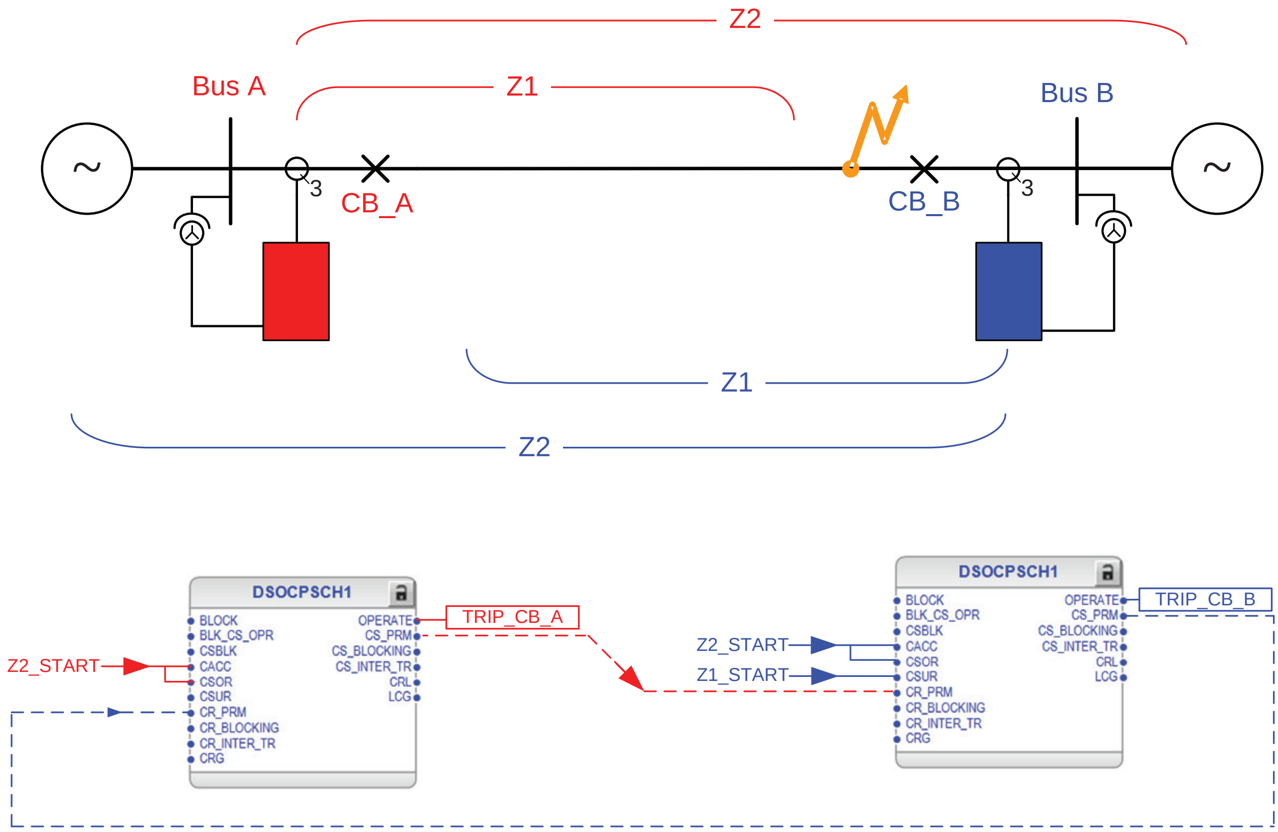


Figure 706: Simplified functional diagram of the permissive overreach scheme

Directional comparison blocking scheme DCB

The directional comparison blocking scheme is enabled with *Scheme type* = "Blocking".

In the blocking scheme, the start signal from the reverse-looking zone Z3 is connected to the CSBLK input to create a CS_BLOCKING signal. The starting of the reverselooking zone indicates that the fault is located outside the protected feeder. The duration of the CSBLK input signal can be prolonged with the *Carrier Min Dur* setting to ensure a sufficient duration of the CS_BLOCKING signal.

The blocking scheme is mainly used to allow the overreaching zone Z2 to trip (activation of the OPERATE output) after the settable *Coordination Time* has elapsed, and if no blocking signal is received from the remote terminal. To prevent a false trip in case of an external fault, the block signal CR_BLOCKING must be received before the *Coordination Time* has elapsed. The start signal from the overreaching zone Z2 is connected to the CACC input.

The *Coordination Time* setting in the blocking scheme depends, for example, on the communication system delay and on the terminal's response times in transmitting the `CS_BLOCKING` signal to the other feeder end. The *Coordination Time* setting must not be zero.

Activating the `BLOCK` input totally blocks the directional comparison blocking scheme. The `CS_PRM` and `OPERATE` outputs can be blocked by the `BLK_CS_OPR` input.

In *Figure 707*, in case of internal faults, the `CS_BLOCKING` signal is not sent because the fault is not sent as it is not seen by the reverse-looking zones (Z3).

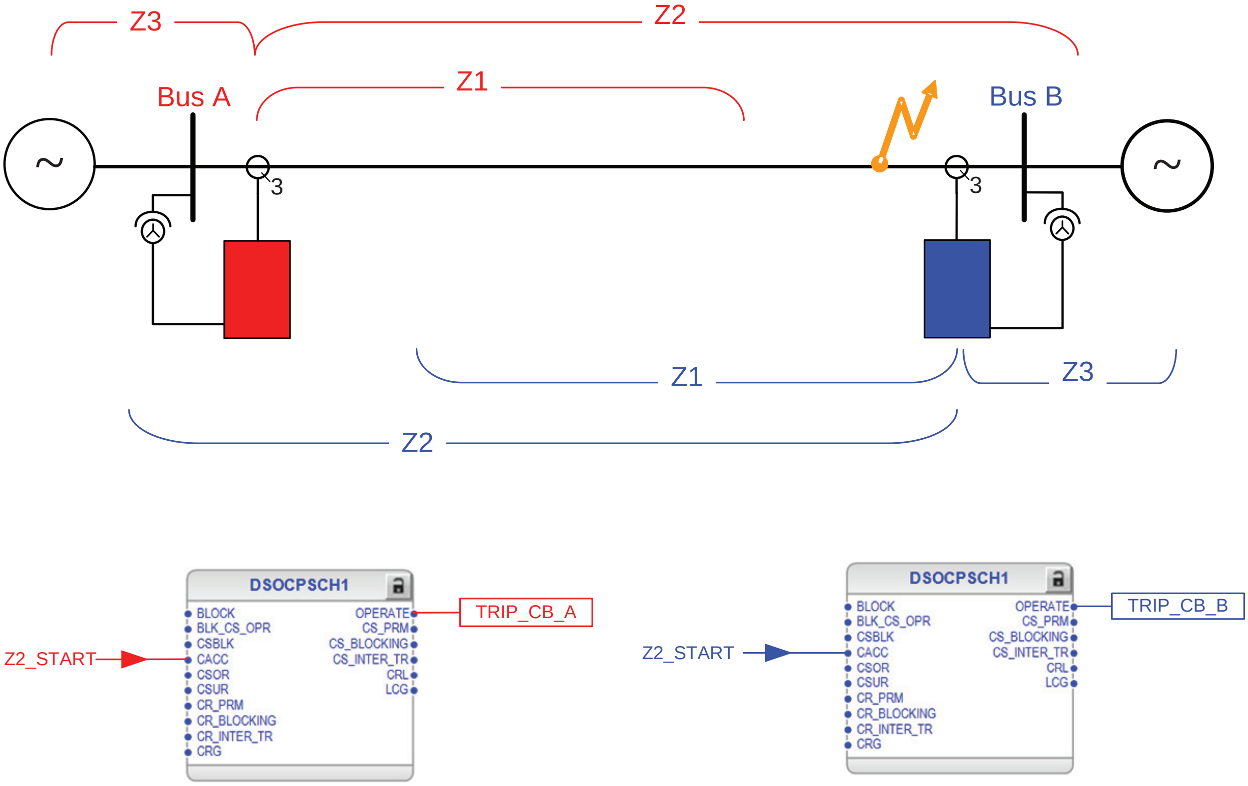


Figure 707: Simplified functional diagram of the blocking scheme, internal fault

In *Figure 708*, in case of external faults, the protection relay at bus B sees the fault in the reverse direction and sends a blocking signal `CS_BLOCKING` to the protection relay at bus A. There is no CB operation at either end.

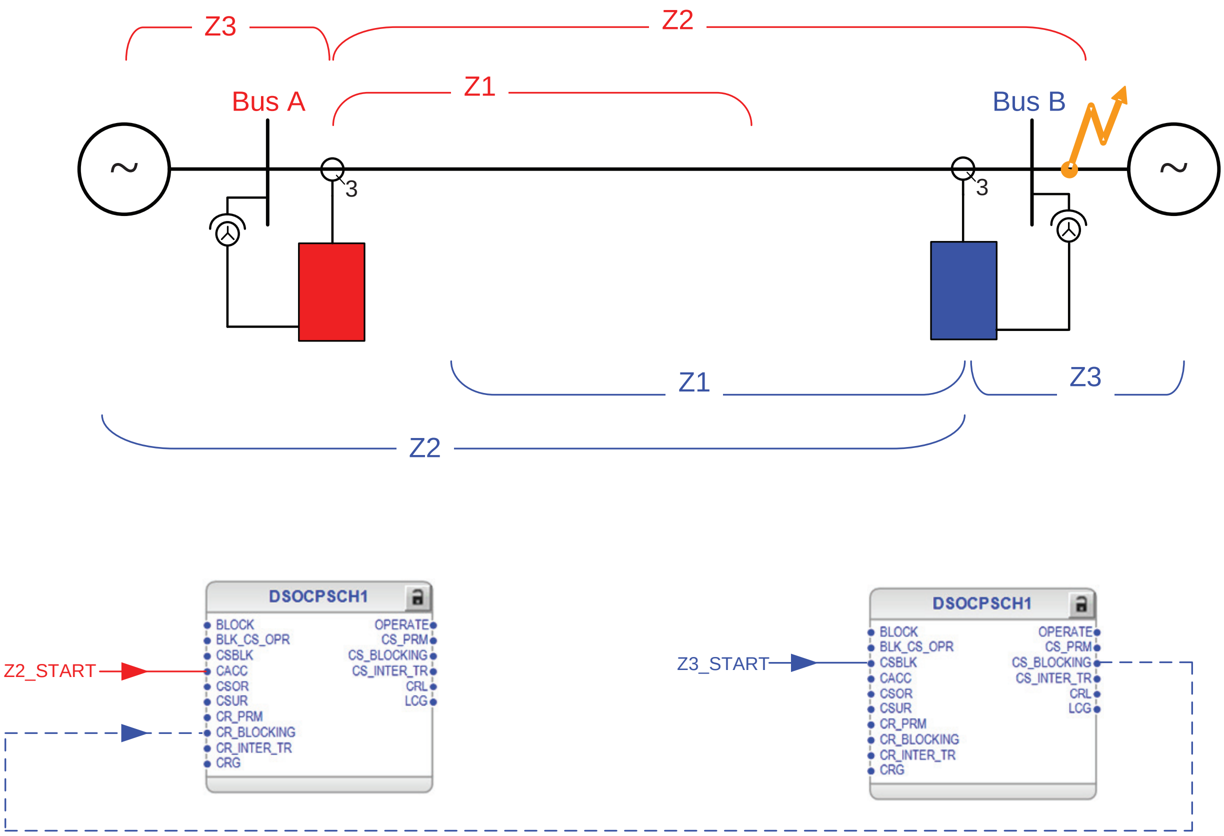


Figure 708: Simplified functional diagram of the blocking scheme, external fault

The unblocking function used with the blocking function provides a possibility to supervise the communication channel. In this case, the CRL output signal is used as a local blocking signal.

The operation mode *Unblock Mode* = "Time window" is not recommended as the blocking is activated only for 150 ms after the guard signal disappears. This results in an unwanted operation of the protection.

Directional comparison unblocking scheme DCUB

The unblocking function is a complementary logic which can be used together with the permissive communication schemes. In the unblocking scheme, the dependability of the permissive schemes is improved by using the loss of guard signal from the communication equipment to create a CRL output signal locally. This enables the permissive scheme to operate even if the communication channel is interrupted or lost.

The unblocking function uses a carrier guard signal which must always be present. The absence of the CRG signal for a time longer than the value of the *Loss of carrier time* setting generates a logical CRL signal. A communication failure shorter than the value of the *Loss of carrier time* setting is always ignored.

The unblocking function is configured with the *Unblock Mode* setting.

- *Unblock Mode* = "Off": The unblocking function is disabled.
- *Unblock Mode* = "Permanent": If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, the logical CRL signal is

generated. The CRL output signal remains active until the CRG signal reappears. The communication failure is not signaled by the LCG output.

- *Unblock Mode* = "Time window": If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, the CRL output signal is generated. The CRL output signal remains active for 150 ms, after which a communication failure is signaled by the LCG output. The LCG output is reset 200 ms after the CRG signal reappears. The purpose of this mode is to ensure tripping during a fixed delay of 150 ms after the loss of communication due to possible consequences of an internal fault. After this time, the accelerated tripping is allowed only if the CR_PRM signal is received again.

With operation modes *Unblock Mode* = "Permanent" and *Unblock Mode* = "Time window", the created CRL output signal is internally ORed with the CR_PRM input to allow the permissive scheme to operate even when the communication channel has been interrupted or lost. The CRL and LCG output signals are also available as outputs for monitoring purposes. Activating the BLOCK input blocks the CRL and LCG outputs.

5.10.5 Application

To achieve fast fault clearing on the part of the protected feeder not covered by the instantaneous zone Z1, the stepped distance protection function can be used with DSOCPSCH.

Applying DSOCPSCH requires a communication channel capable of transmitting an "On" or "Off" signal in each direction. To enable fast tripping, the most important requirement for the communication channel is the communication speed.

The performance of DSOCPSCH is directly related to the communication channel speed, and to the security against false or lost signals. Therefore, dedicated communication channels are recommended. With short distances of up to a few kilometers, a typical communication media is a simple pilot wire based on auxiliary power. With distances of up to 50 km with the integrated communication interface or up to 150 km with external equipment, fibre-optic cables using digital data transmission can be used. To avoid false signals causing unwanted operation, the security of the communication channel should be emphasized. Also, the dependability of the communication channel should be considered to ensure that the signals are reliably transmitted during the power system faults.

DSOCPSCH supports five communication schemes.

- Direct underreaching transfer trip DUTT
- Permissive underreaching transfer trip PUTT
- Permissive overreaching transfer trip POTT
- Directional comparison blocking scheme DCB
- Directional comparison unblocking scheme DCUB

Depending on whether the communication channel is used for sending a block or a trip signal, the communication schemes can be divided into blocking schemes and permissive schemes.

In permissive schemes, the trip signals of the distance zones are interchanged between the terminals to receive a permission to trip during an internal fault. The tripping of the local terminal depends on both the starting of its own forward-looking zone and on the received signal from the opposite terminal. In the underreaching scheme, no signals are sent during an external fault. During an external fault, a trip signal is also sent to the opposite terminal if the fault is seen in the forward direction and the overreaching scheme is used. However, in case of external faults, tripping is always blocked because either no signal is received as the opposite terminal sees a reverse fault or because the signal is received but the fault is seen in the reverse direction. In either case, the blocking is not dependent on the received signal so a lost communication channel does not result in false operation.

In the blocking scheme, a blocking signal is sent to the opposite terminal if the fault is locally seen in the reverse direction, that is, during an external fault. Thus, the blocking is dependent on the received signal, and there is typically a need to delay the tripping of the terminal receiving the blocking signal. This delay depends, for example, on the response times of the communication channel and terminals. During an internal fault, there is no signal transmission between the terminals, so the tripping does not depend on the received signal from the opposite terminal.

In conclusion, compared to the blocking schemes, the permissive schemes are inherently faster and have better security [1] against false tripping, since tripping in an external fault is not possible in case of a channel interruption. In a blocking scheme, a lost communication channel and a simultaneous external fault may lead to a false operation of the protection if the communication channel is not supervised. On the other hand, as the fast trip of the permissive scheme depends on the received signal, its dependability [2] is lower than that of the blocking scheme.

The unblocking scheme enhances the dependability of the permissive scheme. If the communication channel is interrupted and, simultaneously, a fault occurs in the forward direction, tripping is still possible either during a fixed time interval, counting from the beginning of the interruption, or for as long as the communication channel is lost. This is achieved by connecting the supervision output of the implemented communication functionality to the dedicated carrier guard signal input of DSOCPSCH. In general, the unblocking scheme provides better security than the blocking scheme because tripping in external faults is only possible if the fault occurs within the fixed time interval after the beginning of the channel interruption.

The direct transfer trip scheme uses the underreaching zone to trip the local breaker and to transfer the trip signal to a remote terminal. The remote terminal operates immediately based on the received transfer trip signal, without any additional conditions. This scheme is very simple, but the security is low as a spurious signal results in false operation of the protection.

Direct underreaching transfer trip DUTT

In some applications, there is a need to trip the remote-end breaker immediately because of fault detection by the local measurements. This applies, for example, when the transformers or reactors are connected to the system without circuit breakers, or for remote tripping after the operation of the local breaker failure protection (CBFP).

In the direct intertrip scheme (DUTT), the carrier send signal `CS_INTER_TR` is initiated by an underreaching zone, or by the tripping signal from an external protection relay, such as transformer or reactor protection. At the remote end, the received signal initiates a breaker trip immediately without any further local protection criteria. To limit the risk of an unwanted trip due to spurious sending of signals, the trip can be delayed by the *Coordination Time* setting, which should be set to 10...30 ms, depending on the type of the communication channel. The

[1] The ability to block operation in case of an external fault.
[2] The ability to operate in case of an internal fault.

communication channel operating in direct intertripping applications should be secure and dependable.

Setting guidelines for the intertrip scheme DUTT

- *Scheme type* = "Intertrip"
- *Coordination Time* = "0.050" s (10 ms + maximal transmission time)
- *Carrier Min Dur* = "0.1" s

Permissive underreaching transfer trip PUTT

In the permissive underreach scheme, the permission to trip is obtained locally from the underreaching zone and sent to the remote end. The received signal is combined with the local fault indication from the overreaching zone resulting in a trip command after a settable pick-up delay *Coordination Time*.

The protection relay of either feeder end sends a permissive signal to trip the other end. The communication channel must be able to receive and transmit at the same time. In permissive schemes, the communication channel must be fast and secure, but also dependable. Inadequate security causes unwanted tripping for the external faults. Inadequate speed or dependability causes delayed tripping for internal faults.

The CS_PRM signal is issued based on the underreaching zone Z1.

The underreach scheme is not applicable on short feeder lengths because the impedance measurement cannot easily distinguish between the internal and external faults in such cases.

The underreaching zones Z1 at the local and remote ends must overlap to prevent a gap between the protection zones, where the faults are not detected. If the underreaching zone does not meet the required sensitivity, for example, the fault infeed from a remote end, the blocking or permissive overreach scheme is considered.

To achieve an instantaneous trip, the carrier received signal CR_PRM must be received when the overreaching zone Z2 is still starting. In some cases, due to a fault in current distribution, the overreaching zone can operate only after the fault has been cleared by the remote terminal. In this case, there is a risk that if the remote terminal is tripped directly by, for example, zone Z1, the CR_PRM signal issued by the zone resets before the overreaching zone of the local end terminal has operated. To assure a sufficient duration of the CR_PRM signal, the CR_PRM signal can be prolonged by the time *Carrier Min Dur*. The recommended value of the *Carrier Min Dur* setting is "0.1" s.

The received communication signal is combined with the output from the local overreaching zone. Therefore, there is less concern about a false signal causing an incorrect trip, and therefore the timer *Coordination Time* is set to "0". A communication channel failure does not affect the selectivity, but delays the tripping at the other end for certain fault locations.

Setting guidelines for the permissive underreach scheme PUTT

- *Scheme type* = "Permissive Underreach"
- *Coordination Time* = "0" s
- *Carrier Min Dur* = "0.1" s

Permissive overreaching transfer trip POTT

In the permissive overreach scheme, the permission to trip is obtained locally from an overreaching zone and sent to the remote end. The received signal is then combined with the local fault indication from the overreaching zone, resulting in a trip command after a settable pick-up delay *Coordination Time*.

The protection relay at either end of the feeder sends a permissive signal to trip the other end. Therefore the communication channel must be able to receive and transmit at the same time. The communication on permissive schemes should be fast and secure.

The CS_PRM signal is issued based on the overreaching zone Z2.

The permissive overreach scheme can be used for all feeder types and lengths.

In the permissive overreach scheme, the communication channel plays an essential role in obtaining a fast tripping at both ends. Typically, a lost communication channel does not cause false tripping. However, it delays the operation of the protection for the faults anywhere on the feeder.

The communication channel for a permissive overreach scheme must be fast and secure, but also dependable. Inadequate security can cause unwanted tripping for external faults. Inadequate speed or dependability can cause delayed tripping for internal faults.

In the permissive overreaching scheme, the CS_PRM signal can be issued in parallel both from the overreaching and underreaching zones. The CS_PRM signal from the overreaching zone must not be prolonged, while the CS_PRM signal from the underreaching zone must typically be prolonged. In parallel feeder applications, the scheme typically needs to be complemented by the current reversal logic. To ensure the correct operation in this case, the CS_PRM signal must not be prolonged (*Carrier Min Dur* = "0" s). There is no need to delay the tripping while receiving the carrier signal, so the timer *Coordination Time* is set to "0".

Setting guidelines for the permissive overreaching transfer trip scheme POTT

- *Scheme type* = "Permissive Overreach"
- *Coordination Time* = "0" s
- *Carrier Min Dur* = "0.1" s
- *Carrier Min Dur* = "0" s (in case of parallel lines and current reversal logic)

Directional comparison blocking scheme DCB

In the blocking scheme, the reverse-looking zone Z3 is used for sending a block signal to the remote end to block the overreaching zone.

The blocking scheme is very dependable because it operates on faults anywhere on the protected feeder, even if the communication channel is out of service. Conversely, it is less secure than a permissive scheme because it trips for the external faults within the reach of the overreaching local zone if the communication channel is out of service and no block signal is received.

Inadequate speed or low dependability of the communication channel can cause spurious tripping for external faults.

To secure that the blocking signal arrives before the local overreaching zone trips, the trip is delayed by the *Coordination Time* setting. This setting must be set longer than the sum of the maximal transmission time of the channel and the start and response times of the protection relays sending and receiving the CS_BLOCKING signal. A security margin of at least 10 ms should be considered. The time delay *Carrier Min Dur* for prolonging the CS_BLOCKING signal is set to "0".

Setting guidelines for the blocking scheme DCB

- *Scheme type* = "Blocking"
- *Coordination Time* = "0.1" s (10 ms + maximal transmission time)
- *Carrier Min Dur* = "0" s

Directional comparison unblocking scheme DCUB

Metallic communication paths unfavorably affected by fault-generated noise or by other electrical phenomena, such as lightning, are not suitable for conventional permissive schemes that rely on the signal transmitted during a fault in the protected feeder. Principally, the communication media must be properly shielded or otherwise designed to provide an adequate performance during such conditions.

The unblocking scheme can be used to overcome the lower dependability of permissive schemes. The function is used in older, less reliable communication, where the signal has to be sent through the primary fault. The unblocking function uses a carrier guard signal CRG which must always be present, even when no CR_PRM signal is received. Due to the absence of the CRG signal during the security time, the *Loss of carrier time* setting is used as a CR_PRM signal. This also enables a permissive scheme to operate when the communication channel is temporarily lost during an internal fault.

Setting guidelines for the unblocking scheme DCUB

The unblocking function is configured with the *Unblock Mode* setting.

- *Unblock Mode* = "Off": The unblocking function is disabled.
- *Unblock Mode* = "Permanent": If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, a logical carrier received signal CRL is generated. The CRL signal remains active until the CRG signal is present. The communication failure is not signalled by the LCG output. The *Loss of carrier time* setting is set to "35" ms.
- *Unblock Mode* = "Time window": If the CRG signal disappears for a longer time period than the *Loss of carrier time* setting, a CRL signal is generated. The CRL signal remains active for 150 ms, after which a communication failure is signalled by the LCG output. The value of the LCG output is reset 200 ms after the CRG signal reappears. The *Loss of carrier time* setting is set to "35" ms.

5.10.6 Signals

5.10.6.1 DSOCPSCH Input signals

Table 1183: DSOCPSCH Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_CS_OPR	BOOLEAN	0=False	Signal for blocking CS and Operate in all schemes
CSBLK	BOOLEAN	0=False	Reverse directed distance protection zone signal for requesting activation of TxBlk
CACC	BOOLEAN	0=False	Permissive distance protection zone signal
CSOR	BOOLEAN	0=False	Overreaching distance protection zone signal
CSUR	BOOLEAN	0=False	Underreaching distance protection zone signal
CR_PRM	BOOLEAN	0=False	Received teleprotection permissive from the other side
CR_BLOCKING	BOOLEAN	0=False	Received teleprotection blocking from the other side
CR_INTER_TR	BOOLEAN	0=False	Received direct trip from the other side
CRG	BOOLEAN	0=False	Carrier guard signal received

5.10.6.2 DSOCPSCH Output signals

Table 1184: DSOCPSCH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
CS_PRM	BOOLEAN	Permissive transmitted to the other side
CS_BLOCKING	BOOLEAN	Blocking transmitted to the other side
CS_INTER_TR	BOOLEAN	Direct trip transmitted to the other side

Table continues on the next page

Name	Type	Description
CRL	BOOLEAN	Carrier received after unblock logic
LCG	BOOLEAN	Loss of guard

5.10.7 DSOCPSCH Settings

Table 1185: DSOCPSCH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Scheme type	1=None 2=Intertrip 3=Permissive Un-derreach 4=Permissive Over-reach 5=Blocking			3=Permissive Un-derreach	Scheme type, mode of operation
Carrier Min Dur	0...60000	ms	1	100	Minimum duration of a carrier send signal
Coordination Time	0...60000	ms	1	35	Co-ordination tim-er for blocking scheme

Table 1186: DSOCPSCH Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Unblock Mode	1=Off 2=Permanent 3=Time window			1=Off	Operation mode of unblocking logic
Loss of carrier time	0...60000	ms	1	35	Pickup security timer on loss of carrier guard signal

5.10.8 DSOCPSCH Monitored data

Table 1187: DSOCPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
DSOCPSCH	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.10.9 Technical data

Table 1188: DSOCPSCH Technical data

Characteristic	Value
Operate time accuracy	±1.0 % of the set value or ±20 ms

5.11 Communication logic for residual overcurrent RESCPSCH (ANSI 85 67G/N SCHLGC)

5.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Communication logic for residual overcurrent	RESCPSCH	CLN	85 67G/N SCHLGC

5.11.2 Function block

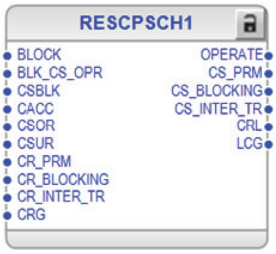


Figure 709: Function block

5.11.3 Functionality

The communication logic for residual overcurrent function RESCPSCH is used to achieve instantaneous fault clearing independent of the fault location on the protected feeder. There are four available communication scheme types.

- Direct underreaching transfer trip DUTT
- Permissive underreaching transfer trip PUTT
- Permissive overreaching transfer trip POTT
- Directional comparison blocking scheme DCB

The directional comparison unblocking scheme DCUB can also be provided by complementing the permissive schemes with an additional logic called the unblocking function, which is also included in RESCPSCH.

If the permissive overreaching scheme is used, some of the power system conditions require additional special logic circuits, such as the current reversal and weak-end infeed logic for residual overcurrent function RCRWPSCH.

5.11.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of RESCPSCH can be described with a module diagram. All the modules in the diagram are explained in the next sections.

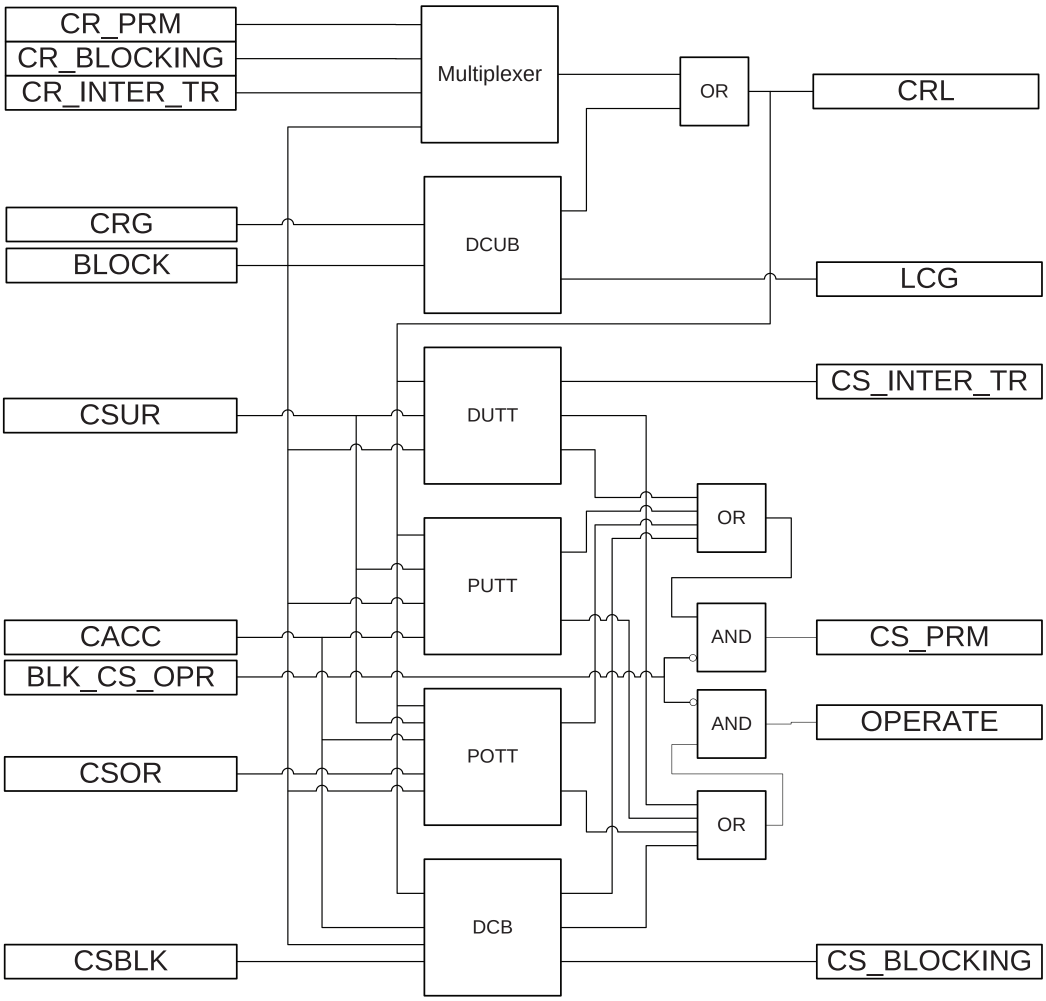


Figure 710: Functional module diagram

The applied communication scheme logic in RESCPSCH is selected with the *Scheme type* setting.

Table 1189: Communication scheme based on the Scheme type value

Scheme type **value**	**Communication scheme**
"Intertrip"	DUTT
"Permissive Underreach"	PUTT
"Permissive Overreach"	POTT
"Blocking"	DCB

The unblocking scheme (DCUB) is enabled with the *Unblock mode* setting.

Multiplexer

The multiplexer connects an input signal to an output based on the value of the *Scheme type* setting.

Table 1190: Connected inputs based on the Scheme type value

Scheme type value	Inputs connected to an output
"Intertrip"	CR_INTER_TR
"Permissive Underreach" or "Permissive Over-reach"	CR_PRM
"Blocking"	CR_BLOCKING

Direct underreaching transfer trip scheme DUTT

The direct intertrip scheme is enabled with *Scheme type* = "Intertrip".

In the direct intertrip scheme, the start signal from the underreaching (instantaneous) residual overcurrent function DEFHPDEF is connected to the CSUR input to create a carrier send CS_INTER_TR signal. The duration of the CSUR input signal can be prolonged by the *Carrier Min Dur* setting to ensure a sufficient duration for the CS_INTER_TR signal.

The local circuit breaker is directly tripped (activation of the OPERATE output) with the carrier received CS_INTER_TR signal after a settable pick-up delay *Coordination time* has elapsed without further local criteria.

The unblocking function (*Unblock mode* = "Permanent" and *Unblock mode* = "Time window") must not be enabled with the DUTT scheme, as the lost guard signal results in an immediate trip of the local circuit breaker.

The activation of the BLOCK input totally blocks the direct intertrip scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

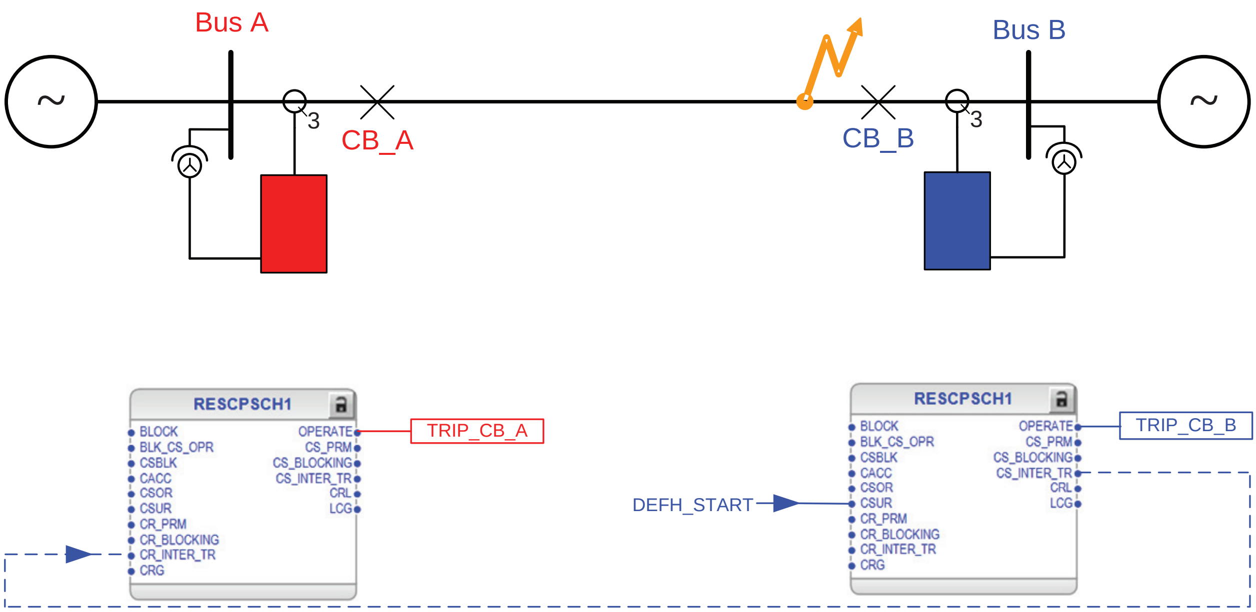


Figure 711: Simplified functional diagram of the direct intertrip scheme

Permissive underreaching transfer trip scheme PUTT

The permissive underreach scheme is enabled with *Scheme type* = "Permissive Underreach".

In the permissive underreach scheme, the start signal from the underreaching (instantaneous) residual overcurrent function DEFHPDEF is connected to the CSUR input to create a CS_PRM signal. The duration of the CSUR input signal can be prolonged by the *Carrier Min Dur* setting to ensure a sufficient duration of the CS_PRM signal.

In the permissive underreach scheme, the CR_PRM signal or CRL signal, if the unblocking function is enabled, is used to allow the overreaching residual overcurrent function DEFLPDEF to trip (activation of the OPERATE output) after the pick-up delay *Coordination time*. The start signal from the overreaching function is connected to the CACC input. A general start signal in the forward direction can also be connected to the CACC input.

The CS_PRM signal is also generated if the CR_PRM signal is received and the local carrier acceleration signal CACC is active.

Activating the BLOCK input totally blocks the permissive underreach scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

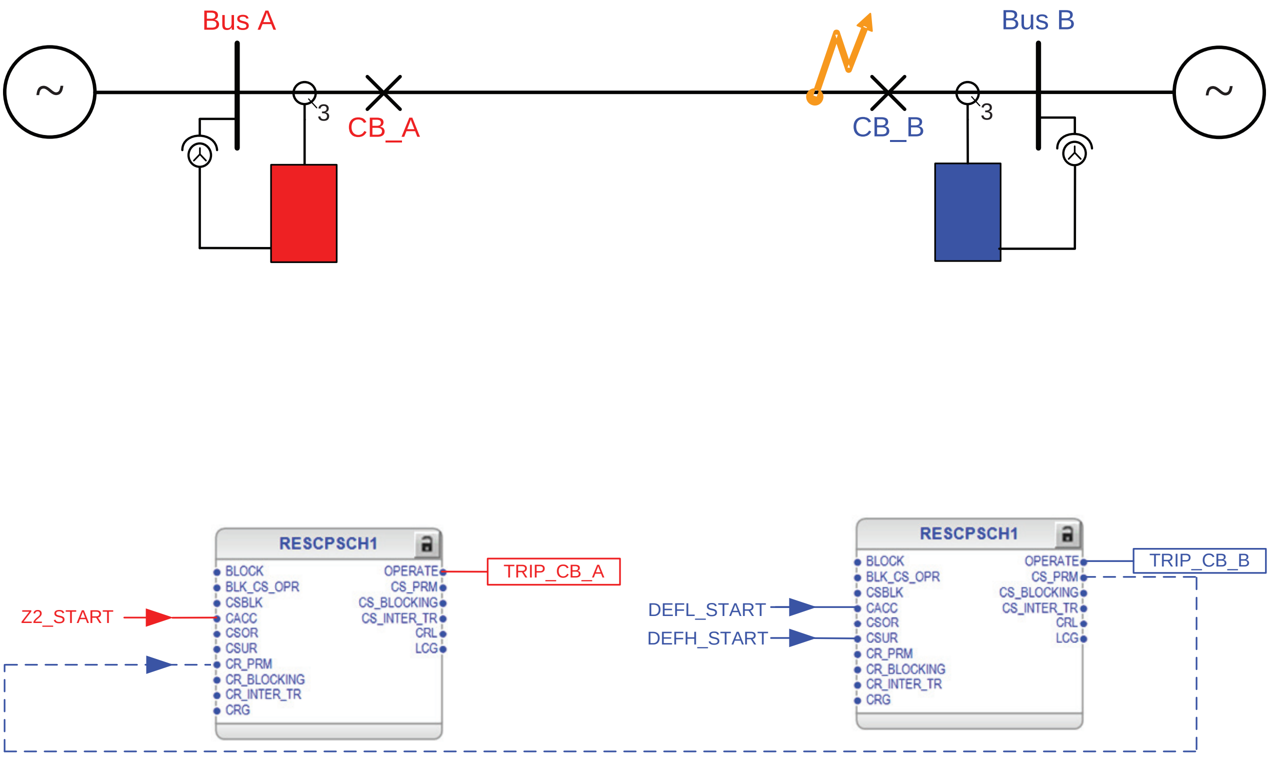


Figure 712: Simplified functional diagram of the permissive underreach scheme

Permissive overrreaching transfer trip scheme POTT

The permissive overreach scheme is enabled with *Scheme type* = "Permissive Overreach".

In this scheme, the START signal from the overreaching residual overcurrent function DEFLPDEF is connected to the CSOR input to create a CS_PRM signal. The CS_PRM signal can also be issued simultaneously from the underreaching residual overcurrent function DEFHPDEF. In this case, the start signal from the underreaching function is connected to the CSUR input. The duration of the CSUR input signal can be prolonged by the *Carrier Min Dur* setting to ensure a sufficient duration of the CS_PRM signal.

In case of parallel feeders, when the external current reversal logic (RCRWPSCH) is enabled, the CS_PRM signal is not prolonged and the value of *Carrier Min Dur* is set to zero to secure correct operation.

In the permissive overreach scheme, the received signal CR_PRM or CRL, if the unblocking function is enabled, is used to allow the overreaching residual overcurrent function DEFLPDEF to trip (activation of the OPERATE output) after the settable pick-up delay *Coordination time*. The start signal from the overreaching zone is connected to the CACC input.

The CS_PRM signal is also generated if the CR_PRM signal is received and the local carrier acceleration signal CACC is active.

Activating the BLOCK input totally blocks the permissive overreach scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

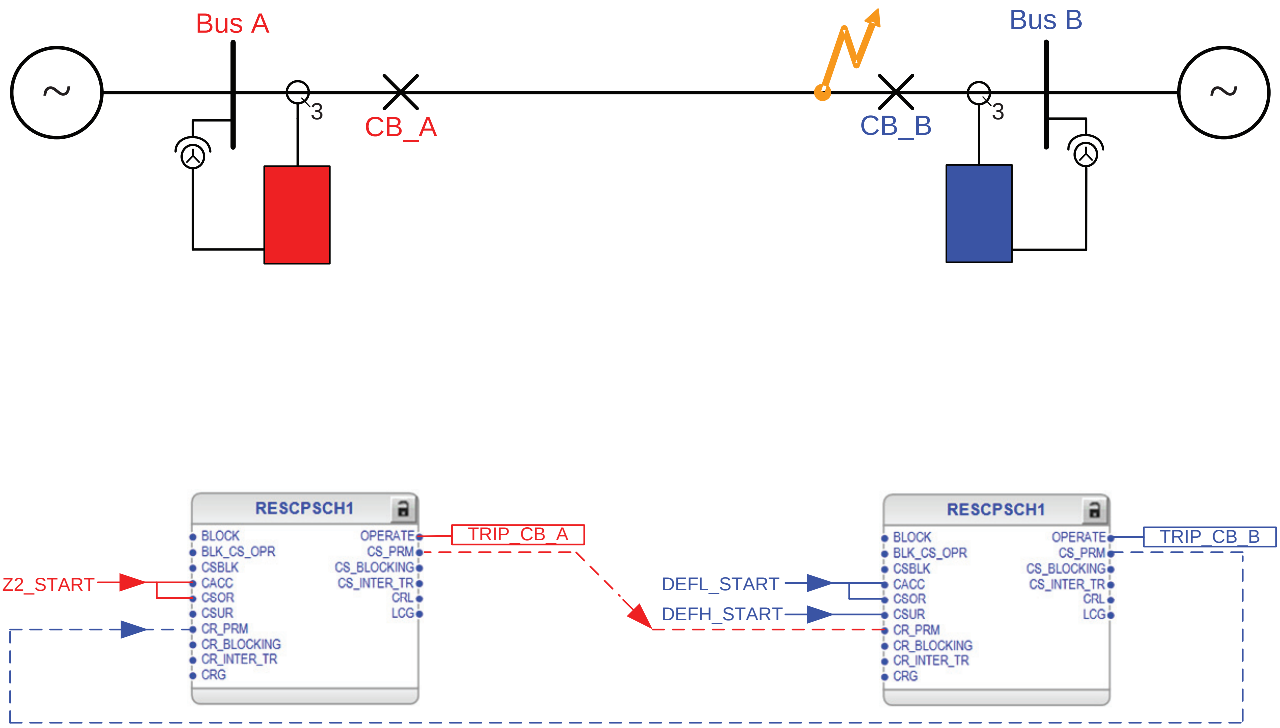


Figure 713: Simplified functional diagram of the permissive overreach scheme

Directional comparison blocking scheme DCB

The directional comparison blocking scheme is enabled with *Scheme type* = "Blocking".

In the blocking scheme, the START signal from the reverse-looking residual overcurrent function DEFLPDEF set to operate for the reverse direction earth fault, is connected to the CSBLK input to create a CS_BLOCKING signal. The starting of the reverse-looking function indicates that the fault is located outside the protected feeder. The duration of the CSBLK input signal can be prolonged with the *Carrier Min Dur* setting to ensure a sufficient duration of the CS_BLOCKING signal.

The blocking scheme is mainly used to allow the forward-looking overreaching residual overcurrent function to trip (activation of the OPERATE output) after the settable *Coordination time*, and if no block signal is received from the remote terminal. To prevent a false trip in case of external faults, the CR_BLOCKING signal must be received before the *Coordination time* has elapsed. The start signal from the overreaching residual overcurrent function DEFLPDEF is connected to the CACC input.

The *Coordination time* setting in the blocking scheme depends, for example, on the communication system delay and on the terminal's response times in transmitting a CS_BLOCKING signal to the other feeder end. The *Coordination time* setting must not be zero.

Activating the BLOCK input totally blocks the directional comparison blocking scheme. The CS_PRM and OPERATE outputs can be blocked by the BLK_CS_OPR input.

In *Figure 714*, in case of internal faults, the CS_BLOCKING signal is not sent as the fault is not seen by the reverse-looking overreaching function.

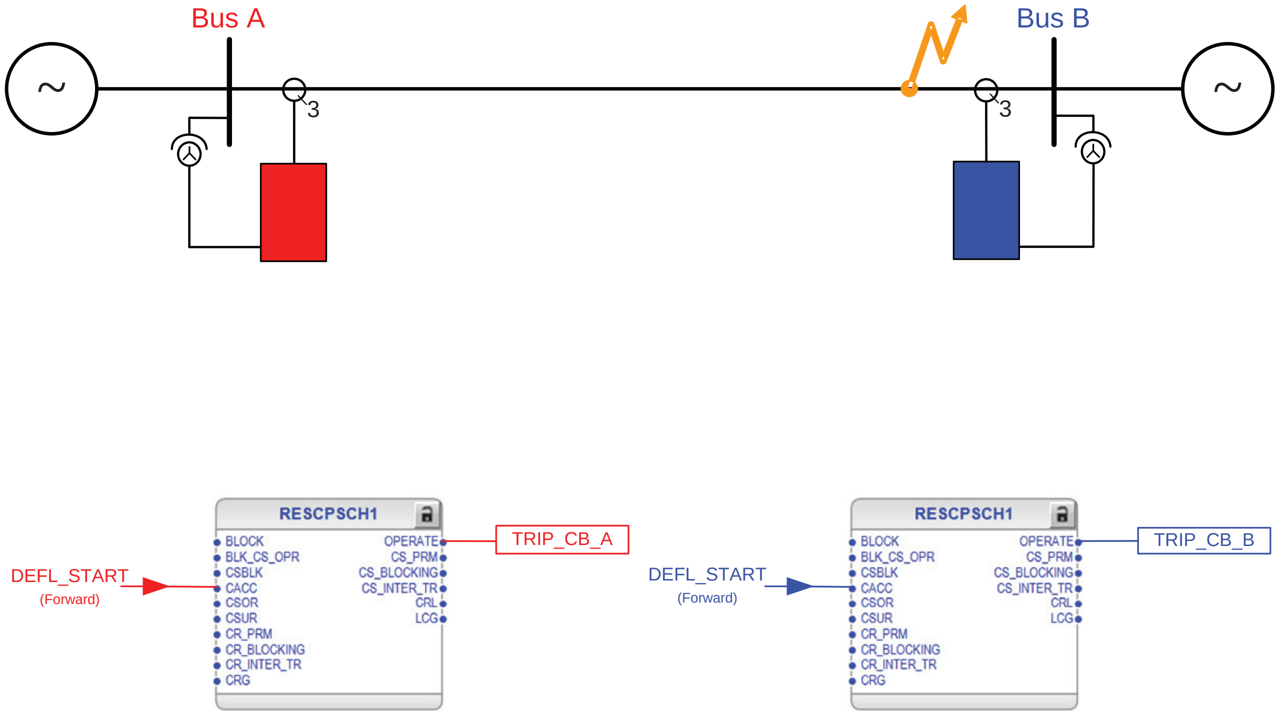


Figure 714: Simplified functional diagram of the blocking scheme, internal fault

In *Figure 715*, in case of external faults, the protection relay at bus B sees the fault in the reverse direction and sends a blocking signal CS_BLOCKING to the protection relay at bus A. There is no CB operation at either end.

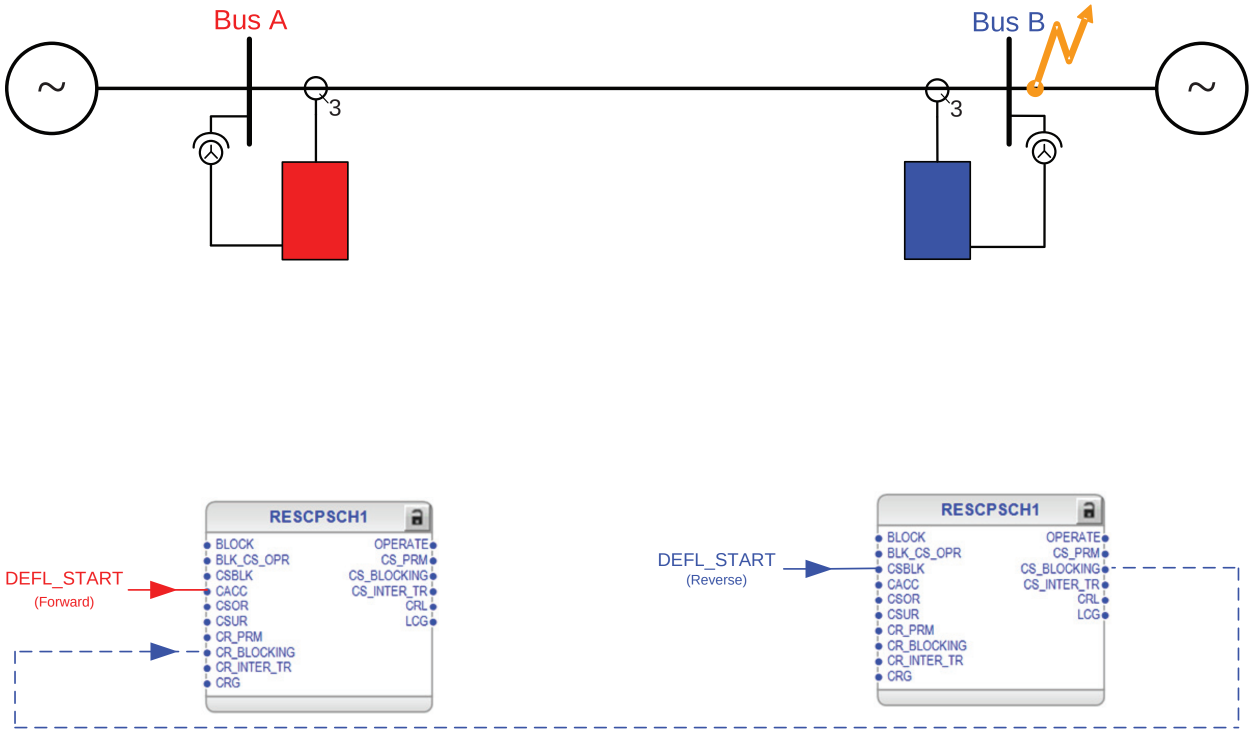


Figure 715: Simplified functional diagram of the blocking scheme, external fault

The unblocking function used with the blocking function provides a possibility to supervise the communication channel. In this case, the CRL output signal is used as a local blocking signal.

The operation mode *Unblock mode* = "Time window" is not recommended as the blocking is activated only for 150 ms after the guard signal disappears. This results in an unwanted operation of the protection.

Directional comparison unblocking scheme DCUB

The unblocking function is a complementary logic which can be used together with the permissive communication schemes. In the unblocking scheme, the dependability of the permissive schemes is improved by using the loss of guard signal from the communication equipment to create a CRL output signal locally. This enables the permissive scheme to operate even if the communication channel is interrupted or lost.

The unblocking function uses a carrier guard signal which must always be present. The absence of the CRG signal for a time longer than the value of the *Loss of carrier time* setting generates a logical CRL signal. A communication failure shorter than the value of the *Loss of carrier time* setting is always ignored.

The unblocking function is configured with the *Unblock mode* setting.

- *Unblock mode* = "Off": The unblocking function is disabled.
- *Unblock mode* = "Permanent": If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, the logical CRL signal is generated. The CRL output signal remains active until the CRG signal reappears. The communication failure is not signaled by the LCG output.

- *Unblock mode* = "Time window": If the CRG signal disappears for a longer time than defined in the *Loss of carrier time* setting, the CRL output signal is generated. The CRL output signal remains active for 150 ms, after which a communication failure is signaled by the LCG output. The LCG output is reset 200 ms after the CRG signal is present again. The purpose of this mode is to ensure tripping during a fixed delay of 150 ms after the loss of communication due to possible consequences of an internal fault. After this time, the accelerated tripping is allowed only if the CR_PRM signal is received again.

With operation modes *Unblock mode* = "Permanent" and *Unblock mode* = "Time window", the created CRL output signal is internally ORed with the CR_PRM input to allow the permissive scheme to operate even when the communication channel has been interrupted or lost. The values of CRL and LCG output signals are also available through the Monitored data view. Activating the BLOCK input blocks the CRL and LCG outputs.

5.11.5 Application

To achieve fast fault clearing on the part of the protected feeder not covered by the instantaneous step of the residual overcurrent protection, the directional residual overcurrent protection can be used with RESCPSCH.

Applying RESCPSCH requires a communication channel capable of transmitting an "On" or "Off" signal in each direction. To enable fast tripping, the most important requirement for communication is the communication speed.

The performance of RESCPSCH is directly related to the communication channel speed, and to the security against false or lost signals. Therefore, dedicated communication channels are recommended. With short distances of up to a few kilometers, a typical communication media is a simple pilot wire based on auxiliary power. With distances of up to 150 km, fibre-optic cables using digital data transmission can be used. To avoid false signals that could cause unwanted operation, the security of the communication channel should be emphasized. Also, the dependability of the communication channel should be considered to ensure that the signals are reliably transmitted during power system faults.

RESCPSCH supports five communication schemes.

- Direct underreaching transfer trip DUTT
- Permissive underreaching transfer trip PUTT
- Permissive overreaching transfer trip POTT
- Directional comparison blocking scheme DCB
- Directional comparison unblocking scheme DCUB

Depending on whether the communication channel is used for sending a block or a trip signal, the communication schemes can be divided into blocking schemes and permissive schemes.

In permissive schemes, the trip signals of the directional residual overcurrent protection are interchanged between the terminals to receive a permission to trip during an internal fault. The tripping of the local terminal depends on both the starting of its own forward-looking function and the received signal from the opposite terminal. In the underreaching scheme, no signals are sent during an external fault. A trip signal is sent to the opposite terminal during an external fault if the fault is seen in the forward direction and the overreaching scheme is used. However, in case of external faults, tripping is always blocked because either no signal is received as the opposite terminal sees a reverse fault or the signal is received but locally the fault is seen in the reverse direction. In either case, the blocking is not dependent on the received signal so a lost communication channel does not result in false operation.

In the blocking scheme, a blocking signal is sent to the opposite terminal if the fault is locally seen in the reverse direction, that is, during an external fault. Thus, the blocking is dependent on the received signal, and there is typically a need to delay the tripping of the terminal receiving the blocking signal. This delay depends, for example, on the response times of the communication channel and terminals. During an internal fault, there is no signal transmission between the terminals, so the tripping does not depend on the received signal from the opposite terminal.

In conclusion, permissive schemes are inherently faster and have better security [1] against false tripping than a blocking scheme, since tripping in an external fault is not possible in case of a channel interruption. In a blocking scheme, a lost communication channel and a simultaneous external fault may lead to a false operation of the protection if the communication channel is not supervised. On the other hand, as the fast trip of the permissive scheme depends on a received signal, its dependability [2] is lower than that of the blocking scheme.

The unblocking scheme enhances the dependability of the permissive scheme. If the communication channel is interrupted and, simultaneously, a fault occurs in the forward direction, tripping is still possible either during a fixed time interval after the beginning of the interruption or as long as the communication channel is lost. This is achieved by connecting the supervision output of the implemented communication functionality to the dedicated carrier guard signal input of RESCPSCH. In general, the unblocking scheme provides better security than the blocking scheme because tripping in external faults is only possible if the fault occurs within the fixed time interval after the beginning of the channel interruption.

The direct transfer trip scheme uses the underreaching function to trip the local breaker and to transfer the trip signal to the remote terminal. The remote terminal operates immediately based on the received transfer trip signal, without any additional conditions. This scheme is very simple, but its security is low as a spurious signal results in false operation of the protection.

Direct underreaching transfer trip DUTT

In some applications, there is a need to trip the remote end breaker immediately because of fault detection by the local measurements. This applies, for example, when the transformers or reactors are connected to the system without circuit breakers, or for remote tripping following the operation of the local breaker failure protection (CBFP).

In the direct intertrip scheme (DUTT), the carrier send signal `CS_INTER_TR` is initiated by the underreaching or the tripping signal of an external protection relay, such as transformer or reactor protection. At the remote end, the received signal initiates the breaker trip immediately without any further local protection criteria. To limit the risk of an unwanted trip due to spurious sending of signals, the trip can be delayed by the *Coordination time* setting, which should be set to 10...30 ms, depending on the type of the communication channel. The communication channel operating in direct intertripping applications should be secure and dependable.

Setting guidelines for the intertrip scheme DUTT

- *Scheme type* = "Intertrip"

[1] The ability to block operation in case of an external fault.
[2] The ability to operate in case of an internal fault.

- *Coordination time* = "0.050" s (10 ms + maximal transmission time)
- *Carrier Min Dur* = "0.1" s

Permissive underreaching transfer trip PUTT

In the permissive underreach scheme, a permission to trip is obtained locally from the underreaching function and sent to the remote end. The received signal is then combined with the local fault indication from the overreaching function resulting in a trip command after a settable pick-up delay *Coordination time*.

The protection relay of either feeder end sends a permissive signal to trip the other end. The communication channel must be able to receive and transmit at the same time. In permissive schemes, the communication channel must be fast and secure, but also dependable. Inadequate security causes unwanted tripping for external faults. Inadequate speed or dependability causes delayed tripping for internal faults.

The CS_PRM signal is issued based on the underreaching residual overcurrent protection function.

The permissive scheme is not applicable on short feeder lengths because the residual overcurrent protection cannot easily distinguish between the internal and external faults in such cases.

The residual overcurrent function may start only at one end due to the system conditions such as weak zero-sequence source at one end, or high fault resistance. However, fast tripping from both ends can be achieved by connecting a general forward start signal to CACC. So, even if the local overreaching residual overcurrent function has not picked up, the local OPERATE output is activated. The function also generates a CS_PRM signal by combining the carrier received CR_PRM signal from a remote end and also the local activation of CACC, giving the permission to a remote function to trip instantaneously.

The CR_PRM signal must be received when the overreaching residual overcurrent protection is still active to achieve an instantaneous trip. In some cases, due to the fault current distribution, the overreaching protection can operate only after the fault has been cleared by the remote terminal. In this case, there is a risk that if the remote terminal is tripped directly by the instantaneous underreaching function, the CS_PRM signal that it issues resets before the overreaching function of the local end terminal is operated. To ensure a sufficient duration of the CR_PRM signal, the CS_PRM signal can be prolonged by time *Carrier Min Dur*. The recommended value of the *Carrier Min Dur* setting is "0.1" s.

The received communication signal is combined with the output from the local overreaching function. Therefore, there is less concern about a false signal causing an incorrect trip. Therefore, the timer *Coordination time* can be set to "0". A communication channel failure does not affect the selectivity, but delays the tripping at the other end for certain fault locations.

Setting guidelines for the permissive underreach scheme PUTT

- *Scheme type* = "Permissive Underreach"
- *Coordination time* = "0" s
- *Carrier Min Dur* = "0.1" s

Permissive overreaching transfer trip POTT

In the permissive overreach scheme, the permission to trip is obtained locally from an overreaching function and sent to the remote end. The received signal is then combined with the local fault indication from the overreaching function, resulting in a trip command after a settable pick-up delay *Coordination time*.

The protection relay at either end of the feeder sends a permissive signal to trip the other end. Therefore the communication channel must be able to receive and transmit at the same time. A general requirement for the communication on permissive schemes is that it should be fast and secure.

In the permissive overreach scheme, the `CS_PRM` signal is issued based on the start of the overreaching residual overcurrent function.

The residual overcurrent function may start at one end due to the system conditions such as weak zero-sequence source at one end, or high fault resistance. However, fast tripping from both ends can be achieved by connecting a general forward start signal to `CACC`. So, even if the local overreaching residual overcurrent function has not picked up, the local `OPERATE` is activated. The function also generates a `CS_PRM` signal by combining the `CR_PRM` signal from a remote end and local activation of `CACC`, giving permission to the remote function to trip instantaneously.

The permissive overreach scheme can be used for all feeder types and lengths.

In the permissive overreach scheme, the communication channel is essential for obtaining fast tripping at both ends. Typically, a lost communication channel does not cause false tripping, but it delays the operation of the protection for the faults on the feeder.

The communication channel for a permissive overreach scheme must be fast and secure, but also dependable. Inadequate security can cause unwanted tripping for external faults. Inadequate speed or dependability can cause delayed tripping for internal faults.

In the permissive overreaching scheme, the `CS_PRM` signal can be issued in parallel both from the overreaching and underreaching functions. The `CS_PRM` signal from the overreaching function must not be prolonged, while the `CS_PRM` signal from the underreaching function must typically be prolonged. In parallel feeder applications, the scheme typically needs to be complemented by the current reversal logic. To ensure a correct operation in this case, the `CS_PRM` signal must not be prolonged (*Carrier Min Dur* = "0" s). There is no need to delay the tripping when receiving the carrier signal, so the time *Coordination time* is set to "0".

Setting guidelines for the permissive overreaching transfer trip scheme POTT

- *Scheme type* = "Permissive Overreach"
- *Coordination time* = "0" s
- *Carrier Min Dur* = "0.1" s
- *Carrier Min Dur* = "0" s (in case of parallel lines and current reversal logic)

Directional comparison blocking scheme DCB

In the blocking scheme, the reverse-looking residual overcurrent function is used for sending a block signal to the remote end to block the overreaching forward-looking residual overcurrent function.

The blocking scheme is very dependable because it operates for faults anywhere on the protected feeder, even if the communication channel is out of service. Conversely, it is less secure than a permissive scheme because it trips for the external faults within the reach of the overreaching local function if the communication channel is out of service and no block signal is received.

Inadequate speed or low dependability of the communication channel can cause spurious tripping for external faults.

To secure that the blocking signal arrives before the local overreaching function trips, the trip is delayed by the *Coordination time* setting. This setting must be set longer than the sum of the maximal transmission time of the channel and the start and response times of the protection relays sending and receiving the CS_PRM signal. A security margin of at least 10 ms should be considered. The time delay *Carrier Min Dur* for prolonging the CS_PRM signal is set to "0".

Setting guidelines for the blocking scheme

- *Scheme type* = "Blocking"
- *Coordination time* = "0.1" s (10 ms + maximal transmission time)
- *Carrier Min Dur* = "0" s

Directional comparison unblocking scheme DCUB

Metallic communication paths adversely affected by fault-generated noise or by other electrical phenomena, such as lightning, are not suitable for conventional permissive schemes that rely on signal transmission during a fault in the protected feeder. Principally, the communication media must be properly shielded or otherwise designed to provide an adequate performance during such conditions.

The unblocking scheme can be used to overcome the lower dependability of permissive schemes. The function is used in older, less reliable communication, where the signal has to be sent through the primary fault. The unblocking function uses a carrier guard signal CRG which must always be present, even when no CR_PRM signal is received. Due to the absence of the CRG signal during the security time, the *Loss of carrier time* setting is used as a CR_PRM signal. This also enables a permissive scheme to operate when the communication channel is temporarily lost during an internal fault.

Setting guidelines for the unblocking scheme

- *Unblock mode* = "Off": The unblocking function is disabled.
- *Unblock mode* = "Permanent": If the CRG signal disappears for a longer time period than defined in the Loss of carrier time setting, a logical carrier received signal CRL is generated. The CRL signal remains active until the CRG signal is present. The communication failure is not signalled by the LCG output. The *Loss of carrier time* setting is set to "35" ms.
- *Unblock mode* = "Time window": If the CRG signal disappears for a longer time period than the *Loss of carrier time* setting, a CRL signal is generated. The CRL signal remains active for 150 ms, after which a communication failure is signalled by the LCG output. The value of the LCG output is reset 200 ms after the CRG signal reappears. The *Loss of carrier time* setting is set to "35" ms.

5.11.6 Signals

5.11.6.1 RESCPSCH Input signals

Table 1191: RESCPSCH Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_CS_OPR	BOOLEAN	0=False	Signal for blocking CS and OPR in all schemes
CSBLK	BOOLEAN	0=False	Reverse residual overcurrent signal for Carrier Send
CACC	BOOLEAN	0=False	Signal to be used for tripping by Communication Scheme
CSOR	BOOLEAN	0=False	Overreaching residual overcurrent signal for Carrier Send
CSUR	BOOLEAN	0=False	Underreaching residual overcurrent signal for Carrier Send
CR_PRM	BOOLEAN	0=False	Received teleprotection permissive from the other side
CR_BLOCKING	BOOLEAN	0=False	Received teleprotection blocking from the other side
CR_INTER_TR	BOOLEAN	0=False	Received direct trip from the other side
CRG	BOOLEAN	0=False	Carrier guard signal received

5.11.6.2 RESCPSCH Output signals

Table 1192: RESCPSCH Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
CS_PRM	BOOLEAN	Permissive transmitted to the other side
CS_BLOCKING	BOOLEAN	Blocking transmitted to the other side
CS_INTER_TR	BOOLEAN	Direct trip transmitted to the other side

Table continues on the next page

Name	Type	Description
CRL	BOOLEAN	Carrier received after unblock logic
LCG	BOOLEAN	Loss of guard

5.11.7 RESCPSCH Settings

Table 1193: RESCPSCH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Scheme type	1=None 2=Intertrip 3=Permissive Underreach 4=Permissive Overreach 5=Blocking			3=Permissive Underreach	Scheme type, mode of operation
Carrier Min Dur	0...60000	ms	1	100	Minimum duration of carrier send signal
Coordination time	0...60000	ms	1	35	Co-ordination timer for blocking scheme

Table 1194: RESCPSCH Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Unblock mode	1=Off 2=Permanent 3=Time window			1=Off	Unblock function mode for scheme type
Loss of carrier time	0...60000	ms	1	35	Pickup security timer on loss of carrier guard signal

5.11.8 RESCPSCH Monitored data

Table 1195: RESCPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
RESCPSCH	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.11.9 Technical data

Table 1196: RESCPSCH Technical data

Characteristic	Value
Operate time accuracy	±1.0 % of the set value or ±20 ms

5.12 Current reversal and weak-end infeed logic CRWPSCH (ANSI 85 21CREV,WEI)

5.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current reversal and weak-end in-feed logic	CRWPSCH	CLCRW	85 21CREV,WEI

5.12.2 Function block

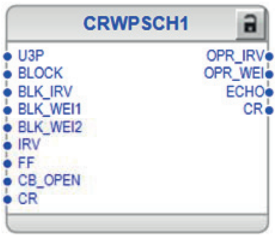


Figure 716: Function block

5.12.3 Functionality

The current reversal and weak-end infeed logic function CRWPSCH can be used when the scheme communication logic DSOCPSCH requires additional logics to operate correctly in all power system conditions.

In parallel feeder applications, the fault current direction on the healthy feeder can change when the circuit breaker on the faulty feeder opens to clear the fault. This can lead to an unwanted operation of the distance protection on the healthy parallel feeder when DSOCPSCH is used with the permissive overreach scheme. The main purpose of the current reversal logic is to prevent such unwanted operations.

The permissive communication schemes can operate only when the protection in the remote terminal can detect the fault. This detection requires sufficient minimum fault current. If such current is not available due to a too weak remote end source, the weak-end infeed logic can be used to overcome the situation and trip the remote end breaker.

5.12.4 Analog channel configuration

CRWPSCH has one analog group input which must be properly configured.

Table 1197: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1198: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phases connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.12.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of CRWPSCH can be described with a module diagram. All the modules in the diagram are explained in the next sections.

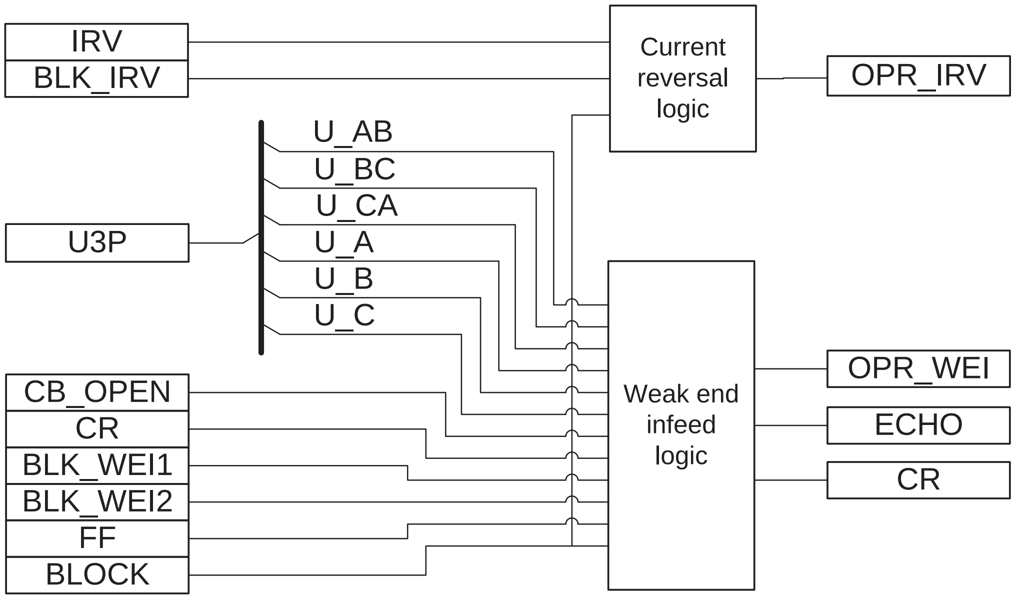


Figure 717: Functional module diagram

Current reversal logic

Current reversal logic is enabled by changing the value of the *Reversal mode* setting to "On".

This logic uses the start signal of the reverse-looking zone (Z3) connected to the IRV input, which is used to recognize the fault in the reverse direction, that is, in the parallel feeder. When the reverse zone is activated after a start delay (the *Reversal time* setting), the logic is ready to issue an OPR_IRV output signal. The OPR_IRV signal is connected to the BLK_CS_OPR input of DSOCPSCH in order to block the sending of the carrier send signal (CS) and the activation of the OPERATE output of the communication logic. The OPR_IRV signal has a drop-off delay defined with the *Reversal reset time* setting.

An internal 10 ms drop-off timer enables the current reversal logic to be activated for the short-duration input signals even if the *Reversal reset time* setting is set to zero.

The BLK_IRV input is used to block the activation of the OPR_IRV output. The BLK_IRV input is typically connected to the forward-looking zone start signals within the terminal. General blocking is achieved by activating the BLOCK input.

Weak-end infeed logic

Weak-end infeed logic is used to activate the distance protection function when the fault current infeed is too low due to, for example, high source impedance or fault current distribution between sources. When activated, the CR signal is logically combined with the local criteria to initiate the tripping of the weak-end breaker. The received signal is echoed back to accelerate the tripping in the opposite end with the stronger source.

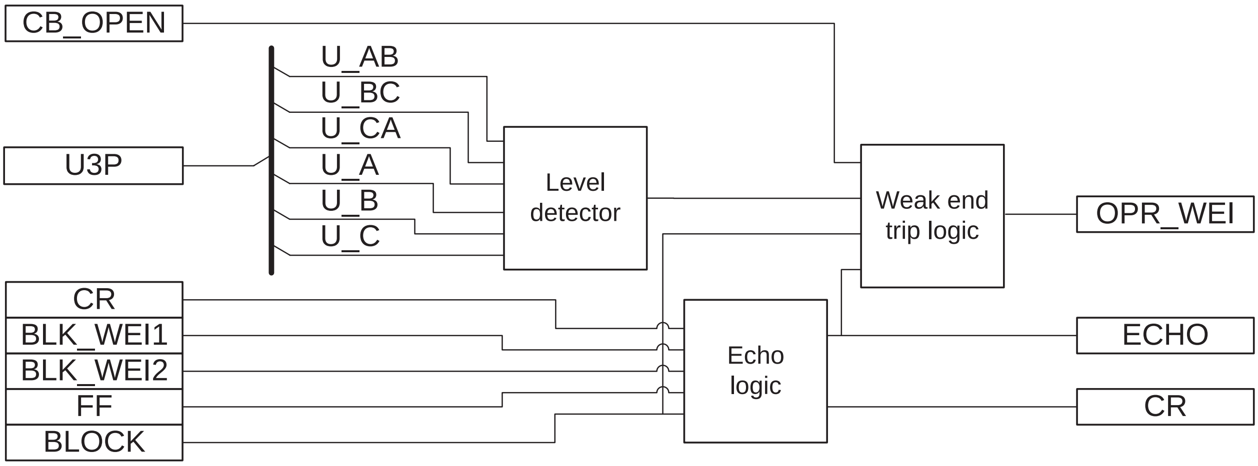


Figure 718: Functional module diagram of weak-end infeed logic

The WEI logic is enabled using the *Wei mode* setting.

- If *Wei mode*= "Off", the WEI logic is disabled.
- If *Wei mode*= "Echo", the WEI logic is enabled without Level detector.
- If *Wei mode*= "Echo and Operate", the WEI logic is enabled with Level detector.

Level detector

Both phase-to-earth and phase-to-phase voltages are monitored. The undervoltage criteria are applied to the phase-to-phase voltages with the *PPV level for Wei* setting and to the phase-to-earth voltages with the *PhV level for Wei*. Level detector sends an enable signal for a phase to Weak-end trip logic when one or more voltages are below the corresponding settings. Level detector blocks the enable signal if all three-phase voltages are above the set value more than 100 ms. This is to avoid sending an unnecessary operate signal if the breaker is already open.

Echo logic

Echo logic returns the received carrier signal with the ECHO output when it receives a CR signal if no fault has been detected by the forward- and reverse-looking zones and the duration of CR is longer than the coordination time delay (setting *Wei Crd time*). The received carrier receive signal is also given as the CR output.

When the WEI logic is enabled at both feeder ends, a spurious signal can be looped round by Echo logic. To avoid a continuous lockup of the system, the duration of the echoed signal is limited to 200 ms.

The ECHO and CR outputs can be blocked by activating the BLOCK input. The FF, BLK_WEI1 and BLK_WEI2 inputs can be used to block the ECHO output. The FF input is usually connected to the functional output of the fuse failure function, and the BLK_WEI1 input is typically connected to the start signals of the forward and reverse directional residual overcurrent functions within the terminal. The BLK_WEI2 signal has an in-built 200 ms drop-off delay. The BLK_WEI2 input is usually connected to all the fault detection functions within the terminal except the residual overvoltage function.

Weak-end trip logic

Weak-end trip logic is activated if it receives an enable signal from Level detector and ECHO output of Echo logic is activated. Then a general trip signal OPR_WEI is activated. The activation of the CB_OPEN input blocks the tripping.

The OPR_WEI output can be blocked by activating the BLOCK input.

5.12.6 Application

Current reversal logic

In parallel feeder applications, when the overreaching permissive communication schemes are used, unselective tripping may result due to the current reversal. Such a condition can occur in the healthy feeder when the fault is cleared in the faulty feeder. The tripping of the healthy parallel feeder may lead to losing the connection between the two buses. To avoid this situation, the current reversal logic (transient blocking logic) can be used.

Assume that Relay A1, Relay A2, Relay B1 and Relay B2 are equipped with DSOCPSCH and the permissive overreach scheme is enabled. A fault occurs at Feeder 1 close to bus B. Relay A2 at the healthy Feeder 2 recognizes the fault in the forward direction within the overreaching zone Z2 and sends a CS signal to Relay B2 according to the POTT scheme. Relay B2 does not recognize the fault in the forward direction and does not operate even though a permissive CR signal is received from Relay A2. Moreover, Relay B2 does not send a permissive signal to Relay A2.

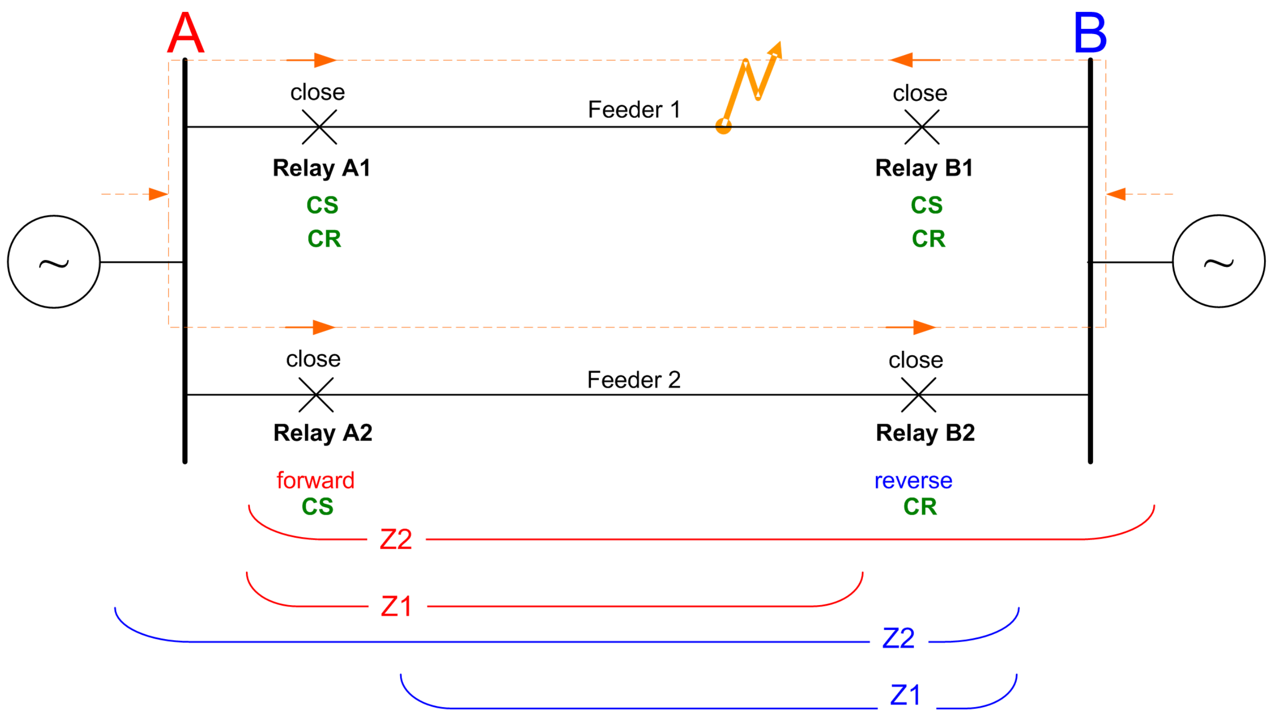


Figure 719: The fault occurs at one of the parallel lines.

The faulty feeder (Feeder 1) is not simultaneously tripped at both ends and it might occur that, for example, the circuit breaker closer to the fault at Relay B1 is tripped faster than the breaker at bus A due to the direct operation of the zone Z1 of Relay

B1. Thus, when the breaker at Relay B1 opens, the direction of the fault current at the healthy feeder (Feeder 2) is reversed.

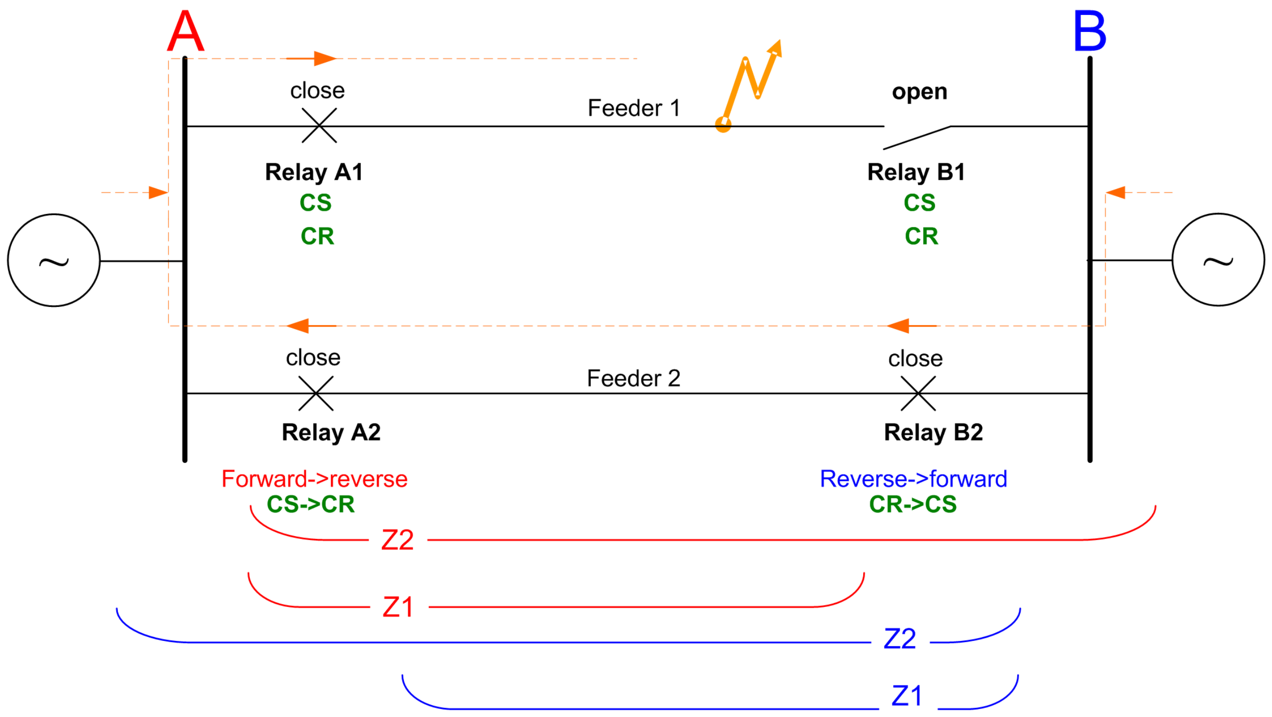


Figure 720: The circuit breaker at Relay B1 opens and creates a current reversal condition

Relay A2 is still sending the CS signal because of the reset time delay of the forward zone of Relay A2 when the overreaching zone of Relay B2 starts to recognize the fault in the forward direction. Relay B2 can malfunction and trip the breaker of the healthy feeder.

This problem can be solved by using the reverse-looking zone (Z3) to recognize the fault in reverse direction and temporarily block the operation of DSOCPSCH due to the current reversal condition. This is used in CRWPSCH.

Weak-end infeed logic

Avoid using the WEI function at both feeder ends. It can only be enabled at the weak end.

The weak-end infeed logic should be used only in permissive schemes.

Setting guidelines for current reversal logic

Setting *Reversal reset time*: Set the *Reversal reset time* setting to the maximum reset time of the communication channel. A minimum setting of 40 ms is recommended. A long *Reversal reset time* setting increases the security against unwanted tripping, but delays the fault clearing if the fault develops in one feeder and involves the other. However, the probability of this type of fault is small.

Setting *Reversal time*: Set the start delay *Reversal time* setting to less than 80 percent of the breaker operate time, but to a minimum of 20 ms.

Setting guidelines for weak-end infeed logic

The WEI function returns the received carrier signal with the ECHO output when it receives the carrier signal (CR) if no fault has been detected by forward- and reverselooking zones and the signal duration is longer than the *Wei Crd time* coordination time delay setting. Set the *Wei Crd time* = "0.010" s to avoid the spurious carrier received signals that activate the WEI logic and cause unwanted communication.

Set the voltage criteria *PPV level for Wei* and *PhV level for Wei* for the weak-end trip to 70 percent of the system's base voltage. The setting should be below the minimum operate voltage of the system but above the voltage that occurs for a fault on the protected feeder. The phase-to-phase elements must be verified not to operate for the phase-to-earth faults.

5.12.7 Signals

5.12.7.1 CRWPSCH Input signals

Table 1199: CRWPSCH Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_IRV	BOOLEAN	0=False	Block of current reversal function
BLK_WEI1	BOOLEAN	0=False	Block of WEI Logic
BLK_WEI2	BOOLEAN	0=False	Block of WEI logic due to operation of other protections
IRV	BOOLEAN	0=False	Activation of current reversal logic
FF	BOOLEAN	0=False	Block of trip from WEI logic through fuse-failure function
CB_OPEN	BOOLEAN	0=False	Block of trip from WEI logic by an open breaker
CR	BOOLEAN	0=False	POR Carrier receive for WEI logic
CR	BOOLEAN	0=False	POR Carrier signal received from remote end

5.12.7.2 CRWPSCH Output signals

Table 1200: CRWPSCH Output signals

Name	Type	Description
OPR_IRV	BOOLEAN	Operation of WEI logic in phase B
OPR_WEI	BOOLEAN	Operation of WEI logic in phase C
ECHO	BOOLEAN	Carrier send by WEI logic
CR	BOOLEAN	POR Carrier signal received from remote end

5.12.8 CRWPSCH Settings

Table 1201: CRWPSCH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reversal mode	1=Off 2=On			1=Off	Operating mode of Current Reversal Logic
Wei mode	1=Off 3=Echo 4=Echo and Operate			1=Off	Operating mode of WEI logic
PhV level for Wei	0.10...0.90	xUn	0.01	0.70	Phase to Neutral voltage for detection of fault condition
PPV level for Wei	0.10...0.90	xUn	0.01	0.70	Phase to Phase voltage for detection of fault condition
Reversal time	0...60000	ms	10	20	Pickup time for current reversal logic
Reversal reset time	0...60000	ms	10	60	Time Delay to prevent Carrier send and local trip
Wei Crd time	0...60000	ms	10	10	Coordination time for the WEI logic

5.12.9 CRWPSCH Monitored data

Table 1202: CRWPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
CRWPSCH	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.12.10 Technical data

Table 1203: CRWPSCH Technical data

Characteristic	Value
Operate accuracy	At the frequency $f = f_n$
	±1.5 % of the set value or ±0.002 × U_n
Operate time accuracy	±1.0 % of the set value or ±20 ms

5.13 Current reversal and weak-end infeed logic for residual overcurrent RCRWPSCH (ANSI 85 67G/N CREV,WEI)

5.13.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current reversal and weak-end in-feed logic for residual overcurrent	RCRWPSCH	CLCRWN	85 67G/N CREV,WEI

5.13.2 Function block

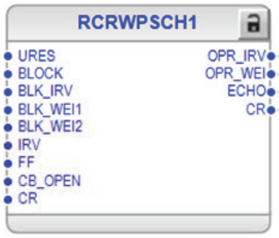


Figure 721: Function block

5.13.3 Functionality

The current reversal and weak-end infeed logic for residual overcurrent function RCRWPSCH can be used when the communication logic for residual overcurrent RESCPSCH requires additional logics to operate correctly in all power system conditions.

In parallel feeder applications, the direction of the fault current on the healthy feeder can change when the circuit breaker on the faulty feeder opens to clear the fault. This can lead to an unwanted operation of the residual overcurrent protection on the healthy parallel feeder when RESCPSCH with the permissive overreach scheme is used. The main purpose of the current reversal logic is to prevent such unwanted operations.

The permissive communication schemes can operate only when the protection in the remote terminal can detect the fault. This detection requires sufficient minimum fault current. If such current is not available due to too weak a remote end source, the WEI logic can be used to overcome the situation and trip the remote end breaker.

5.13.4 Analog channel configuration

RCRWPSCH has one analog group input which must be properly configured.

Table 1204: Analog inputs

Input	Description
URES [1]	Residual voltage (measured or calculated), necessary when *Wei mode* is set to "Echo and Operate"

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 1205: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected to calculate the residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.13.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of RCRWPSCH can be described with a module diagram. All the modules in the diagram are explained in the next sections.

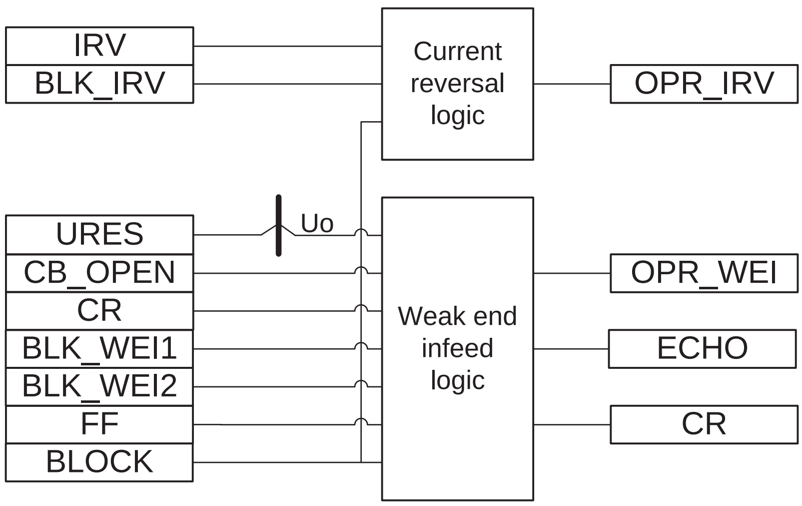


Figure 722: Functional module diagram

[1] Can be connected to GRPOFF if *Wei mode* is set to "Off" or "Echo".

Current reversal logic

Current reversal logic is enabled by changing the value of the *Reversal mode* setting to "On".

Current reversal logic uses the start signal of the reverse directional residual overcurrent function connected to the IRV input, which is used to recognize the fault in the reverse direction, that is, in the parallel feeder. When the reverse directional residual overcurrent function is activated, the logic is ready to issue an OPR_IRV output signal after a start delay (setting *Reversal time*). The OPR_IRV signal is connected to the BLK_CS_OPR input of the scheme communication logic function to block the sending of the carrier send signal (CS) and the activation of the OPERATE output of the communication logic. The OPR_IRV signal has a drop-off delay defined with the *Reversal reset time* setting.

An internal 10 ms drop-off timer is provided which ensures the current reversal logic is activated for short-duration input signals, even if the *Reversal reset time* setting is set to zero.

The BLK_IRV input is used to block the activation of the OPR_IRV output. The BLK_IRV input is typically connected to the start signals of the forward-looking residual overcurrent function in the terminal. General blocking is achieved by activating the BLOCK input.

Weak-end infeed (WEI) logic

The WEI logic is used to activate the residual overcurrent protection function when the fault current infeed is too low due to, for example, high source impedance or fault current distribution between sources. When activated, the carrier receive (CR) signal is logically combined with the local criteria to initiate the tripping of the weak-end breaker. The received signal is also echoed back to accelerate the tripping at the opposite end with the stronger source.

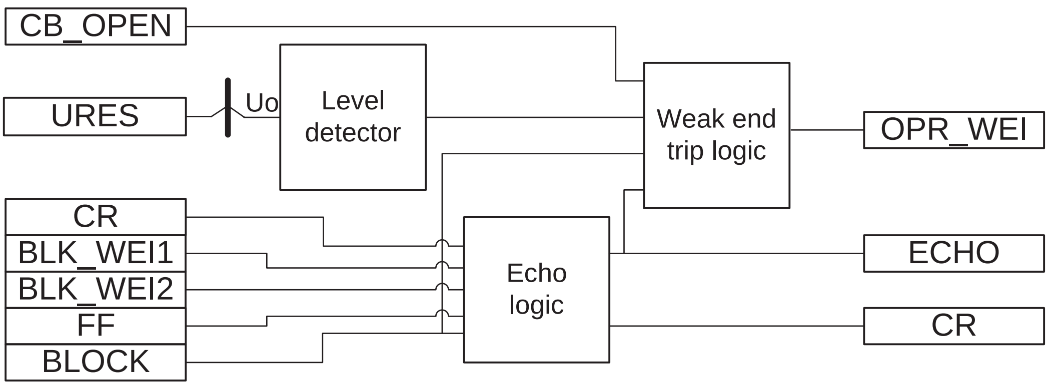


Figure 723: Functional module diagram of Weak-end infeed logic

The WEI logic is enabled using the *Wei mode* setting.

- If *Wei mode* = "Off", the WEI logic is disabled.
- If *Wei mode* = "Echo", the WEI logic is enabled without Level detector.
- If *Wei mode* = "Echo and Operate", the WEI logic is enabled with Level detector.

Level detector

Level detector sends an enabling signal to Weak-end trip logic when the residual voltage is above the *Residual voltage Val* setting.

Echo logic

Echo logic returns the received carrier signal with the ECHO output when it receives a carrier receive signal (CR) if no fault has been detected by the forward and reverse directional residual overcurrent functions and the duration of CR is longer than the coordination time delay (the setting *Wei Crd time*). The received carrier receive signal is also given as the CR output.

When the WEI logic is enabled at both feeder ends, a spurious signal can be looped round by Echo logic. To avoid a continuous lockup of the system, the duration of the echoed signal is limited to 200 ms.

The ECHO and CR outputs can be blocked by activating the BLOCK input. The FF, BLK_WEI1 and BLK_WEI2 inputs can be used to block the ECHO output. The FF input is usually connected to the functional output of the fuse failure function, and the BLK_WEI1 input is typically connected to the start signals of the forward and reverse directional residual overcurrent functions in the terminal. The BLK_WEI2 signal has an in-built 200 ms drop-off delay and is usually connected to all the fault detection functions in the terminal except the residual overvoltage function.

Weak-end trip logic

Weak-end trip logic is activated if it receives an enable signal from Level detector and ECHO output of Echo logic is activated. Then a general trip signal OPR_WEI is activated. The activation of the CB_OPEN input blocks the tripping.

The OPR_WEI output can be blocked by activating the BLOCK input.

5.13.6 Application

Current reversal logic

When the overreaching permissive communication schemes are used in parallel feeder applications, the current reversal can result in unselective tripping. Such a condition can occur in the healthy feeder when the fault is cleared in the faulty feeder. The tripping of the healthy parallel feeder can lead to losing the connection between the two buses. To avoid this situation, the current reversal logic (transient blocking logic) can be used.

In the current reversal condition, the relays Relay A1, Relay A2, Relay B1 and Relay B2 can be equipped with the scheme communication logic RESCPSCH and the permissive overreach scheme can be enabled.

A fault occurs at Feeder 1 close to bus B. Relay A2 at the healthy feeder 2 recognizes the fault in the forward direction and sends a CS signal to Relay B2 according to the PUTT scheme. Relay B2 does not recognize the fault in the forward direction and hence does not send a permissive signal to Relay A2.

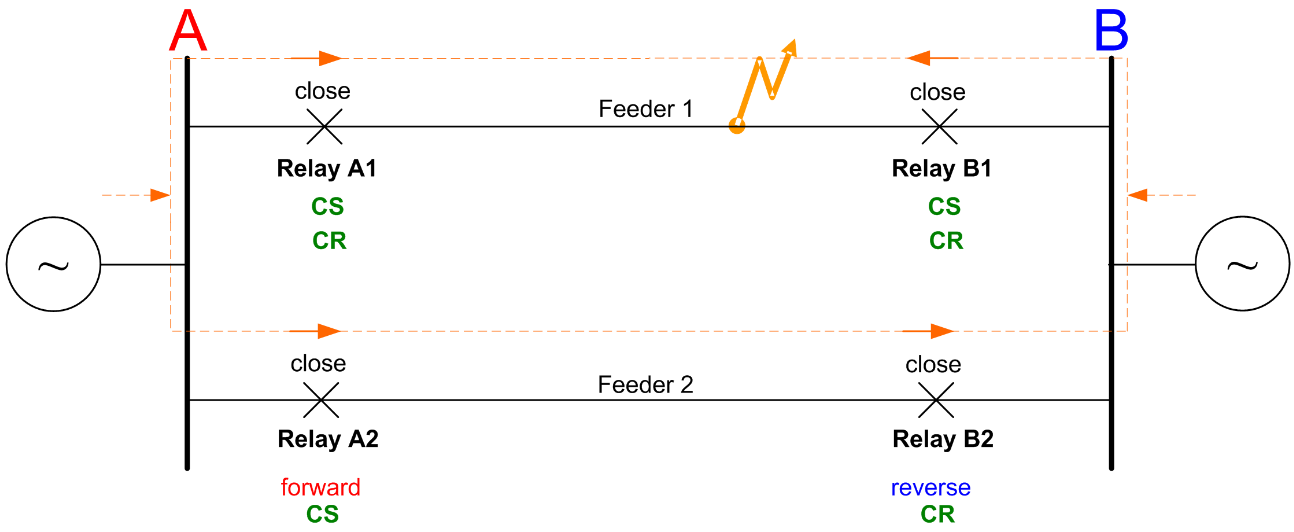


Figure 724: Fault occurs at one of the parallel lines. CS=carrier signal sending, CR=carrier signal receiving

The faulty feeder (Feeder 1) is not simultaneously tripped at both ends and, for example, the circuit breaker closer to the fault at Relay B1 may be tripped faster than the breaker at bus A. As a result, when the breaker at Relay B1 opens, the direction of the fault current at the healthy feeder (Feeder 2) is reversed.

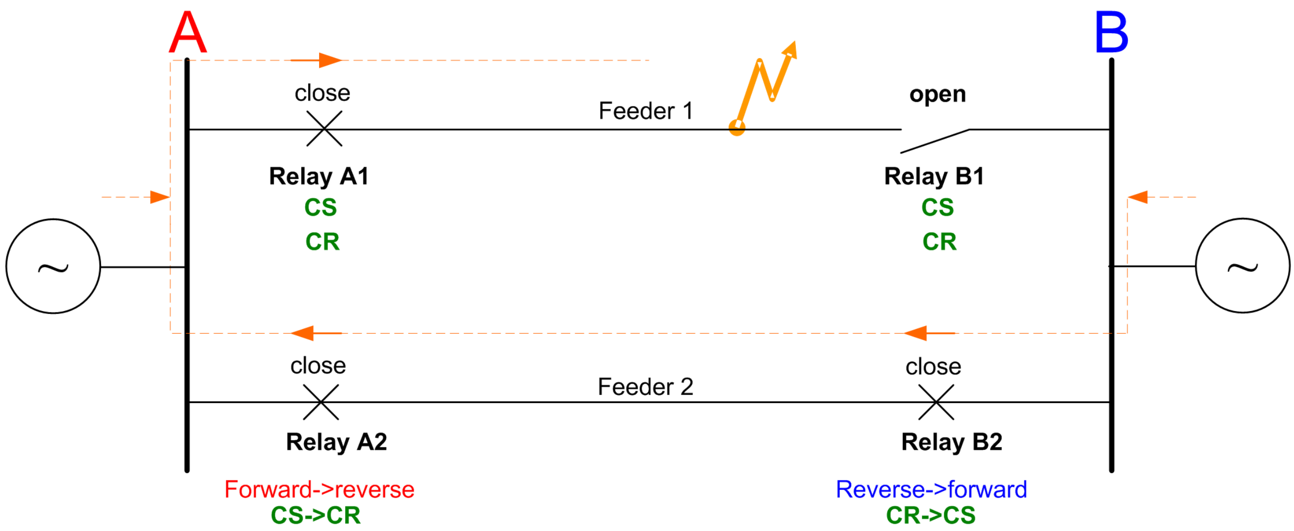


Figure 725: Circuit breaker at Relay B1 opens and creates a current reversal condition. CS=carrier signal sending, CR=carrier signal receiving

Relay A2 still sends the CS signal because of the reset time delay of the forward direction residual overcurrent function of Relay A2. When Relay B2 starts to recognize the fault in the forward direction, Relay B2 can malfunction and trip the breaker of the healthy feeder.

This problem can be solved using the reverse directional residual overcurrent function to recognize the fault in reverse direction and temporarily block the operation of the scheme communication logic due to the current reversal condition. This is used in RCRWPSCH.

Weak-end infeed (WEI) logic

Do not use the WEI function at both feeder ends. It can only be enabled at the weak end.

The WEI logic is recommended to be used only in the permissive schemes.

Setting guidelines for current reversal logic

Reversal reset time: This setting can be set to the maximum reset time of the communication channel. A minimum setting of 40 ms is recommended. A long *Reversal reset time* setting increases the security against unwanted tripping, but delays the fault clearing if the fault develops from one feeder to involve the other. However, the probability of this type of fault is small.

Reversal time: Set the start delay reversal time below 80 percent of the breaker operate time, but to a minimum of 20 ms.

Setting guidelines for Weak-end infeed (WEI) logic

The WEI logic returns the received carrier signal with the `ECHO` output when it receives the carrier signal (CR) if no fault has been detected by the forward and reverse directional measuring elements and the duration is longer than the *Wei Crd time* coordination time delay setting. To prevent the spurious carrier receive signals from activating the WEI logic and causing unwanted communication, the *Wei Crd time* setting can be set to "0.010 s".

5.13.7 Signals

5.13.7.1 RCRWPSCH Input signals

Table 1206: RCRWPSCH Input signals

Name	Type	Default	Description
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
BLK_IRV	BOOLEAN	0=False	Block of current reversal function
BLK_WEI1	BOOLEAN	0=False	Block of WEI Logic
BLK_WEI2	BOOLEAN	0=False	Block of WEI logic due to operation of other protections
IRV	BOOLEAN	0=False	Activation of current reversal logic
FF	BOOLEAN	0=False	Block of trip from WEI logic through fuse-failure function

Table continues on the next page

Name	Type	Default	Description
CB_OPEN	BOOLEAN	0=False	Block of trip from WEI logic by an open breaker
CR	BOOLEAN	0=False	POR Carrier receive for WEI logic
CR	BOOLEAN	0=False	POR Carrier signal received from remote end

5.13.7.2 RCRWPSCH Output signals

Table 1207: RCRWPSCH Output signals

Name	Type	Description
OPR_IRV	BOOLEAN	Operation of current reversal logic
OPR_WEI	BOOLEAN	Operation of WEI logic
ECHO	BOOLEAN	Carrier send by WEI logic
CR	BOOLEAN	POR Carrier signal received from remote end

5.13.8 RCRWPSCH Settings

Table 1208: RCRWPSCH Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reversal mode	1=Off 2=On			1=Off	Operating mode of Current Reversal Logic
Wei mode	1=Off 3=Echo 4=Echo and Operate			1=Off	Operating mode of WEI logic
Residual voltage Val	0.05...0.70	xUn	0.01	0.25	Neutral voltage setting for fault conditions measurement
Reversal time	0...60000	ms	10	20	Pickup time for current reversal logic
Reversal reset time	0...60000	ms	10	60	Time Delay to prevent Carrier send and local trip
Wei Crd time	0...60000	ms	10	0	Coordination time for the WEI logic

5.13.9 RCRWPSCH Monitored data

Table 1209: RCRWPSCH Monitored data

Name	Type	Values (Range)	Unit	Description
RCRWPSCH	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.13.10 Technical data

Table 1210: RCRWPSCH Technical data

Characteristic	Value
Operate accuracy	At the frequency $f = f_n$
	±1.5 % of the set value or ±0.002 × U_n
Operate time accuracy	±1.0 % of the set value or ±20 ms

5.14 Three-phase power directional element DPSRDIR (ANSI 67P-TC)

5.14.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase power directional element	DPSRDIR	I1->	67P-TC

5.14.2 Function block

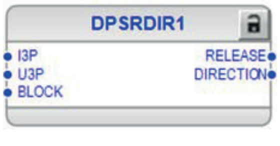


Figure 726: Function block

5.14.3 Functionality

The three-phase power directional element function DPSRDIR is used to detect positive-sequence power direction. The output of the function is used for blocking or releasing other functions in protection scheme.

The directional positive-sequence power protection contains a blocking functionality which blocks function output and resets Timer.

DPSRDIR executes on the direction of positive-sequence power and not the value. If overpower or underpower is needed, refer to DOPPDPR and DUPPDPR. DPSRDIR is generally used for directional controls.

5.14.4 Analog channel configuration

DPSRDIR has two analog group inputs which must be properly configured.

Table 1211: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1212: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.14.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of DPSRDIR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

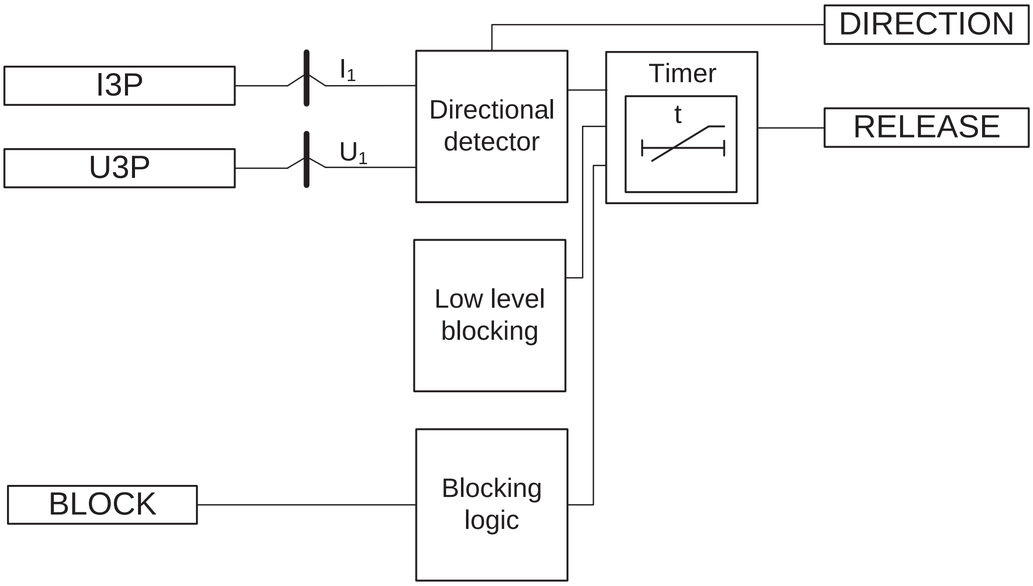


Figure 727: Functional module diagram

Directional detector

The Directional detector module compares the angle of the positive-sequence current I1 to the angle of the positive-sequence voltage V1. Using the positive-sequence voltage angle as reference, the positive-sequence current angle is compared to the *Characteristic angle* setting. If the angular difference is within the operating sector selected with the *Directional mode* setting, the On signal is sent to Timer.

The operating sector is defined by the setting *Min forward angle*, *Max forward angle*, *Min reverse angle* and *Max reverse angle*. The options that can be selected for the *Directional mode* setting are "Forward" and "Reverse".

The sector limits are always given as positive degree values.

The *Characteristic angle* setting is also known as Relay Characteristic Angle (RCA), Relay Base Angle or Maximum Torque Line.

Low-level blocking

For a reliable operation, signal levels should be greater than the minimum level. If they are not greater than the minimum level, Timer is blocked. If the amplitude of the positive-sequence current is greater than the *Min trip current* value and the positive-sequence voltage amplitude is greater than the *Min trip voltage* value, the On signal is sent to Timer.

Timer

Once activated, the internal operating timer is started. The Timer characteristic is according to definite time DT. When Timer has reached the value of *Release delay time*, the RELEASE output is activated. If a drop-off situation happens, that is, if the operating current moves outside the operating sector or signal amplitudes drop below the minimum level before *Release delay time* is exceeded, the Timer reset state is activated. If the drop-off continues for more than *Reset delay time*, Timer is deactivated.

Blocking logic

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates the RELEASE output and resets Timer.

5.14.6 Application

The three-phase power directional element function DPSRDIR improves the possibility to obtain a selective function of the overcurrent protection in meshed networks. DPSRDIR is used to block or release other overcurrent protection functions.

5.14.7 Signals

5.14.7.1 DPSRDIR Input signals

Table 1213: DPSRDIR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

5.14.7.2 DPSRDIR Output signals

Table 1214: DPSRDIR Output signals

Name	Type	Description
RELEASE	BOOLEAN	Release signal if direction criteria is satisified
DIRECTION	Enum	Direction information

5.14.8 DPSRDIR Settings

Table 1215: DPSRDIR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Release delay time	0...1000	ms	1	10	Release delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Max forward angle	0...90	deg	1	88	Maximum phase angle in forward direction
Max reverse angle	0...90	deg	1	88	Maximum phase angle in reverse direction
Min forward angle	0...90	deg	1	88	Minimum phase angle in forward direction
Min reverse angle	0...90	deg	1	88	Minimum phase angle in reverse direction
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode

Table 1216: DPSRDIR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 1217: DPSRDIR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Min operate current	0.01...1.00	xIn	0.01	0.10	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.30	Minimum operating voltage

5.14.9 DPSRDIR Monitored data

Table 1218: DPSRDIR Monitored data

Name	Type	Values (Range)	Unit	Description
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
DPSRDIR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.15 Neutral power directional element DNZSRDIR (ANSI 67N-TC)

5.15.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Neutral power directional element	DNZSRDIR	I2->, Io->	67N-TC

5.15.2 Function block

Figure 728: Function block

5.15.3 Functionality

Neutral power directional element function DNZSRDIR is used to detect negative or residual power direction. The output of the function is used for blocking or releasing other functions in protection scheme.

In negative-sequence voltage selection, if the angle difference between negativesequence voltage and negative-sequence current is in a predefined direction (either in forward or reverse direction), DNZSRDIR gives a release signal after a definite time delay.

In residual voltage selection, if the angle difference between residual voltage and residual current is in a predefined direction (either in forward or reverse direction), DNZSRDIR gives release signal after a definite time delay.

This function contains a blocking functionality which blocks the function output and resets Timer.

DNZSRDIR executes on the direction of either negative-sequence or zero-sequence power and not the value. The function is generally used for directional controls.

5.15.4 Analog channel configuration

DNZSRDIR has four analog group inputs which must be properly configured.

Table 1219: Analog inputs

Input	Description
I3P [1]	Three-phase currents, necessary when Pol quantity is "Neg. seq. volt."
IRES [2]	Residual current (measured or calculated), necessary when Pol quantity is "Zero seq. volt."
U3P [1]	Three-phase voltages, necessary when Pol quantity is "Neg. seq. volt."
URES [2]	Residual voltage (measured or calculated), necessary when Pol quantity is "Zero seq. volt."

See the preprocessing function blocks in this document for the possible signal sources.The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 1220: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two phase voltage channels connected but it is recommended to connect all three voltage channels.
URES calculated	The function requires that all three voltage channels are connected to calculate residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.15.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of DNZSRDIR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

[1] Can be connected to GRPOFF if *Pol quantity* is set to "Zero seq. volt.".
[2] Can be connected to GRPOFF if *Pol quantity* is set to "Neg. seq. volt.".

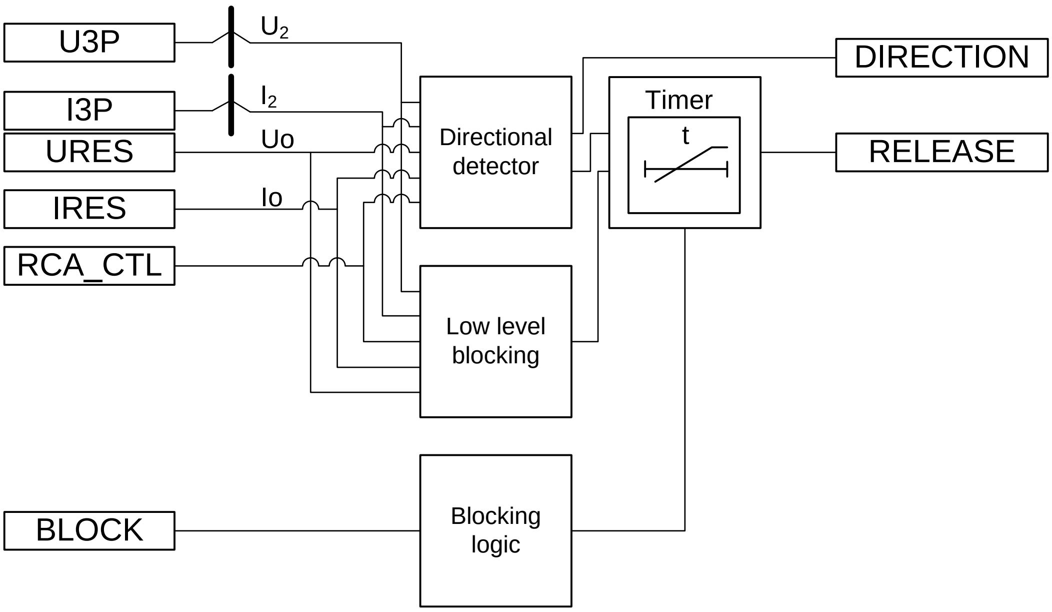


Figure 729: Functional module diagram

Directional detector

When "Neg. seq. volt." selection is made using the *Pol quantity* setting, the Directional detector module compares the angle of the negative-sequence current (I_2) to the negative-sequence voltage ($–U_2$). Using the negative-sequence voltage angle as the reference, the negative-sequence current angle is compared to the *Characteristic angle* setting. If the angle difference is within the operating sector selected by *Direction mode* setting, the Enable signal is sent to Timer.

The value of *Characteristic angle* should be chosen in such way that all the faults in the operating direction are seen in the operating zone and all the faults in the opposite direction are seen in the backward zone.

The operating sector is defined by the settings *Max forward angle*, *Max reverse angle*, *Min forward angle* and *Min reverse angle*. The options that can be selected for *Directional mode* settings are “Forward” and “Reverse”.

Characteristic angle is also known as Relay Characteristic Angle RCA, Relay Base Angle or Maximum Torque Line.

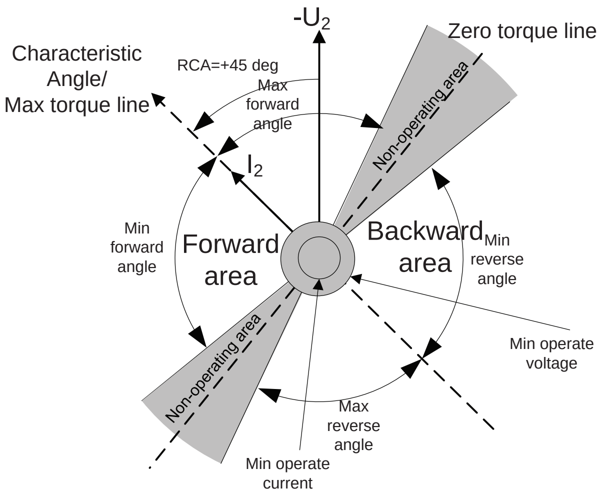


Figure 730: Configurable directional setting when "Neg. seq. volt." selection is made using the Pol quantity setting

When *Zero seq. volt.* voltage selection is made using *Pol quantity* setting, the directional detector module compares the angle of the residual current to the residual voltage. Using the residual voltage as reference, the residual current angle is compared to the *Characteristic angle* setting. If the angle difference is within the operating sector selected by the *Directional mode* setting, the Enable signal is sent to Timer.

The polarizing quantity (residual voltage) is inverted because of switched voltage measurement cables, the correction can be done by setting the *Pol reversal* setting to "True", which rotates the polarizing quantity by 180 degrees.

The directional characteristic for the measured or calculated residual power is same.

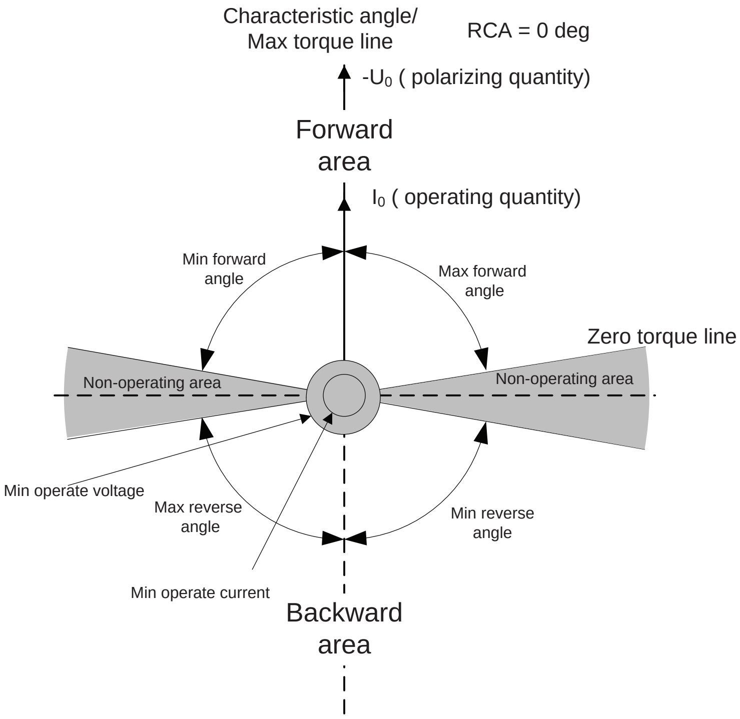


Figure 731: Configurable directional setting for Zero seq. volt. (residual voltage) using the Pol quantity setting

The *Characteristic angle* setting is done based on method of grounding employed in the network. For example, in case of an isolated network, *Characteristic angle* is set to –90°, and in case of a compensated network, *Characteristic angle* is set to 0° and 60° for solidly grounded systems. In general *Characteristic angle* is selected so that it matches close to the expected fault angle value, which results in maximum sensitivity. *Characteristic angle* can be set anywhere between –179° to +180°. The figures show examples of the operating area with RCA set to +60° and –90°, respectively.

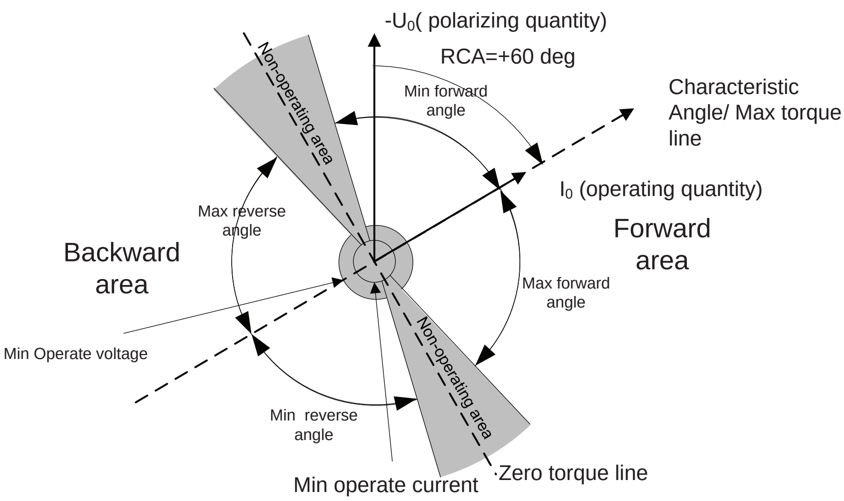


Figure 732: Configurable directional characteristics (RCA =+60 ˚) for a solidly earthed network

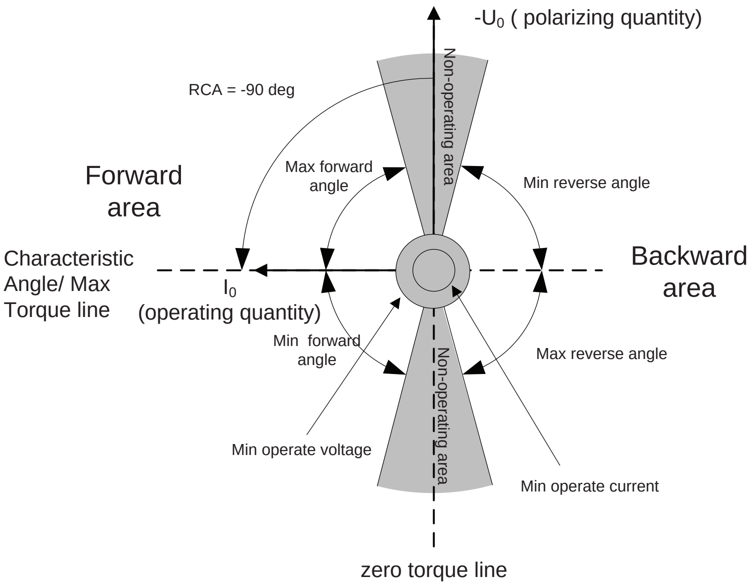


Figure 733: Configurable directional characteristics (RCA = -90 ˚) for an isolated network

Characteristic angle should be set to a positive value if the operating signal lags the polarizing quantity -VG or -VN, respectively, and a negative value if operating signal leads the polarizing quantity, respectively.

Table 1221: Recommended Characteristic angle setting for different network

Type of network	Characteristic angle recommended
Compensated network	0°
Solidly grounded network	+60°
Isolated network	–90°

The *Characteristic angle* setting is adjusted to the operation according to the method of neutral-point grounding, so that in an isolated network *Characteristic angle* is –90° and in a compensated network 0°. In addition, *Characteristic angle* can be changed via the control signal RCA_CTL, in which case the alternatives are –90° and 0°. The operation of the `RCA_CTL` input depends on the *Characteristic angle* setting.

The Peterson coil or the grounding resistor may be temporarily out of operation. To keep the protection scheme selective, it is necessary to update the *Characteristic angle* settings accordingly. This is done with an auxiliary input in the relay which receives a signal from an auxiliary switch of the disconnector of the Peterson coil in compensated networks or of the grounding resistor in grounded network as a result the *Characteristic angle* is set automatically to suit the earthing method.

Table 1222: Characteristic angle control for the RCA_CTL condition

Characteristic angle Setting	RCA_CTL=FALSE	RCA_CTL=TRUE
–90°	*Characteristic angle* = –90°	*Characteristic angle* = 0°
0°	*Characteristic angle* = 0°	*Characteristic angle* = –90°

When the phase angle criterion is used, the DIRECTION output indicates on which operating sector the negative or residual power is measured.

Low-level blocking

For a reliable operation, signal levels should be greater than the minimum level. If they are not greater than the minimum level, Timer is blocked.

In the "Neg. seq. volt." polarization selection using the *Pol quantity* setting, if the amplitude of the negative-sequence current is greater than the *Min operate current* value and the negative-sequence voltage amplitude is greater than the *Min operate voltage* value, the Enable signal is sent to Timer.

In the "Zero seq. volt." polarization selection using *Pol quantity*, if the amplitude of the residual current is greater than the *Min operate current* value and residual voltage amplitude is greater than the *Min operate voltage* value, the Enable signal is sent to Timer.

Timer

Once activated, the internal operating timer is started. The Timer characteristic is according to DT. When Timer has reached the value of *Release delay time*, the RELEASE output is activated. If a drop-off situation happens, that is, if the operating current moves out of the operating sector or signal amplitudes drop below the minimum levels, before *Release delay time* is exceeded, the Timer reset state is activated. If the drop-off continues for more than *Reset delay time*, Timer is deactivated.

Blocking logic

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates RELEASE output and resets Timer.

5.15.6 Application

The neutral power directional element function DNZSRDIR improves the possibility to obtain selective function of the overcurrent protection in meshed networks. DNZSRDIR is used to block or release other overcurrent protection functions.

5.15.7 Signals

5.15.7.1 DNZSRDIR Input signals

Table 1223: DNZSRDIR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage

Table continues on the next page

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

5.15.7.2 DNZSRDIR Output signals

Table 1224: DNZSRDIR Output signals

Name	Type	Description
RELEASE	BOOLEAN	Release signal if direction criteria is satisified
DIRECTION	Enum	Direction information

5.15.8 DNZSRDIR Settings

Table 1225: DNZSRDIR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Release delay time	0...1000	ms	10	10	Release delay time
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode
Characteristic angle	-179...180	deg	1	60	Characteristic angle
Max forward angle	0...180	deg	1	88	Maximum phase angle in forward direction
Min forward angle	0...180	deg	1	88	Minimum phase angle in forward direction
Max reverse angle	0...180	deg	1	88	Maximum phase angle in reverse direction
Min reverse angle	0...180	deg	1	88	Minimum phase angle in reverse direction

Table 1226: DNZSRDIR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Pol quantity	3=Zero seq. volt. 4=Neg. seq. volt.			3=Zero seq. volt.	Reference quantity used to determine fault direction

Table 1227: DNZSRDIR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time
Min operate current	1.0...100.0	%In	0.1	10.0	Minimum operating current
Min operate voltage	1.0...100.0	%Un	0.1	30.0	Minimum operating voltage
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity

5.15.9 DNZSRDIR Monitored data

Table 1228: DNZSRDIR Monitored data

Name	Type	Values (Range)	Unit	Description
ANGLE_RCA	FLOAT32	-180.00...180.00	deg	Angle between operating angle and characteristic angle
DNZSRDIR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.16 Load blinder LBRDOB (ANSI 21LB)

5.16.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
Load blinder	LBRDOB	LB	21LB

5.16.2 Function block

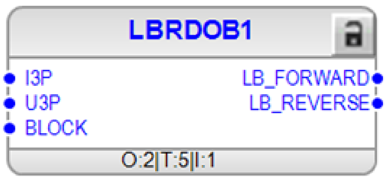


Figure 734: Function block

5.16.3 Functionality

Load blinder, or Load encroachment, function LBRDOB is used to block the directional overcurrent protection aiming at avoiding incorrect trip in case of heavy loading condition in network whose power factor close to 1.00.

Operation principle is based on calculated positive sequence impedance. Function provides blocking signal if positive sequence impedance is in load blinder forward or reverse area.

5.16.4 Analog channel configuration

LBRDOB has two analog group inputs which must be properly configured.

Table 1229: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1230: Special conditions

Condition	Description
U3P connected real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

5.16.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of Load blinder LBRDOB can be described by using a module diagram (see *Figure 735*). All the modules in the diagram are explained in the next sections.

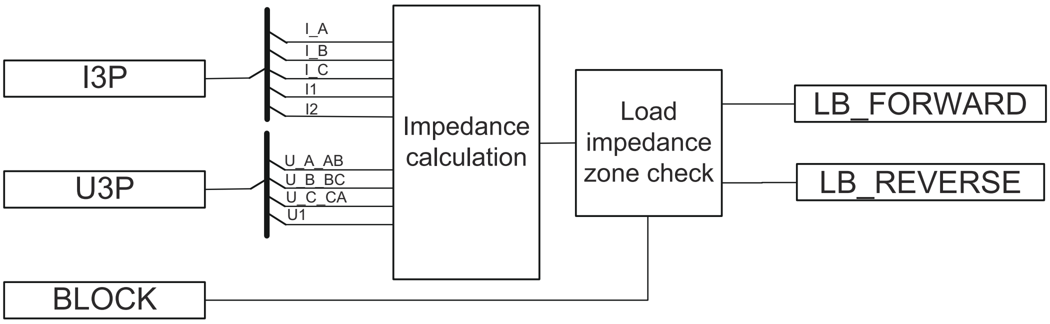


Figure 735: Functional module diagram

Impedance calculation

The impedance calculation is enabled if the negative sequence current stays below the *Max Ng Seq current* setting and the positive sequence voltage stays above the *Min Ps Seq voltage* setting.

The positive sequence impedance phasor $\bar{Z}_1$ is calculated according to:

$$\bar{Z}_1 = \frac{\bar{U}_1}{\bar{I}_1}$$

(Equation 312)

where $\bar{U}_1$ is positive sequence voltage phasor and $\bar{I}_1$ is positive sequence current phasor.

The calculated positive sequence impedance amplitude *Z1_AMPL* (primary ohms) and angle *Z1_ANGLE* (degrees) are available in monitored data view.

The calculated impedance is converted to primary ohms as the operating characteristics are defined with settings in primary ohms.

Load impedance zone check

The forward and reverse load blinder sectors are defined separately. The load blinder forward area, or load-out region, or load exporting is limited with the *Max impedance angle* and *Min impedance angle*. Similarly, these two setting parameters are also as limitations for the load blinder reverse area, or load-in region, or load importing. the *Resistive reach Fw* is maximum resistive load on forward load blinder area. *Resistive reach Rv* is maximum resistive load on reverse load blinder area. Characteristics are shown *Figure 736*.

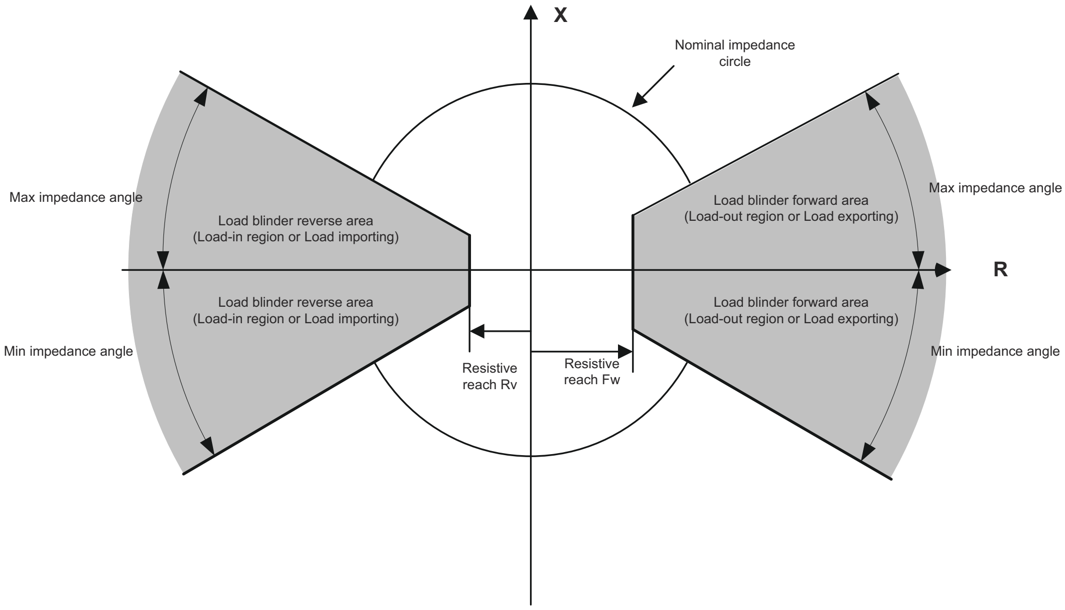


Figure 736: Operating sectors for load blinder

The blinder directional operation can be selected with the *Directional mode* setting. The alternatives are "Non-directional", "Forward" and "Reverse" operation.

Forward operation is allowed if *Directional mode* is set to “Forward”. If the resistive part value of positive sequence impedance is higher than *Resistive reach Fw* and the angle of positive sequence impedance stays in the range limited with the *Max impedance angle* and *Min impedance angle* on forward area, the function output LB_FORWARD is activated.

Reverse operation is allowed if *Directional mode* is set to “Reverse”. If the resistive part value of positive sequence impedance exceeds the limitation of *Resistive reach Rv* and the angle of positive sequence impedance stays in the range limited with the *Max impedance angle* and *Min impedance angle* on reverse area, the function output LB_REVERSE is activated.

In case *Directional mode* is set to “Non-directional”, operation is allowed both directions according to conditions described above.

Activation of the BLOCK input deactivates the function outputs.

5.16.6 Application

Load blinder or load encroachment, function LBRDOB is used to block the directional overcurrent protection aiming at avoiding incorrect trip in case of heavy loading condition in network. In general, the active power increases to the level leading to a high power factor, the network turns into heavy load status, and there exists risk of incorrect trip for the directional overcurrent protection because of high level of load current.

The suitability of *Resistive reach Fw* and *Resistive reach Rv* settings will influence the activation of load blinder function. If *Resistive reach Fw* and *Resistive reach Rv* are set beyond the network minimal resistive load, the function will not be activated in the case that the load impedance approaches the network minimal impedance load. Hence, the absolute values of *Resistive reach Fw* and *Resistive reach Rv* should be set less than that of the minimal resistive load.

The blinder in forward direction, *Resistive reach Fw*, can be calculated according to

$$Resistive\ reach\ Fw = K \cdot \frac{U^2_{expmin}}{P_{expmax}}$$

(Equation 313)

where:

P_{expmax}	is the maximum exporting active power
U_{expmin}	is minimum phase-to-phase voltage when the exporting active power occurs
K	is a security factor to ensure that the setting of *Resistive reach Fw* less than minimal resistive load, with a recommended value 0.8.

The resistive boundary *Resistive reach Rv* can be obtained in the same way as *Resistive reach Fw*, but replace the maximum exporting active power P_{expmax} and the corresponding voltage U_{expmin} with the maximum importing active power P_{impmax} and the corresponding voltage U_{impmin}.

The *Max impedance angle* and *Min impedance angle* are symmetric in forward and reverse direction, these values are recommended to set the maximum possible load angle when load active power arrives at top. A value bigger than 20° must be used.

5.16.7 Signals

5.16.7.1 LBRDOB Input signals

Table 1231: LBRDOB Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

5.16.7.2 LBRDOB Output signals

Table 1232: LBRDOB Output signals

Name	Type	Description
LB_FORWARD	BOOLEAN	Load discrimination active in forward direction
LB_REVERSE	BOOLEAN	Load discrimination active in reverse direction

5.16.8 Settings

5.16.8.1 LBRDOB Settings

Table 1233: LBRDOB Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Resistive reach Fw	1.00...6000.00	ohm	0.01	150.00	Resistive forward reach for load discrimination
Resistive reach Rv	1.00...6000.00	ohm	0.01	150.00	Resistive reverse reach for load discrimination
Max impedance angle	5...85	deg	1	25	Maximum angle for load area
Min impedance angle	-85...-5	deg	1	-25	Minimum angle for load area
Directional mode	1=Non-directional 2=Forward 3=Reverse			2=Forward	Directional mode

Table 1234: LBRDOB Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				

Table 1235: LBRDOB Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min Ps Seq voltage	0.1...1.0	xUn	0.1	0.1	Minimum positive sequence voltage
Max Ng Seq current	0.01...10.00	xIn	0.01	0.20	Maximum negative sequence current

5.16.9 Monitored data

5.16.9.1 LBRDOB Monitored data

Table 1236: LBRDOB Monitored data

Name	Type	Values (Range)	Unit	Description
Z1_AMPL	FLOAT32	0.00...99999.00	ohm	Positive sequence impedance amplitude
Z1_ANGLE	FLOAT32	-180.00...180.00	deg	Positive sequence impedance phase angle
LBRDOB	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.16.10 Technical data

Table 1237: LBRDOB Technical Data

Characteristic	Value
Operation accuracy	Depending on the frequency of the current measured: f_n
	Current: ±1.5% of the set value or ±0.002 × I_n Voltage: ±1.5% of the set value or ±0.002 × U_n Impedance accuracy: ±3% of the set value (In range load angle<75 deg) ±4.5% of the set value (In range 75 deg<load angle<83 deg)

Table continues on the next page

Characteristic	Value
	±8% of the set value (In range load angle>83 deg) Phase angle: ±2°
Reset ratio	Typically 0.96
Operation time [1, 2]	Typically 30 ms
Reset time	Typically 25 ms

[1] f_n= 50Hz, results based on statistical distribution of 1000 measurements
[2] Includes the delay of the signal output contact

6 Supervision functions

6.1 Trip circuit supervision TCSSCBR (ANSI TCM)

6.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Trip circuit supervision	TCSSCBR	TCS	TCM

6.1.2 Function block

Figure 737: Function block

6.1.3 Functionality

The trip circuit supervision function TCSSCBR is designed to supervise the control circuit of the circuit breaker. The invalidity of a control circuit is detected by using a dedicated output contact that contains the supervision functionality. The failure of a circuit is reported to the corresponding function block in the relay configuration.

The function starts and operates when TCSSCBR detects a trip circuit failure. The operating time characteristic for the function is DT. The function operates after a predefined operating time and resets when the fault disappears.

The function contains a blocking functionality. Blocking deactivates the ALARM output and resets the timer.

6.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of TCSSCBR can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

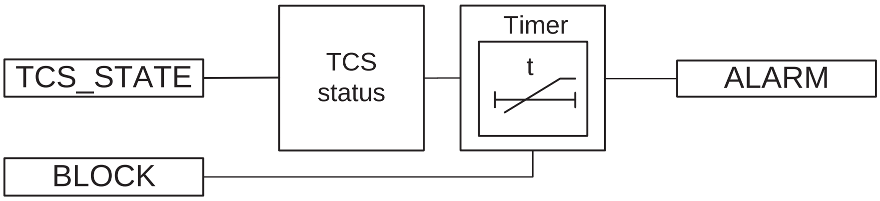


Figure 738: Functional module diagram

TCS status

This module receives the trip circuit status from the hardware. A detected failure in the trip circuit activates the timer.

Timer

Once activated, the timer runs until the set value of *Operate delay time* has elapsed. The time characteristic is according to DT. When the operation timer has reached the maximum time value, the `ALARM` output is activated. If a drop-off situation occurs during the operate time up counting, the fixed 0.5 s reset timer is activated. After that time, the operation timer is reset.

The `BLOCK` input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the `BLOCK` input prevents the `ALARM` output to be activated.

6.1.5 Application

TCSSCBR detects faults in the electrical control circuit of the circuit breaker. The function can supervise both open and closed coil circuits. This supervision is necessary to find out the vitality of the control circuits continuously.

Figure 739 shows an application of the trip circuit supervision function use. Example of both mechanical (on the left) and static (on the right) outputs TCS connections are shown.

The mechanical outputs (PODPx) are used in both AC or DC circuits, and polarity is insignificant. The static outputs (SPOx) can be used in DC only and polarity must be correct.

The best solution is to connect an external R_{ext} shunt resistor in parallel with the circuit breaker internal contact as shown with the dashed line. This way, although the circuit breaker auxiliary contact is open, TCS can see the trip circuit through R_{ext}. The R_{ext} resistor should have such a resistance that the current through the circuit breaker coil remains small, that is, it does not harm or overload the circuit breaker's trip coil if the trip is latched/locked-out.

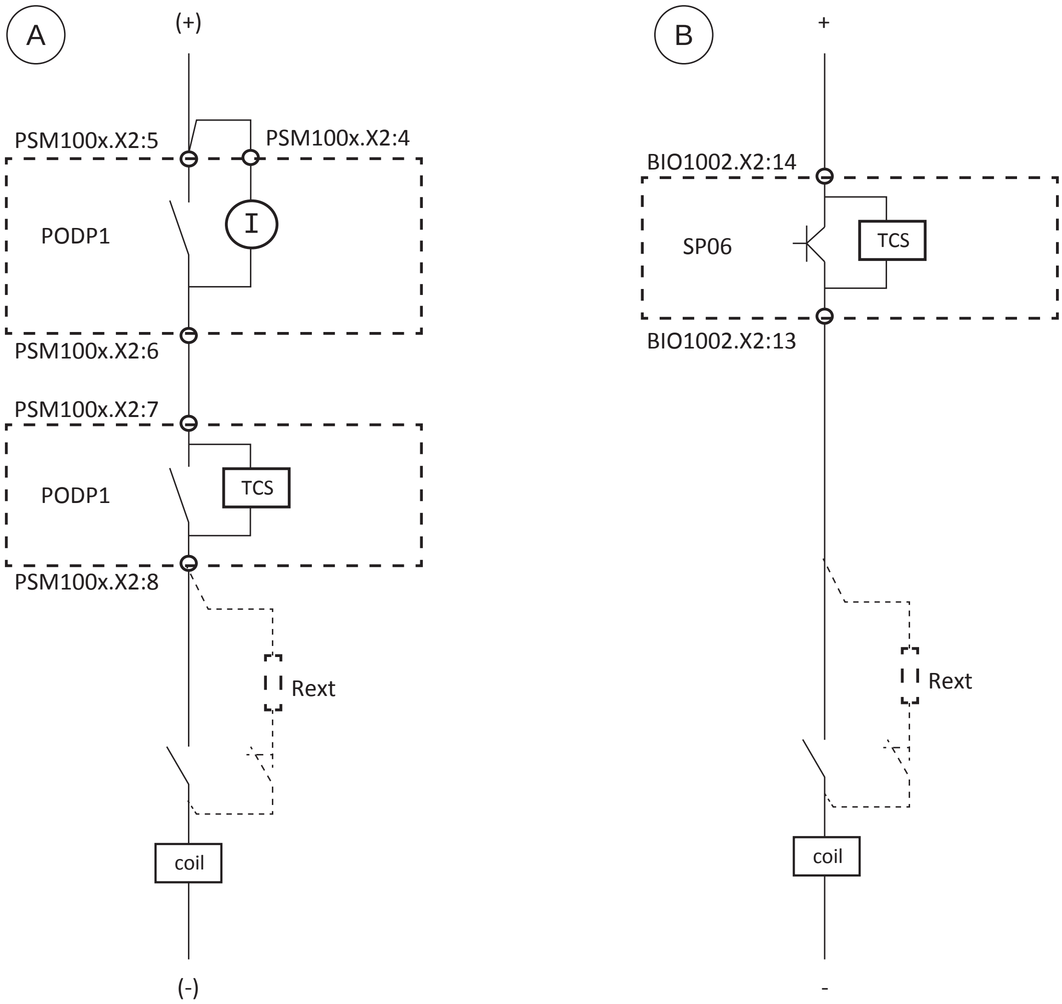


Figure 739: Operating principle of the trip-circuit supervision, single-pole connection

If TCS is required only in a closed position, the external shunt resistance can be omitted. When the circuit breaker is in the open position, TCS sees the situation as a faulty circuit. One way to avoid TCS operation in this situation is to block the supervision function whenever the circuit breaker is open.

It is also recommended to block the supervision function when the trip output is active. Otherwise, TCS issues an alarm if the trip remains active over the set TCS *Operate delay time*.

Figure 740 shows a double-pole connection of the trip circuit supervision. For the static output, this requires using SPO5 or SPO6 output in series of the circuit.

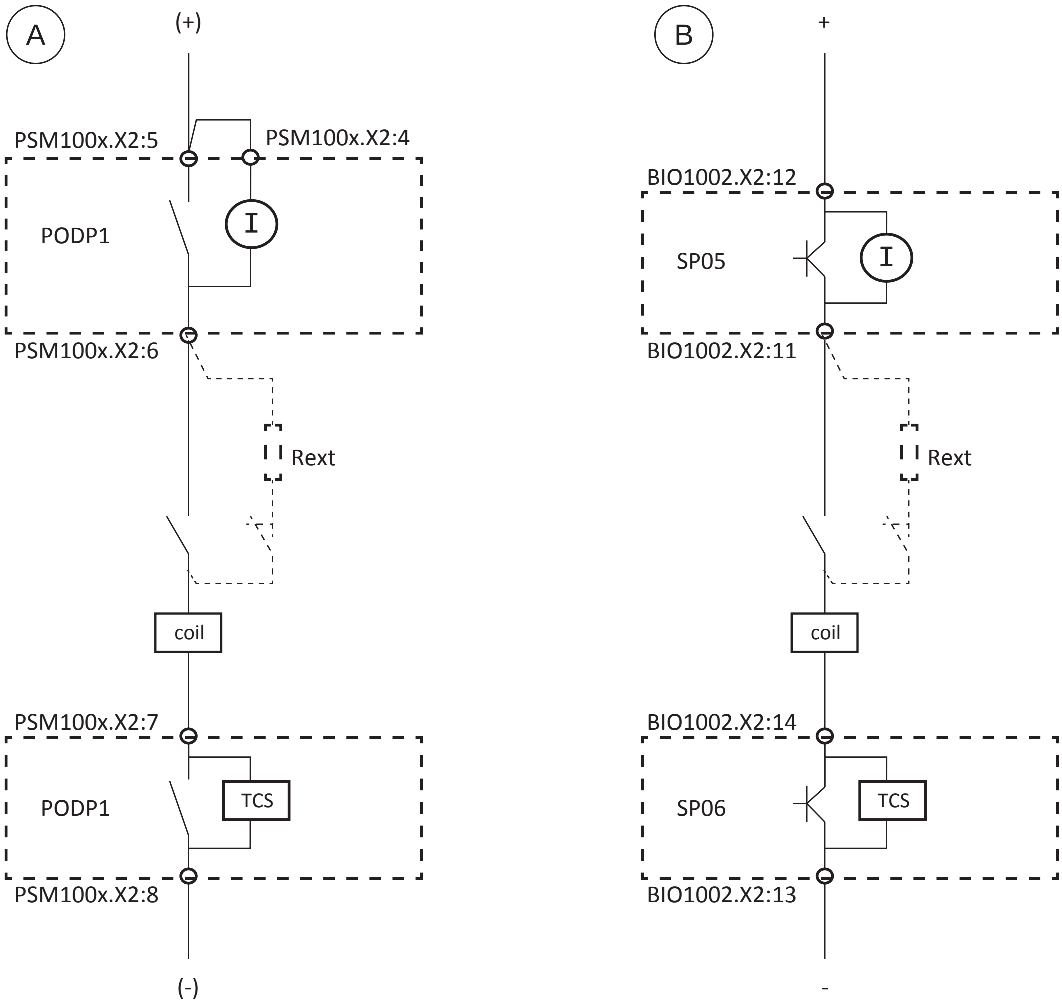


Figure 740: Operating principle of the trip-circuit supervision, double-pole connection

Trip circuit supervision and other trip contacts

It is typical that the trip circuit contains more than one trip contact in parallel, for example in transformer feeders where the trip of a Buchholz relay is connected in parallel with the feeder terminal and other relays involved. The supervising current cannot detect if one or all the other contacts connected in parallel are not connected properly.

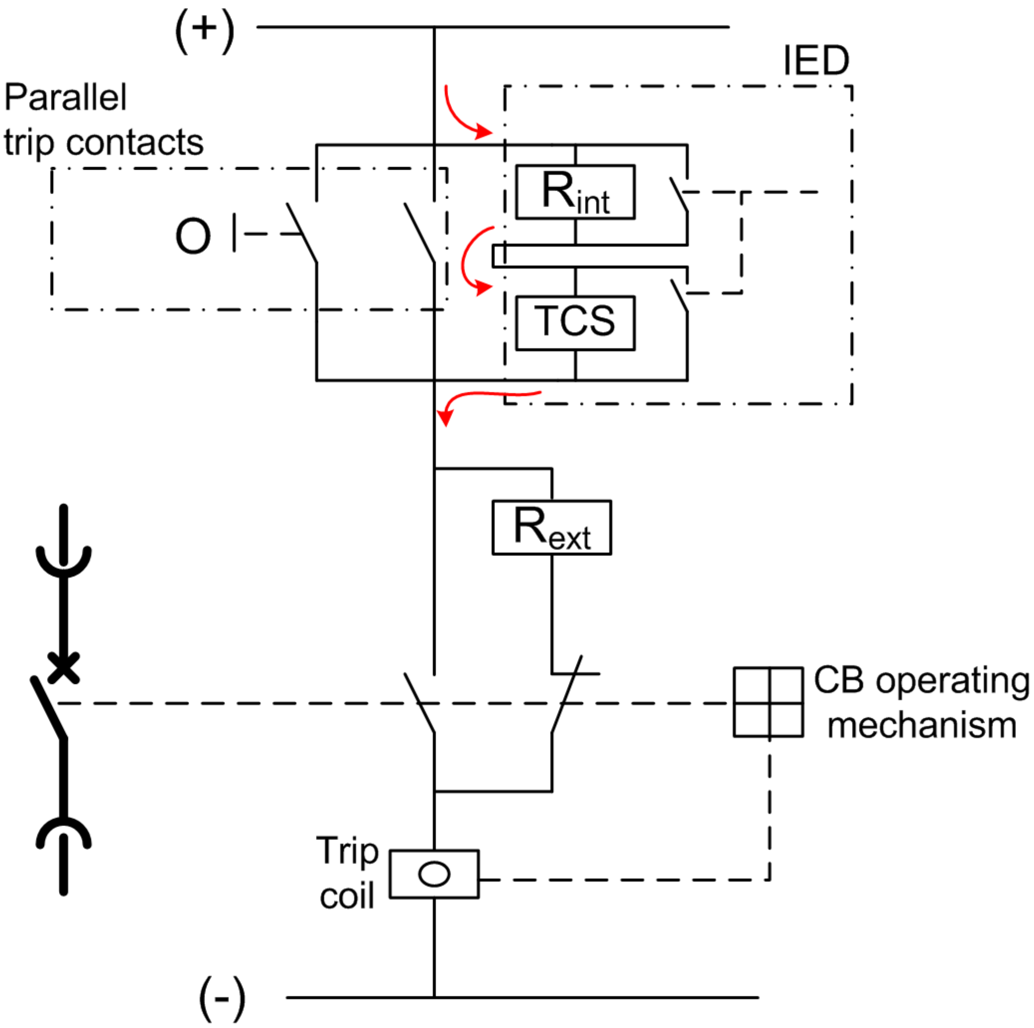


Figure 741: Constant test current flow in parallel trip contacts and trip circuit supervision

In case of parallel trip contacts, the recommended way to do the wiring is that the TCS test current flows through all wires and joints.

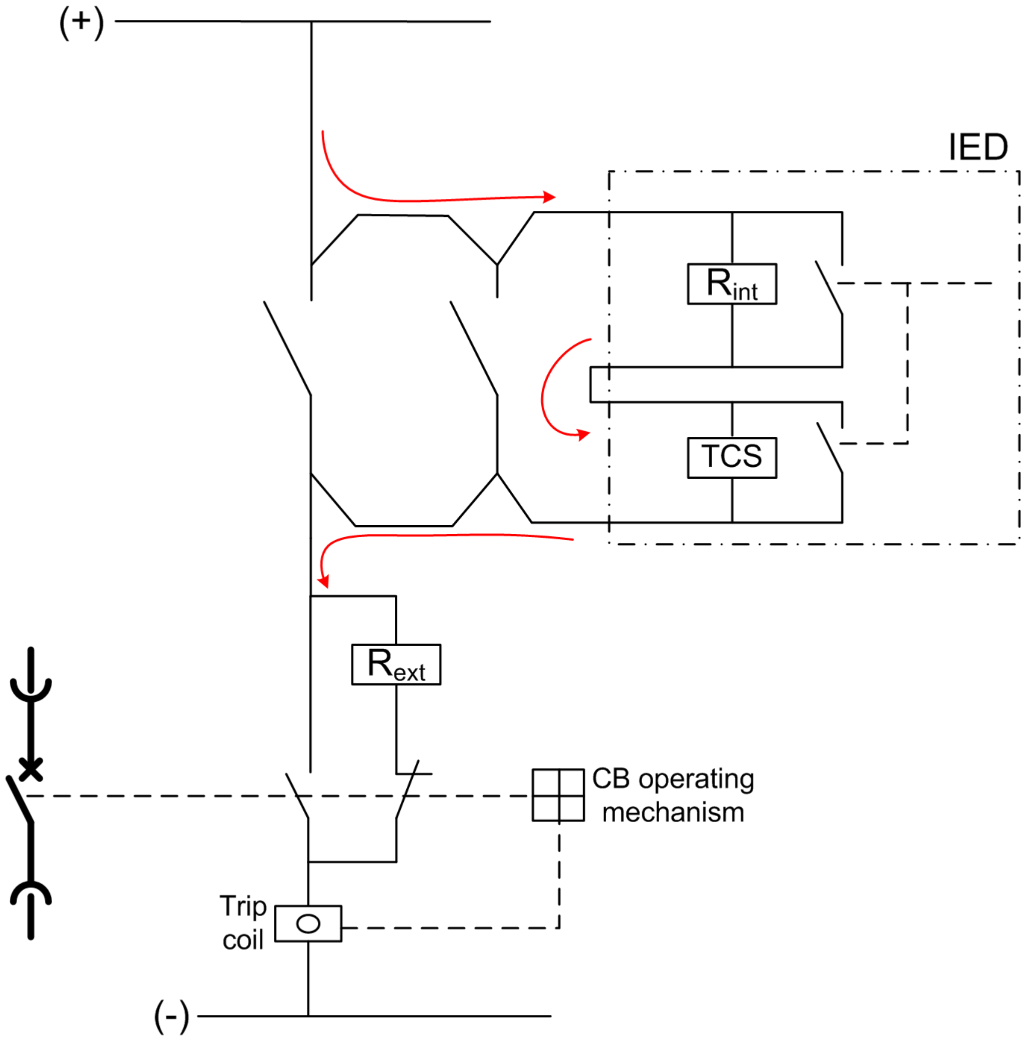


Figure 742: Improved connection for parallel trip contacts where the test current flows through all wires and joints

Several trip circuit supervision functions parallel in circuit

Not only the trip circuit often have parallel trip contacts, it is also possible that the circuit has multiple TCS circuits in parallel. Each TCS circuit causes its own supervising current to flow through the monitored coil and the actual coil current is a sum of all TCS currents. This must be taken into consideration when determining the resistance of R_{ext}.

Setting the TCS function in a protection relay not-in-use does not typically affect the supervising current injection.

Trip circuit supervision with auxiliary relays

Many retrofit projects are carried out partially, that is, the old electromechanical relays are replaced with new ones but the circuit breaker is not replaced. This creates a problem that the coil current of an old type circuit breaker can be too high for the protection relay trip contact to break.

The circuit breaker coil current is normally cut by an internal contact of the circuit breaker. In case of a circuit breaker failure, there is a risk that the protection relay trip contact is destroyed since the contact is obliged to disconnect high level of electromagnetic energy accumulated in the trip coil.

An auxiliary relay can be used between the protection relay trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCS circuit in the protection relay monitors the healthy auxiliary relay coil, not the circuit breaker coil. The separate trip circuit supervision relay is applicable for this to supervise the trip coil of the circuit breaker.

Dimensioning of the external resistor

Under normal operating conditions, the applied external voltage is divided between the relay's internal circuit and the external trip circuit so that at the minimum 20 V (15...20 V) remains over the relay's internal circuit. Should the external circuit's resistance be too high or the internal circuit's too low, for example due to welded relay contacts, a fault is detected.

Mathematically, the operation condition can be expressed as:

$$U_C - U_D - I_C \cdot (R_s + R_{ext}) \geq 20V \quad AC / DC$$

(Equation 314)

U_c	Operating voltage over the supervised trip circuit
U_D	Voltage drop over internal 3 mA current drain, about 6.5 V
I_c	Measuring current through the trip circuit, appr. 1.5 mA (0.99...1.72 mA)
R_{ext}	External shunt resistance
R_s	Trip coil resistance

If the external shunt resistance is used, it has to be calculated not to interfere with the functionality of the supervision or the trip coil. Too high a resistance causes too high a voltage drop, jeopardizing the requirement of at least 20 V over the internal circuit, while a resistance too low can enable false operations of the trip coil.

Table 1238: Values recommended for the external resistor R ext

Operating voltage U_c	Shunt resistor R_{ext}
48 V AC/DC	1.2 kΩ, 5 W
60 V AC/DC	5.6 kΩ, 5 W
110...130 V AC/DC	22 kΩ, 5 W
220...250 V AC/DC	33 kΩ, 5 W

Due to the requirement that the voltage over the TCS contact must be 20 V or higher, the correct operation is not guaranteed with auxiliary operating voltages lower than 48 V DC because of the voltage drop in U_D and R_{ext} and the operating coil or even voltage drop of the feeding auxiliary voltage system which can cause too low voltage values over the TCS contact. In this case, erroneous alarming can occur.

At lower (<48 V DC) auxiliary circuit operating voltages, it is recommend either touse the static output and single-pole connection (as then there is no internal currentdrain and U_D = 0 V), or not to use R_{ext} and block TCS when the circuit breaker isopen.

Using power output contacts without trip circuit supervision

In case of mechanical outputs, if TCS is not used, the internal current drain (PSM100x.X2:4, PSM100x.X2:9 and PSM100x.X2:14 in PODP1, PODP2 and PODP2 outputs, respectively) can be left unconnected. The output can then be used as a normal power output.

Incorrect connections and use of trip circuit supervision

Although the TCS circuit in the PODP1, PODP2 and PODP2 outputs consists of two separate contacts, it must be noted that those are designed to be used as series connected to guarantee the breaking capacity given in the technical manual of the protection relay. *Figure 743* shows incorrect usage of a TCS circuit when only one of the contacts is used.

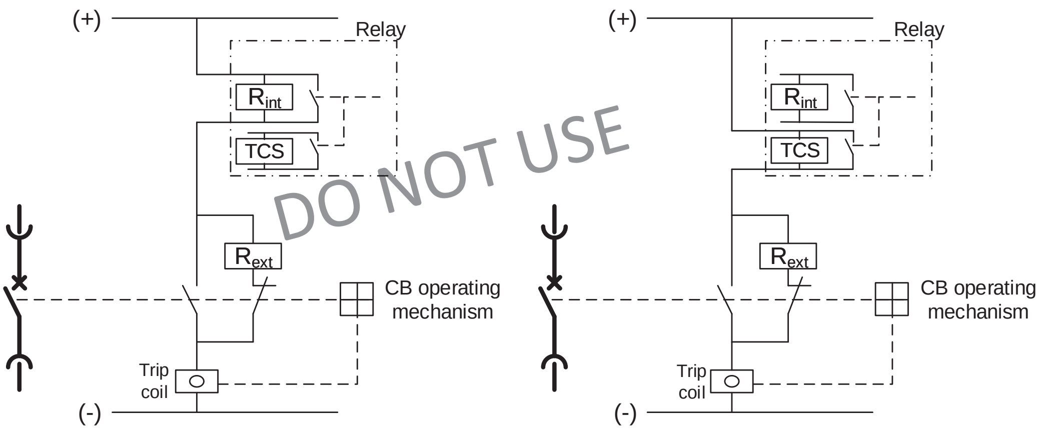


Figure 743: Incorrect connection of trip-circuit supervision

6.1.6 Signals

6.1.6.1 TCSSCBR Input signals

Table 1239: TCSSCBR Input signals

Name	Type	Default	Description
TCS_STATE	BOOLEAN	0=False	Trip circuit supervision status
BLOCK	BOOLEAN	0=False	Block input status

6.1.6.2 TCSSCBR Output signals

Table 1240: TCSSCBR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.1.7 TCSSCBR Settings

Table 1241: TCSSCBR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operate delay time	1000...300000	ms	1	3000	Operate delay time

Table 1242: TCSSCBR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	20...60000	ms	1	1000	Reset delay time

6.1.8 TCSSCBR Monitored data

Table 1243: TCSSCBR Monitored data

Name	Type	Values (Range)	Unit	Description
TCSSCBR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.2 Current circuit supervision CCSPVC (ANSI CCM)

6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current circuit supervision	CCSPVC	MCS 3I	CCM

6.2.2 Function block

Figure 744: Function block

6.2.3 Functionality

The current circuit supervision function CCSPVC is used for monitoring current transformer secondary circuits.

CCSPVC calculates internally the sum of phase currents (I_A, I_B and I_C) and compares the sum against the measured single reference current (I_REF). The reference current must originate from other three-phase CT cores than the phase currents (I_A, I_B and I_C) and it is to be externally summated, that is, outside the protection relay.

CCSPVC detects a fault in the measurement circuit and issues an alarm or blocks the protection functions to avoid unwanted tripping.

It must be remembered that the blocking of protection functions at an occurring open CT circuit means that the situation remains unchanged and extremely high voltages stress the secondary circuit.

6.2.4 Analog channel configuration

CCSPVC has two analog group inputs which must be properly configured.

Table 1244: Analog inputs

Input	Description
I3P	Three-phase currents
IRES	Residual current (measured)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1245: Special conditions

Condition	Description
IRES measured	In case IRES needs to be derived, the function requires that all CT cores, except for the one used for phase current measurement, must be used and summed externally.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

6.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CCSPVC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

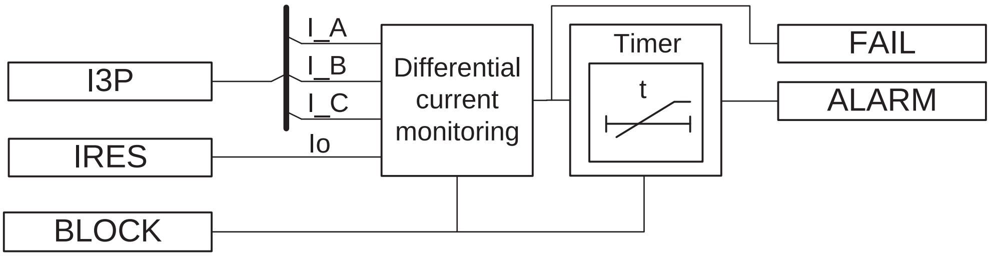


Figure 745: Functional module diagram

Differential current monitoring

Differential current monitoring supervises the difference between the summed phase currents I_A, I_B and I_C and the reference current I_REF.

The current operating characteristics can be selected with the *Start value* setting. When the highest phase current is less than 1.0 × In, the differential current limit is defined with *Start value*. When the highest phase current is more than 1.0 × In, the differential current limit is calculated with the equation.

$$MAX(I\_A, I\_B, I\_C) \times Start\ value$$

(Equation 315)

The differential current is limited to 1.0 × In.

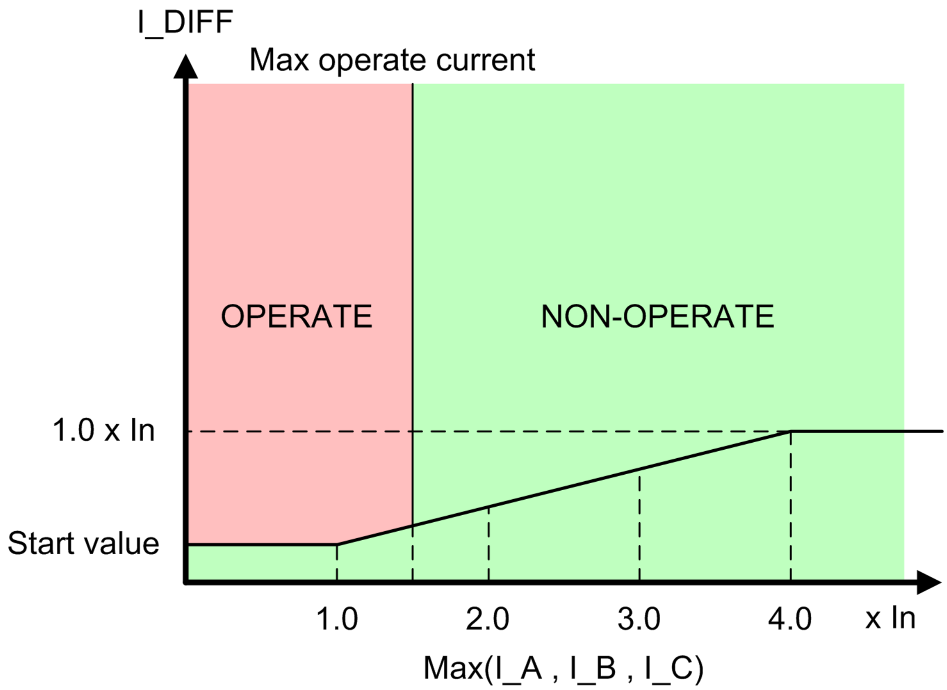


Figure 746: CCSPVC operating characteristics

When the differential current I_DIFF is in the operating region, the `FAIL` output is activated.

The function is internally blocked if any phase current is higher than the set *Max operate current*. When the internal blocking activates, the FAIL output is deactivated immediately. The internal blocking is used for avoiding false operation during a fault situation when the current transformers are saturated due to high fault currents.

The value of the differential current is available in the monitored data view on the LHMI or through other communication tools. The value is calculated with the equation.

$$I\_DIFF = \left| \overline{I\_A} + \overline{I\_B} + \overline{I\_C} \right| - \left| \overline{I\_REF} \right|$$

(Equation 316)

The *Start value* setting is given in units of ×In of the phase current transformer. The possible difference in the phase and reference current transformer ratios is internally compensated by scaling I_REF with the value derived from the *Primary current* setting values. These setting parameters can be found in the Basic functions section.

The activation of the BLOCK input deactivates the FAIL output immediately.

Timer

The timer is activated with the FAIL signal. The ALARM output is activated after a fixed 200 ms delay. FAIL needs to be active during the delay.

When the internal blocking is activated, the FAIL output deactivates immediately. However, the ALARM output deactivates after a fixed delay of three seconds.

The function resets when the differential current is below the start value and the highest phase current is more than 5 percent of the nominal current (0.05 × In).

If the current falls to zero when the FAIL or ALARM outputs are active, the deactivation of these outputs is prevented.

The activation of the BLOCK input deactivates the ALARM output.

6.2.6 Application

Open or short-circuited current transformer cores can cause unwanted operation in many protection functions such as differential, earth-fault current and negative-sequence current functions. When currents from two independent three-phase sets of CTs or CT cores measuring the same primary currents are available, reliable current circuit supervision can be arranged by comparing the currents from the two sets. When an error in any CT circuit is detected, the protection functions concerned can be blocked and an alarm given.

In case of high currents, the unequal transient saturation of CT cores with a different remanence or saturation factor can result in differences in the secondary currents from the two CT cores. An unwanted blocking of protection functions during the transient stage must then be avoided.

The supervision function must be sensitive and have a short operation time to prevent unwanted tripping from fast-acting, sensitive numerical protections in case of faulty CT secondary circuits.

Open CT circuits create extremely high voltages in the circuits, which may damage the insulation and cause further problems. This must be taken into consideration especially when the protection functions are blocked.

When the reference current is not connected to the protection relay, the function should be turned off. Otherwise, the `FAIL` output is activated when unbalance occurs in the phase currents even if there was nothing wrong with the measurement circuit.

Reference current measured with core-balanced current transformer

CCSPVC compares the sum of phase currents to the current measured with the core-balanced CT.

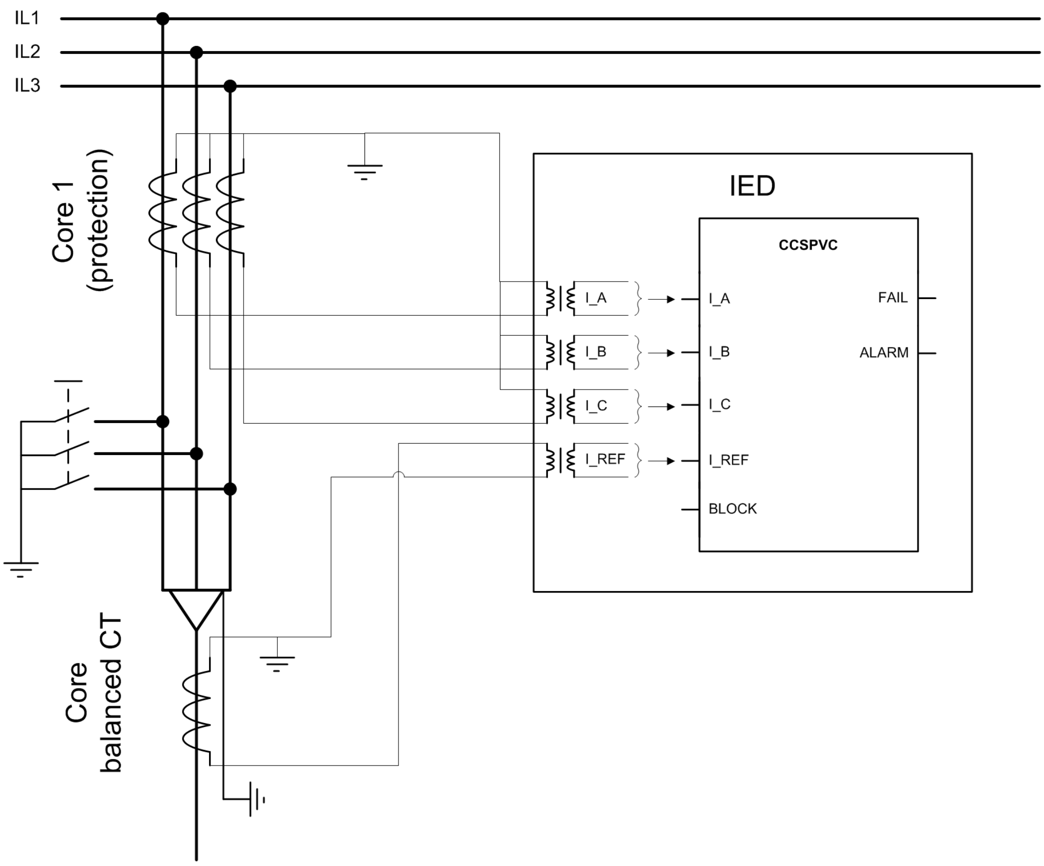


Figure 747: Connection diagram for reference current measurement with core-balanced current transformer

Current measurement with two independent three-phase sets of CT cores

Figure 748 and *Figure 749* show diagrams of connections where the reference current is measured with two independent three-phase sets of CT cores.

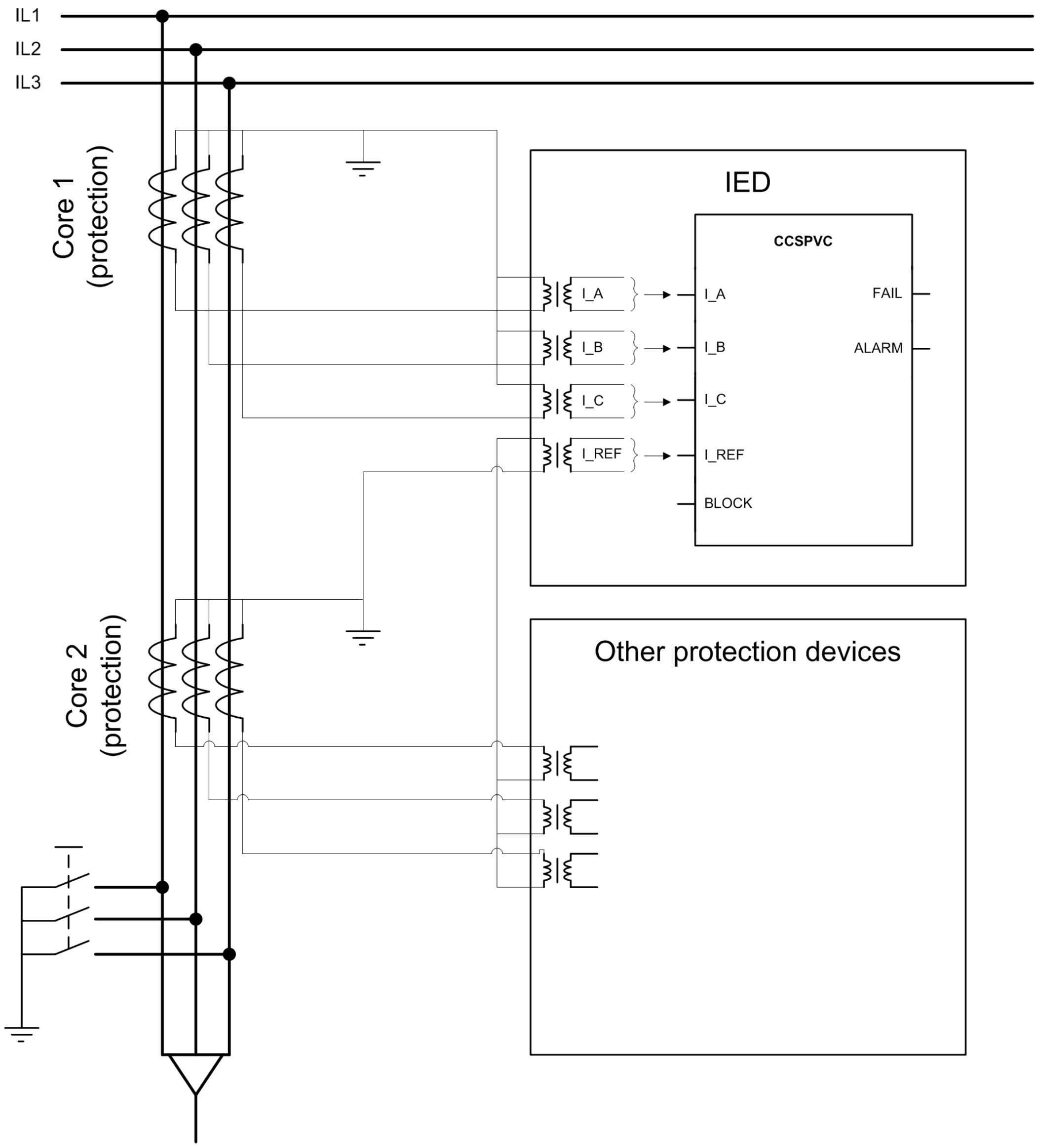


Figure 748: Connection diagram for current circuit supervision with two sets of three-phase current transformer protection cores

When using the measurement core for reference current measurement, it should be noted that the saturation level of the measurement core is much lower than with the protection core. This should be taken into account when setting the current circuit supervision function.

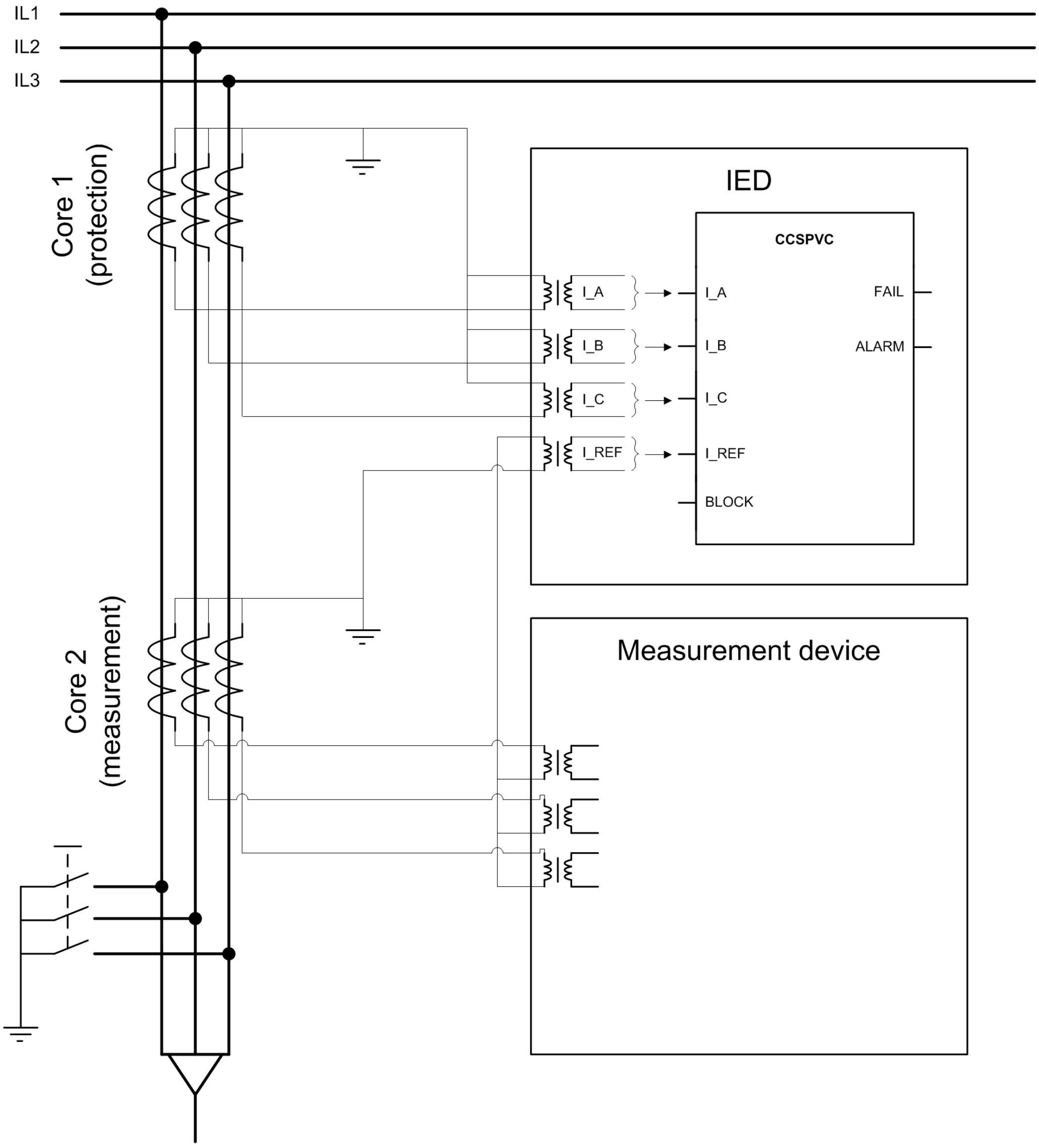


Figure 749: Connection diagram for current circuit supervision with two sets of three-phase current transformer cores (protection and measurement)

Example of incorrect connection

The currents must be measured with two independent cores, that is, the phase currents must be measured with a different core than the reference current. A connection diagram shows an example of a case where the phase currents and the reference currents are measured from the same core.

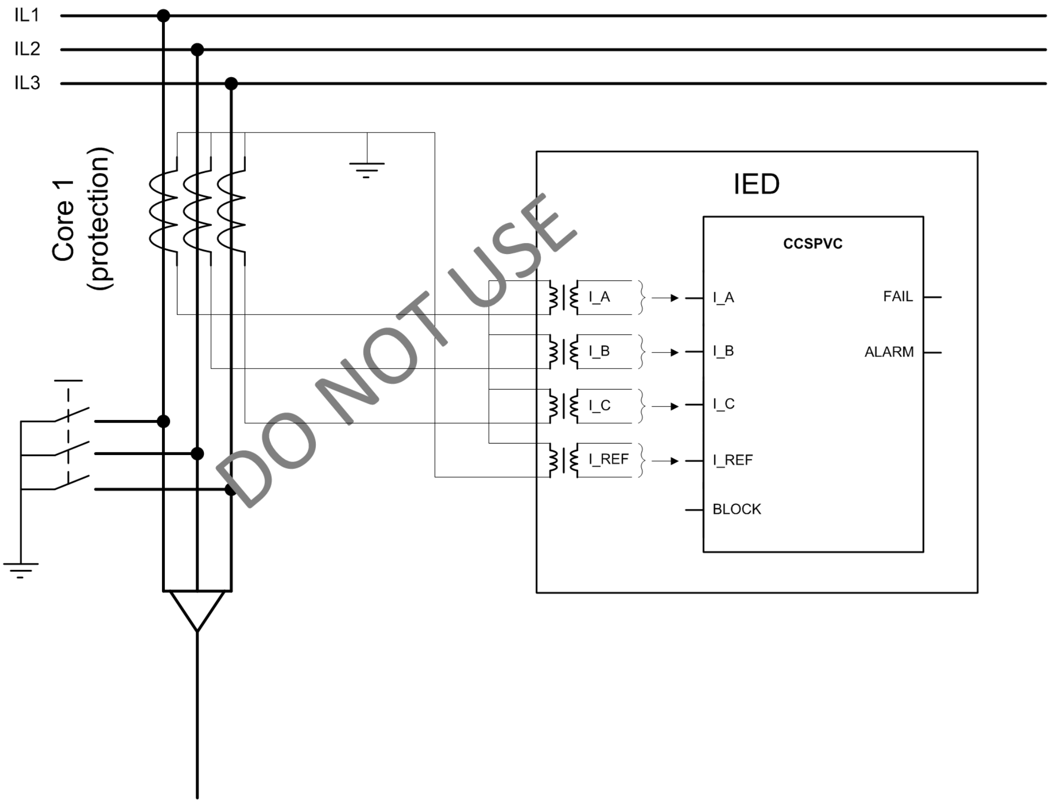


Figure 750: Example of incorrect reference current connection

6.2.7 Signals

6.2.7.1 CCSPVC Input signals

Table 1246: CCSPVC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

6.2.7.2 CCSPVC Output signals

Table 1247: CCSPVC Output signals

Name	Type	Description
FAIL	BOOLEAN	Fail output
ALARM	BOOLEAN	Alarm output

6.2.8 CCSPVC Settings

Table 1248: CCSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On / Off
Start value	0.05...0.50	xIn	0.01	0.05	Minimum operate current differential level

Table 1249: CCSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Max operate current	1.00...5.00	xIn	0.01	1.50	Block of the function at high phase current

6.2.9 CCSPVC Monitored data

Table 1250: CCSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
IDIFF	FLOAT32	0.00...40.00	xIn	Differential current
CCSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.2.10 Technical data

Table 1251: CCSPVC Technical data

Characteristic	Value
Operate time (including the delay of the output contact)	<30 ms

6.2.11 Technical revision history

Table 1252: CCSPVC Technical revision history

Product connectivity level	Technical revision	Change
PCL4	F	Setting *Start value* maximum extended to 0.50xIn.

6.3 Current transformer supervision for high-impedance protection scheme HZCCxSPVC (ANSI CCM_A, CCM_B, CCM_C)

6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current transformer supervision for high-impedance protection scheme for phase A	HZCCASPVC	MCS I_A	CCM_A
Current transformer supervision for high-impedance protection scheme for phase B	HZCCBSPVC	MCS I_B	CCM_B
Current transformer supervision for high-impedance protection scheme for phase C	HZCCCSPVC	MCS I_C	CCM_C

6.3.2 Function block

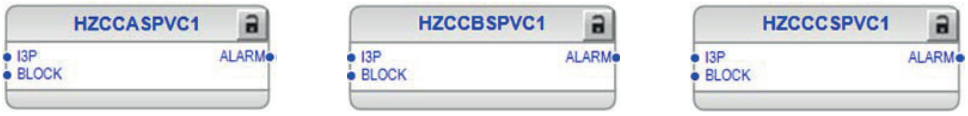


Figure 751: Function block

6.3.3 Functionality

The current transformer supervision for high-impedance protection scheme function HZCCxSPVC is a dedicated phase-segregated supervision function to be used along with the high-impedance differential protection for detecting the broken CT secondary wires. The differential current is taken as an input for the protection relay. During normal CT condition, the value of the differential current is zero. However, when the CT is broken, the secondary differential current starts flowing and it is used for generating alarms.

To avoid maloperation, HZCCxSPVC should have a sensitive setting, compared to the high-impedance differential protection. The function is likely to start under through-fault conditions. However, by incorporating a high time delay (3 s or more), the downstream protection clears the fault before an alarm is generated.

HZCCxSPVC generates an alarm when the differential current exceeds the set limit. The function operates within the DT characteristic.

HZCCxSPVC contains a blocking functionality. It is possible to block the function output, Timer or the whole function.

6.3.4 Analog channel configuration

HZCCxSPVC has one analog group input which must be properly configured.

Table 1253: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

6.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of HZCCxSPVC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

The module diagram illustrates all the phases of the function. However, the functionality is described only for phase A. The functionality for phase B and C is identical.

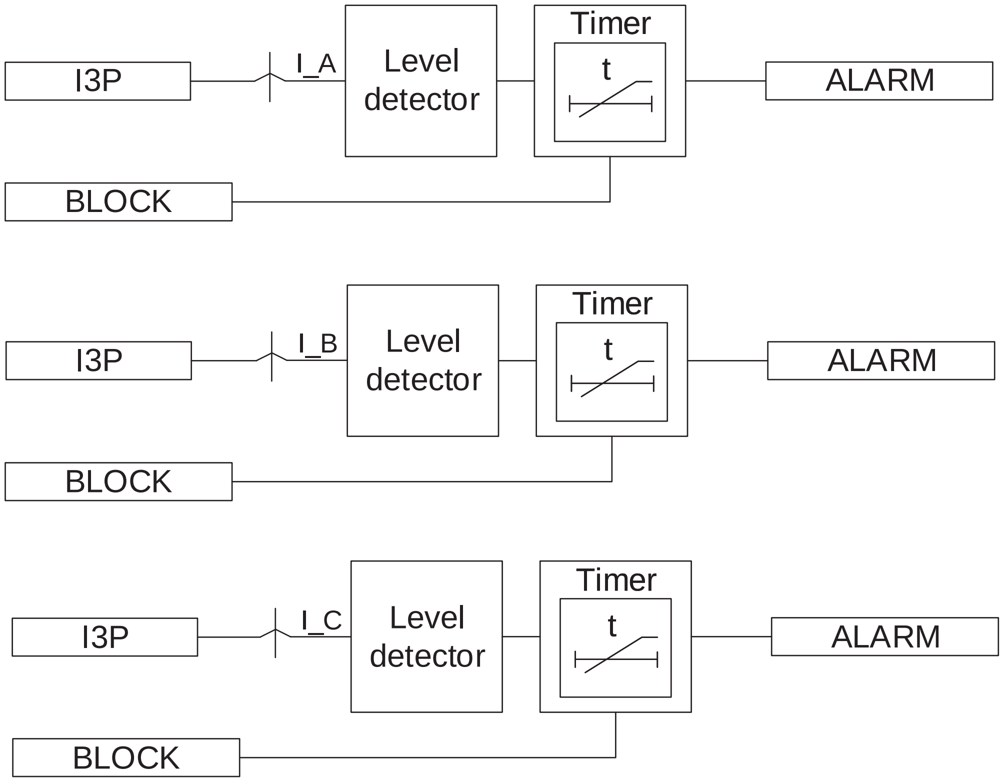


Figure 752: Functional module diagram

Level detector

This module compares the differential current `I_A` to the set *Start value*. The timer module is activated if the differential current exceeds the value set in the *Start value* setting.

Timer

The time characteristic is according to DT. When the alarm timer reaches the value set by *Alarm delay time*, the `ALARM` output is activated. If the fault disappears before the module generates an alarm signal, the reset timer is activated. If the reset timer reaches the value set by *Reset delay time*, the alarm timer resets. The activation of the `BLOCK` signal resets the Timer and deactivates the `ALARM` output.

Lockout logic

HZCCxSPVC is provided with the possibility to activate a lockout for the `ALARM` output depending on the *Alarm output mode* setting. In the "Lockout" mode, the `ALARM` must be reset manually from the LHMI Clear menu after checking the CT secondary circuit. In the "Non-latched" mode, the `ALARM` output functions normally, that is, it resets as soon as the fault is cleared.

6.3.6 Measuring modes

The function operates on two alternative measurement modes, DFT and Peak-to-Peak. The measurement mode is selected using the *Measurement mode* setting.

6.3.7 Application

HZCCxSPVC is a dedicated phase-segregated supervision function to be used along with the high-impedance differential protection for detecting the broken CT secondary wires. The operation principle of HZCCxSPVC is similar to the high-impedance differential protection function HIxPDIF. However, the current setting of HZCCxSPVC is set to be much more sensitive than HIxPDIF and it operates with a higher time delay. A typical example of the HZCCxSPVC *Start value* setting is 0.1 pu with an *Alarm delay time* of 3 s or more.

As the current setting of HZCCxSPVC is more sensitive than the actual differential stage, it can start internally under the through-fault conditions; however, a sufficient time delay prevents false alarm. If the bus wire is broken, differential current arises depending on the load of the feeder with the broken bus wire.

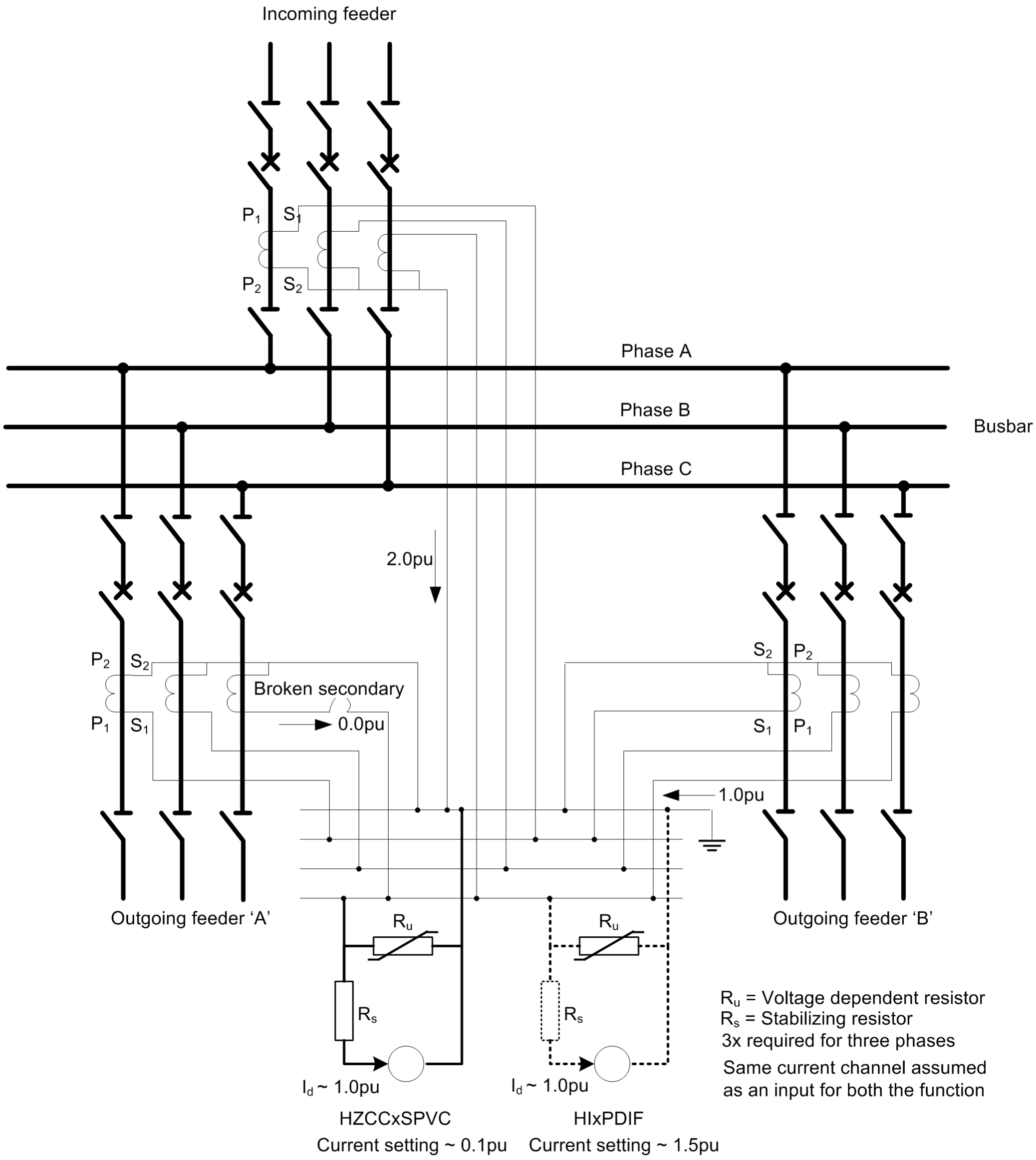


Figure 753: Broken secondary detection by HZCCxSPVC

In the example, the incoming feeder is carrying a load of 2.0 pu and both outgoing feeders carry an equal load of 1.0 pu However, both HIxPDIF and HZCCxSPVC consider the current as an increased differential or unbalance current because of the broken CT wire in phase C. Both HIxPDIF and HZCCxSPVC receive the differential current of approximately 1.0 pu The main differential protection HIxPDIF cannot operate because of the higher current setting.

All CTs must have the same ratio.

The ALARM output of the CT supervision function can be used to energize an auxiliary relay which can short-circuit the current CT wires, making the busbar differential protection inoperative. This arrangement does not prevent unwanted operation of HIxPDIF if the start setting is below the rated load. For example, if the start setting for HIxPDIF in the example is set as 0.8 pu HIxPDIF operate before HZCCxSPVC.

6.3.8 Signals

6.3.8.1 HZCCASPVC Input signals

Table 1254: HZCCASPVC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating blocking mode

6.3.8.2 HZCCBSPVC Input signals

Table 1255: HZCCBSPVC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating blocking mode

6.3.8.3 HZCCCSPVC Input signals

Table 1256: HZCCCSPVC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for activating blocking mode

6.3.8.4 HZCCASPVC Output signals

Table 1257: HZCCASPVC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.3.8.5 HZCCBSPVC Output signals

Table 1258: HZCCBSPVC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.3.8.6 HZCCCSPVC Output signals

Table 1259: HZCCCSPVC Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.3.9 Settings

6.3.9.1 HZCCASPVC Settings

Table 1260: HZCCASPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	1.0...100.0	%In	0.1	10.0	Start value, percentage of the nominal current
Alarm delay time	100...300000	ms	10	3000	Alarm delay time
Alarm output mode	1=Non-latched 3=Lockout			3=Lockout	Select the operation mode for alarm output

Table 1261: HZCCASPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

6.3.9.2 HZCCBSPVC Settings

Table 1262: HZCCBSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	1.0...100.0	%In	0.1	10.0	Start value, percentage of the nominal current
Alarm delay time	100...300000	ms	10	3000	Alarm delay time
Alarm output mode	1=Non-latched 3=Lockout			3=Lockout	Select the operation mode for alarm output

Table 1263: HZCCBSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

6.3.9.3 HZCCCSPVC Settings

Table 1264: HZCCCSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	1.0...100.0	%In	0.1	10.0	Start value, percentage of the nominal current
Alarm delay time	100...300000	ms	10	3000	Alarm delay time
Alarm output mode	1=Non-latched 3=Lockout			3=Lockout	Select the operation mode for alarm output

Table 1265: HZCCCSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	10	20	Reset delay time
Measurement mode	2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode

6.3.10 Monitored data

6.3.10.1 HZCCASPVC Monitored data

Table 1266: HZCCASPVC Monitored data

Name	Type	Values (Range)	Unit	Description
HZCCASPVC	Enum	1=on 2=blocked 3=test 4=test/blocked		Status

Name	Type	Values (Range)	Unit	Description
		5=off		

6.3.10.2 HZCCBSPVC Monitored data

Table 1267: HZCCBSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
HZCCBSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.3.10.3 HZCCCSPVC Monitored data

Table 1268: HZCCCSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
HZCCCSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.3.11 Technical data

Table 1269: HZCCxSPVC Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the current measured: f_n ±2 Hz
	±1.5 % of the set value or ±0.002 × I_n
Reset time	<40 ms
Reset ratio	Typically 0.96
Retardation time	<35 ms
Operate time accuracy in definite time mode	±1.0 % of the set value or ±20 ms

6.4 Protection communication supervision PCSITPC (ANSI PCS)

6.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Protection communication supervision	PCSITPC	PCS	PCS

6.4.2 Function block

Figure 754: Function block

6.4.3 Functionality

The protection communication supervision function PCSITPC monitors the protection communication channel. PCSITPC blocks the line differential protection functions when interference in the protection communication channel is detected. The blocking takes place automatically for the LNPLDF and BSTGAPC functions which are dependent on the continuous availability of the protection communication channel.

The protection communication channel is continuously monitored by PCSITPC. The function detects missing or delayed protection telegrams. Protection telegrams are used for transferring the sampled analog and other protection related data. Missing or delayed protection telegrams can jeopardize the demand operate speed of the differential protection.

When a short-term interference is detected in the protection communication channel, the function issues a warning and the line differential functions are automatically internally blocked. PCSITPC reacts fast for the protection communication interferences. The blocking takes place at the latest when a communication interruption lasting for two fundamental network periods is detected. When a severe and long lasting interference or total interruption in the protection communication channel is detected, an alarm is issued (after a five-second delay). The protection communication supervision quality status is exchanged continuously online by the local and remote PCSITPC instances. This ensures that both local and remote ends protection blocking is issued coordinately. This further enhances the security of the line differential protection by forcing both line end protection relays to the same blocking state during a protection communication interference, even in cases where the interference is detected with only one line end protection relay. There is also the *Reset delay time* settings parameter available which is used for changing the required interference-free time before releasing the line-differential protection back in operation after a blocking due to an interference in communication.

6.4.4 Operation principle

The operation of protection communication supervision can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

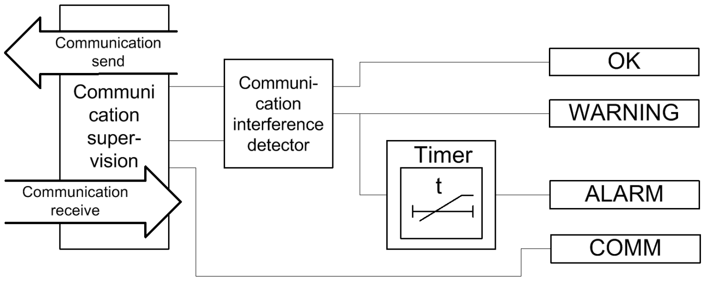


Figure 755: Functional module diagram

Communication supervision

The protection communication is supervised because the differential calculation is dependent on the refreshing of new analog phasor samples from the remote terminal within the protection telegram. The new protection telegram also updates the status of the binary signals sent by the remote terminal. The calculation of the differential current is based on comparing the remote and local terminal measured current samples. It is therefore essential that the protection communication telegrams are supervised and the result of the sample latency calculation can be used further in the differential current calculation. When the communication is able to receive telegrams correctly from the remote end via the communication media, the communication is assumed to be operating correctly and the COMM output is kept active.

Communication interference detector

The communication interference detector continuously measures and observes the sample latency of the protection telegrams. This value is also available as monitored data. The function provides three output signals of which only the corresponding one is active at a time depending on if the protection communication supervision is in OK, WARNING or ALARM. The OK state indicates the correct operation of the protection. The WARNING state indicates that the protection is internally blocked due to detected interference. The WARNING state is switched to ALARM if the interference lasts for a longer period. These output signals are set to the FALSE state until the first telegram is received over the communication link and supervision is started. The protection communication supervision can sometimes be in the WAITING state. This state indicates that the terminal is waiting for the communication to start or restart from the remote end terminal.

Timer

Once activated with the WARNING signal, the timer has a constant time delay value of five seconds. If the communication failure exists after the delay, the ALARM output is activated.

6.4.5 Application

Communication principle

Analog samples, trip-, start- and user programmable signals are transferred in each protection telegram and the exchange of these protection telegrams is done eight times per power system cycle (every 2.5 ms when F_n = 50 Hz).

Master-Master communication arrangement is used in the two-terminal line differential solution. Current samples are sent from both line ends and the protection algorithms are also executed on both line ends. The direct-intertrip, however, ensures that both ends are always operated simultaneously.

Time synchronization

In numerical line differential protection, the current samples from the protections which are located geographically apart from each other must be time coordinated so that the current samples from both ends of the protected line can be compared without introducing irrelevant errors. The time coordination requires an extremely high accuracy.

As an example, an inaccuracy of 0.1 ms in a 50 Hz system gives a maximum amplitude error of approximately around 3 percent. An inaccuracy of 1 ms gives a maximum amplitude error of approximately 31 percent. The corresponding figures for a 60 Hz system are 4 and 38 percent respectively.

In the protection relay, the time coordination is done with an echo method. The protection relays create their own time reference between each other so that the system clocks do not need to synchronize.

The figure shows that in the time synchronization the transmission time to send a message from station B to station A, T1→T2, and the time to receive a message from A to B, T4→T5, are measured. The station A protection relay delay from the sampling to the start of send, T3→T4, and the local delay from receive to the station B protection relay sampling T5→T6 time, are also measured for the station B protection relay, and vice versa. This way the time alignment factor for the local and remote samples is achieved.

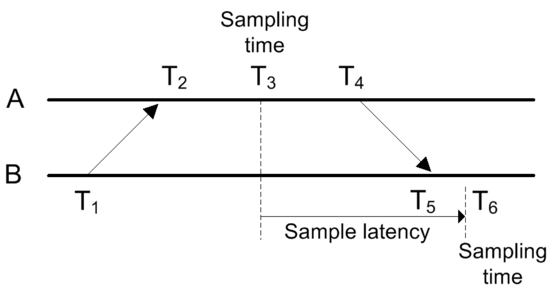


Figure 756: Measuring sampling latency

$$P_d = \frac{(T_2 - T_1) + (T_5 - T_4)}{2}$$

(Equation 317)

$$S_d = P_d + (T_4 - T_3) + (T_6 - T_5)$$

(Equation 318)

The sampling latency S_d is calculated for each telegram on both ends. The algorithm assumes that the one-way propagation delay P_d is equal for both directions.

The echo method without GPS can be used in telecommunication transmission networks as long as delay symmetry exists, that is, the sending and receiving delays are equal.

6.4.6 Signals

6.4.6.1 PCSITPC Output signals

Table 1270: PCSITPC Output signals

Name	Type	Description
OK	BOOLEAN	Protection communication ok
WARNING	BOOLEAN	Protection communication warning
ALARM	BOOLEAN	Protection communication alarm
COMM	BOOLEAN	Communication detected, active when data is received

6.4.7 PCSITPC Settings

Table 1271: PCSITPC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	100...300000	ms	10	1000	Reset delay time from alarm and warning into ok state
Alarm count	0...99999		1	0	Set new alarm count value
Warning count	0...99999		1	0	Set new warning count value

6.4.8 PCSITPC Monitored data

Table 1272: PCSITPC Monitored data

Name	Type	Values (Range)	Unit	Description
HEALTH	Enum	1=Ok 2=Warning 3=Alarm -2=Waiting		Communication link health
ALARM_CNT	INT32	0...99999		Number of alarms detected

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
WARN_CNT	INT32	0...99999		Number of warnings detected
SMPL_LATENCY	FLOAT32	0.000...99.999	ms	Measured sample latency
PROPAGTN_DLY	FLOAT32	0.000...99.999	ms	Measured propagation delay
RND_TRIP_DLY	FLOAT32	0.000...99.999	ms	Measured round trip delay
T_ALARM_CNT	Timestamp			Time when alarm count was last changed
T_WARN_CNT	Timestamp			Time when warning count was last changed

6.5 Fuse failure supervision SEQSPVC (ANSI VCM, 60)

6.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fuse failure supervision	SEQSPVC	FUSEF	VCM, 60

6.5.2 Function block

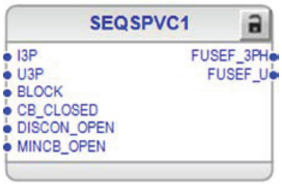


Figure 757: Function block

6.5.3 Functionality

The fuse failure supervision function SEQSPVC is used to block the voltage-measuring functions when failure occurs in the secondary circuits between the voltage transformer (or combi sensor or voltage sensor) and protection relay to avoid misoperations of the voltage protection functions.

SEQSPVC has two algorithms, a negative sequence-based algorithm and a delta current and delta voltage algorithm.

A criterion based on the delta current and the delta voltage measurements can be activated to detect three-phase fuse failures which usually are more associated with the voltage transformer switching during station operations.

6.5.4 Analog channel configuration

SEQSPVC has two analog group inputs which all must be properly configured.

Table 1273: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1274: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

6.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of SEQSPVC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

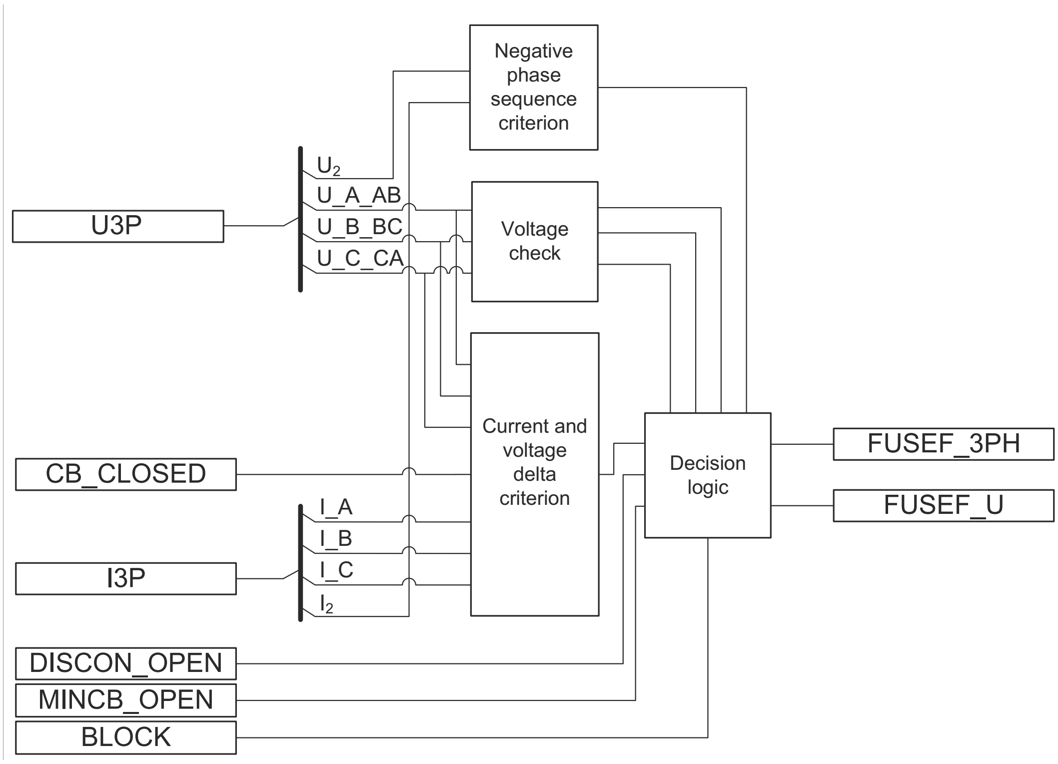


Figure 758: Functional module diagram

Negative phase-sequence criterion

A fuse failure based on the negative-sequence criterion is detected if the measured negative-sequence voltage exceeds the set *Neg Seq voltage Lev* value and the measured negative-sequence current is below the set *Neg Seq current Lev* value. The detected fuse failure is reported to the decision logic module.

Voltage check

The phase voltage magnitude is checked when deciding whether the fuse failure is a three, two or a single-phase fault.

The module makes a phase-specific comparison between each voltage input and the *Seal in voltage* setting. If the input voltage is lower than the setting, the corresponding phase is reported to the decision logic module.

Current and voltage delta criterion

The delta function can be activated by setting the *Change rate enable* parameter to "True". Once the function is activated, it operates in parallel with the negative sequence-based algorithm. The current and voltage are continuously measured in all three phases to calculate:

- Change of voltage dU/dt
- Change of current dI/dt

The calculated delta quantities are compared to the respective set values of the *Current change rate* and *Voltage change rate* settings.

The delta current and delta voltage algorithms detect a fuse failure if there is a sufficient negative change in the voltage amplitude without a sufficient change in the current amplitude in each phase separately. This is performed when the circuit breaker is closed. Information about the circuit breaker position is connected to the CB_CLOSED input.

There are two conditions for activating the current and voltage delta function.

- The magnitude of dU/dt exceeds the corresponding value of the *Voltage change rate* setting and magnitude of dI/dt is below the value of the *Current change rate* setting in any phase at the same time due to the closure of the circuit breaker (CB_CLOSED = TRUE).
- The magnitude of dU/dt exceeds the value of the *Voltage change rate* setting and the magnitude of dI/dt is below the *Current change rate* setting in any phase at the same time and the magnitude of the phase current in the same phase exceeds the *Min Op current delta* setting.

The first condition requires the delta criterion to be fulfilled in any phase at the same time as the circuit breaker is closed. Opening the circuit breaker at one end and energizing the line from the other end onto a fault could lead to an improper operation of SEQSPVC with an open breaker. If this is considered to be an important disadvantage, the CB_CLOSED input is to be connected to FALSE. In this way only the second criterion can activate the delta function.

The second condition requires the delta criterion to be fulfilled in one phase together with a high current for the same phase. The measured phase current is used to reduce the risk of a false fuse failure detection. If the current on the protected line is low, a voltage drop in the system (not caused by the fuse failure) is not followed by a current change and a false fuse failure can occur. To prevent this, the minimum phase current criterion is checked.

The fuse failure detection is active until the voltages return above the *Min Op voltage delta* setting. If a voltage in a phase is below the *Min Op voltage delta* setting, a new fuse failure detection for that phase is not possible until the voltage returns above the setting value.

Decision logic

If voltages are Wye-connected, it is recommended to scale the default values of voltage-based settings with 1/sqrt(3) because the default setting values apply for Delta-connected settings.

The fuse failure detection outputs FUSEF_U and FUSEF_3PH are controlled according to the detection criteria or external signals.

Table 1275: Fuse failure output control

Fuse failure detection criterion	Conditions and function response
Negative-sequence criterion	If a fuse failure is detected based on the negative sequence criterion, the FUSEF_U output is activated.
	If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the *Seal in voltage* setting with *Enable seal in* turned to "True", the function activates the FUSE_3PH output signal.

Table continues on the next page

Fuse failure detection criterion	Conditions and function response
	The FUSEF_U output signal is also activated if all the phase voltages are above the *Seal in voltage* setting for more than 60 seconds and at the same time the negative sequence voltage is above *Neg Seq voltage Lev* for more than 5 seconds, all the phase currents are below the *Current dead Lin Val* setting and the circuit breaker is closed, that is, CB_CLOSED is TRUE.
Current and voltage delta function criterion	If the current and voltage delta criterion detects a fuse failure condition, but all the voltages are not below the *Seal in voltage* setting, only the FUSEF_U output is activated.
	If the fuse failure detection is active for more than five seconds and at the same time all the phase voltage values are below the set value of the *Seal in voltage* setting with *Enable seal in* turned to "True", the function activates the FUSE_3PH output signal.
External fuse failure detection	The MINCB_OPEN input signal is supposed to be connected through a protection relay binary input to the N.C. auxiliary contact of the miniature circuit breaker protecting the VT secondary circuit. The MINCB_OPEN signal sets the FUSEF_U output signal to block all the voltage-related functions when MCB is in the open state.
	The DISCON_OPEN input signal is supposed to be connected through a protection relay binary input to the N.C. auxiliary contact of the line disconnector. The DISCON_OPEN signal sets the FUSEF_U output signal to block the voltage-related functions when the line disconnector is in the open state.

It is recommended to always set *Enable seal in* to "True". This secures that the blocked protection functions remain blocked until normal voltage conditions are restored if the fuse failure has been active for 5 seconds, that is, the fuse failure outputs are deactivated when the normal voltage conditions are restored.

The activation of the BLOCK input deactivates both FUSEF_U and FUSEF_3PH outputs.

6.5.6 Application

Some protection functions operate on the basis of the measured voltage value in the protection relay point. These functions can fail if there is a fault in the measuring circuits between the voltage transformer (or combi sensor or voltage sensor) and protection relay.

A fault in the voltage-measuring circuit is called a fuse failure. This term is misleading since a blown fuse is just one of the many possible reasons for a broken circuit. Since incorrectly measured voltage can result in a faulty operation of some of the protection functions, it is important to detect the fuse failures. A fast fuse failure detection is one of the means to block voltage-based functions before they operate.

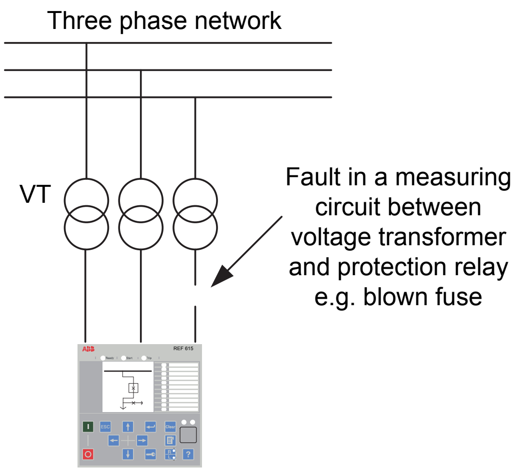


Figure 759: Fault in a circuit from the voltage transformer to the protection relay

A fuse failure occurs due to blown fuses, broken wires or intended substation operations. The negative sequence component-based function can be used to detect different types of single-phase or two-phase fuse failures. However, at least one of the three circuits from the voltage transformers must be intact. The supporting delta-based function can also detect a fuse failure due to three-phase interruptions.

In the negative sequence component-based part of the function, a fuse failure is detected by comparing the calculated value of the negative sequence component voltage to the negative sequence component current. The sequence entities are calculated from the measured current and voltage data for all three phases. The purpose of this function is to block voltage-dependent functions when a fuse failure is detected. Since the voltage dependence differs between these functions, SEQSPVC has two outputs for this purpose.

6.5.7 Signals

6.5.7.1 SEQSPVC Input signals

Table 1276: SEQSPVC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block of function

Table continues on the next page

Name	Type	Default	Description
CB_CLOSED	BOOLEAN	0=False	Active when circuit breaker is closed
DISCON_OPEN	BOOLEAN	0=False	Active when line dis-connector is open
MINCB_OPEN	BOOLEAN	0=False	Active when external MCB opens protected voltage circuit

6.5.7.2 SEQSPVC Output signals

Table 1277: SEQSPVC Output signals

Name	Type	Description
FUSEF_3PH	BOOLEAN	Three-phase start of function
FUSEF_U	BOOLEAN	General start of function

6.5.8 SEQSPVC Settings

Table 1278: SEQSPVC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

Table 1279: SEQSPVC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Neg Seq current Lev	0.03...0.20	xIn	0.01	0.03	Operate level of neg seq undercur-rent element
Neg Seq voltage Lev	0.03...0.20	xUn	0.01	0.10	Operate level of neg seq overvolt-age element
Current change rate	0.01...0.50	xIn	0.01	0.15	Operate level of change in phase current
Voltage change rate	0.25...0.90	xUn	0.01	0.40	Operate level of change in phase voltage
Change rate enable	0=False 1=True			0=False	Enabling operation of change based function
Min Op voltage del-ta	0.01...1.00	xUn	0.01	0.50	Minimum operate level of phase volt-age for delta calcu-lation
Min Op current del-ta	0.01...1.00	xIn	0.01	0.10	Minimum operate level of phase cur-rent for delta calcu-lation
Seal in voltage	0.01...1.00	xUn	0.01	0.50	Operate level of seal-in phase volt-age

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Enable seal in	0=False 1=True			0=False	Enabling seal in functionality
Current dead Lin Val	0.05...1.00	xIn	0.01	0.05	Operate level for open phase current detection

6.5.9 SEQSPVC Monitored data

Table 1280: SEQSPVC Monitored data

Name	Type	Values (Range)	Unit	Description
SEQSPVC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.5.10 Technical data

Table 1281: SEQSPVC Technical data

Characteristic		Value	
Operate time [1]	NPS function	U_{Fault} = 1.1 × set *Neg Seq voltage Lev*	<33 ms
		U_{Fault} = 5.0 × set *Neg Seq voltage Lev*	<18 ms
	Delta function	ΔU = 1.1 × set *Voltage change rate*	<30 ms
		ΔU = 2.0 × set *Voltage change rate*	<24 ms

[1] Includes the delay of the signal output contact, f_n = 50 Hz, fault voltage with nominal frequency injected from random phase angle, results based on statistical distribution of 1000 measurements.

6.6 Runtime counter for machines and devices MDSOPT (ANSI OPTM)

6.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Runtime counter for machines and devices	MDSOPT	OPTS	OPTM

6.6.2 Function block

Figure 760: Function block

6.6.3 Functionality

The runtime counter for machines and devices function MDSOPT calculates and presents the accumulated operation time of a machine or device as the output. The unit of time for accumulation is hour. The function generates a warning and an alarm when the accumulated operation time exceeds the set limits. It utilizes a binary input to indicate the active operation condition.

The accumulated operation time is one of the parameters for scheduling a service on the equipment like motors. It indicates the use of the machine and hence the mechanical wear and tear. Generally, the equipment manufacturers provide a maintenance schedule based on the number of hours of service.

6.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of MDSOPT can be described using a module diagram. All the modules in the diagram are explained in the next sections.

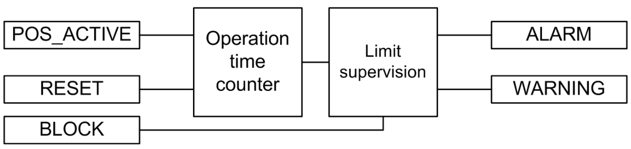


Figure 761: Functional module diagram

Operation time counter

This module counts the operation time. When POS_ACTIVE is active, the count is continuously added to the time duration until it is deactivated. At any time the OPR_TIME output is the total duration for which POS_ACTIVE is active. The unit of time duration count for OPR_TIME is hour. The value is available through the Monitored data view.

The OPR_TIME output is a continuously increasing value and it is stored in a non-volatile memory. When POS_ACTIVE is active, the OPR_TIME count starts increasing from the previous value. The count of OPR_TIME saturates at the final value of 299999, that is, no further increment is possible. The activation of RESET can reset the count to the *Initial value* setting.

Limit supervision

This module compares the motor run-time count to the set values of *Warning value* and *Alarm value* to generate the WARNING and ALARM outputs respectively when the counts exceed the levels.

The activation of the WARNING and ALARM outputs depends on the *Operating time mode* setting. Both WARNING and ALARM occur immediately after the conditions are met if *Operating time mode* is set to “Immediate”. If *Operating time mode* is set to “Timed Warn”, WARNING is activated within the next 24 hours at the time of the day set using the *Operating time hour* setting. If *Operating time mode* is set to “Timed Warn Alm”, the WARNING and ALARM outputs are activated at the time of day set using *Operating time hour*.

The *Operating time hour* setting is used to set the hour of day in Coordinated Universal Time (UTC). The setting has to be adjusted according to the local time and local daylight-saving time.

The function contains a blocking functionality. Activation of the BLOCK input blocks both WARNING and ALARM.

6.6.5 Application

The machine operating time since commissioning indicates the use of the machine. For example, the mechanical wear and lubrication requirement for the shaft bearing of the motors depend on the use hours.

If some motor is used for long duration runs, it might require frequent servicing, while for a motor that is not used regularly the maintenance and service are scheduled less frequently. The accumulated operating time of a motor together with the appropriate settings for warning can be utilized to trigger the condition based maintenance of the motor.

The operating time counter combined with the subsequent reset of the operating-time count can be used to monitor the motor's run time for a single run.

Both the long term accumulated operating time and the short term single run duration provide valuable information about the condition of the machine and device. The information can be co-related to other process data to provide diagnoses for the process where the machine or device is applied.

6.6.6 Signals

6.6.6.1 MDSOPT Input signals

Table 1282: MDSOPT Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block input status
POS_ACTIVE	BOOLEAN	0=False	When active indicates the equipment is running
RESET	BOOLEAN	0=False	Resets the accumulated operation time to initial value

6.6.6.2 MDSOPT Output signals

Table 1283: MDSOPT Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm accumulated operation time exceeds Alarm value
WARNING	BOOLEAN	Warning accumulated operation time exceeds Warning value

6.6.7 MDSOPT Settings

Table 1284: MDSOPT Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Warning value	0...299999	h	1	8000	Warning value for operation time supervision
Alarm value	0...299999	h	1	10000	Alarm value for operation time supervision

Table 1285: MDSOPT Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Initial value	0...299999	h	1	0	Initial value for operation time supervision
Operating time hour	0...23	h	1	0	Time of day when alarm and warning will occur
Operating time mode	1=Immediate 2=Timed Warn			1=Immediate	Operating time mode for warning and alarm

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Timed Warn Alm				

6.6.8 MDSOPT Monitored data

Table 1286: MDSOPT Monitored data

Name	Type	Values (Range)	Unit	Description
MDSOPT	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
OPR_TIME	INT32	0...299999	h	Total operation time in hours

6.6.9 Technical data

Table 1287: MDSOPT Technical data

Description	Value
Motor runtime measurement accuracy [1]	±0.5 %

6.7 Motor start counter MSCPMRI (ANSI 66)

6.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor start counter	MSCPMRI	n<	66

6.7.2 Function block

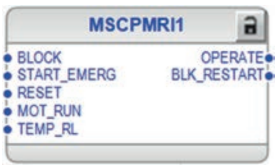


Figure 762: Function block

[1] Of the reading, for a stand-alone relay, without time synchronization

6.7.3 Functionality

The motor start counter function MSCPMRI counts the number of motor starts and distinguishes between cold and warm starts. The allowed number is generally provided by the motor manufacturer. The motor starting MOT_START output of the motor start-up supervision function is used to count the starts. The motor thermal level TEMP_RL calculated by the thermal overload protection is used to distinguish between a cold and warm start.

The function contains a blocking functionality. It is possible to block the function outputs or the function itself.

6.7.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of MSCPMRI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

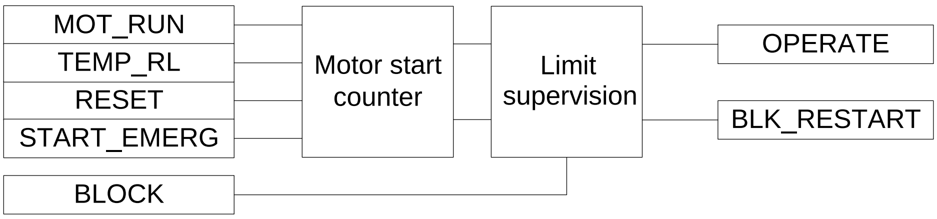


Figure 763: Functional module diagram

Motor start counter

This module counts the number of motor starts. The value of the cold count COLD_COUNT and warm count WARM_COUNT is available in the Monitored data view. On the rising edge of MOT_RUN, the module increments the cold start counter. If the thermal content available at the TEMP_RL input is above the set *Warm start level* when the rising edge of the MOT_RUN input is received, both cold and warm start counter values are incremented.

If *Operation* of the thermal overload protection for motors function MPTTR is set as "Off", the TEMP_RL value is not available. In this case, the warm start counter does not increase.

The counter decrease timer also starts at the first increment of the cold start counter (that is the first time when the counter increases from zero). When *Cnt decrease time* elapses, both cold and warm start counters decrease by one and the counter decrease timer restarts. This is repeated until both cold and warm counters are zero.

When the motor is not in operation, that is, the motor is in stop condition, it takes more time to cool. During such condition *Cnt decrease time* is multiplied by a *Cnt Dec timer Mult* setting.

The motor start detection is available at the MOT_START output of the motor start-up supervision function STTPMSU. The MOT_START output of STTPMSU must be connected to the MOT_RUN input of this function in Application Configuration in PCM600. Similarly, the TEMP_RL output of MPTTR must be connected to the TEMP_RL input of this function in Application Configuration in PCM600.

When the emergency start signal START_EMERG is set high and if the value of the cold or warm counter is above its start value setting, the value of the counter is set one count less than the respective maximum number of start value setting. This disables BLK_RESTART and OPERATE which makes the restart of motor possible.

The values can be reset by activating the RESET binary input. The activation of the RESET input also resets the counter decrease timer. The counter value can also be reset on the Clear menu.

Limit supervision

This module compares the motor cold and warm count to the set *Max Num cold start* and *Max Num warm start*, respectively. The BLK_RESTART output is activated when either the cold or the warm start counter reaches the set *Max Num cold start* or *Max Num warm start*, respectively. The OPERATE output is activated when either the cold or the warm start counter exceeds the set *Max Num cold start* or *Max Num warm start*, respectively.

When the BLK_RESTART output is active, T_RST_ENA shows the possible time for the next restart. The value of T_RST_ENA is calculated as the time left for both counters to decrease below their maximum number of starts.

Activation of the BLOCK input blocks both OPERATE and BLK_RESTART outputs.

6.7.5 Application

Repeated motor starts increase the temperature to a high value in the stator or rotor windings, or both, unless enough time is allowed for the heat to dissipate. To ensure a safe operation, it is necessary to provide a fixed-time interval between starts or limit the number of starts within a period of time. This is why the motor manufacturers have restrictions on how many starts are allowed in a defined time interval.

This function counts the number of cold and warm starts and provides a block restart signal when the number of starts reaches the permitted limit. The customer can use this signal for blocking a new start operation. An operate signal is also available which can be used to disconnect the motor when the number of starts exceeds the limit.

6.7.6 Signals

6.7.6.1 MSCPMRI Input signals

Table 1288: MSCPMRI Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
START_EMERG	BOOLEAN	0=False	Signal to indicate the need of emergency start
RESET	BOOLEAN	0=False	Reset cold and warm start counter value
MOT_RUN	BOOLEAN	0=False	Signal to show that motor start up is in progress
TEMP_RL	FLOAT32	0.00	Thermal level of the motor

6.7.6.2 MSCPMRI Output signals

Table 1289: MSCPMRI Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate signal
BLK_RESTART	BOOLEAN	Restart inhibited

6.7.7 MSCPMRI Settings

Table 1290: MSCPMRI Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Warm start level	20.0...100.0	%	0.1	35.0	Thermal threshold to define a warm start
Max Num cold start	1...10		1	2	Maximum number of cold start allowed
Max Num warm start	1...10		1	1	Maximum number of warm start allowed
Cnt decrease time	1...180	min	1	60	Counter decrease time

Table 1291: MSCPMRI Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Cnt Dec timer Mult	1.00...10.00		0.01	1.00	Multiplier for counter decrease timer

Table 1292: MSCPMRI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On

6.7.8 MSCPMRI Monitored data

Table 1293: MSCPMRI Monitored data

Name	Type	Values (Range)	Unit	Description
COLD_COUNT	INT32	0...100		Count value of cold start
WARM_COUNT	INT32	0...100		Count value of warm start
T_RST_ENA	INT32	0...180	min	Time left for restart when lockstart is enabled in minutes
MSCPMRI	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.8 Three-phase remanent undervoltage supervision MSVPR (ANSI 27R)

6.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase remanent undervoltage supervision	MSVPR	3U<R	27R

6.8.2 Function block

Figure 764: Function block

6.8.3 Functionality

The three-phase remanent undervoltage supervision function MSVPR is used to supervise the remanent voltage of the motor. The rotor with high inertia load may continue to rotate after the primary supply voltage is switched off. Re-energizing the motor immediately can result in catastrophic failure.

MSVPR gives permissive output when the remanent voltage of the motor reaches a safe level to re-energize. Supervision can be selected for one-phase or for three-phase operation. MSVPR can also adapt to a frequency range of 10...70 Hz.

The function contains a blocking functionality. It is possible to block the function output, timer or the function itself.

6.8.4 Analog channel configuration

MSVPR has one analog group input which must be properly configured.

Table 1294: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1295: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected when *Phase supervision* is set to "A or AB", "B or BC" or "C or CA".
	The function requires that all three voltage channels are connected if *Phase supervision* is set to "A&B&C or AB&BC&CA".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

6.8.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of MSVPR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

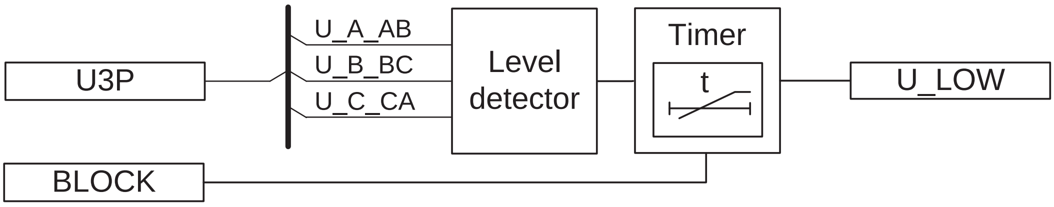


Figure 765: Functional module diagram

Level detector

The *Voltage selection* setting is used for selecting the phase-to-earth or phase-tophase voltages for supervision.

The voltage measurement can adapt the frequency to a range of 10...70 Hz.

Level detector supports one- or three-phase operation. Selection can be made with setting *Phase supervision*.

Table 1296: Functionality depending on Phase supervision

Value of *Phase supervision*	Functionality
1 = A or AB 2 = B or BC 4 = C or CA	This selection implements single-phase voltage supervision on the selected phase. If the measured voltage of the supervised phase is lower than the set value of the *Start value* setting, Level detector enables the Timer module.
7 = A&B&C or AB&BC&CA	This selection implements three-phase voltage supervision. The measured voltage of three supervised phases is compared against the *Start value* setting. If the number of phases where the voltage is below the setting matches the Num of phases setting, Level detector enables the Timer module.

Timer

Once activated, Timer runs until the value of *Operate delay time* has elapsed. The time characteristic is according to DT. When the operation timer has reached the value of *Operate delay time*, the U_LOW output is activated.

In a drop-off case, the remanent voltage returns to a value higher than the set value of *Start value* before *Operate delay time* is exceeded. Also, the timer reset state is activated. The reset timer runs until the *Reset delay time* value is exceeded. If the duration of the voltage drop-off exceeds the set Reset delay time, the operate timer is reset and the U_LOW output is deactivated.

The BLOCK input can be controlled with a binary input, a horizontal communication input or an internal signal of the relay program. The activation of the BLOCK input resets Timer and prevents the U_LOW output from being activated.

6.8.6 Application

Systems with critical motor applications provide a backup power source that can be switched in when the primary power source becomes faulty. When the power to a motor is suddenly lost, the motor terminal voltage does not immediately fall to zero because the rotating motor now acts as a generator producing its own voltage. Remanent voltage decays as the motor comes to a stop at a rate depending on the motor and load. Connecting the backup power source while the remanent voltage is at a high level can result in damage to the motor shaft and windings.

MSVPR is used to monitor the motor remanent voltage over a decaying frequency after power supply is lost, before allowing connection of backup power. It provides a permissive signal indicating when the backup power can be safely connected.

This application example describes the re-energization process. MSVPR is used to supervise the Bus1 remanent voltage. Control logic is used to detect the loss of primary power source and initiate the transfer to backup power. Normally, bus tie breaker CB5 is open and motor voltage power is supplied by incoming Feeder1 (see *Figure 766*).

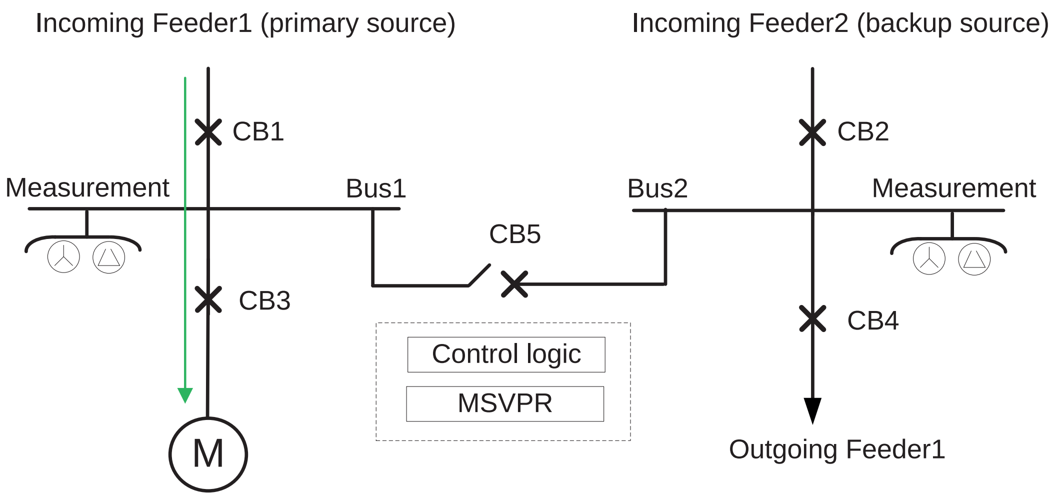


Figure 766: Example of remanent voltage supervision before fault

CB1 is tripped when a fault occurs on incoming Feeder1. MSVPR gives permission to control logic when the remanent voltage of the motor reaches a safe level on Bus1. Control logic closes the tie breaker CB5 if closing conditions are met. Finally, the motor is re-energized by incoming Feeder2 (see *Figure 767*).

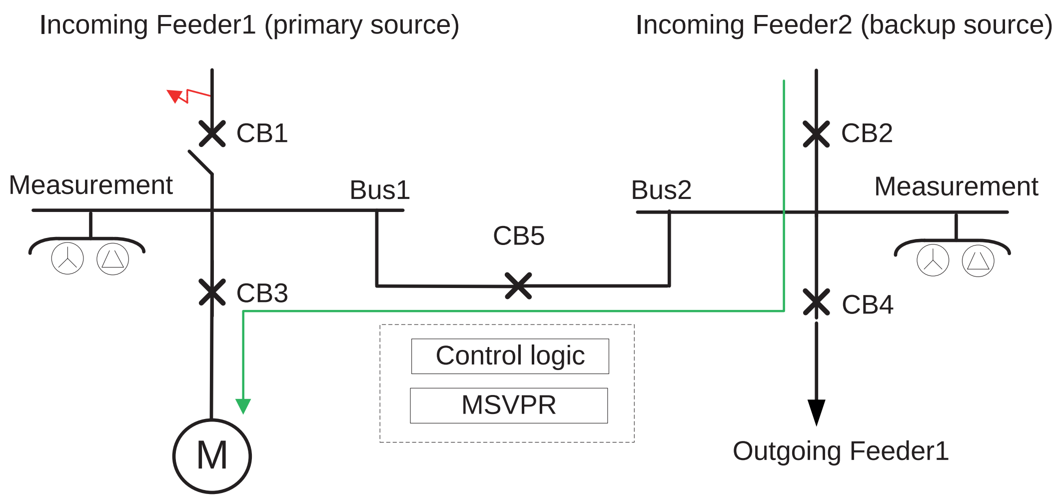


Figure 767: Example of remanent voltage supervision after fault

MSVPR runs in the range of 10...70 Hz. If the frequency is lower than 10 Hz, the motor terminal voltage is very low. The remanent voltage setting is typically set to 20...30 percent of the rated voltage.

6.8.7 Signals

6.8.7.1 MSVPR Input signals

Table 1297: MSVPR Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

6.8.7.2 MSVPR Output signals

Table 1298: MSVPR Output signals

Name	Type	Description
U_LOW	BOOLEAN	Low remanent voltage

6.8.8 MSVPR Settings

Table 1299: MSVPR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Start value	0.05...1.20	xUn	0.01	0.25	Start value
Operate delay time	100...300000	ms	100	100	Operate delay time
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			3=3 out of 3	Number of phases required for voltage supervision
Phase supervision	1=A or AB 2=B or BC 4=C or CA 7=A&B&C or AB&BC&CA			7=A&B&C or AB&BC&CA	Monitored voltage phase

Table 1300: MSVPR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reset delay time	0...60000	ms	1	20	Reset delay time

6.8.9 MSVPR Monitored data

Table 1301: MSVPR Monitored data

Name	Type	Values (Range)	Unit	Description
U_AMPL_A	FLOAT32	0.00...5.00	xUn	Remanent voltage of phase A
U_AMPL_B	FLOAT32	0.00...5.00	xUn	Remanent voltage of phase B
U_AMPL_C	FLOAT32	0.00...5.00	xUn	Remanent voltage of phase C
U_AMPL_AB	FLOAT32	0.00...5.00	xUn	Remanent voltage of phase to phase AB
U_AMPL_BC	FLOAT32	0.00...5.00	xUn	Remanent voltage of phase to phase BC
U_AMPL_CA	FLOAT32	0.00...5.00	xUn	Remanent voltage of phase to phase CA
MSVPR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.8.10 Technical data

Table 1302: MSVPR Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage:
	20 Hz < f ≤ 70 Hz: ±1.5 % of the set value or ±0.002 × U_n 10 Hz < f ≤ 20 Hz: ±4.0 % of the set value or ±0.002 × U_n
Reset time	Typically 40 ms
Reset ratio	Typically 1.04
Operate time accuracy in definite time mode	±1.0 % of the set value or ±20 ms

6.9 Current circuit supervision for transformers CTSRCTF (ANSI CCM 3I,I2)

6.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current circuit supervision for trans-formers	CTSRCTF	MCS 3I,I2	CCM 3I,I2

6.9.2 Function block

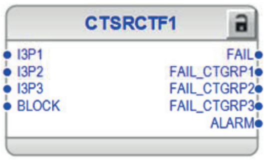


Figure 768: Function block

6.9.3 Functionality

The current circuit supervision for transformers function CTSRCTF is used for monitoring the current transformer secondary circuit where a separate reference current transformer input for comparison is not available or where a separate voltage channel for calculating or measuring the zero-sequence voltage is not available. CTSRCTF can be used for detecting the single-phase failure on the current transformer secondary for protection application involving two or three sets of the three-phase current transformers.

CTSRCTF detects a fault in the measurement circuit and issues an alarm which can be used for blocking the protection functions, for example, differential protection, to avoid unwanted tripping.

CTSRCTF is internally blocked in case of a transformer under no-load condition or if a current in any one phase exceeds the set maximum limit.

6.9.4 Analog channel configuration

CTSRCTF has three analog group inputs which must be properly configured.

Table 1303: Analog inputs

Input	Description
I3P1	Three-phase currents
I3P2	Three-phase currents
I3P3	Three-phase currents, can be connected to `GRPOFF`

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

6.9.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of CTSRCTF can be described with a module diagram. All the modules in the diagram are explained in the next sections.

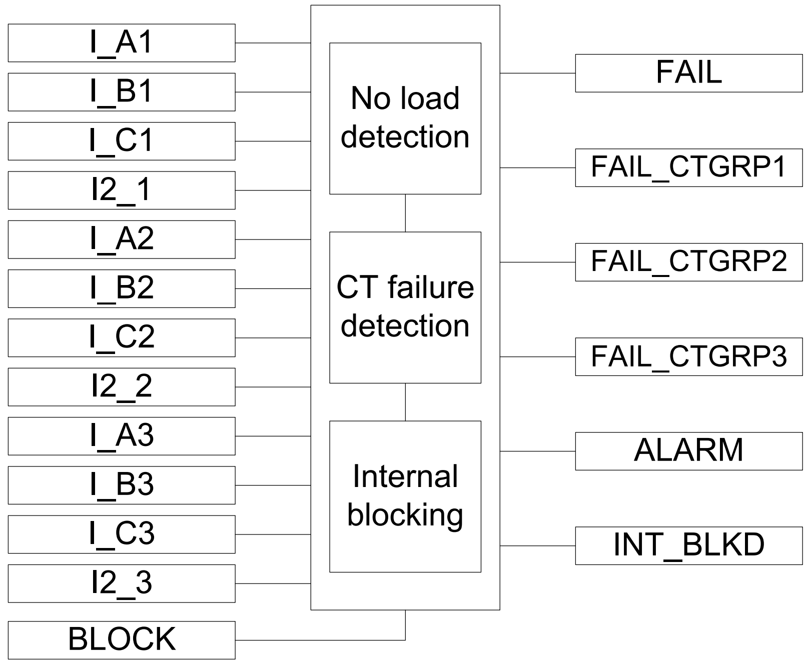


Figure 769: Functional module diagram

No-load detection

No-load detection module detects the loading condition. If all the three-phase currents of any two sets of current transformer are zero, the protected equipment is considered to be in the no-load condition and the function is internally blocked by activating the `INT_BLKD` output.

To avoid any false operation, the function is also internally blocked if any two-phase currents of any set of current transformers are below *Min operate current*. This activates `INT_BLKD`. The value of the Min operate current setting depends on the type of equipment to be protected. For example, in case of transformer protection, *Min operate current* depends on the no-load current rating. Typically, it can be set equal to the transformer no-load current rating.

CT failure detection

This module detects the CT secondary failure in any sets of current transformers. The module continuously scans the value of all the three-phase currents in all groups of current transformers to detect any sudden drop in the current value to zero. The detection of a zero current should not be the only criterion for considering a fault in the current transformer secondary. Two other criteria are evaluated to confirm the CT failure:

- A zero current due to the CT failure does not result in a negative-sequence current on healthy CT sets.

  On the detection of a zero current in any phase on either group of CT, the negative-sequence current I_2 is further evaluated. For a genuine CT secondary failure, the magnitude of I_2 changes only on the side where zero current has been detected. The change in the magnitude of I_2 (ΔI_2) on the other sets of the current transformer (other than where zero current is detected) is calculated. If the change is detected on the healthy sets of CT, it is an indication of system failure.

- A zero current due to the CT failure does not result in a phase angle difference between the healthy phases.

  If a system faults happens on the phase A, it results in a change in the phase angle difference between phase B and phase C. This change in the phase angle difference between the healthy phases is evaluated in all three sets of current transformer, and if the change is detected in any set of CT, it is an indication of the system failure.

If both conditions are satisfied at zero current, the FAIL output is activated immediately. The ALARM output is activated after a fixed 200 ms delay. FAIL needs to be active during the delay. The outputs FAIL, CTGRP1, FAIL_CTGRP2 and FAIL_CTGRP3 are activated according to the CT group where the secondary failure is detected.

Activation of the BLOCK input deactivates the FAIL and ALARM outputs.

It is not possible to detect the CT secondary failure happening simultaneously with the system faults or failures or two simultaneous failures in the secondary circuit. The function resets if the zero current does not exist longer than 200 ms.

Internal blocking

This module blocks the function internally under specific condition to avoid any false operation during a system fault situation. When any of the following condition is satisfied, the function is internally blocked and the FAIL output is deactivated immediately.

- Magnitude of any phase current for any group of current transformers exceeds the *Max operate current* setting. The magnitude of phase current is calculated from the peak-to-peak value.
- Magnitude of the negative-sequence current I_2 on the healthy set of current transformer exceeds the *Max Nq Seq current* setting.

The INT_BLKD output is activated when FAIL is deactivated if any of the above conditions is satisfied. The ALARM output is also deactivated after a fixed three-second delay after the FAIL output is deactivated.

6.9.6 Application

Open or short-circuited current transformer secondary can cause unwanted operation in many protection functions, such as earth-fault current and differential. The simplest method for detecting the current transformer secondary failure is by comparing currents from two independent three-phase sets of CTs or the CT cores measuring the same primary currents. Another widely used method is the detection of a zero-sequence current and zero-sequence voltage. The detection of a zero-sequence current in the absence of a zero-sequence voltage is an indication of the current transformer secondary failure. However, both methods have disadvantages as they require an additional set of current transformer, or a voltage channel is needed for detecting a zero-sequence voltage.

The methods may not be applicable where additional current channels or voltage channels are not available. This CT secondary circuit supervision presents an algorithm that can be used as an example for detecting the CT secondary failure used for the unit protection of a two-winding or three-winding transformer. However, the function has a limitation that it cannot detect failure in case of equipment under protection in no-load condition or when two simultaneous secondary CT failures occur.

The detection of a zero current in any one phase is a partial indication of failure in the current transformer secondary. Furthermore, if this current zero is due to the failure in the current transformer secondary, it results in a change in the magnitude of the negative-sequence current in the group only where current zero has been detected. However, changes in the negative-sequence current in other groups of three-phase current transformers at the instance of zero-current detection is an indication of a system problem. Also, it may happen that after the detection of a failure in the current transformer secondary, a fault may occur in the system. During such condition, functions are internally blocked.

Phase discontinuity

A zero current detected due to the phase discontinuity results in an asymmetry in all the sets of the current transformer, which then results in a change in the negative-sequence current (ΔI_2) in the healthy set. This change in the negative-sequence current on the healthy sides, that is, other than where a zero current has been detected, blocks the function.

In case of a lightly loaded transformer (up to 30 %) the change in the negative-sequence current may be very negligible. However, a phase discontinuity results in a change in the phase angle difference between two healthy phases in the set of CTs where a zero current has been detected as well as on the primary side of the transformer. This change in the value of the angle blocks the function internally.

Overload / System short circuit condition

It is required that any overload or short circuit conditions after a CT failure should block the function. During overload or short circuit condition, the phase current increases beyond its rated value; if any phase current on any set of current transformer exceeds the set limit, the function is blocked internally. Also in case of an unsymmetrical fault, the negative-sequence current increases. If the negative-sequence current increases beyond the set limit, the function is blocked internally. The overcurrent and negative-sequence current setting both can be set equal to the overcurrent and negative-sequence protection function start value.

The internal blocking is thus useful for avoiding false operation during a fault situation.

6.9.7 Signals

6.9.7.1 CTSRCTF Input signals

Table 1304: CTSRCTF Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
I3P3	SIGNAL	-	Three-phase currents 3
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

6.9.7.2 CTSRCTF Output signals

Table 1305: CTSRCTF Output signals

Name	Type	Description
FAIL	BOOLEAN	CT secondary failure
FAIL_CTGRP1	BOOLEAN	CT secondary failure group 1
FAIL_CTGRP2	BOOLEAN	CT secondary failure group 2
FAIL_CTGRP3	BOOLEAN	CT secondary failure group 3
ALARM	BOOLEAN	Alarm

6.9.8 CTSRCTF Settings

Table 1306: CTSRCTF Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Min operate current	0.01...0.50	xIn	0.01	0.02	Minimum operate current
Max operate current	1.00...5.00	xIn	0.01	1.30	Maximum operate current
Max Ng Seq current	0.01...1.00	xIn	0.01	0.10	Maximum I2 current in healthy set

6.9.9 CTSRCTF Monitored data

Table 1307: CTSRCTF Monitored data

Name	Type	Values (Range)	Unit	Description
INT_BLKD	BOOLEAN	0=False		Function blocked internally

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		1=True		
CTSRCTF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.9.10 Technical data

Table 1308: CTSRCTF Technical data

Characteristic	Value
Operate time (including the delay of the output contact)	<30 ms

7 Condition monitoring functions

7.1 Circuit-breaker condition monitoring SSCBR (ANSI 52CM)

7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit-breaker condition monitor-ing	SSCBR	CBCM	52CM

7.1.2 Function block

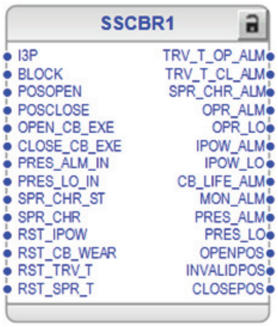


Figure 770: Function block

7.1.3 Functionality

The circuit-breaker condition monitoring function SSCBR is used to monitor different parameters of the circuit breaker. The breaker requires maintenance when the number of operations has reached a predefined value. The energy is calculated from the measured input currents as a sum of I^yt values. Alarms are generated when the calculated values exceed the threshold settings.

The function contains a blocking functionality which can be used to block the function outputs.

7.1.4 Analog input configuration

SSCBR has one analog group input which must be properly configured.

Table 1309: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

7.1.5 Operation principle

The circuit breaker condition monitoring function includes different metering and monitoring sub-functions. The functions can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”. The operation counters are cleared when *Operation* is set to “Off”.

The operation of SSCBR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

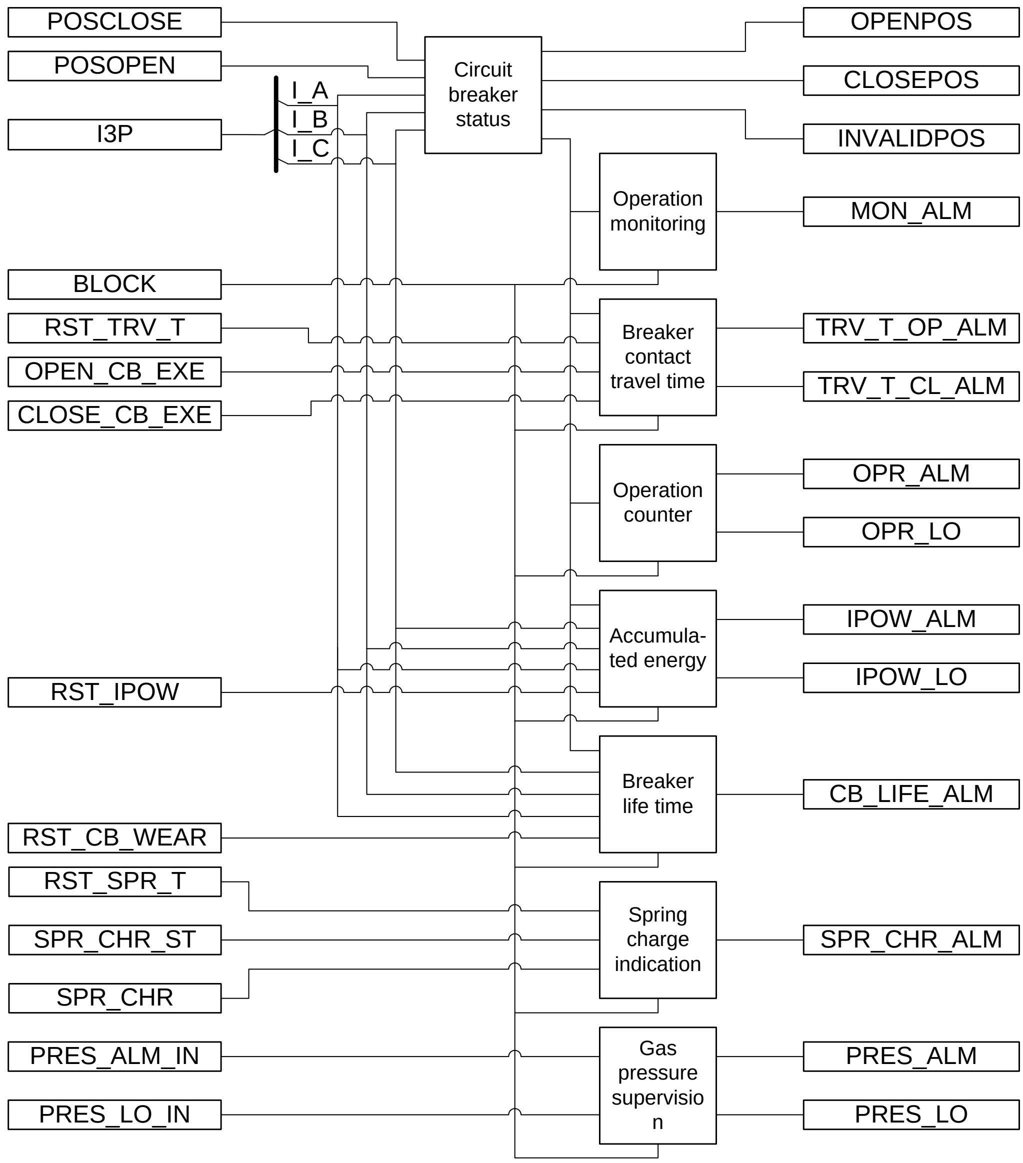


Figure 771: Functional module diagram

7.1.5.1 Circuit breaker status

The Circuit breaker status sub-function monitors the position of the circuit breaker, that is, whether the breaker is in open, closed or invalid position. The operation of the breaker status monitoring can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

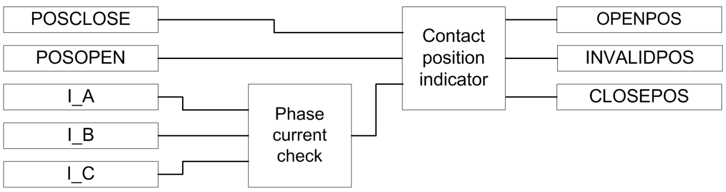


Figure 772: Functional module diagram for monitoring circuit breaker status

Phase current check

This module compares the three phase currents to the setting *Acc stop current*. If the current in a phase exceeds the set level, information about the phase is reported to the contact position indicator module.

Contact position indicator

The OPENPOS output is activated when the auxiliary input contact POSCLOSE is FALSE, the POSOPEN input is TRUE and all the phase currents are below the setting *Acc stop current*.

The CLOSEPOS output is activated when the auxiliary POSOPEN input is FALSE and the POSCLOSE input is TRUE.

The INVALIDPOS output is activated when both the auxiliary contacts have the same value, that is, both are in the same logical level, or if the auxiliary input contact POSCLOSE is FALSE and the POSOPEN input is TRUE and any of the phase currents exceed the setting Acc stop current.

The status of the breaker is indicated by the binary outputs OPENPOS, INVALIDPOS and CLOSEPOS for open, invalid and closed position respectively.

7.1.5.2 Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring subfunction is to indicate if the circuit breaker has not been operated for a long time.

The operation of the circuit breaker operation monitoring can be described with a module diagram. All the modules in the diagram are explained in the next sections.

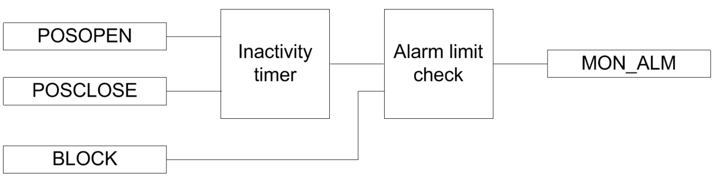


Figure 773: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring

Inactivity timer

The module calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. The calculation is done by monitoring the states of the POSOPEN and POSCLOSE auxiliary contacts.

The inactive days INA_DAYS is available in the monitored data view. It is also possible to set the initial inactive days with the *Ini inactive days* parameter.

Alarm limit check

When the inactive days exceed the limit value defined with the *Inactive Alm days* setting, the MON_ALM alarm is initiated. The time in hours at which this alarm is activated can be set with the *Inactive Alm hours* parameter as coordinates of UTC. The alarm signal MON_ALM can be blocked by activating the binary input BLOCK.

7.1.5.3 Breaker contact travel time

The Breaker contact travel time module calculates the breaker contact travel time for the closing and opening operation. The operation of the breaker contact travel time measurement can be described with a module diagram. All the modules in the diagram are explained in the next sections.

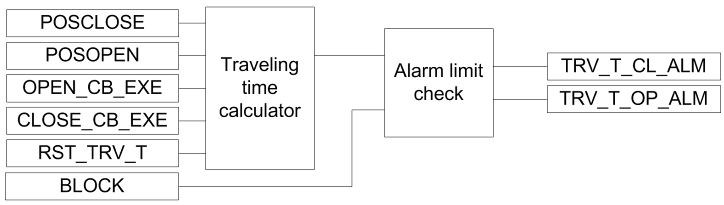


Figure 774: Functional module diagram for breaker contact travel time

Traveling time calculator

The travel time can be calculated using two different methods based on the setting *Travel time Clc mode*.

When the setting *Travel time Clc mode* is “From Pos to Pos”, the contact travel time of the breaker is calculated from the time between auxiliary contacts' state change. The opening travel time is measured between the opening of the POSCLOSE auxiliary contact and the closing of the POSOPEN auxiliary contact. The travel time is also measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

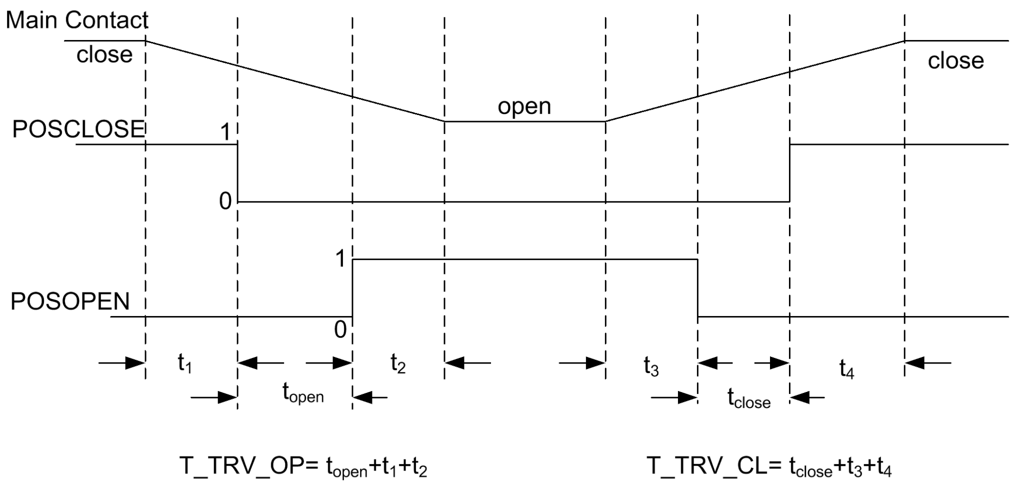


Figure 775: Travel time calculation when Travel time Clc mode is “From Pos to Pos”

There is a time difference t_1 between the start of the main contact opening and the opening of the POSCLOSE auxiliary contact. Similarly, there is a time gap t_2

between the time when the POSOPEN auxiliary contact opens and the main contact is completely open. To incorporate the time $t_1 + t_2$, a correction factor needs to be added with t_{open} to get the actual opening time. This factor is added with the *Opening time Cor* (= $t_1 + t_2$) setting. The closing time is calculated by adding the value set with the *Closing time Cor* ($t_3 + t_4$) setting to the measured closing time.

When the setting *Travel time Clc mode* is "From Cmd to Pos", the contact travel time of the breaker is calculated from the time between the circuit breaker opening or closing command and the auxiliary contacts' state change. The opening travel time is measured between the rising edge of the OPEN_CB_EXE command and the POSOPEN auxiliary contact. The closing travel time is measured between the rising edge of the CLOSE_CB_EXEC command and the POSCLOSE auxiliary contact.

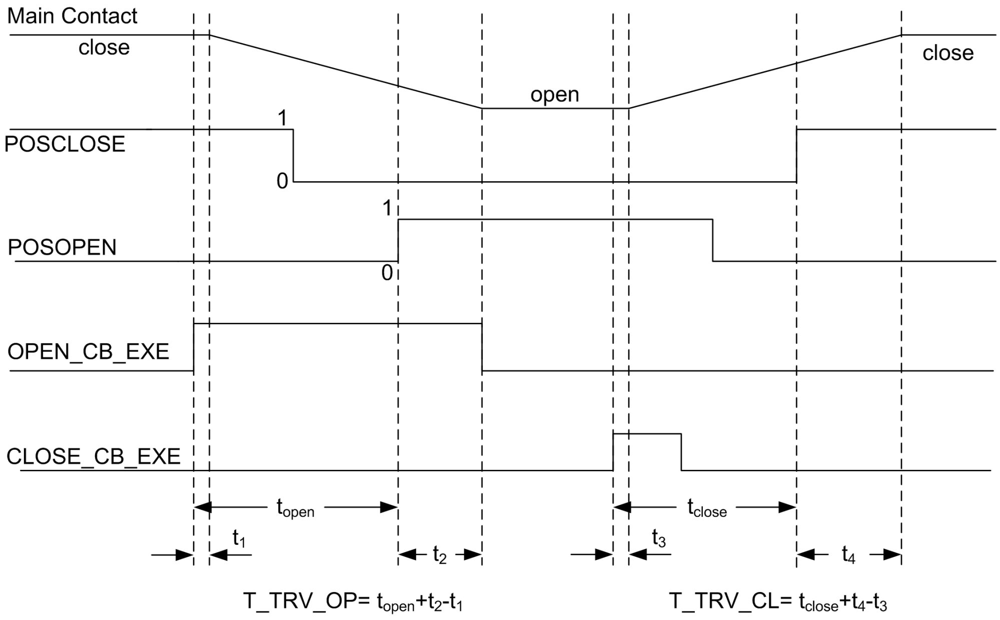


Figure 776: Travel time calculation when Travel time Clc mode is "From Cmd to Pos"

There is a time difference t_1 between the start of the main contact opening and the OPEN_CB_EXE command. Similarly, there is a time gap t_2 between the time when the POSOPEN auxiliary contact opens and the main contact is completely open. Therefore, to incorporate the times t_1 and t_2, a correction factor needs to be added with t_{open} to get the actual opening time. This factor is added with the *Opening time Cor* (= $t_2 - t_1$) setting. The closing time is calculated by adding the value set with the *Closing time Cor*($t_4 - t_3$) setting to the measured closing time.

The last measured opening travel time T_TRV_OP and the closing travel time T_TRV_CL are available in the monitored data view on the LHMI or through tools via communications.

Alarm limit check

When the measured opening travel time is longer than the value set with the *Open alarm time* setting, the TRV_T_OP_ALM output is activated. Respectively, when the measured closing travel time is longer than the value set with the *Close alarm time* setting, the TRV_T_CL_ALM output is activated.

It is also possible to block the TRV_T_CL_ALM and TRV_T_OP_ALM alarm signals by activating the BLOCK input.

7.1.5.4 Operation counter

The operation counter subfunction calculates the number of breaker operation cycles. The opening and closing operations are both included in one operation cycle. The operation counter value is updated after each opening operation.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

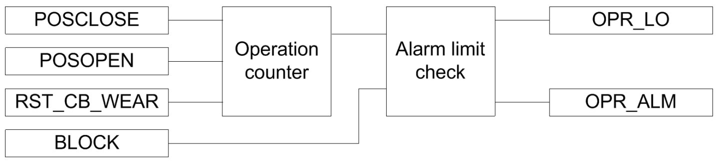


Figure 777: Functional module diagram for counting circuit breaker operations

Operation counter

The operation counter counts the number of operations based on the state change of the binary auxiliary contacts inputs POSCLOSE and POSOPEN.

The number of operations NO_OPR is available in the monitored data view on the LHMI or through tools via communications. The old circuit breaker operation counter value can be taken into use by writing the value to the *Counter initial Val* parameter and by setting the parameter *CB wear values* in the clear menu from WHMI or LHMI.

Alarm limit check

The OPR_ALM operation alarm is generated when the number of operations exceeds the value set with the *Alarm Op number* threshold setting. However, if the number of operations increases further and exceeds the limit value set with the *Lockout Op number* setting, the OPR_LO output is activated.

The binary outputs OPR_LO and OPR_ALM are deactivated when the BLOCK input is activated.

7.1.5.5 Accumulation of I y t

Accumulation of the I ^{y}t module calculates the accumulated energy.

The operation of the module can be described with a module diagram. All the modules in the diagram are explained in the next sections.

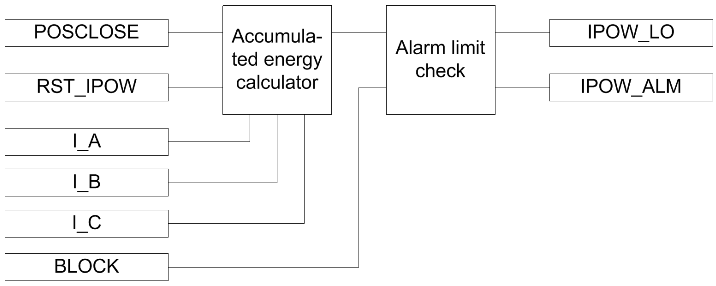


Figure 778: Functional module diagram for calculating accumulative energy and alarm

Accumulated energy calculator

This module calculates the accumulated energy I ^{y}t [(kA) ^{y}s]. The factor y is set with the *Current exponent* setting.

The calculation is initiated with the POSCLOSE input opening events. It ends when the RMS current becomes lower than the *Acc stop current* setting value.

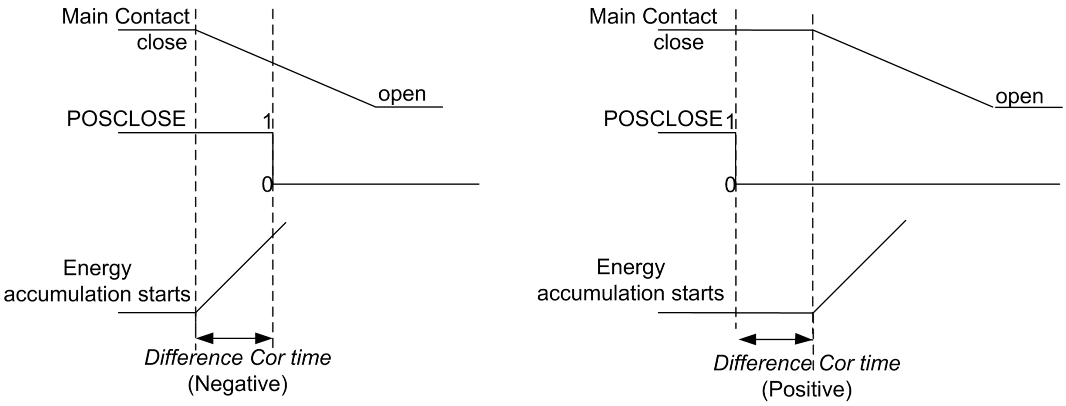


Figure 779: Significance of the Difference Cor time setting

The *Difference Cor time* setting is used instead of the auxiliary contact to accumulate the energy from the time the main contact opens. If the setting is positive, the calculation of energy starts after the auxiliary contact has opened and when the delay is equal to the value set with the *Difference Cor time* setting. When the setting is negative, the calculation starts in advance by the correction time before the auxiliary contact opens.

The accumulated energy outputs IPOW_A (_B, _C) are available in the monitored data view on the LHMI or through tools via communications. The values can be reset by setting the parameter *CB accum. currents power* setting to true in the clear menu from WHMI or LHMI.

Alarm limit check

The IPOW_ALM alarm is activated when the accumulated energy exceeds the value set with the *Alm Acc currents Pwr* threshold setting. However, when the energy exceeds the limit value set with the *LO Acc currents Pwr* threshold setting, the IPOW_LO output is activated.

The IPOW_ALM and IPOW_LO outputs can be blocked by activating the binary input BLOCK.

7.1.5.6 Remaining life of circuit breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer. The remaining life is decremented at least with one when the circuit breaker is opened.

The operation of the remaining life of the circuit breaker subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

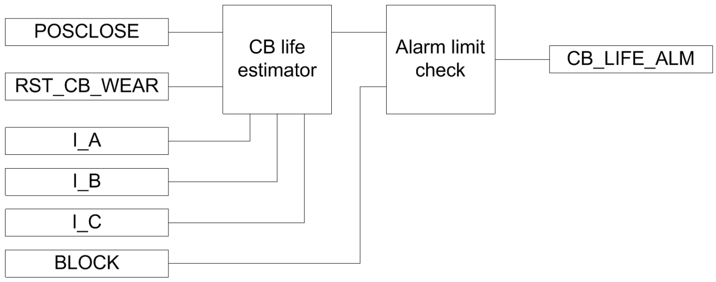


Figure 780: Functional module diagram for estimating the life of the circuit breaker

CB life estimator

CB life estimator module calculates the remaining life of the circuit breaker. The *Op number rated* and *Op number fault* parameters set the number of operations the breaker can perform at the rated current and at the rated fault current. If the tripping current is lower than the rated operating current set with the *Rated Op current* setting, the remaining operation of the breaker reduces by one operation. If the tripping current is higher than the rated fault current set with the *Rated fault current* setting, the remaining operation of the breaker reduces by *Op number rated* divided by *Op number fault*. The remaining life reduction of the tripping current in between these two values is calculated based on the trip curve given by the manufacturer.

$$Directional\ Coef = \frac{\log\left(\frac{Op\ number\ fault}{Op\ number\ rated}\right)}{\log\left(\frac{Rated\ fault\ current}{Rated\ Op\ current}\right)}$$

(Equation 319)

$$Remaining\ life\ reduction = \left(\frac{I_{fault}}{Rated\ Op\ current}\right)^{-Directional\ Coef}$$

(Equation 320)

The remaining life is calculated separately for all three phases and it is available as a monitored data value CB_LIFE_A (_B,_C). The values can be cleared by setting the parameter CB wear values in the clear menu from WHMI or LHMI.

Clearing *CB wear values* also resets the operation counter.

Alarm limit check

When the remaining life of any phase drops below the *Life alarm level* threshold setting, the corresponding circuit breaker life alarm CB_LIFE_ALM is activated.

It is possible to deactivate the CB_LIFE_ALM alarm signal by activating the binary input BLOCK. The old circuit breaker operation counter value can be taken into use by writing the value to the *Initial CB Rmn life* parameter and resetting the value via the clear menu from WHMI or LHMI.

7.1.5.7 Circuit breaker spring-charged indication

The circuit breaker spring-charged indication subfunction calculates the spring charging time.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

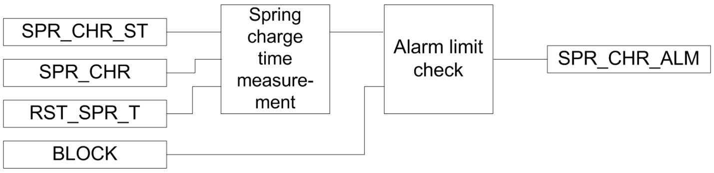


Figure 781: Functional module diagram for circuit breaker spring-charged indication and alarm

Spring charge time measurement

Two binary inputs, SPR_CHR_ST and SPR_CHR, indicate spring charging started and spring charged, respectively. The spring-charging time is calculated from the difference of these two signal timings.

The spring charging time T_SPR_CHR is available in the monitored data view on the LHMI or through tools via communications.

Alarm limit check

If the time taken by the spring to charge is more than the value set with the *Spring charge time* setting, the subfunction generates the SPR_CHR_ALM alarm.

It is possible to block the SPR_CHR_ALM alarm signal by activating the BLOCK binary input.

7.1.5.8 Gas pressure supervision

The gas pressure supervision subfunction monitors the gas pressure inside the arc chamber.

The operation of the subfunction can be described with a module diagram. All the modules in the diagram are explained in the next sections.

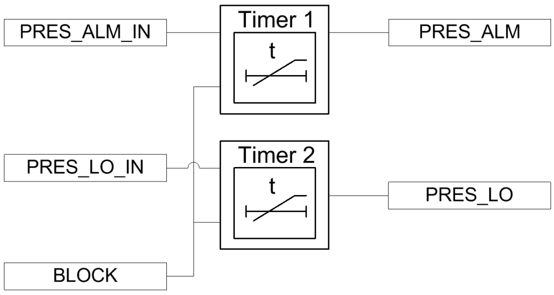


Figure 782: Functional module diagram for circuit breaker gas pressure alarm

The gas pressure is monitored through the binary input signals PRES_LO_IN and PRES_ALM_IN.

Timer 1

When the PRES_ALM_IN binary input is activated, the PRES_ALM alarm is activated after a time delay set with the *Pressure alarm time* setting. The PRES_ALM alarm can be blocked by activating the BLOCK input.

Timer 2

If the pressure drops further to a very low level, the PRES_LO_IN binary input becomes high, activating the lockout alarm PRES_LO after a time delay set with the *Pres lockout time* setting. The PRES_LO alarm can be blocked by activating the BLOCK input.

7.1.6 Application

SSCBR includes different metering and monitoring subfunctions.

Circuit breaker status

Circuit breaker status monitors the position of the circuit breaker, that is, whether the breaker is in an open, closed or intermediate position.

Circuit breaker operation monitoring

The purpose of the circuit breaker operation monitoring is to indicate that the circuit breaker has not been operated for a long time. The function calculates the number of days the circuit breaker has remained inactive, that is, has stayed in the same open or closed state. There is also the possibility to set an initial inactive day.

Breaker contact travel time

High traveling times indicate the need for the maintenance of the circuit breaker mechanism. Therefore, detecting excessive traveling time is needed. During the opening cycle operation, the main contact starts opening. The auxiliary contact A opens, the auxiliary contact B closes and the main contact reaches its opening position. During the closing cycle, the first main contact starts closing. The auxiliary contact B opens, the auxiliary contact A closes and the main contact reaches its closed position. The travel times are calculated based on the state changes of the auxiliary contacts and the adding correction factor to consider the time difference of the main contact's and the auxiliary contact's position change.

Operation counter

Routine maintenance of the breaker, such as lubricating breaker mechanism, is generally based on a number of operations. A suitable threshold setting to raise an alarm when the number of operation cycle exceeds the set limit helps preventive maintenance. This can also be used to indicate the requirement for oil sampling for dielectric testing in case of an oil circuit breaker.

The change of state can be detected from the binary input of the auxiliary contact. There is a possibility to set an initial value for the counter which can be used to initialize this functionality after a period of operation or in case of refurbished primary equipment.

Accumulation of I y t

Accumulation of $I^{y}t$ calculates the accumulated energy $\Sigma I^{y}t$, where the factor y is known as the current exponent. The factor y depends on the type of the circuit breaker. For oil circuit breakers, the factor y is normally 2. In case of a high-voltage system, the factor y can be 1.4...1.5.

Remaining life of the breaker

Every time the breaker operates, the life of the circuit breaker reduces due to wearing. The wearing in the breaker depends on the tripping current, and the remaining life of the breaker is estimated from the circuit breaker trip curve provided by the manufacturer.

Example for estimating the remaining life of a circuit breaker

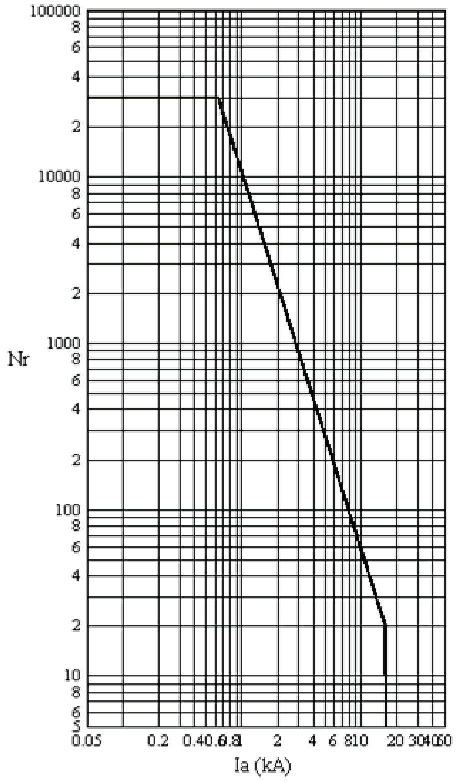


Figure 783: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter

Nr	the number of closing-opening operations allowed for the circuit breaker
Ia	the current at the time of tripping of the circuit breaker

Calculation for estimating the remaining life

Figure 783 shows that there are 30,000 possible operations at the rated operating current of 630 A and 20 operations at the rated fault current 16 kA. Therefore, if the tripping current is 10 kA, one operation at 10 kA is equivalent to 30,000/60=500 operations at the rated current. It is also assumed that prior to this tripping, the remaining life of the circuit breaker is 15,000 operations. Therefore, after one operation of 10 kA, the remaining life of the circuit breaker is 15,000-500=14,500 at the rated operating current.

Spring-charged indication

For normal operation of the circuit breaker, the circuit breaker spring should be charged within a specified time. Therefore, detecting long spring-charging time indicates that it is time for the circuit breaker maintenance. The last value of the spring-charging time can be used as a service value.

Gas pressure supervision

The gas pressure supervision monitors the gas pressure inside the arc chamber. When the pressure becomes too low compared to the required value, the circuit breaker operations are locked. A binary input is available based on the pressure levels in the function, and alarms are generated based on these inputs.

7.1.7 Signals

7.1.7.1 SSCBR Input signals

Table 1310: SSCBR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block input status
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for closeposition of apparatus from I/O
OPEN_CB_EXE	BOOLEAN	0=False	Signal for open command to coil
CLOSE_CB_EXE	BOOLEAN	0=False	Signal for close command to coil
PRES_ALM_IN	BOOLEAN	0=False	Binary pressure alarm input
PRES_LO_IN	BOOLEAN	0=False	Binary pressure input for lockout indication
SPR_CHR_ST	BOOLEAN	0=False	CB spring charging started input
SPR_CHR	BOOLEAN	0=False	CB spring charged input
RST_IPOW	BOOLEAN	0=False	Reset accumulation energy
RST_CB_WEAR	BOOLEAN	0=False	Reset input for CB remaining life and operation counter
RST_TRV_T	BOOLEAN	0=False	Reset input for CB closing and opening travel times
RST_SPR_T	BOOLEAN	0=False	Reset input for the charging time of the CB spring

7.1.7.2 SSCBR Output signals

Table 1311: SSCBR Output signals

Name	Type	Description
TRV_T_OP_ALM	BOOLEAN	CB open travel time exceeded set value
TRV_T_CL_ALM	BOOLEAN	CB close travel time exceeded set value
SPR_CHR_ALM	BOOLEAN	Spring charging time has crossed the set value
OPR_ALM	BOOLEAN	Number of CB operations exceeds alarm limit
OPR_LO	BOOLEAN	Number of CB operations exceeds lockout limit
IPOW_ALM	BOOLEAN	Accumulated currents power (Iyt),exceeded alarm limit
IPOW_LO	BOOLEAN	Accumulated currents power (Iyt),exceeded lockout limit
CB_LIFE_ALM	BOOLEAN	Remaining life of CB exceeded alarm limit
MON_ALM	BOOLEAN	CB 'not operated for long time' alarm
PRES_ALM	BOOLEAN	Pressure below alarm level
PRES_LO	BOOLEAN	Pressure below lockout level
OPENPOS	BOOLEAN	CB is in open position
INVALIDPOS	BOOLEAN	CB is in invalid position (not positively open or closed)
CLOSEPOS	BOOLEAN	CB is in closed position

7.1.8 SSCBR Settings

Table 1312: SSCBR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Acc stop current	5.00...500.00	A	0.01	10.00	RMS current setting below which engy acm stops
Open alarm time	0...200	ms	10	40	Alarm level setting for open travel time in ms
Close alarm time	0...200	ms	10	40	Alarm level Setting for close travel time in ms
Spring charge time	0...60	s	1	15	Setting of alarm for spring charging time of CB in s

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Alarm Op number	0...99999		1	200	Alarm limit for number of operations
Lockout Op number	0...99999		1	300	Lock out limit for number of operations
Current exponent	0.00...5.00		0.01	2.00	Current exponent setting for energy calculation
Difference Cor time	-10...10	ms	1	5	Corr. factor for time dif in aux. and main contacts open time
Alm Acc currents Pwr	0.00...20000.00		0.01	2500.00	Setting of alarm level for accumulated currents power
LO Acc currents Pwr	0.00...20000.00		0.01	2500.00	Lockout limit setting for accumulated currents power
Initial CB Rmn life	0...99999		1	5000	Initial value for the CB remaining life
Rated Op current	100.00...6300.00	A	0.01	1000.00	Rated operating current of the breaker
Rated fault current	500.00...99999.00	A	0.01	5000.00	Rated fault current of the breaker
Op number rated	1...99999		1	10000	Number of operations possible at rated current
Op number fault	1...10000		1	1000	Number of operations possible at rated fault current
Inactive Alm days	0...9999		1	2000	Alarm limit value of the inactive days counter
Travel time Clc mode	1=From Cmd to Pos 2=From Pos to Pos			2=From Pos to Pos	Travel time calculation mode selection

Table 1313: SSCBR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Opening time Cor	-100...100	ms	1	10	Correction factor for open travel time in ms
Closing time Cor	-100...100	ms	1	10	Correction factor for CB close travel time in ms
Counter initial Val	0...99999		1	0	The operation numbers counter initialization value
Ini Acc currents Pwr	0.00...20000.00		0.01	0.00	Initial value for accumulation energy (Iyt)
Life alarm level	0...99999		1	500	Alarm level for CB remaining life
Pressure alarm time	0...60000	ms	1	10	Time delay for gas pressure alarm in ms
Pres lockout time	0...60000	ms	10	10	Time delay for gas pressure lockout in ms
Ini inactive days	0...9999		1	0	Initial value of the inactive days counter
Inactive Alm hours	0...23	h	1	0	Alarm time of the inactive days counter in hours

7.1.9 SSCBR Monitored data

Table 1314: SSCBR Monitored data

Name	Type	Values (Range)	Unit	Description
T_TRV_OP	FLOAT32	0...60000	ms	Travel time of the CB during opening operation
T_TRV_CL	FLOAT32	0...60000	ms	Travel time of the CB during closing operation
T_SPR_CHR	FLOAT32	0.00...99.99	s	The charging time of the CB spring
NO_OPR	INT32	0...99999		Number of CB operation cycle
INA_DAYS	INT32	0...9999		The number of days CB has been inactive
CB_LIFE_A	INT32	-99999...99999		CB Remaining life phase A
CB_LIFE_B	INT32	-99999...99999		CB Remaining life phase B
CB_LIFE_C	INT32	-99999...99999		CB Remaining life phase C
IPOW_A	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase A
IPOW_B	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase B
IPOW_C	FLOAT32	0.000...30000.000		Accumulated currents power (Iyt), phase C
SSCBR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

7.1.10 Technical data

Table 1315: SSCBR Technical data

Characteristic	Value
Current measuring accuracy	±1.5 % or ±0.002 × I_n (at currents in the range of 0.1…10 × I_n) ±5.0 % (at currents in the range of 10…40 × I_n)
Operate time accuracy	±1.0 % of the set value or ±20 ms
Travelling time measurement	+10 ms / -0 ms

7.2 Motor controlled earthing switch and disconnector supervision ESDCSSWI (ANSI 29CM)

7.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Motor controlled earthing switch and disconnector supervision	ESDCSSWI	ESDCCM	29CM

7.2.2 Function block

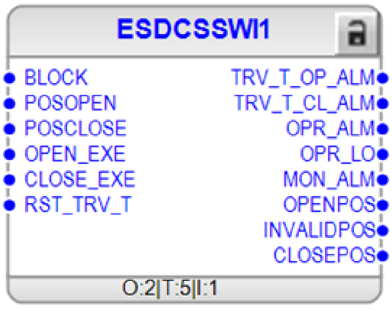


Figure 784: Function block

7.2.3 Functionality

The motor controlled earthing switch and disconnector supervision (ESDCSSWI) is used for monitoring switch status, inactivity, contact travel time and operation counter. Function can be used for condition monitoring and as indicator for maintenance need.

7.2.4 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of ESDCSSWI is described by using a module diagram (see figure below). All the modules in the diagram are explained in the next sections.

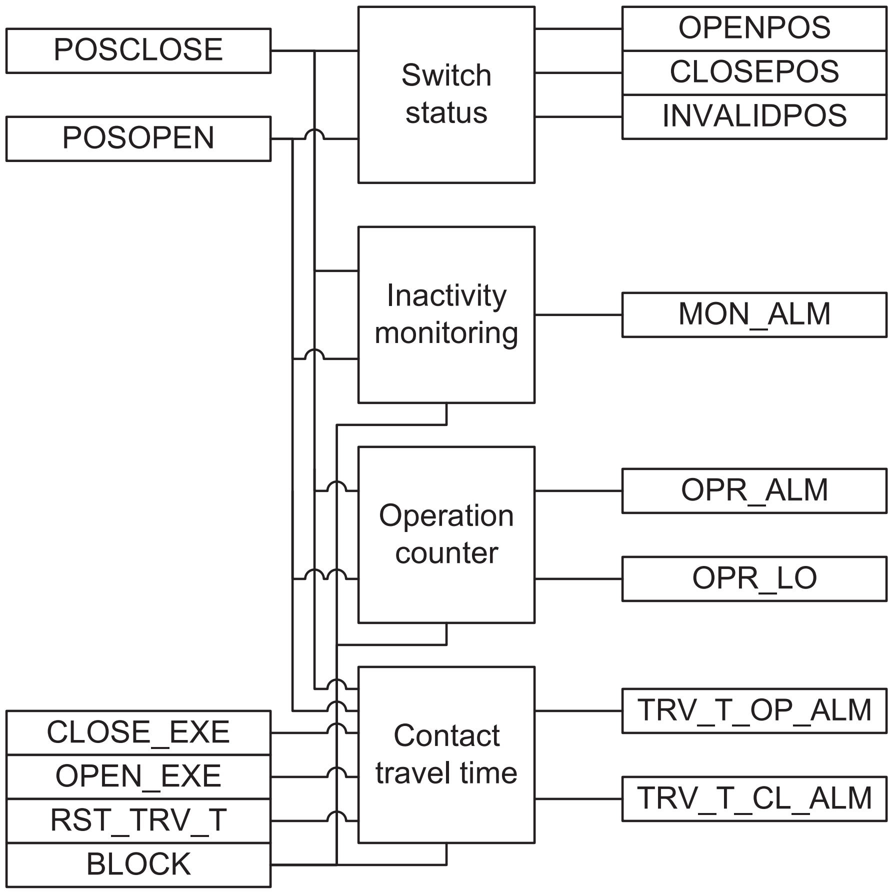


Figure 785: Functional module diagram

7.2.4.1 Switch status

This module monitors the position of the earthing switch or disconnector, that is, whether the switch is in an open, closed, intermediate or faulty position.

The OPENPOS output is activated when the auxiliary input contact POSCLOSE input is FALSE and the POSOPEN input is TRUE. The CLOSEPOS output is activated when the POSOPEN input is FALSE and the *POSCLOSE* input is TRUE.

The INVALIDPOS output is activated when both auxiliary contacts have the same value, that is, both are in the same logical level.

7.2.4.2 Inactivity monitoring

The purpose of the inactivity monitoring is to indicate if the earthing switch or disconnector has not been operated for a long time.

This module calculates the number of days the earthing switch or disconnector has remained inactive, that is, has stayed in the same open, closed and intermediate or faulty state. The calculation is done by monitoring the states of the POSOPEN, POSCLOSE auxiliary contacts. The inactive days INA_DAYS is available in the monitored data view. For relay retrofit installations, it is possible to initialize

INA_DAYS to certain value with *Ini inactive days* setting. The inactive days INA_DAYS will reset to zero when there is change in auxiliary contact.

When the INA_DAYS exceeds the limit value defined with the *Inactive Alm days* setting, the MON_AL alarm is activated. The time during the day when alarm is forwarded can be set with the *Inactive Alm hours* parameter. The warning signal MON_ALM can be blocked by activating the binary input BLOCK.

7.2.4.3 Operation counter

This module calculates the number of operation cycles which means the combination of opening and closing operation of switch. The operation counter is increased on each opening operation of the switch.

The number of operations NO_OPR is available in the monitored data view. The former operation counter value can be taken into use by writing the value to the *Counter initial Val* parameter setting and can be cleared by setting the parameter *Operation counter* in the clear menu from WHMI or LHMI.

The OPR_ALM operation warning is generated when the number of operations exceeds the value set with the *Alarm Op number* threshold setting. However, if the number of operations increases further and exceeds the limit value set with the Lockout Op number setting, the OPR_LO output is activated.

The binary outputs OPR_ALM and OPR_LO are deactivated when the BLOCK input is activated.

7.2.4.4 Contact travel time

This module calculates the contact travel time for the closing and opening operation. the travel time can be calculated in two different ways based on setting *Travel time Clc* mode.

When setting *Travel time Clc* mode is “From Pos to Pos”, the contact travel time of the earthing switch or disconnector is calculated from the time between auxiliary contacts’ state change. The opening travel time is measured between the opening of the POSCLOSE auxiliary contact and the closing of the POSOPEN auxiliary contact. The closing travel time is measured between the opening of the POSOPEN auxiliary contact and the closing of the POSCLOSE auxiliary contact.

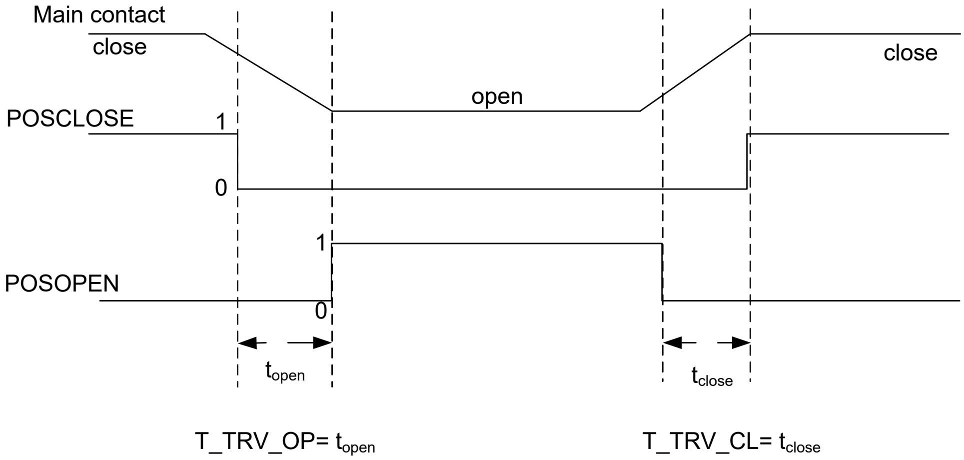


Figure 786: Travel time calculation when Travel time Clc mode is “From Pos to Pos

When setting *Travel time Clc* mode is “From Cmd to Pos”, the contact travel time of the earthing switch or disconnector is calculated from the time between opening or closing command and auxiliary contacts’ state change. The opening travel time is measured between rising edge of OPEN_EXE command and POSOPEN auxiliary contact. The closing travel time is measured between rising edge of the CLOSE_EXE command and POSCLOSE auxiliary contact.

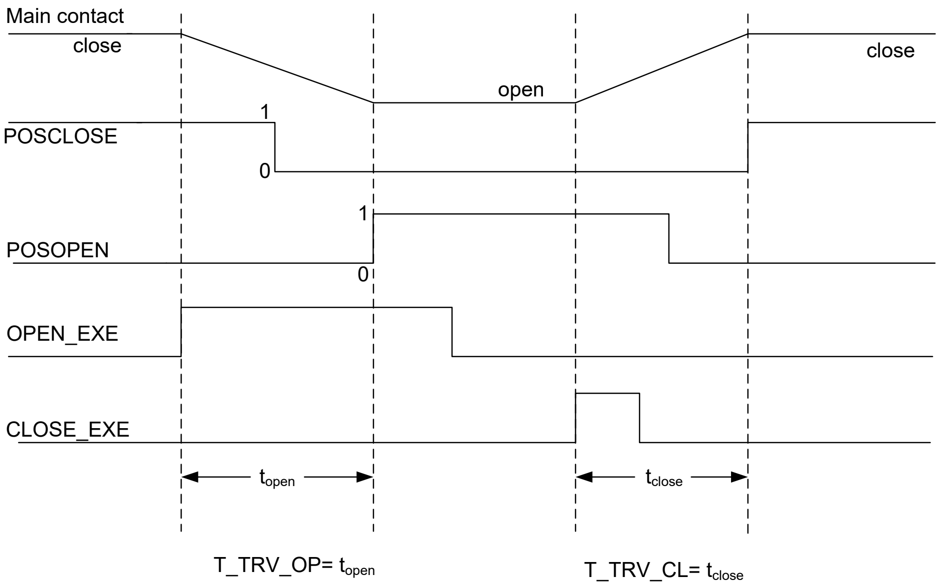


Figure 787: Travel time calculation when Travel time Clc mode is “From Cmd to Pos”

The last measured opening travel time T_TRV_OP and the closing travel time T_TRV_CL are available in the monitored data.

The maximum measured opening travel time T_TRV_MAX_OP and the maximum measured closing travel time T_TRV_MAX__CL are available in the monitored data.

The last measured and maximum travel time are stored in nonvolatile memory and these values are not cleared until the reset input (RST_TRV_ T) is set to TRUE or reset from the clear menu.

When the measured opening travel time is longer than the value set with the *Open alarm time* setting, the TRV_T_OP_ALM output is activated. Respectively, when the measured closing travel time is longer than the value set with the *Close alarm time* setting, the TRV_T_CL_ALM output is activated.

It is also possible to block the TRV_T_CL_ALM and TRV_T_OP_ALM alarm signals by activating the BLOCK input.

7.2.5 Application

Earthing switches or disconnectors are usually located either in metal- clad draw out switchgear or outside in switch yard or pole mounted pole mounted. These switches are operated on no load when circuit breaker is opened. Mechanical actuation is affected due to continued exposure of varying weather conditions. Supervision of following parameters helps understanding the mechanical condition and need for maintenance:

- Increasing contact travel time might be indication e.g., of mechanical wear or lubrication problem.
- Certain maintenance actions are dependent on operation counter value.
- Mechanism may be stuck if switch is in same position long period of time. Inactivity time measurement guides operator for periodic movement.

7.2.6 Signals

7.2.6.1 ESDCSSWI Input signals

Table 1316: ESDCSSWI Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block all the alarm and lockout indications
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O
OPEN_EXE	BOOLEAN	0=False	Signal for open command to coil
CLOSE_EXE	BOOLEAN	0=False	Signal for close command to coil
RST_TRV_T	BOOLEAN	0=False	Reset input for switch closing and opening travel times

7.2.6.2 ESDCSSWI Output signals

Table 1317: ESDCSSWI Output signals

Name	Type	Description
TRV_T_OP_ALM	BOOLEAN	Switch open travel time exceeded set value
TRV_T_CL_ALM	BOOLEAN	Switch close travel time exceeded set value
OPR_ALM	BOOLEAN	Number of switch operations exceeds alarm limit
OPR_LO	BOOLEAN	Number of switch operations exceeds lockout limit
MON_ALM	BOOLEAN	Switch not operated for long time alarm
OPENPOS	BOOLEAN	Apparatus open position
INVALIDPOS	BOOLEAN	Apparatus position is invalid
CLOSEPOS	BOOLEAN	Apparatus closed position

7.2.7 ESDCSSWI Settings

Table 1318: ESDCSSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Open alarm time	40...30000	ms	10	15000	Alarm level setting for open travel time in ms
Close alarm time	40...30000	ms	10	15000	Alarm level setting for close travel time in ms
Alarm Op number	0...99999		1	200	Alarm limit for number of operations
Inactive Alm days	0...9999		1	2000	Alarm limit value of the inactive days counter
Travel time Clc mode	1=From Cmd to Pos 2=From Pos to Pos			2=From Pos to Pos	Travel time mode selection
Lockout Op number	0...99999		1	300	Lock out limit for number of operations

Table 1319: ESDCSSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Counter initial Val	0...99999		1	0	Operation numbers counter initialization
Ini inactive days	0...9999		1	0	Initial value of the inactive days counter
Inactive Alm hours	0...23	h	1	0	Alarm time of the inactive days counter in hours

7.2.8 ESDCSSWI Monitored data

Table 1320: ESDCSSWI Monitored data

Name	Type	Values (Range)	Unit	Description
T_TRV_OP	FLOAT32	0...60000	ms	Travel time of the switch during opening operation
T_TRV_CL	FLOAT32	0...60000	ms	Travel time of the switch during closing operation
T_TRV_MAX_OP	FLOAT32	0...60000	ms	Maximum travel time during opening operation
T_TRV_MAX_CL	FLOAT32	0...60000	ms	Maximum travel time during closing operation
NO_OPR	INT32	0...99999		Number of switch operation cycle
INA_DAYS	INT32	0...9999		The number of days switch has been inactive
ESDCSSWI	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

7.2.9 Technical data

Table 1321: ESDCSSWI technical data

Characteristic	Value
Operate time accuracy	±1.0 % of the set value or ±20 ms
Travelling time measurement	+10 ms / -5 ms

7.3 Hot-spot and insulation ageing rate monitoring for transformers HSARSPTR (ANSI 26/49HS)

7.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Hot-spot and insulation ageing rate monitoring for transformers	HSARSPTR	3Ihp>T	26/49HS

7.3.2 Function block

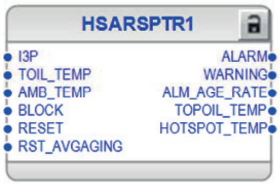


Figure 788: Function block

7.3.3 Functionality

The hot-spot and insulation ageing rate monitoring for transformers function HSARSPTR is used for online monitoring of transformers. The function monitors the hot-spot temperature of the transformer winding and the ageing rate of the insulation caused by thermal stress. The function can be applied for new transformers as well as for transformers already in service.

The hot-spot temperature and loss of life of transformer are calculated for one winding of the transformer from three phase currents and RTD inputs for top oil temperature and ambient temperature.

The hot-spot temperature and the momentary ageing rate are calculated based on the IEC 60076-7 or the IEEE C57.91-2011 standard, depending upon a user defined setting. The total ageing and loss of transformer insulation life is calculated in years.

The function generates `WARNING` and `ALARM` signals if the calculated hot-spot temperature exceeds the set value.

7.3.4 Analog channel configuration

HSARSPTR has one analog group input which must be properly configured.

Table 1322: Analog signals

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings.

For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

7.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of HSARSPTR can be described with a module diagram. All modules in the diagram are explained in the next sections.

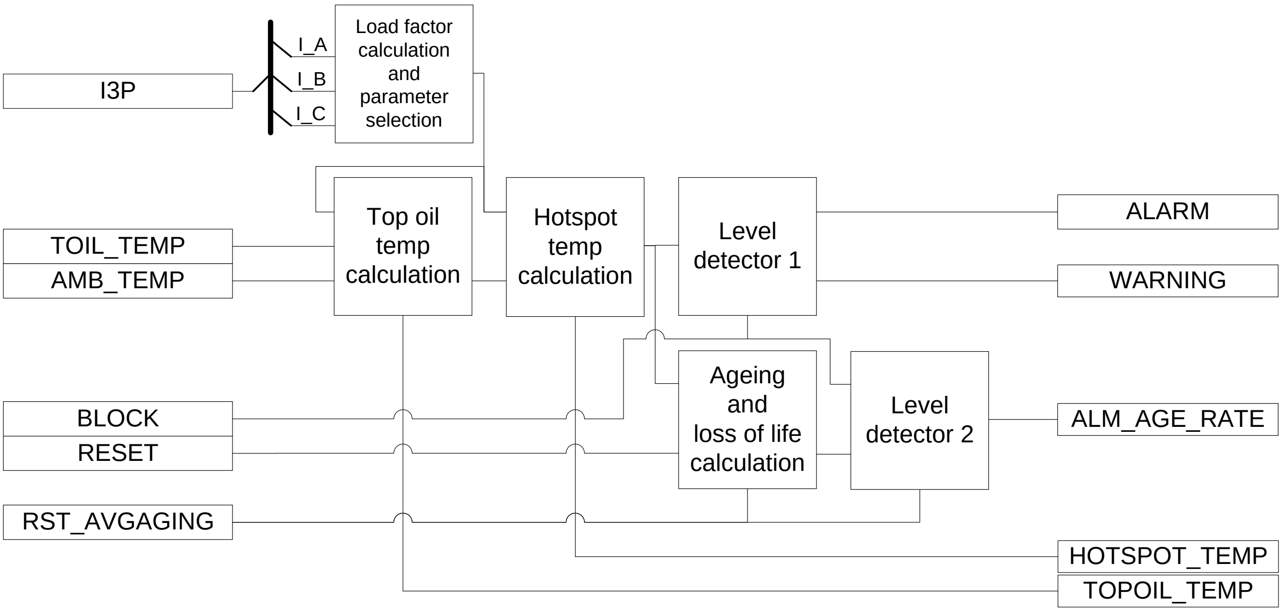


Figure 789: Functional module diagram

7.3.5.1 Load factor calculation and parameter selection

The transformer top oil and hot-spot temperatures are dependent on the load factor, the winding conductor properties and the cooling oil properties of the transformer. This module calculates the load factor based on the measured phase currents and selects the transformer parameters based on user defined settings.

Load factor calculation

Load factor is a ratio of the load current to the rated current. Since the thermal content of all the three phase currents influence the temperature inside the transformer, the load factor is calculated as a ratio of the root of sum of squared phase currents to three times the rated current.

$$K = \sqrt{\frac{I\_A^2 + I\_B^2 + I\_C^2}{3 \cdot I_{rated}^2}}$$

(Equation 321)

Where

K	Load factor
I_A, I_B and I_C	RMS value of input phase currents (Amperes)
I_{rated}	Rated current (Amperes)

If *Transformer type* is set to “Single phase”, the denominator consists only of I^2_{rated} instead of $3 \times I^2_{rated}$.

Equation 321 assumes that voltage is constant and tap changer position is not considered.

For a star-delta transformer, it is recommended to use the function on the star winding, since the circulating zero sequence currents (in case of unbalance) cannot be measured on the delta winding of the transformer.

Transformer parameter selection

The transformer parameters are selected based on the *Parameter Sel method*, *Cooling mode*, *Transformer type*, and *Transformer rating* settings.

If the *Parameter Sel method* setting is set to "IEC", the transformer parameters' values are automatically selected as per the IEC 60076-7 guidelines based on *Table 1323*.

Table 1323: Constants based IEC guidelines

	Distribution Transformers	Medium and Large power transformers			
Cooling mode	**ONAN**	**ONAN**	**ONAF**	**OFAF**	**ODAF**
Oil Exponent (x)	0.8	0.8	0.8	1.0	1.0
Winding Exponent (y)	1.6	1.3	1.3	1.3	2.0
Constant K11 (k_{11})	1.00	0.50	0.50	1.00	1.00
Constant K21 (k_{21})	1.00	2.00	2.00	1.30	1.00
Constant K22 (k_{22})	2.00	2.00	2.00	1.00	1.00
Oil Time Constant (τ_0) [minutes]	180	210	150	90	90
Winding Tm Constant (τ_w) [minutes]	4	10	7	7	7

If *Parameter Sel method* is set to "IEEE", the constants are selected as per the IEEE C57.91™-2011 standard based on *Table 1324*.

Table 1324: Constants based on IEEE guidelines

	Distribution Transformers	Medium and Large power transformers			
Cooling mode	**ONAN**	**ONAN**	**ONAF**	**OFAF**	**ODAF**
Oil Exponent (x)	0.8	0.8	0.8	0.8	1.0
Winding Exponent (y)	0.8	0.8	0.9	0.9	1.0
Constant K11 (k_{11})	1.00	1.00	1.00	1.00	1.00

Table continues on the next page

	Distribution Transformers	Medium and Large power transformers			
Cooling mode	**ONAN**	**ONAN**	**ONAF**	**OFAF**	**ODAF**
Constant K21 (k_{21})	1.00	1.00	1.00	1.00	1.00
Constant K22 (k_{22})	1.00	1.00	1.00	1.00	1.00
Oil Time Constant (τ_0) [minutes]	180	210	150	90	90
Winding Tm Constant (τ_w) [minutes]	4	10	7	7	7

A transformer is a distribution transformer if the *Transformer rating* setting < 2.5 MVA and *Transformer type* is set to "Three phase" or if the *Transformer rating* setting < 0.833 MVA and *Transformer type* is set to "Single phase".

Transformer parameters vary with the material used for winding and insulating oil. The *Parameter Sel method* setting can be set to "Manual" and the constants can be set individually through the *Oil exponent*, *Winding exponent*, *Constant K11*, *Constant K21*, *Constant K22*, *Oil time constant* and *Winding Tm constant* settings.

If *Parameter Sel method* is set to "Manual", the *Cooling mode* setting has no effect on the transformer parameters.

Since there is no direct *Cooling mode* based time constants' selection mentioned in the IEEE Std C57.91™- 2011 standard, the oil time constant (τ_0) and winding time constant (τ_w) in *Table 1324* are kept same as in *Table 1323*.

For more accuracy, the values of the constants can be entered manually by setting *Parameter Sel method* to "Manual".

7.3.5.2 Top oil temp calculation

The function receives two sensor inputs for measuring top oil temperature and ambient temperature.

The top oil temperature of the tank is obtained through a sensor placed at the upper inner turn of the winding. If the top oil temperature sensor status `TOIL_SNSFLT` is FALSE, the top oil temperature is directly obtained from the `TOIL_TEMP` input.

If the status of `TOIL_SNSFLT` is TRUE, indicating that the sensor is faulty, the top oil temperature is calculated with the help of measured ambient temperature.

The status of the ambient temperature sensor is obtained through the `AMB_SNSFLT` binary input. If `AMB_SNSFLT` is FALSE, indicating the healthy status of the sensor, the ambient temperature is directly measured through the `AMB_TEMP` input. Else, if `AMB_SNSFLT` is TRUE, the ambient temperature is taken from the *Average ambient Tmp* setting.

The formula for calculating the top oil temperature from the measured or set ambient temperature is shown in *Equation 322*.

$$D\theta_{0(n)} = \frac{Dt}{(k_{11} \cdot \tau_o)} \cdot \left(\left[\frac{1 + (K^2 \cdot R)}{1 + R} \right]^x \cdot \Delta\theta_{or} - \left[\theta_{0(n-1)} - \theta_a \right] \right)$$

(Equation 322)

Where

$\theta_{0(n)}$	Top oil temperature in the tank at n^{th} time step
θ_a	Ambient temperature [°C]
$\Delta\theta_{or}$	Top oil temperature rise over ambient temperature at rated load, given by the setting *Top oil Tmp rise*
R	Ratio of losses at rated current to no load losses, given by the setting *Ratio of losses*

k_{11}, τ_0, K and x are as defined in the Parameter selection module in *Figure 789*.

The D operator implies a difference in the associated variable that corresponds to each time step Dt. At each time step, the n^{th} value of $D\theta_{0(n)}$ is calculated from the $(n-1)^{th}$ value.

The initial conditions are calculated by setting the time derivative equal to zero in $D\theta_{0(n)}$ equation, resulting in the following equations.

$$\theta_{0(0)} = \left[\frac{1 + (K^2 \cdot R)}{1 + R} \right]^x \cdot \Delta\theta_{or} + \theta_a$$

(Equation 323)

The top oil temperature at the n^{th} time step is calculated as shown below.

$$TOPOIL\_TEMP = \theta_{0(n-1)} + D\theta_{0(n)}$$

(Equation 324)

The measured/calculated top oil temperature TOPOIL_TEMP is available in the Monitored data view.

If the top oil temperature sensor is valid, the `TOPOIL_TEMP` output is equal to the measured top oil temperature `TOIL_TEMP` input.

7.3.5.3 Hot-spot temp calculation

Winding hot-spot temperature depends on the winding temperature rise due to the load factor and oil flow. These two factors act complimentary to each other in the influence of temperature rise.

The differential equations for hot-spot temperature rise above top oil temperature is solved as the sum of two differential equations.

$$\Delta\theta_{h(n)} = \Delta\theta_{h1(n)} - \Delta\theta_{h2(n)}$$

(Equation 325)

The two differential equations are shown in *Equation 326* and *Equation 327*.

$$D\Delta\theta_{h1(n)} = \frac{Dt}{(k_{22} \cdot \tau_w)} \cdot \left(k_{21} \cdot \Delta\theta_{hr} \cdot K^y - \Delta\theta_{h1(n-1)}\right)$$

(Equation 326)

$$D\Delta\theta_{h2(n)} = \frac{Dt}{\left(\left(\frac{1}{k22}\right) \cdot \tau_o\right)} \cdot \left((k_{21} - 1) \cdot \Delta\theta_{hr} \cdot K^y - \Delta\theta_{h2(n-1)}\right)$$

(Equation 327)

Where

$\Delta\theta_{hr}$	Hot-spot-to-top-oil gradient at rated current [°C]

The constants τ_w, k_{21}, k_{22} and y are varying according to the *Cooling mode* setting and are obtained from the Load factor calculation and parameter selection module.

The rated hot-spot to top oil gradient, HS_TOIL_GRA ($\Delta\theta_{hr}$), is calculated using the formula as shown in *Equation 328*.

$$\Delta\theta_{hr} = \frac{Hotspot\ Tmp\ rise - Top\ oil\ Tmp\ rise}{\left(\frac{Current\ type\ test}{I_{rated}}\right)^y}$$

(Equation 328)

Where

I_{rated}	Rated current of the transformer
Hotspot Tmp rise	Hot-spot temperature rise over ambient at rated load
Top oil Tmp rise	Top oil temperature rise over ambient at rated load
Current type test	Current applied in type testing to reach rated hot-spot temperature

At each time step, the n^{th} value of $D\Delta\theta_{h1(n)}$ and $D\Delta\theta_{h2(n)}$ are calculated from the (n-1) value; the solutions of which are combined in accordance with the hot-spot temperature rise equation.

$$\Delta\theta_{h1(n)} = \Delta\theta_{h1(n-1)} + D\Delta\theta_{h1(n)}$$

(Equation 329)

$$\Delta\theta_{h2(n)} = \Delta\theta_{h2(n-1)} + D\Delta\theta_{h2(n)}$$

(Equation 330)

The initial conditions are calculated by setting the time derivative equal to zero in$D\Delta\theta_{h1(n)}$ and $D\Delta\theta_{h2(n)}$ equations, resulting in the following equations.

$$\Delta\theta_{h1(0)} = k_{21} \cdot \Delta\theta_{hr} \cdot K^{y}$$

(Equation 331)

$$\Delta\theta_{h2(0)} = (k_{21} - 1) \cdot \Delta\theta_{hr} \cdot K^{y}$$

(Equation 332)

The final hot-spot temperature is calculated as the sum of top oil temperature and the rise of hot-spot temperature over the top oil temperature.

The hot-spot temperature at the nth time step is calculated as shown in *Equation 333*.

$$HOTSPOT\_TEMP = \theta_{o(n)} + \Delta\theta_{h(n)}$$

(Equation 333)

The calculated hot-spot temperature HOTSPOT_TEMP and rated hot-spot to top oil gradient, HS_TOIL_GRA are available in the Monitored data view.

7.3.5.4 Level detector 1

This module compares the calculated hot-spot temperature, HOTSPOT_TEMP value with the *Alarm level* and *Warning level* settings.

If HOTSPOT_TEMP is greater than the *Warning level*, the module activates the WARNING output after a settable *Warning delay time*.

If HOTSPOT_TEMP is greater than the *Alarm level*, the module activates the ALARM output after a settable *Alarm delay time*.

Assuming existing conditions, as long as the alarm/warning conditions are not reached, the module calculates the available load reserve in percentage to reach the alarm condition LD_RSV_ALM_PCT and to reach the warning condition, LD_RSV_WRN_PCT. These outputs can be obtained from the Monitored data view.

If the warning condition is reached, the LD_RSV_WRN_PCT output is forced to zero and if the alarm condition is reached, LD_RSV_ALM_PCT is forced to zero.

The load reserve outputs are only indicative and are calculated based on rated current, assuming the same ambient temperature and cooling modes. If, for any reason, the load reserve calculation is not feasible, the load reserve outputs are shown as zero.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates WARNING and ALARM outputs and resets the internal timers.

7.3.5.5 Ageing and loss of life calculation

This module calculates the rate at which transformer insulation ageing is accelerating compared with the ageing rate at rated hot-spot temperature and equivalent ageing over a time period.

If transformer insulation paper is not upgraded, that is, if setting *Insul paper type* is set to "Normal", the setting *Ageing rate method* selects between the IEC and IEEE methods of calculation. If *Ageing rate method* is set to "IEC", the relative ageing rate is calculated as shown in Equation 334.

$$V_{IEC} = 2^{\frac{(\theta_h - 98)}{6}}$$

(Equation 334)

If the setting *Ageing rate method* is set to "IEEE", the ageing rate is calculated as shown in Equation 335.

$$V_{IEEE} = e^{\frac{15000}{110+273} - \frac{15000}{\theta_h + 273}}$$

(Equation 335)

Where

V_{IEC}	Momentary ageing rate as per IEC method
V_{IEEE}	Momentary ageing rate as per IEEE method
θ_h	The calculated hot-spot temperature

If the setting *Insul paper type* is set to "Upgraded", the IEEE method is used for calculating the ageing rate irrespective of the value of *Ageing rate method* setting.

The calculated value of the relative ageing rate, AGEING_RATE is given as an output in the Monitored data view.

The module also calculates the average ageing rate, AVG_AGE_RATE, over a specified time period given by the *Avg Age rate period* setting. The setting *Avg Age rate period* can be set to "DAY", "WEEK", "MONTH" or "YEAR".

For example, if the *Avg Age rate period* is set to "MONTH", the output AVG_AGE_RATE is updated every day with the average ageing rate since the day the calculation started. Once a month is completed, the AVG_AGE_RATE is calculated over the previous 30 days. That is, after the 31st day, the average ageing rate is calculated from day 2 to day 31 and so on.

If the *Avg Age rate period* is set to "DAY", "WEEK" or "MONTH", the calculated AVG_AGE_RATE is refreshed every day at 12:00 hours, but if it is set to "YEAR", the AVG_AGE_RATE is refreshed once in 30 days.

The calculated AVG_AGE_RATE is given as an output in the Monitored data view.

The function considers month as 30 days and correspondingly a year as 12 months or 360 days.

Loss of life calculation

The momentary loss of life can be calculated as the product of the momentary ageing rate and the time step over which the momentary ageing is calculated.

$$DL_n = V_n \cdot Dt$$

(Equation 336)

The total loss of life is the sum of the momentary loss of life and the total loss of life until time, n-1.

$$L_n = L_{n-1} + DL_n$$

(Equation 337)

The initial loss of life L_0, is taken from the setting *Initial loss of life*.

For new transformer installations, the *Initial loss of life* setting should be “0”. For previously installed transformers, the *Initial loss of life* can be set to the consumed transformer life in months.

The calculated value of the loss of life in years, LOSS_OF_LIFE, is given as an output in the Monitored data view.

The calculated value of LOSS_OF_LIFE can be reset through the input RESET.

7.3.5.6 Level detector 2

This module compares the ALM_AGE_RATE output with the setting *Alarm level Age Rte*.

If the calculated AVG_AGE_RATE over the *Avg Age rate period* setting is greater than *Alarm level Age Rte*, the module activates the binary output ALM_AGE_RATE.

The binary input RST_AVGAGING can be used to reset the output ALM_AGE_RATE and also the calculated value of AVG_AGE_RATE.

Once the RST_AVGAGING input is active, the average ageing rate values stored over the *Avg Age rate period* setting is erased and the calculation of AVG_AGE_RATE is restarted.

If the *Avg Age rate period* is set to "YEAR", the output AVG_AGE_RATE is refreshed once in 30 days starting from the time the relay is installed or since the last activation of binary input RST_AVGAGING.

The activation of the BLOCK input deactivates the ALM_AGE_RATE output.

7.3.6 Application

The insulation used in transformer windings is paper oil insulation that can degrade over a period of time. The deterioration of insulation is a time function of temperature, moisture and oxygen content. With modern oil preservation systems, the moisture and oxygen contributions to insulation deterioration can be minimized, leaving insulation temperature as the controlling parameter.

Since, in most of the transformers the temperature distribution is not uniform, the part that is operating at the highest (hot-spot) temperature normally undergoes the greatest deterioration. Hot-spot temperature of winding needs to be monitored continuously in order to not exceed the flashover value of transformer insulation oil. The first step in monitoring the insulation age is the calculation of hot-spot temperature of the transformer.

A simplified representation of the variation of temperature inside the transformer is shown in *Figure 790* (IEC 60076-7).

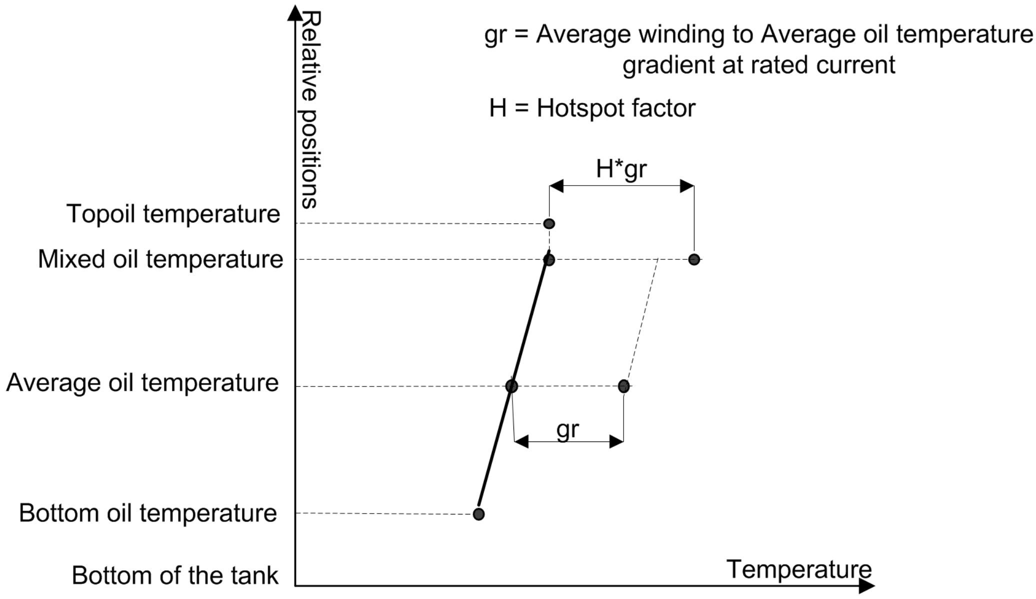


Figure 790: Transformer thermal diagram

The winding hot-spot temperature depends on the load losses, type of cooling and ambient temperature. Usually the conductors near the top of the winding experience the maximum leakage field and the highest surrounding oil temperature (due to convection effect). It is natural to consider that the top conductors contain the hottest spot. Measurements have shown that the hottest spot can also be moved to lower conductors.

Direct measurement of hot-spot temperature with fiber optic probes became available in mid 1980s. Experience has shown that there might be gradients of more than 10 °C between different locations at the top of a transformer winding. It is unlikely that the insertion of one to three sensors detect the real hot-spot. Direct measurement of hot-spot temperature is difficult and it is calculated using the empirical formulae.

The hot-spot temperature calculation is dependent upon the thermal properties of the winding material, cooling oil and the cooling mode of the transformer. The thermal model may also differ from IEC and IEEE markets, though the underlying principle of temperature calculation remains the same. The transformer constants are decided based on a user defined setting to select the preferred type of thermal model (IEC, IEEE or Manual).

For most transformers in service, the top oil temperature inside a winding is difficult to measure. On the other hand, the top oil temperature at the top of the tank is well known, either by measurement or by calculation. The winding hot-spot temperature rise above the top oil temperature is calculated. By adding this value to the measured or calculated top oil temperature, the winding hot-spot temperature is obtained. A pictorial representation of the location of top oil temperature sensor is shown in *Figure 791*.

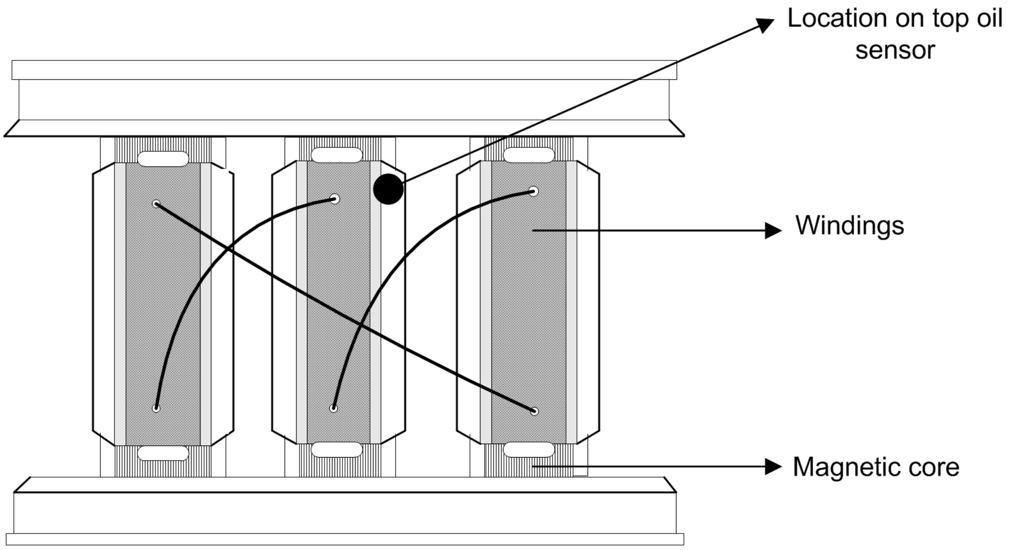


Figure 791: Location of top oil sensor

`WARNING` and `ALARM` signals are provided for the operator to take corrective actions to reduce the temperature inside the transformer. Corrective actions include switching on coolers, reducing the load on the transformers and so on.

Normally, warning level is set to indicate if the temperature is nearing the limiting value and alarm is generated when the limiting condition has reached. Hence, alarm level is set at a higher value than the warning level.

The function only calculates hot-spot temperature based on the load factor of the winding. This function does not calculate the rise in actual hot-spot temperature, which occurs due to oil flow blockage or malfunction of cooler groups. That said, the set oil and winding properties can be updated manually to indicate this change.

Based on the calculated hot-spot temperature, the function calculates the relative ageing, that is, the accelerated or decelerated ageing of the insulation at current load compared to its ageing at rated load. The variation of ageing acceleration factor with respect to the hot-spot temperature for a sample transformer is plotted in *Figure 792*. Here, 110 °C is taken as the rated hot-spot temperature at which point an ageing acceleration factor of 1.0 is achieved.

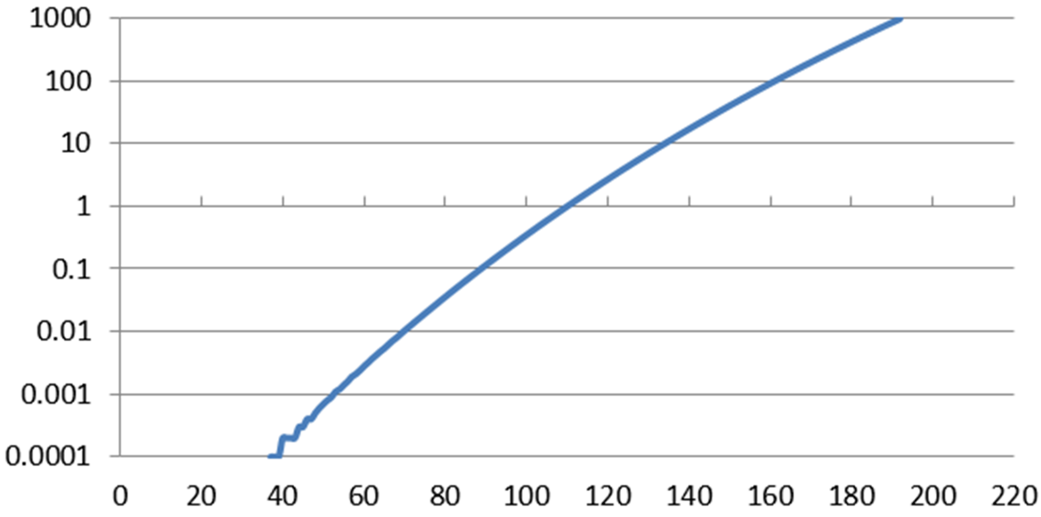


Figure 792: Variation of insulation ageing factor with hot-spot temperature (Graph produced using values from Table 11 of IEEE Std. C57.91-1995)

The variation of insulation life with respect to the hot-spot temperature depends upon the type of insulation paper used. Thermally upgraded insulation paper neutralizes the production of acids caused by the hydrolysis of the material over the lifetime of the transformer and slows down insulation ageing when compared to the normal insulation paper (IEC 60076-7). The proper selection of insulation paper type is needed for better accuracy of loss of life calculation.

In certain cases, it is necessary to monitor the loading of the transformer over a defined time period. For example, during a planned overloading of a transformer for a period of one month. In such cases it is important to know the ageing rate during that period of overload rather than the overall loss of life transformer. Hence, an additional output on average ageing rate over a settable average ageing period is provided in the function.

The function can be applied for new transformers and also for transformers already in service using the *Initial loss of life* setting.

7.3.7 Signals

7.3.7.1 HSARSPTR Input signals

Table 1325: HSARSPTR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
TOIL_TEMP	FLOAT32	0	Measured top oil temperature
AMB_TEMP	FLOAT32	0	Measured ambient temperature

Table continues on the next page

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RESET	BOOLEAN	0=False	Reset loss of life calculation
RST_AVGAGING	BOOLEAN	0=False	Reset average ageing rate calculation

7.3.7.2 HSARSPTR Output signals

Table 1326: HSARSPTR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal
WARNING	BOOLEAN	Warning signal
ALM_AGE_RATE	BOOLEAN	Alarm signal for Avg ageing rate over set time period
TOPOIL_TEMP	FLOAT32	Calculated value of top oil temperature
HOTSPOT_TEMP	FLOAT32	Calculated value of hot spot temperature

7.3.8 HSARSPTR Settings

Table 1327: HSARSPTR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Cooling mode	1=ONAN 2=ONAF 3=OFAF 4=ODAF			1=ONAN	Transformer cooling method
Alarm level	50.0...350.0	°C	0.1	120.0	Alarm level for hotspot temperature
Warning level	50.0...350.0	°C	0.1	100.0	Warning level for hotspot temperature
Alarm delay time	0...3600000	ms	10	10000	Time delay for hotspot temperature alarm
Warning delay time	0...3600000	ms	10	10000	Time delay for hotspot temperature warning
Average ambient Tmp	-20.00...70.00	°C	0.01	20.00	Average ambient temperature

Table 1328: HSARSPTR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Transformer type	1=Single phase 2=Three phase			2=Three phase	Number of phases of the transformer
Parameter Sel method	1=IEC 2=IEEE 3=Manual			1=IEC	Transformer parameter selection method
Ageing rate method	1=IEC 2=IEEE			1=IEC	Ageing rate calculation method
Insul paper type	1=Normal 2=Upgraded			1=Normal	Type of transformer paper insulation
Transformer rating	1.00...500.00	MVA	0.01	2.50	Rating of the transformer
Initial loss of life	0...1000		1	0	Initial value for winding insulation loss of life in months
Hotspot Tmp rise	50.0...350.0	°C	0.1	80.0	Hotspot temperature rise over ambient at rated load
Top oil Tmp rise	50.0...350.0	°C	0.1	65.0	Top oil temperature rise over ambient at rated load
Current type test	0.01...2.00	xIn	0.01	1.00	Current applied in type testing to reach rated hotspot Temp
Ratio of losses	0.1...500000.0		0.1	25.0	Ratio of load losses at rated load to no-load losses
CT ratio correction	0.200...5.000		0.001	0.200	Current transformer ratio correction factor
Oil exponent	0.10...10.00		0.01	0.10	User defined value for oil exponent
Winding exponent	0.10...10.00		0.01	0.10	User defined value for winding exponent
Constant K11	0.01...10.00		0.01	1.00	User defined value of thermal model constant K11
Constant K21	0.01...10.00		0.01	1.00	User defined value of thermal model constant K21
Constant K22	0.01...10.00		0.01	2.00	User defined value of thermal model constant K22
Oil time constant	1...20000	s	1	10800	Oil time constant in seconds
Winding Tm constant	1...20000	s	1	240	Winding time constant in seconds
Alarm level Age Rte	0.00...100.00		0.01	1.00	Alarm level for average ageing rate over set time period

Table 1329: HSARSPTR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Avg Age rate period	4=DAY 5=WEEK			6=MONTH	Time period over which average ageing rate is calculated

Parameter	Values (Range)	Unit	Step	Default	Description
	6=MONTH 7=YEAR				

7.3.9 HSARSPTR Monitored data

Table 1330: HSARSPTR Monitored data

Name	Type	Values (Range)	Unit	Description
HS_TOIL_GRA	FLOAT32	0...1000		Rated hot spot to top oil temperature gradient
LD_RSV_WRN_PCT	FLOAT32	0.0...1000.0	%	Percentage load reserve for reaching warning condition
LD_RSV_ALM_PCT	FLOAT32	0.0...1000.0	%	Percentage load reserve for reaching alarm condition
AGEING_RATE	FLOAT32	0.00...50.00		Momentary relative ageing rate
LOSS_OF_LIFE	FLOAT32	0...100		Loss of life in years
AVG_AGE_RATE	FLOAT32	0...100		Average ageing rate over set time period
HSARSPTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

7.3.10 Technical data

Table 1331: HSARSPTR technical data

Characteristic	Value
Warning/alarm time accuracy	±1.0 % of the set value or ±0.50 s

7.4 Cable fault detection RCFD (ANSI CFD)

7.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Cable fault detection	RCFD	CFD	CFD

7.4.2 Function block

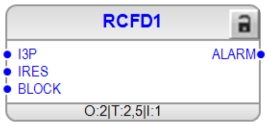


Figure 793: Function block

7.4.3 Functionality

The self-clearing fault detection function (RCFD) calculates half cycle DFT of the current signal for all the three phases and earth and uses it to detect a self-clearing fault pronounced primarily in cable networks.

The function provides individual counter values for number of times a self-clearing fault is observed in each phase and earth. The function determines the self-clearing fault is detected in all three phases or earth.

7.4.4 Analog input configuration

RCFD has two analog group inputs which must be properly configured.

Table 1332: Analog inputs

Input	Description
I3P	Three-phase currents.
IRES	Measured residual current

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

7.4.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled.

The operation of RCFD can be described by using a module diagram (see Figure *Figure 794* below). All the modules in the diagram are explained in the next sections.

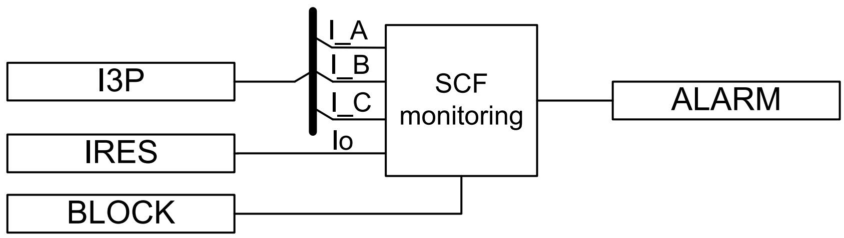


Figure 794: Functional module diagram

7.4.5.1 SCF monitoring

The SCF(Self Clearing Fault) monitoring module provides measurement channel specific monitoring for phase and residual currents. Following table lists the options for monitoring and available monitored data values.

Table 1333: SCF monitoring options and data values

Measurement channel	Calculated ½ cycle DFT current	Start detection	SCF indication	SCF counter
Phase A current (I_A)	I_CLC_AMPL_A	STR_DET_A	SLFCLR_FLT_A	SLFCLR_CNT_A
Phase B current (I_B)	I_CLC_AMPL_B	STR_DET_B	SLFCLR_FLT_B	SLFCLR_CNT_B
Phase C current (I_C)	I_CLC_AMPL_C	STR_DET_C	SLFCLR_FLT_C	SLFCLR_CNT_C
Residual current (Io)	I_CLC_AMPL_N	STR_DET_N	SLFCLR_FLT_N	SLFCLR_CNT_N

Half cycle DFT values are calculated for the SCF detection. Values are available in monitored data. If the calculated phase current (or residual current) exceeds above set *Phase start value* (or *Residual start value*), then the corresponding start detection in monitored data is set to TRUE. Monitored data is set to FALSE once fault current has dropped below start value.

The module calculates the duration for currents continuously staying above the set *Phase start value* (or *Residual start value*). If the calculated duration is between ¼ cycles and cycles set by *Maximum fault cycle*, then it is regarded as the SCF and corresponding SCF indication in monitored data is set to TRUE. Simultaneously corresponding SCF counter in monitored data is increased.

The parameter settings *Residual start value*, *Residual current limit* are dimmed when *Ena selfclear Det EF* setting is set to “FALSE”. And also Monitoring for residual current (Io), can be disabled by setting *Ena selfclear Det EF* to “FALSE”.

If the setting *Adaptive Str Val Ena* is set to TRUE. the adaptive phase and residual start value are defined based on the one-minute phase and residual averages, the *Minimum load current* (for phase) and *Residual current limit* (for earth) setting.

At end of the every healthy state one-minute period, new one-minute phase and residual current averages are calculated. If it is greater than the *Minimum load current* (for phase) and *Residual current limit* (for earth) setting, then the adaptive start value will be updated as twice the calculated value.

If one-minute phase and ground averages are less than the *Minimum load current* and *Residual current limit*, then the adaptive start value are set to twice the *Minimum load current* and *Residual current limit*.

In case fault is detected, the adaptive start value will hold the last updated one-minute average of phase and residual current.

The adaptive start values of corresponding phases (or residual) are displayed in monitored data ADP_ST_VAL_A, ADP_ST_VAL_B, ADP_ST_VAL_C and ADP_ST_VAL_N.

If the SCF is detected in at least one phase or residual current channel, the ALARM output is set to TRUE. When one phase detects a fault, the algorithm waits for 1 cycle time and if during this period two other phases also detect fault, then the fault is considered as three phase SCF and the SLFCLR_3PH in monitored data is set to TRUE.

The counter type monitored data can be reset to their initial value along with the all the outputs in the monitored data via a control parameter RCFD1 reset that is located under the clear menu.

When BLOCK input is activated, the ALARM output is set to FALSE, and also the Boolean type monitored data are set to FALSE and ADP_ST_VAL_x (phase A,B and C) are defaulted to *Phase start value* setting (ADP_ST_VAL_N is defaulted to *Residual start value* setting), Counter type monitored data are not affected and will retain last SCF fault count.

7.4.6 Application

The self-clearing fault will not the damage the cable initially, but if the frequency of the self-clearing fault slowly increases and causes the cable insulation breakdown.

7.4.7 Signals

7.4.7.1 RCFD Input signals

Table 1334: RCFD Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

7.4.7.2 RCFD Output signals

Table 1335: RCFD Output signals

Name	Type	Description
ALARM	BOOLEAN	Self clearing fault alarm

7.4.8 RCFD Settings

Table 1336: RCFD Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Phase start value	0.10...40.00	xIn	0.01	0.10	Fault current threshold
Maximum fault cycle	1...20		1	5	Fault detect threshold parameter in fundamental cycles
Minimum load current	0.00...1.00	xIn	0.10	0.10	Absolute minimum loading on the feeder
Adaptive Str Val Ena	0=False 1=True			0=False	Adaptive threshold enable
Residual start value	0.10...40.00	xIn	0.01	0.50	Fault residual current threshold
Residual current limit	0.00...1.00	xIn	0.10	0.10	Absolute maximum residual current under normal condition

Table 1337: RCFD Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Ena selfclear Det EF	0=False 1=True			0=False	Self clearing fault on EF

7.4.9 RCFD Monitored data

Table 1338: RCFD Monitored data

Name	Type	Values (Range)	Unit	Description
SLFCLR_FLT	BOOLEAN	0=False 1=True		Self clearing fault detected
SLFCLR_3PH	BOOLEAN	0=False 1=True		Three phase self clearing fault detected
STR_DET_A	BOOLEAN	0=False 1=True		Detection started (phase A)
STR_DET_B	BOOLEAN	0=False 1=True		Detection started (phase B)
STR_DET_C	BOOLEAN	0=False 1=True		Detection started (phase C)
STR_DET_N	BOOLEAN	0=False 1=True		Detection started (residual)
SLFCLR_CNT_A	INT32	0...10000		Number of self clearing fault detected (phase A)
SLFCLR_CNT_B	INT32	0...10000		Number of self clearing fault detected (phase B)
SLFCLR_CNT_C	INT32	0...10000		Number of self clearing fault detected (phase C)
SLFCLR_CNT_N	INT32	0...10000		Self clearing fault detected (residual)
SLFCLR_FLT_A	BOOLEAN	0=False 1=True		Self clearing fault detected (phase A)
SLFCLR_FLT_B	BOOLEAN	0=False 1=True		Self clearing fault detected (phase B)
SLFCLR_FLT_C	BOOLEAN	0=False 1=True		Self clearing fault detected (phase C)
SLFCLR_FLT_N	BOOLEAN	0=False 1=True		Self clearing fault detected (residual)
ADP_ST_VAL_A	FLOAT32	0.00...40.00	xIn	Used adaptive start value (phase A)
ADP_ST_VAL_B	FLOAT32	0.00...40.00	xIn	Used adaptive start value (phase B)
ADP_ST_VAL_C	FLOAT32	0.00...40.00	xIn	Used adaptive start value (phase C)
ADP_ST_VAL_N	FLOAT32	0.00...40.00	xIn	Used adaptive start value (residual)
I_CLC_AMPL_A	FLOAT32	0.00...40.00	xIn	Calculated current magnitude (phase A)
I_CLC_AMPL_B	FLOAT32	0.00...40.00	xIn	Calculated current magnitude (phase B)
I_CLC_AMPL_C	FLOAT32	0.00...40.00	xIn	Calculated current magnitude (phase C)
I_CLC_AMPL_N	FLOAT32	0.00...40.00	xIn	Calculated current magnitude (residual)
RCFD	Enum	1=on 2=blocked		Status

Name	Type	Values (Range)	Unit	Description
		3=test 4=test/blocked 5=off		

7.4.10 Technical data

Table 1339: RCFD Technical data

Characteristic	Value		
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz		
	±2.5% of the set value or 0.005 xI_n		
Alarm time[1, 2]	Minimum	Typical	Maximum
	10 ms	15 ms	20 ms

7.5 Diesel generator monitoring and protection DGMGAPC (ANSI 32/40G)

7.5.1 Identification

Table 1340: Function identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Diesel generator monitoring and protection function	DGMGAPC	P><, U/f ><	32/40G

1 Results based on statistical distribution of 1000 measurements
2 Measured with static signal output (SSO)

7.5.2 Function block

Figure 795: Function block

7.5.3 Functionality

The Diesel generator monitoring and protection DGMGAPC function protects industrial power plants and vessels from faults which are not easily detected by normal protection functions. The most important of such faults are the over/under fueling of diesel engines and over/under excitation of generators.

DGMGAPC protects the generators in isochronous load sharing, droop load sharing and base load modes. The function performs topology determination to identify the components connected in its own electrical network and exchanges relevant data with all other relays having DGMGAPC function and present in the same IEC61850 network.

The DGMGAPC identifies a fault in the generator by comparing its behavior to its current governor mode or with reference to other generators in the network. When a fault is detected, the function will signal the fault to the Power Management System (PMS). If the fault condition deteriorates, the function issues commands to stop the engine or to de-excite the generator. It then issues a trip command to the Generator Circuit Breaker (GCB).

7.5.4 Analog channel configuration

DGMGAPC has two analog group inputs which must be properly configured.

Table 1341: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1342: Special conditions

Condition	Description
U3P connected real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

7.5.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "on" the function is enabled and respectively "off" means function is disabled.

The operation of DGMGAPC can be described by using a module diagram (see *Figure 796*). All the modules in the diagram are explained in the next sections.

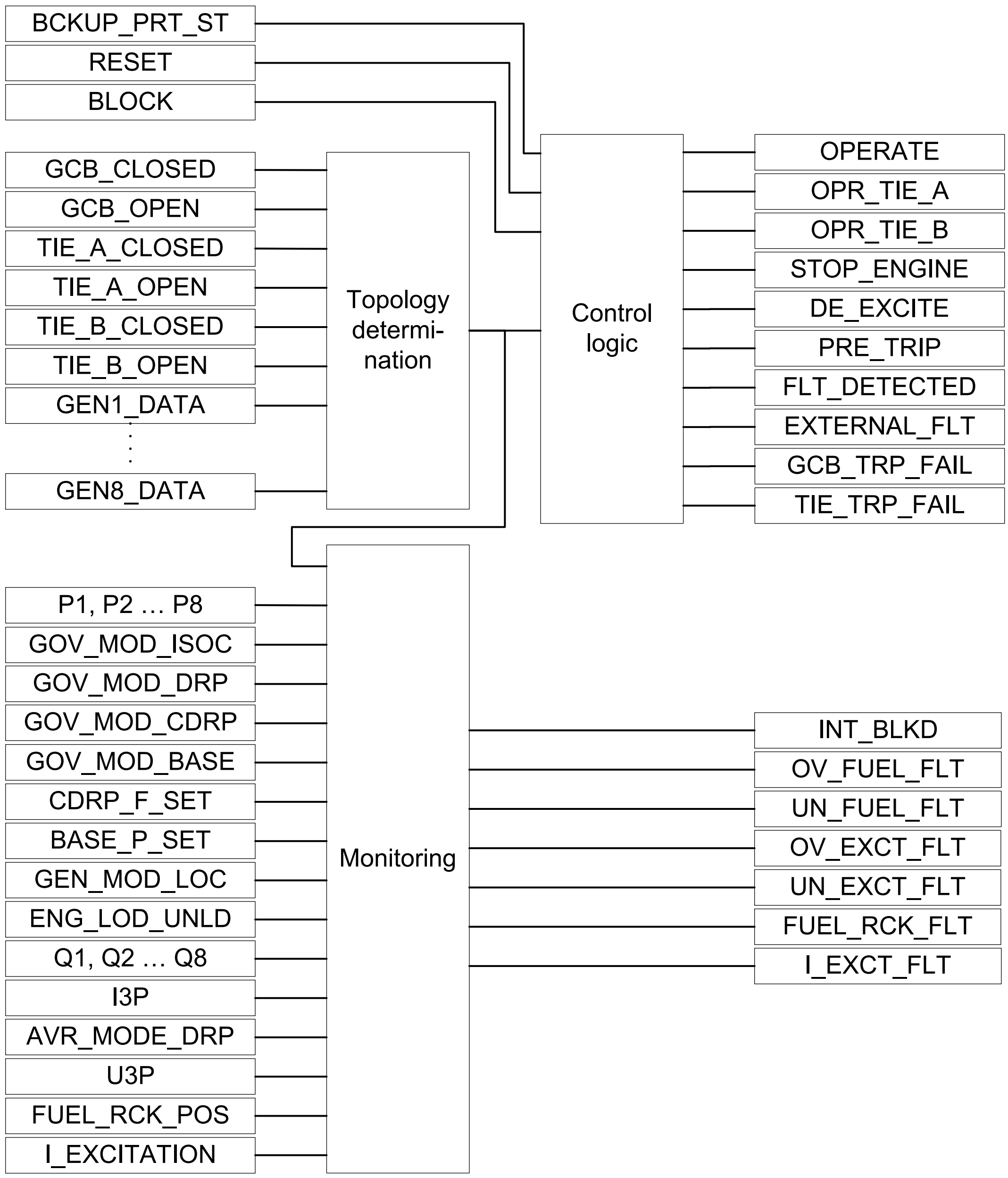


Figure 796: Functional module diagram

7.5.5.1 Topology determination

The Topology determination module identifies the group of busbar and generators that are electrically connected and calculates the subnetwork number for each group. The maximum network configuration considered is 8 generators, 8 GCBs and 8 tie breakers.

Some typical busbar arrangements in a Diesel Generator Monitoring and protection System (DGMS) are shown in *Figure 797* and *Figure 798*.

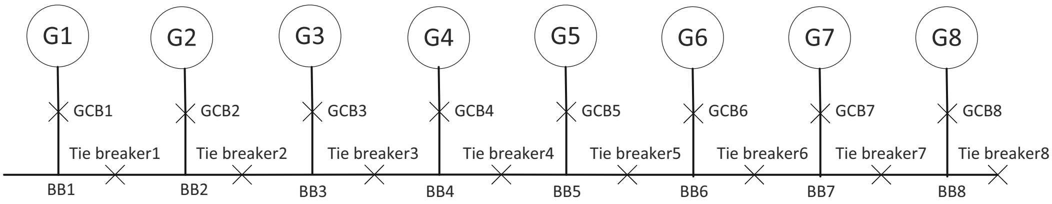


Figure 797: Topology of a DGMS system with all generators in a single network

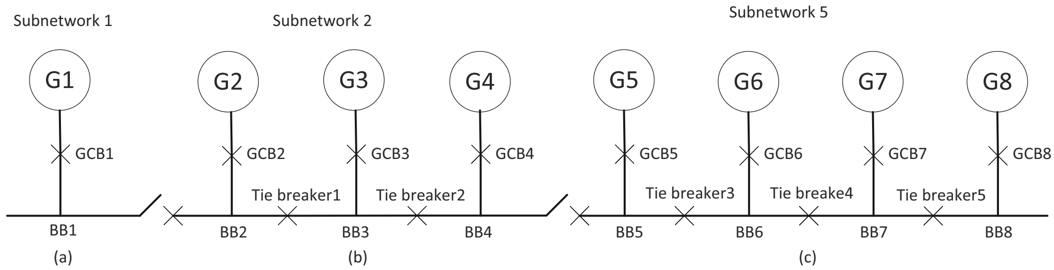


Figure 798: Topology of a DGMS system with 3 subnetworks

The connection of a generator to a particular busbar can be configured by using corresponding settings, *Gn 1 busbar Num* to *Gn 8 busbar Num*. Each of the settings can be set to values “Bus 1” to “Bus 8” or to “Not configured”.

For example, if generator 1 is connected to busbar1, then *Gn 1 busbar Num* is set to “Bus 1”. If suppose there are only four generators in the system, then settings *Gn 5 busbar Num* to *Gn 8 busbar Num* are set to “Not configured”.

The numbering of each GCB is assumed to be same as the number given to the generator it is connected to. That is, GCB1 assumed to be connected to generator 1, GCB2 to generator 2 and so on.

The tie breaker connects different busbar to form the different subnetwork groups. Each tie breaker connects two busbars and these are referred to as bus A and bus B. Hence, two settings are used to indicate the connection of a tie breaker to the two busbars.

For example: If tie breaker 1 connects busbar1 and busbar2, then setting *Tie 1 busbar A Num* is set to “Bus 1” and *Tie 1 busbar B Num* is set to “Bus 2”. If a tie breaker is not configured in the network, it is set to “Not configured”.

The entire network configuration can be modeled in a similar method using settings *Tie 2 busbar A Num, Tie 2 busbar B Num … Tie 8 busbar A Num and Tie 8 busbar B Num*.

Once the entire network has been defined using the settings as mentioned above, the module identifies the existing network topology through the status of GCBs and the tie breakers. The status of the local GCB is obtained through confirmed closed and open inputs `GCB_CLOSED` and `GCB_OPEN`, whereas the adjacent tie breaker statuses are received through inputs, `TIE_A_CLOSED`, `TIE_A_OPEN`, `TIE_B_CLOSED` and `TIE_B_OPEN`. The status of other GCBs and tie breakers are obtained from corresponding weighted integer inputs `GEN1_DATA` … `GEN8_DATA`.

The module expects that the tie breaker which connects to the lower numbered busbar is configured as tie breaker A and the tie breaker which connects to the higher numbered busbar as tie breaker B.

For example, if Generator 2 is connected to busbar2 and the busbar2 connects to busbars 1 and 3 through tie breakers 1 and 2 as shown in *Figure 796*. Then the status of tie breaker1 shall be received through inputs `TIE_A_CLOSED` and `TIE_A_OPEN` and the status of tie breaker 2 is shall be received as `TIE_B_CLOSED` and `TIE_B_OPEN`.

If one of the tie breakers of the generator under consideration is not configured or connects to a non-configured busbar, then the module expects the status of the other tie breaker through inputs `TIE_B_CLOSED` and `TIE_B_OPEN`.

The inputs `GEN1_DATA` to `GEN8_DATA` are received from other generators in the system. Each of these inputs contain information on the status of GCB, status of the adjacent tie breakers, governor and Automatic Voltage Regulator (AVR) modes, generator local mode status, backup protection status, fault status and tie breaker trip failure indication in the respective generators from where the information is being received.

The setting *Local generator Num* is used to set the local generator number. Based on this setting the local active/reactive power, circuit breaker statuses, governor and excitation system information are associated to the corresponding generator.

Though 8 inputs, `GEN1_DATA … GEN8_DATA`, are provided to receive information from other generators, the input corresponding to the local generator need not be connected.

That is, if *Local generator Num* is set to "5", then `GEN5_DATA` needs to be left unconnected and any information connected to this input would not be used by the function.

Based on this information, the Topology determination module determines the different subnetwork groups. Each network group is assigned a network number which is the lowest busbar number in the sub group.

For example in *Figure 798* (c), the subnetwork group has busbar 5, 6, 7 and 8. Hence the subnetwork number of this group is 5.

If an element is not electrically connected to any busbar, then a zero subnetwork number is assigned. The DGMGAPC function will be disabled in those networks whose subnetwork number will be zero.

When the quality bit of local GCB status input indicates that the data is not reliable, then the corresponding breaker status is considered open and rest of the modules in the function are disabled. If the quality bits of the local tie breakers status indicate that data is not reliable, then that tie breaker is considered as open and the generators connected through that tie breaker are suspended from participating in the monitoring function.

In case the quality of the status of the adjacent tie breakers are not reliable, then the module may identify the status of the same tie breaker using the data received from the adjacent generator sharing the same tie breaker.

The subnetwork numbers of eight generators are available in monitored data `SBNW_GEN1` to `SBNW_GEN8`. The subnetwork numbers of tie breakers are available in monitored data `SBNW_TIE_CB1` to `SBNW_TIE_CB8`.

If the inputs `GEN1_DATA … GEN8_DATA` indicate that a network generator is faulty, then it is indicated in the respective monitored data output `FAULT_GEN1 … FAULT_GEN8` and the data corresponding to those generators are not used in other modules of DGMGAPC.

7.5.5.2 Monitoring

Monitoring module consists of Fuel fault detection, Excitation fault detection, Fuel rack monitoring and Excitation current monitoring as shown in *Figure 799*.

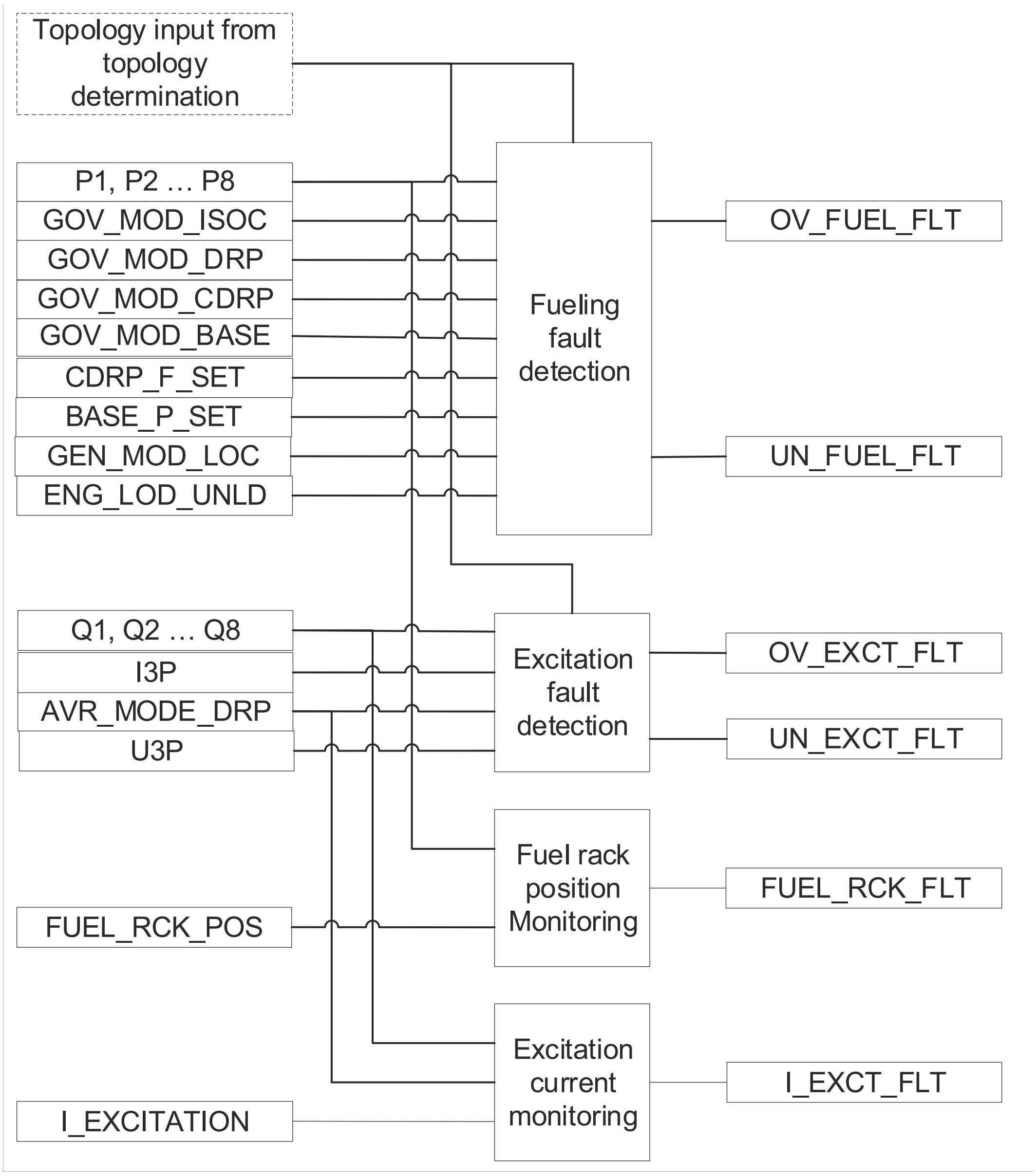


Figure 799: Submodules of Monitoring

Fueling fault detection

This module detects over/under fueling faults in the fuel system or engine governor, which result in the generator producing excessive active power (over fueling condition) or insufficient active power (under fueling condition).

Fueling faults are detected by two methods which are Correlation algorithm and Voting algorithm. The module activates `OV_FUEL_FLT` output in case of over fueling fault detection and `UN_FUEL_FLT` output in case of under fueling fault. Fueling faults are reported to Control logic module.

If the input GEN_MOD_LOC is 1, indicating that the generator is in local mode, then the Fueling fault detection module is disabled. If the quality status of the local active power input is faulty, then the module is disabled and INT_BLKD output is activated.

If one of the generators present in the same subnetwork is faulty, then that generator is removed from comparison in the Fueling fault detection module.

The input ENG_LOD_UNLD suggests whether the engine is in loading or unloading condition. When the engine is in loading condition (confirmed by GCB position change from open to close) the fueling fault detection is disabled until the generated power reaches 80% of the average loading of generators in the same subnetwork or until the elapsing of *Disable time*, whichever is faster. When the function is in unloading condition (i.e. GCB continues to remain in closed position), then the module is blocked until the elapsing of *Disable time*. As the GCB status change and ENG_LOD_UNLD input may not come together, by using settings (*Wait time signal status* - Wait time for Load/Unload signal and *Wait time status signal* - Wait time for GCB status and Load/Unload signal) the confirmation of loading/ unloading of engine is done.

Correlation algorithm:

The Correlation algorithm compares the active power of the local generator, to its expected behavior in the current governor mode.

The algorithm can be disabled through the setting *Disable Fuel Crl*.

The function has 8 active power inputs, P1 … P8. The input corresponding to the setting *Local generator Num*, would be considered as the local active power.

For example, if *Local generator Num* is set to “1”, then P1 is considered as the local generator active power output.

Correlation algorithm uses different criteria based on the governor mode. The governor mode information is obtained through the four binary inputs GOV_MOD_ISOC, GOV_MOD_DRP, GOV_MOD_CDRP and GOV_MOD_BASE. The governor and AVR modes of other generators are obtained through inputs GEN1_DATA … GEN8_DATA. In case any generator in the same subnetwork is communicated to be faulty, through the inputs GEN1_DATA … GEN8_DATA, then that generator is not considered in the Correlation algorithm.

If the input GOV_MOD_ISOC is active, the function monitors the system frequency and active power of all generators in the same subnetwork and with the same governor mode. If the frequency of the network exceeds the set *Expected frequency* over and above the margin *Max Freq Dev Isoc*, and if the local active power is more than the rest of the generators by a margin *Max P Dev Crl*, then the generator is deemed faulty and OV_FUEL_FLT output is activated.

If the frequency of the network is below the set *Expected frequency* over and above the margin *Max Freq Dev Isoc*, and if the local active power is less than the rest of the generators by a margin *Max P Dev Crl*, then the generator is deemed faulty and UN_FUEL_FLT output is activated. The fueling fault detection algorithm in isochronous mode needs at least 2 generators in parallel and operating in same mode.

When the input GOV_MOD_DRP is active, the function compares the local active power and system frequency with the set droop curve. Deviation above or below this curve (for over and under fueling conditions respectively) by a margin greater than *Max Freq deviation*, indicates a failure of the governor or the fuel system. The droop curve is set using the settings *F set point no load* and *Frequency droop*. A sample droop characteristics and the associated settings are shown in *Figure 800*.

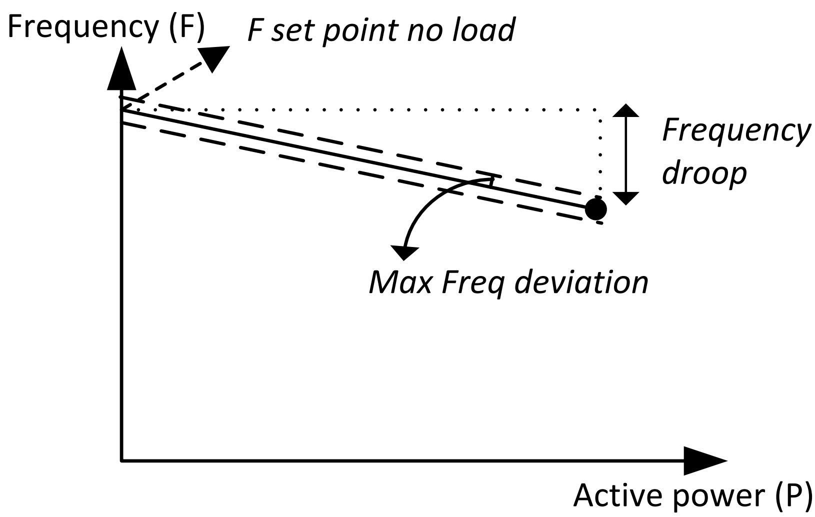


Figure 800: Frequency vs. Active power droop characteristics

When the input GOV_MOD_CDRP is active, then the central PMS shifts the droop curve parallel to the existing curve, through inputs CDRP_F_SET. The CDRP_F_SET input is a 0-20mA signal obtained through an RTD input, directly gives the no load set point frequency for the generator, using which the droop characteristic is generated. The calculated frequency limit at a particular load is displayed in monitored data F_CALC_LIMIT. If the network frequency value deviates over/under the F_CALC_LIMIT by a margin greater than set *Max Freq deviation*, the OV_FUEL_FLT or UN_FUEL_FLT outputs are activated. When the generator is in compensated droop mode and if the quality of the signal CDRP_F_SET is not reliable, the module is disabled and INT_BLKD output is activated.

When input GOV_MOD_BASE is active, the local active power is compared to the load set point received from PMS, BASE_P_SET. The BASE_P_SET input is a 0-20mA signal obtained through an RTD input. If the local active power deviates from this set point by a margin greater than the set *Max P Dev Crl*, it indicates an over/under fueling fault. In case the quality of the signal BASE_P_SET is not reliable when generator is in base mode, then the correlation module is disabled and INT_BLKD output is activated.

Any one among the binary inputs from governor, for example, GOV_MOD_ISOC, GOV_ MOD_DRP, GOV_MOD_CDRP and GOV_MOD_BASE can be active at a given time. If more than one of them is active or if none of them is active, then the output INT_BLKD is activated and the Correlation algorithm is stopped.

Table 1343 indicates the method of detecting over/under fueling faults in a diesel generator system. For simplicity, the local active power will simply be called P in the tables below.

Table 1343: Correlation algorithm for detecting fueling faults

Type of fault	Governor mode	Fault detection criteria	Output activation
Over fueling fault	GOV_MOD_ISOC = TRUE	F > (*Expected frequency* + *Max Freq Dev Isoc*) AND Local active power (P) > MAX(P1, P2, … P8) + *Max P Dev Crl* Note: Only generators within the same subnetwork are considered for comparison.	OV_FUEL_FLT
	GOV_MOD_DRP = TRUE	F > *F set point no load* – ((*Frequency droop**0.01) * P) + *Max Freq deviation*	
	GOV_MOD_CDRP = TRUE	F > F_CALC_LIMIT + *Max Freq deviation*	
	GOV_MOD_BASE = TRUE	P > BASE_P_SET + *Max P Dev Crl*	
Under fueling fault	GOV_MOD_ISOC = TRUE	F < (*Expected frequency* - *Max Freq Dev Isoc*) AND P < MIN(P1, P2, … P8) - *Max P Dev Crl* Note: Only generators within the same subnetwork are considered for comparison.	UN_FUEL_FLT
	GOV_MOD_DRP = TRUE	F < *F set point no load* - ((*Frequency droop**0.01) * P) - *Max Freq deviation*	
	GOV_MOD_CDRP = TRUE	F < F_CALC_LIMIT - *Max Freq deviation*	
	GOV_MOD_BASE = TRUE	P < BASE_P_SET - *Max P Dev Crl*	

Voting algorithm:

Voting algorithm is applied to groups of generators running in parallel. Voting algorithm compares the behavior of the local generator with rest of the generators in the connected network and if the load on local generator deviates excessively from the others, it is identified as faulty.

The algorithm needs minimum three generators (including the local generator) running in parallel.

The algorithm can be disabled through the setting *Disable Fuel voting*. *Table 1344* shows the method of detecting fueling faults using the voting algorithm.

Table 1344: Voting algorithm for detecting fueling faults

Type of fault	Fault detection criteria	Output activation
Over fueling fault	Number of generators in parallel with same governor mode >= 3 AND MAX(P1, P2, … P8) – MIN(P1, P2 … P8) < *Max P Dev Vot* (This check ensures that the network generators, **excluding local generator**, are operating with similar load) AND P > MAX (P1, P2… P8) + *Max P Dev Vot* (This is to check if the local generator load (P) is deviating significantly from other generators in the same network)	OV_FUEL_FLT
Under fueling fault	Number of generators in parallel with same governor mode >= 3 AND MAX(P1, P2, … P8) – MIN(P1, P2 … P8) < *Max P Dev Vot* AND P < MIN (P1, P2… P8) - *Max P Dev Vot*	UN_FUEL_FLT

If the generator is identified as faulty by the Correlation algorithm, then the generator is removed from the Voting algorithm. Similarly if a network generator is communicated to be faulty via inputs GEN1_DATA … GEN8_DATA, or if the quality of any of the inputs GEN1_DATA … GEN8_DATA is unreliable, then that generator is also removed from the Voting algorithm. This prevents misdiagnosis by Voting algorithm in the event that several generators should suffer from a common mode failure.

Excitation fault detection

This module detects problems with the generator excitation or AVR, which result in excessive reactive power (over excitation) or insufficient reactive power (under excitation) production by the generator.

As in Fueling fault detection block, the excitation faults are also detected by Correlation algorithm and Voting algorithm. The module activates OV_EXCT_FLT in case of over excitation fault detection and UN_EXCT_FLT output in case of under excitation fault. These two signals are available as outputs. Once an excitation fault is detected, the module initiates the Control logic module.

If the input AVR_MODE_DRP is FALSE, indicating that the automatic voltage regulator is not in droop mode, then the module is disabled. If the quality status of the local reactive power input is faulty, then the module is disabled and INT_BLKD output is activated. If generator present in the same subnetwork is faulty or if the quality status of reactive power of a generator is faulty, then that generator is removed from comparison in the Fueling fault detection module. INT_BLKD_STS enumerated monitored data indicates the effect of signal loss (quality faulty) on all the four algorithms (i.e. Fueling Fault-Correlation, Fueling Fault-Voting, Excitation Fault-Correlation and Excitation Fault-Voting).

Correlation algorithm:

The generator excitation system normally follows the droop characteristic. Hence, the average generator phase-phase bus voltage (Uavg), derived from the three phase input `U3P`, and local generator reactive power are compared to the set droop curve. Deviation above/below this curve indicates over/under excitation condition.

The Correlation algorithm for excitation faults can be disabled through the setting *Disable Ext Crl*. The droop curve is set through the settings *U set point no load* and *Voltage droop*.

Table 1345 shows the criteria for detecting excitation faults using Correlation algorithm.

Table 1345: Correlation algorithm for identifying excitation faults

Type of fault	Fault detection criteria	Output activation
Over excitation fault	Uavg > *U set point no load* - ((*Voltage droop* *0.01) * Q) + *Max Volts deviation*	OV_EXCT_FLT
Under excitation fault	Uavg < *U set point no load* - ((*Voltage droop* * 0.01) * Q) - *Max Volts deviation*	UN_EXCT_FLT

Voting algorithm:

As in Fueling fault detection block, the Voting algorithm for excitation faults is also applied when at least 3 generators (including the local generator) are running in parallel. Whenever necessary, the algorithm can be disabled through the setting *Disable Ext Voting*.

Table 1346 shows the criteria for identifying excitation faults using Voting algorithm.

Table 1346: Voting algorithm for identifying excitation faults

Type of fault	Fault detection criteria	Output activation
Over excitation fault	Number of generators in parallel with same governor mode >= 3 AND MAX(Q1, Q2, … Q8) – MIN(Q1, Q2 … Q8) < *Max Q Dev Vot* (Check to ensure that the network generators, **excluding local generator**, are operating with similar load) AND Q > MAX(Q1, Q2 … Q8) + *Max Q Dev Vot*	OV_EXCT_FLT

Table continues on the next page

Type of fault	Fault detection criteria	Output activation
	(Check if the local reactive power (**Q**) is deviating significantly from other generators in the same network)	
Under excitation fault	Number of generators in parallel with same governor mode >= 3 AND MAX(Q1, Q2, … Q8) – MIN(Q1, Q2 … Q8) < *Max Q Dev Vot* AND Q < MIN(Q1, Q2 … Q8) - *Max Q Dev Vot*	UN_EXCT_FLT

Among the 8 reactive power inputs, `Q1 … Q8`, the input corresponding to the setting *Local generator Num*, would be considered as the local reactive power. For example, if *Local generator Num* is set to "1", then `Q1` is considered as the local generator reactive power output.

Fuel rack position monitoring

This module compares the position of the engine's fuel rack, obtained as input `FUEL_RCK_POS`, to the active power, P. The `FUEL_RCK_POS` input is a 0-20mA signal obtained through an `RTD` input. An offset linear relationship, refer *Figure 801*, is assumed between the fuel rack position and the generator active power.

The droop characteristics can be parameterized using the settings *Rack Pos no load* and *Rack Pos gain*. If the performance of the generator set deviates over/under the set droop curve, the fuel rack system is identified as faulty and the output `FUEL_RCK_FLT` is activated. The module can be disabled using the setting *Disable Fuel Rck Mon*.

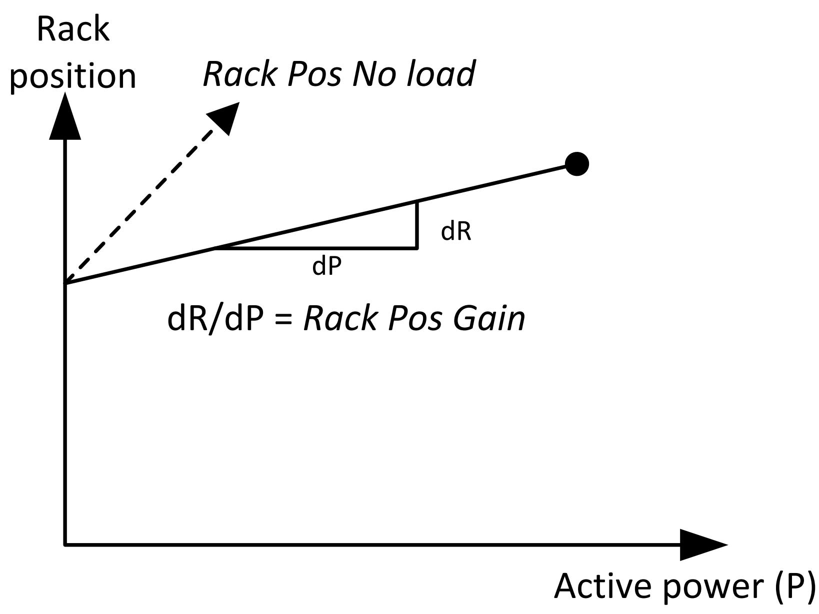


Figure 801: Rack position vs. Active power output of the generator

Excitation current monitoring

The excitation current, `I_EXCITATION`, produced by the AVR is compared to the reactive power output, `Q`, of the generator. A linear relationship is assumed between `I_EXCITATION` and `Q`. The `I_EXCITATION` input is a 0-20mA signal obtained through an `RTD` input and is in primary Amperes.

The droop characteristics can be parameterized using the settings *Ext current no load* and *Ext current gain*. If the performance of the generator deviates from this relationship, the module activates the output `I_EXCT_FLT`. The module can be disabled using the setting *Disable Ext Cur Mon*.

For both the Fuel rack position monitoring and the Excitation current monitoring modules, an internal delay of 100ms is assumed before activation of `FUEL_RCK_FLT` and `I_EXCT_FLT` outputs. This delay is to enable the generator mechanics to respond to the changes in fuel rack position and excitation current.

7.5.5.3 Control logic

Once activated by either the Fuel fault detection module or by the Excitation fault detection module, the Control logic module activates the `FLT_DETECTED` output. This output serves as an indication for the operator or the central PMS to start standby engines or alter the power sharing between healthy diesel generators.

If the network frequency and voltage deteriorate beyond control, the module activates the `STOP_ENGINE` (incase of fueling faults) and `DE_EXCITE` (incase of excitation faults) to protect the system. The logic for the same has been shown in *Table 1347* and *Table 1348*.

The over/under fueling and over/under excitation logic will be checked only if the local active and reactive power are above 2% of nominal value respectively. When the local active and reactive power are less than 2%, the OPERATE output is issued instantaneously.

Table 1347: Criteria for activation of STOP_ENGINE output

Fault type	Criteria	Output
Over fueling fault	MIN (P1 … P8) < *Min active power* That is, One among the **network generators (excluding the local generator)** enter reverse power OR F > *Max Freq limit* + *Max Freq deviation*	STOP_ENGINE
Under fueling fault	(MAX (P1 … P8) > *Max active power* That is, One among the **network generators** enter over power region OR F < *Min Freq limit* – *Max Freq deviation*) AND P < 0.0 That is, **local generator** enters reverse power zone.	

Table 1348: Criteria for activation of DE_EXCITE output

Fault type	Criteria	Output
Over excitation fault	MIN(Q1 … Q8) < *Min reactive power* OR Uavg > *Max voltage limit* + *Max Volts deviation*	DE_EXCITE
Under excitation fault	(Uavg < *Min voltage limit* – *Max Volts deviation* OR I_MAX > 100% of nominal value I_MAX = Maximum of the three phase currents obtained from input I3P) AND Q < 0.0 That is, **local generator** enters reverse reactive power zone.	

The activation of STOP_ENGINE or DE_EXCITE outputs, activates the PRE_TRIP output and initiates the operate delay timer. The timer characteristic is based on DT. Once the time set by *Operate delay time* elapses or when active power (for fueling faults)/ reactive power (for excitation faults) falls below 2% of nominal value, the OPERATE output is activated to open the generator circuit breaker.

In case the active or reactive power does not fall below 2% of nominal value within the set *Operate delay time*, after the activation of STOP_ENGINE or DE_EXCITE outputs respectively, the EXTERNAL_FLT output is activated along with OPERATE output.

The *Min active power*, *Max active power*, *Min reactive power* and *Max reactive power* settings should be set such that the faulty generator is tripped by its own DGMGAPC function before a healthy generator is tripped on over/under power/excitation condition.

The opening of the generator circuit breaker is monitored through the inputs GCB_CLOSED and GCB_OPEN. If the confirmation of GCB opening is not obtained with in the set *Max CB trip delay*, from the instant of activating OPERATE output, the OPR_TIE_A and OPR_TIE_B outputs are activated to trip the tie breakers and GCB_TRP_FAIL output is activated.

If any of the inputs GEN1_DATA … GEN8_DATA indicate that backup protection is triggered in one of the generators in its own subnetwork, then the module activates the outputs OPR_TIE_A and OPR_TIE_B after the set *Backup delay time*, to protect the local diesel generator from tripping due to faults in other network generators.

The module continues to monitor the tie breaker status through inputs TIE_A_CLOSED, TIE_A_OPEN, TIE_B_CLOSED and TIE_B_OPEN. If after another *Max CB trip delay*, the confirmed opening information of tie breakers is not obtained then the module activates TIE_TRP_FAIL output.

The information on tie A or tie B side breaker tripping failure is shared with other DGMGAPC functions in the network through output GEN_DATA to initiate tripping of tie breaker. If the DGMGAPC function receives tie breaker trip failure indication from a generator which shares a tie breaker with the local generator, then the module initiates tripping of that shared tie breaker through either or both outputs OPR_TIE_A and OPR_TIE_B to protect the local generator.

The activated binary outputs, OPERATE, OPR_TIE_A, OPR_TIE_B and EXTERNAL_FLT, will remain active unless the RESET input is activated either from LHMI or through communication.

The module combines the binary information, namely, the GCB status, adjacent tie breaker statuses, Governor Mode, AVR mode, Generator local mode information, backup protection activation (BCKUP_PRT_ST), fault status of the generator (PRE_TRIP activation), A or B side tie breaker trip failure indication into output GEN_DATA. This output is available in the monitored data and is communicated to other DGMGAPC functions in the network on GOOSE. The active and reactive power inputs of the local generator are also communicated over GOOSE for usage as inputs in other DGMGAPC functions.

The binary input BLOCK can be used to block the function, for example, during synchronization of switchboard sections and when the engine is placed in manual control. The activation of the BLOCK input deactivates all module binary outputs, binary monitored data and resets the internal timers.

7.5.6 Application

The function is intended towards a set of diesel generators with similar characteristics interconnected with busbar and tie-breakers.

The DGMGAPC function is mainly used to protect the diesel generator from the over/under fueling of the diesel engines and over/under excitation of the generators. These faults are not easily detected by the traditional protection relay algorithms, which can result in healthy generators behaving abnormally in an attempt to maintain the system voltage and frequency within acceptable limits. This can lead to a cascade fault in which all the healthy generators are disconnected, leaving only the faulty unit running. Without the healthy generators to maintain the frequency and voltage, the faulty generator will also be tripped, resulting in a complete blackout of that part of the industrial network.

The DGMGAPC function identifies the existing network topology and the generators are compared with the expected behavior corresponding to their operation mode or with other generators with in the network.

Two algorithms are used to detect fueling and excitation faults, namely, Correlation and Voting algorithms. The Correlation algorithm compares the generator behavior with the set operation mode of the governor. If the local generator is deviating significantly then it is identified as faulty. The Voting algorithm works on the assumption that, generators share the load similarly. Hence a generator is identified as faulty, if the local generation is moving significantly away from the rest of the generators in the network. Any generator identified as faulty will not be used in either of the algorithms.

Real and reactive power for the local generator is obtained from power measurement function PEMMXU and for the network generator over GOOSE. As an example, a part of application configuration with two generators is shown in *Figure 802*. Here, Generator1 is the local generator whose real and reactive power is obtained from PEMMXU and Generator2 is the network generator whose real and reactive power are obtained over GOOSE.

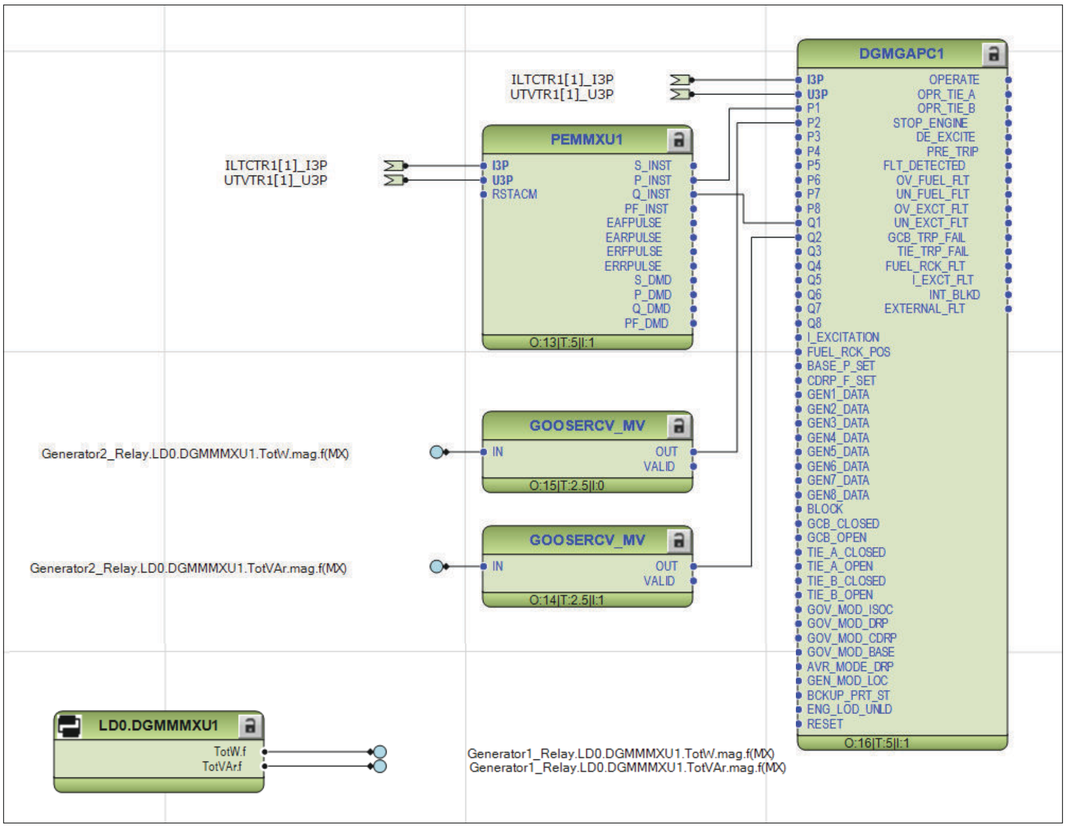


Figure 802: Example application configuration for real and reactive power connection

Once a generator is identified faulty an indication is sent to PMS for starting the backup generators, or to alter the power sharing between healthy generators, which would allow the faulty generator to be offloaded and tripped. But in case the system deteriorates, the function issues commands to shut down the engine or de-excite the generator. It then issues the command to open the GCB. In case the GCB tripping is unsuccessful, the function opens the neighboring tie breakers.

The network topology identification enables the function to locate a particular fault in the network and trip the neighboring tie breakers of healthy generators in case a network generator is faulty and is still not tripped.

The application configuration needs to ensure that in case any protection functions like, over speed protection or over voltage protection or if generator operates outside stability limit then a signal needs to be sent to shut down the diesel engine and open the GCB.

This needs to be configured outside the DGMGAPC function block.

The function monitors the fuel rack position and excitation current of the generator and rises an alarm in case they are deviating from the set operation mode.

7.5.7 Signals

7.5.7.1 DGMGAPC Input signals

Table 1349: DGMGAPC Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
P1	FLOAT32	0.0	Active power of net-work generator 1
P2	FLOAT32	0.0	Active power of net-work generator 2
P3	FLOAT32	0.0	Active power of net-work generator 3
P4	FLOAT32	0.0	Active power of net-work generator 4
P5	FLOAT32	0.0	Active power of net-work generator 5
P6	FLOAT32	0.0	Active power of net-work generator 6
P7	FLOAT32	0.0	Active power of net-work generator 7
P8	FLOAT32	0.0	Active power of net-work generator 8
Q1	FLOAT32	0.0	Reactive power of network generator 1
Q2	FLOAT32	0.0	Reactive power of network generator 2
Q3	FLOAT32	0.0	Reactive power of network generator 3
Q4	FLOAT32	0.0	Reactive power of network generator 4
Q5	FLOAT32	0.0	Reactive power of network generator 5
Q6	FLOAT32	0.0	Reactive power of network generator 6
Q7	FLOAT32	0.0	Reactive power of network generator 7
Q8	FLOAT32	0.0	Reactive power of network generator 8
I_EXCITATION	FLOAT32	0.0	Excitation current of the generator
FUEL_RCK_POS	FLOAT32	0.0	Fuel rack position of the governor
BASE_P_SET	FLOAT32	0.0	Set active power lim-it in generator base load mode

Table continues on the next page

Name	Type	Default	Description
CDRP_F_SET	FLOAT32	0.0	Compensated droop no load set point frequency from PMS
GEN1_DATA	INT32	0	Data received from network generator 1
GEN2_DATA	INT32	0	Data received from network generator 2
GEN3_DATA	INT32	0	Data received from network generator 3
GEN4_DATA	INT32	0	Data received from network generator 4
GEN5_DATA	INT32	0	Data received from network generator 5
GEN6_DATA	INT32	0	Data received from network generator 6
GEN7_DATA	INT32	0	Data received from network generator 7
GEN8_DATA	INT32	0	Data received from network generator 8
BLOCK	BOOLEAN	0=False	Block input to block all binary outputs
GCB_CLOSED	BOOLEAN	0=False	Local generator circuit breaker closed position status
GCB_OPEN	BOOLEAN	0=False	Local generator circuit breaker open position status
TIE_A_CLOSED	BOOLEAN	0=False	Adjacent tie breaker A closed position
TIE_A_OPEN	BOOLEAN	0=False	Adjacent tie breaker A open position
TIE_B_CLOSED	BOOLEAN	0=False	Adjacent tie breaker B closed position
TIE_B_OPEN	BOOLEAN	0=False	Adjacent tie breaker B open position
GOV_MOD_ISOC	BOOLEAN	0=False	Governor isochronous mode status
GOV_MOD_DRP	BOOLEAN	0=False	Governor droop mode status
GOV_MOD_CDRP	BOOLEAN	0=False	Governor compensated droop mode status
GOV_MOD_BASE	BOOLEAN	0=False	Governor base load mode status

Table continues on the next page

Name	Type	Default	Description
AVR_MODE_DRP	BOOLEAN	0=False	Automatic voltage regulator mode
GEN_MOD_LOC	BOOLEAN	0=False	Generator in local mode
BCKUP_PRT_ST	BOOLEAN	0=False	Backup protection activated
ENG_LOD_UNLD	BOOLEAN	0=False	Engine loading or unloading in progress
RESET	BOOLEAN	0=False	Reset the correlation and voting algorithms and timer

7.5.7.2 DGMGAPC Output signals

Table 1350: DGMGAPC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
OPR_TIE_A	BOOLEAN	Operate tie breaker A
OPR_TIE_B	BOOLEAN	Operate tie breaker B
STOP_ENGINE	BOOLEAN	Stop fuel inflow to the engine
DE_EXCITE	BOOLEAN	De excite the generator
PRE_TRIP	BOOLEAN	Pre-trip signal indicating imminent trip of generator
FLT_DETECTED	BOOLEAN	Fault detected in the local generator
OV_FUEL_FLT	BOOLEAN	Over fueling fault detected
UN_FUEL_FLT	BOOLEAN	Under fueling fault detected
OV_EXCT_FLT	BOOLEAN	Over excitation fault detected
UN_EXCT_FLT	BOOLEAN	Under excitation fault detected
GCB_TRP_FAIL	BOOLEAN	Trip command to generator circuit breaker failed
TIE_TRP_FAIL	BOOLEAN	Trip command to tie breaker failed
FUEL_RCK_FLT	BOOLEAN	Fault in fuel rack of the governor
I_EXCT_FLT	BOOLEAN	Fault in excitation system of the generator
INT_BLKD	BOOLEAN	Internal block status
EXTERNAL_FLT	BOOLEAN	Gen P/Q not controlled due to fault in external system

7.5.8 Settings

7.5.8.1 DGMGAPC Settings

Table 1351: DGMGAPC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Disable Fuel Crl	0=False 1=True			0=False	Disable correlation algorithm for fueling faults
Disable Fuel voting	0=False 1=True			0=False	Disable voting algorithm for fueling faults
Disable Ext Crl	0=False 1=True			0=False	Disable correlation algorithm for excitation faults
Disable Ext voting	0=False 1=True			0=False	Disable voting algorithm for excitation faults
Disable Fuel Rck Mon	0=False 1=True			0=False	Disable fuel rack position monitoring
Disable Ext Cur Mon	0=False 1=True			0=False	Disable excitation current monitoring
Min Freq limit	0.95...1.00	xFn	0.01	0.95	Minimum Freq limit below which STOP_ENGINE is activated
Max Freq limit	1.00...1.05	xFn	0.01	1.05	Maximum Freq limit above which STOP_ENGINE is activated
Min voltage limit	0.5...1.5	xUn	0.1	0.8	Minimum voltage limit below which DE_EXCITE is activated
Max voltage limit	0.5...1.5	xUn	0.1	1.2	Maximum voltage limit above which DE_EXCITE is activated
Operate delay time	10...300000	ms	10	600	Operate delay time
Max CB trip delay	10...300000	ms	10	600	Maximum time delay for detection of CB status
Disable time	10...3600000	ms	10	60000	Function disable time during engine loading/unloading
Backup delay time	10...300000	ms	10	100	Operate delay time for backup protection

Table 1352: DGMGAPC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Min active power	0.01...1.00	xSn	0.01	0.05	Active power limit below which STOP_ENGINE is activated
Max active power	0.10...2.00	xSn	0.01	1.00	Active power limit above which STOP_ENGINE is activated

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Min reactive power	0.01...1.00	xSn	0.01	0.05	Reactive power limit below which DE_EXCITE is activated
Max reactive power	0.10...2.00	xSn	0.01	1.00	Reactive power limit above which DE_EXCITE is activated
Expected frequency	0.95...1.05	xFn	0.01	1.00	Expected frequency of the network in isochronous mode
F set point no load	0.10...2.00	xFn	0.01	1.00	No load frequency of the generator for droop characteristics
Frequency droop	0.00...100.00	%Fn	0.01	5.00	Percentage frequency droop from no load to full load
U set point no load	0.10...2.00	xUn	0.01	1.00	No load voltage of the generator
Voltage droop	0.00...100.00	%Un	0.01	10.00	Percentage voltage droop from no load to full load
Rack Pos no load	0.00...100.00	%	0.01	0.00	Fuel rack position on no load
Rack Pos gain	0.01...10.00		0.01	1.00	Rate of change of rack position from no load to full load
Ext current no load	0.0010...1.0000	xIn	0.0005	0.0100	Excitation current when generator is on no load
Ext current gain	0.0100...10.0000		0.0005	1.0000	Rate of change of excitation Curr from no load to full load

Table 1353: DGMGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Total Num of Gn	1...8		1	8	Total number of generators
Total Num of tie	1...8		1	8	Total number of tie
Reset delay time	20...15000	ms	10	100	Reset delay time

Table 1354: DGMGAPC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Max Freq deviation	0.00...0.10	xFn	0.01	0.01	Maximum allowed deviation in frequency
Max Freq Dev Isoc	0.00...0.10	xFn	0.01	0.01	Maximum allowed deviation in frequency for isochronous mode
Max Volts deviation	0.00...0.10	xUn	0.01	0.01	Maximum allowed deviation in voltage
Max P Dev Crl	0.00...0.10	xSn	0.01	0.01	Maximum allowed deviation in active power for correlation
Max P Dev Vot	0.00...0.10	xSn	0.01	0.01	Maximum allowed deviation in active power for voting

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Max Q Dev Vot	0.00...0.10	xSn	0.01	0.01	Maximum allowed deviation in reac-tive power for voltng
Local generator Num	1...8		1	1	Local generator number
Gn 1 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 1
Gn 2 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 2
Gn 3 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 3
Gn 4 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 4
Gn 5 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7			0=Not configured	Busbar number of generator 5

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=Bus8				
Gn 6 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 6
Gn 7 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 7
Gn 8 busbar Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar number of generator 8
Tie 1 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar A number of tie breaker 1
Tie 1 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 1
Tie 2 busbar A Num	0=Not configured			0=Not configured	Busbar A number of tie breaker 2

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8				
Tie 2 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 2
Tie 3 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar A number of tie breaker 3
Tie 3 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 3
Tie 4 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar A number of tie breaker 4
Tie 4 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3			0=Not configured	Busbar B number of tie breaker 4

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8				
Tie 5 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar A number of tie breaker 5
Tie 5 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 5
Tie 6 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar A number of tie breaker 6
Tie 6 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 6
Tie 7 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6			0=Not configured	Busbar A number of tie breaker 7

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	7=Bus7 8=Bus8				
Tie 7 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 7
Tie 8 busbar A Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar A number of tie breaker 8
Tie 8 busbar B Num	0=Not configured 1=Bus1 2=Bus2 3=Bus3 4=Bus4 5=Bus5 6=Bus6 7=Bus7 8=Bus8			0=Not configured	Busbar B number of tie breaker 8
Wait time signal status	0...100	ms	1	50	Wait time between Load/Unload signal and GCB status
Wait time status signal	0...100	ms	1	50	Wait time between GCB status and Load/Unload signal

7.5.9 DGMGAPC Monitored data

Table 1355: DGMGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
I_MAX	FLOAT32	0.00...5.00	xIn	Maximum of the three phase input currents
F_CALC_LIMIT	FLOAT32	0.00...2.00	xFn	Calculated Freq limit in governor compensated droop mode
GEN_DATA	INT32	0...8191		Generator data sent on GOOSE for usage in Ntw DGMGAPC
P_LOCAL	FLOAT32	-499999.9...499999.9	kW	Active power output of generator

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Q_LOCAL	FLOAT32	-499999.9...499999.9	kVAr	Reactive power output of generator
INT_BLKD_STS	Enum	0=None 1=Fuel Crl 2=Fuel Vot 3=Fuel Crl Vot 4=Ext Crl 5=Fuel Ext Crl 6=Fuel Vot Ext Crl 7=Fuel Crl Vot Ext Crl 8=Ext Vot 9=Fuel Crl Ext Vot 10=Fuel Ext Vot 11=Fuel Crl Vot Ext Vot 12=Ext Crl Vot 13=Fuel Crl Ext Crl Vot 14=Fuel Vot Ext Crl Vot 15=Fuel Ext Crl Vot		Internal block status
GEN_STATE	Enum	-1=Unknown 1=Stopped 3=Started 5=Disabled		Current operating state
FAULT_GEN1	BOOLEAN	0=False 1=True		Fault in network generator 1
FAULT_GEN2	BOOLEAN	0=False 1=True		Fault in network generator 2
FAULT_GEN3	BOOLEAN	0=False 1=True		Fault in network generator 3
FAULT_GEN4	BOOLEAN	0=False 1=True		Fault in network generator 4
FAULT_GEN5	BOOLEAN	0=False 1=True		Fault in network generator 5
FAULT_GEN6	BOOLEAN	0=False 1=True		Fault in network generator 6
FAULT_GEN7	BOOLEAN	0=False 1=True		Fault in network generator 7
FAULT_GEN8	BOOLEAN	0=False 1=True		Fault in network generator 8
SBNW_GEN1	INT32	0...8		Subnetwork number of generator 1
SBNW_GEN2	INT32	0...8		Subnetwork number of generator 2
SBNW_GEN3	INT32	0...8		Subnetwork number of generator 3
SBNW_GEN4	INT32	0...8		Subnetwork number of generator 4
SBNW_GEN5	INT32	0...8		Subnetwork number of generator 5

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
SBNW_GEN6	INT32	0...8		Subnetwork number of generator 6
SBNW_GEN7	INT32	0...8		Subnetwork number of generator 7
SBNW_GEN8	INT32	0...8		Subnetwork number of generator 8
SBNW_TIE_CB1	INT32	0...8		Subnetwork number of tie breaker 1
SBNW_TIE_CB2	INT32	0...8		Subnetwork number of tie breaker 2
SBNW_TIE_CB3	INT32	0...8		Subnetwork number of tie breaker 3
SBNW_TIE_CB4	INT32	0...8		Subnetwork number of tie breaker 4
SBNW_TIE_CB5	INT32	0...8		Subnetwork number of tie breaker 5
SBNW_TIE_CB6	INT32	0...8		Subnetwork number of tie breaker 6
SBNW_TIE_CB7	INT32	0...8		Subnetwork number of tie breaker 7
SBNW_TIE_CB8	INT32	0...8		Subnetwork number of tie breaker 8
DGMGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

7.5.10 Technical data

Table 1356: Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage and current: f_n ±2 Hz
	Voltage: ±1.5% of the set value or 0.002 xU_n Frequency: ±5 mHz Active power: ±3% of the set value or 0.002 xS_n Reactive power: ±3% of the set value or 0.002 xS_n
Operate time accuracy	±1.0% of the set value or ±20 ms
Reset ratio	Typically 0.96/1.04

8 Measurement functions

8.1 Basic measurements

8.1.1 Functions

The three-phase current measurement function CMMXU is used for monitoring and metering the phase currents of the power system.

The three-phase voltage measurement function VMMXU is used for monitoring and metering the phase-to-phase voltages of the power system. The phase-to-earth voltages are available in VPHMMXU.

Single-phase voltage measurement function VAMMXU is used for monitoring and metering the single-phase voltage of the power system.

The residual current measurement function RESCMMXU is used for monitoring and metering the residual current of the power system.

The residual voltage measurement function RESVMMXU is used for monitoring and metering the residual voltage of the power system.

The frequency measurement function FMMXU is used for monitoring and metering the frequency of the power system.

The sequence current measurement CSMSQI is used for monitoring and metering the phase sequence currents.

The sequence voltage measurement VSMSQI is used for monitoring and metering the phase sequence voltages.

The frequency measurement FMMXU is used for monitoring and metering the power system frequency.

The three-phase power and energy measurement PEMMXU is used for monitoring and metering the active power (P), reactive power (Q), apparent power (S) and power factor (PF) and for calculating the accumulated energy separately as forward active, reversed active, forward reactive and reversed reactive. PEMMXU calculates these quantities using the fundamental frequency phasors, that is, the DFT values of the measured phase current and phase voltage signals.

The information of the measured quantity is available for the operator both locally in LHMI or WHMI and remotely to a network control center with communication.

If the measured data in LHMI or WHMI is within parentheses, there are some problems to express the data.

8.1.2 Measurement functionality

The functions can be enabled or disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

Some of the measurement functions operate on two alternative measurement modes: "DFT" and "RMS". The measurement mode is selected with the *X Measurement mode* setting. Depending on the measuring function if the measurement mode cannot be selected, the measuring mode is "DFT".

Demand value calculation

The demand values are calculated separately for each measurement function and per phase when applicable. The available measurement modes are "Linear" and "Logarithmic". The "Logarithmic" measurement mode is only effective for phase current and residual current demand value calculations. The demand value calculation mode is selected with the setting parameter **Configuration** > **Measurements** > **A demand Av mode**. The time interval for all demand value calculations is selected with the setting parameter **Configuration** > **Measurements** > **Demand interval**.

The demand time interval is synchronized to the real-time clock of the protection relay. When the demand time interval or calculation mode is changed, it initializes the demand value calculation. For the very first demand value calculation interval, the values are stated as invalid until the first refresh is available.

The "Linear" calculation mode uses the periodic sliding average calculation of the measured signal over the demand time interval. A new demand value is obtained once in a minute, indicating the analog signal demand over the demand time interval proceeding the update time. The actual rolling demand values are stored in the memory until the value is updated at the end of the next time interval.

The "Logarithmic" calculation mode uses the periodic calculation using a log10 function over the demand time interval to replicate thermal demand ammeters. The logarithmic demand calculates a snapshot of the analog signal every 1/15 x demand time interval.

Each measurement function has its own recorded data values. In protection relay, these are found in **Monitoring** > **Recorded data** > **Measurements**. In the technical manual these are listed in the monitored data section of each measurement function. These values are periodically updated with the maximum and minimum demand values. The time stamps are provided for both values.

Reset of Recorded data initializes a present demand value to the minimum and maximum demand values.

Value reporting

The measurement functions are capable of reporting new values for network control center (SCADA system) based on various functions.

- Zero-point clamping
- Deadband supervision
- Limit value supervision

In the three-phase voltage measurement function VMMXU the supervision functions are based on the phase-to-phase voltages. However, the phase-to-earth voltage values are also reported with the phase-to-phase voltages.

GOOSE is an event based protocol service. Analog GOOSE uses the same event generation functions as vertical SCADA communication for updating the measurement values. Update interval of 500 ms is used for data that do not have zero-point clamping, deadband supervision or limit value supervision.

Zero-point clamping

A measured value under the zero-point clamping limit is forced to zero. This allows the noise in the input signal to be ignored. The active clamping function forces both the actual measurement value and the angle value of the measured signal to zero. In the three-phase or sequence measuring functions, each phase or sequence component has a separate zero-point clamping function. The zero-value detection operates so that once the measured value exceeds or falls below the value of the zero-clamping limit, new values are reported.

Table 1357: Zero-point clamping limits

Function	Zero-clamping limit
Three-phase current measurement (CMMXU)	1 % of nominal (In)
Three-phase voltage measurement (VMMXU)	1 % of nominal (Un)
Phase-to-earth voltage measurement (VPHMMXU)	1 % of nominal (Un)
Residual current measurement (RESCMMXU)	1 % of nominal (In)
Residual voltage measurement (RESVMMXU)	1 % of nominal (Un)
Phase sequence current measurement (CSMSQI)	1 % of the nominal (In)
Phase sequence voltage measurement (VSMSQI)	1 % of the nominal (Un)
Three-phase power and energy measurement (PEMMXU)	1.5 % of the nominal (Sn)

When the frequency measurement function FMMXU is unable to measure the network frequency in the undervoltage situation, the measured values are set to the nominal and also the quality information of the data set accordingly. The undervoltage limit is fixed to 10 percent of the nominal for the frequency measurement.

Limit value supervision

The limit value supervision function indicates whether the measured value of X_INST exceeds or falls below the set limits. The measured value has the corresponding range information X_RANGE and has a value in the range of 0 to 4:

- 0: "normal"
- 1: "high"
- 2: "low"
- 3: "high-high"
- 4: "low-low"

The range information changes and the new values are reported.

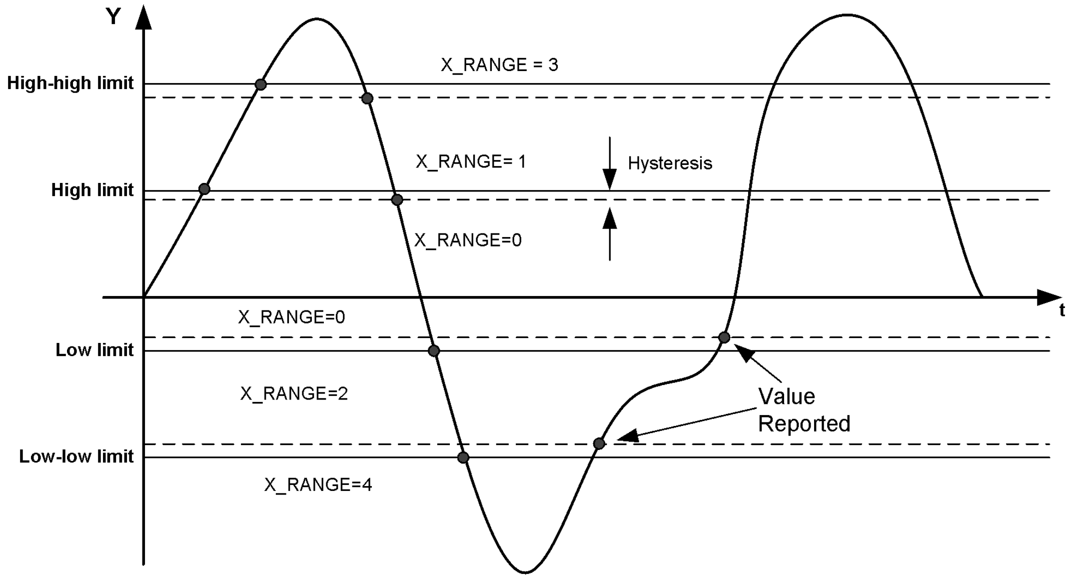


Figure 803: Presentation of operating limits

The range information can also be decoded into boolean output signals on some of the measuring functions and the number of phases required to exceed or undershoot the limit before activating the outputs and can be set with the *Num of phases* setting in the three-phase measurement functions CMMXU and VMMXU. The limit supervision boolean alarm and warning outputs can be blocked.

Table 1358: Settings for limit value supervision

Function	Settings for limit value supervision	
Three-phase current measurement (CMMXU)	High limit	*A high limit*
	Low limit	*A low limit*
	High-high limit	*A high high limit*
	Low-low limit	*A low low limit*
Three-phase voltage measurement (VMMXU)	High limit	*V high limit*
	Low limit	*V low limit*
	High-high limit	*V high high limit*
	Low-low limit	*V low low limit*
Phase voltage measurement (VPHMMXU)	High limit	*V high limit*
	Low limit	*V low limit*
	High-high limit	*V high high limit*
	Low-low limit	*V low low limit*
Single-phase voltage measurement (VAMM-XU)	High limit	*V high limit*
	Low limit	*V low limit*
	High-high limit	*V high high limit*
	Low-low limit	*V low low limit*
Residual current measurement (RESCMMXU)	High limit	*A high limit res*

Table continues on the next page

Function	Settings for limit value supervision	
	Low limit	–
	High-high limit	*A Hi high limit res*
	Low-low limit	–
Frequency measurement (FMMXU)	High limit	*F high limit*
	Low limit	*F low limit*
	High-high limit	*F high high limit*
	Low-low limit	*F low low limit*
Residual voltage measurement (RESVMMXU)	High limit	*V high limit res*
	Low limit	–
	High-high limit	*V Hi high limit res*
	Low-low limit	–
Phase sequence current measurement (CSMSQI)	High limit	*Ps Seq A high limit, Ng Seq A high limit, Zro A high limit*
	Low limit	*Ps Seq A low limit, Ng Seq A low limit, Zro A low limit*
	High-high limit	*Ps Seq A Hi high Lim, Ng Seq A Hi high Lim, Zro A Hi high Lim*
	Low-low limit	*Ps Seq A low low Lim, Ng Seq A low low Lim, Zro A low low Lim*
Phase sequence voltage measurement (VSMSQI)	High limit	*Ps Seq V high limit, Ng Seq V high limit, Zro V high limit*
	Low limit	*Ps Seq V low limit, Ng Seq V low limit, Zro V low limit*
	High-high limit	*Ps Seq V Hi high Lim, Ng Seq V Hi high Lim, Zro V Hi high Lim*
	Low-low limit	*Ps Seq V low low Lim, Ng Seq V low low Lim,*
Three-phase power and energy measurement (PEMMXU)	High limit	–
	Low limit	–
	High-high limit	–
	Low-low limit	–

Deadband supervision

The deadband supervision function reports the measured value according to integrated changes over a time period. In *Figure 804* the values are reported at points Y1, Y2, Y3 and Y4. There is no value report at the end of |A3 + A4 + A5 + A6 + A7| because the positive and negative areas counteract each other. The integrated changes, |A3 + A4 + A5 + A6 + A7|, equal approximately zero.

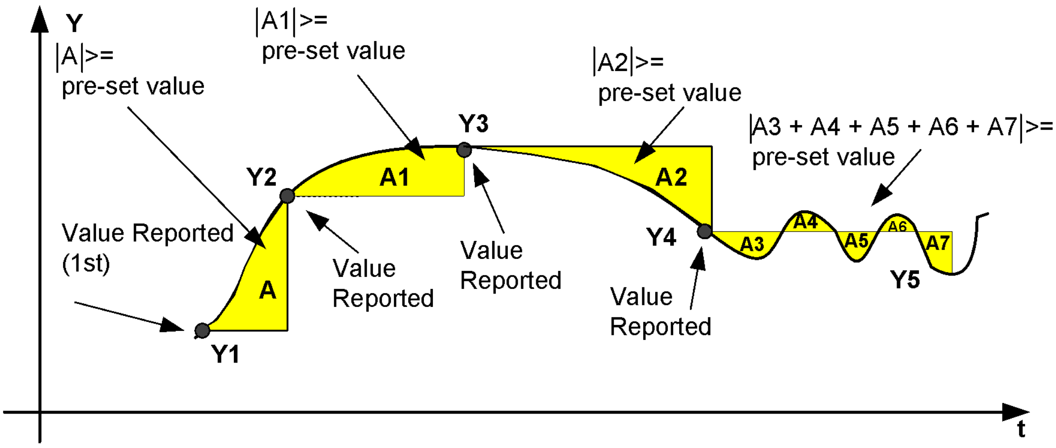


Figure 804: Integral deadband supervision

The deadband value used in the integral calculation is configured with the *X deadband* setting. The value represents the percentage of the difference between the maximum and minimum limit in the units of 0.001 percent x seconds.

The reporting delay of the integral algorithms in seconds is calculated with the formula:

$$t(s) = \frac{(\max - \min) \times deadband / 1000}{|\Delta Y| \times 100\%}$$

(Equation 338)

Example for CMMXU:

A deadband = 2500 (2.5 % of the total measuring range of 40)

`I_INST_A` = `I_DB_A` = 0.30

If `I_INST_A` changes to 0.40, the reporting delay is:

$$t(s) = \frac{(40 - 0) \times 2500 / 1000}{|0.40 - 0.30| \times 100\%} = 10s$$

Table 1359: Parameters for deadband calculation

Function	Settings	Minimum/maximum
Three-phase current measurement (CMMXU)	*A deadband*	*0.04/40*
Three-phase voltage measurement (VMMXU)	*V deadband*	*0.004/4*
Phase voltage measurement (VMHMMXU)	*V deadband*	*0.004/4*
Single-phase voltage measurement (VAMM-XU)	*V deadband*	*0.004/4*
Residual current measurement (RESCMMXU)	*A deadband res*	*0.04/40*
Residual voltage measurement (RESVMMXU)	*V deadband res*	*0.004/4*
Frequency measurement (FMMXU)	*F deadband*	*0.04/40*

Table continues on the next page

Function	Settings	Minimum/maximum
Phase sequence current measurement (CSMSQI)	*Ps Seq A deadband, Ng Seq A deadband, Zro A deadband*	*0.04/40*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V deadband, Ng Seq V deadband, Zro V deadband*	*0.004/4*
Three-phase power and energy measurement (PEMMXU)	*Power deadband*	*0.01/0.1*

Power and energy calculation

The three-phase power is calculated from the selected voltage and current measurements as described in *Table 1360*. The setting *Measurement mode* determines which voltage and current measurements are used.

It is also possible to use positive-sequence components for calculating the apparent power, which makes the determination of power insensitive to any asymmetry in currents or voltages.

Table 1360: Measured apparent power

Measurement mode **setting values**	**Power calculation**
PhsA, PhsB, PhsC	$\overline{S} = \overline{U_A} \cdot \overline{I_A}^* + \overline{U_B} \cdot \overline{I_B}^* + \overline{U_C} \cdot \overline{I_C}^*$ (Equation 339)
Arone	$\overline{S} = \overline{U_{AB}} \cdot \overline{I_A}^* - \overline{U_{BC}} \cdot \overline{I_C}^*$ (Equation 340)
Pos Seq	$\overline{S} = 3 \cdot \overline{U_1} \cdot \overline{I_1}^*$ (Equation 341)
PhsAB	$\overline{S} = \overline{U_{AB}} \cdot \left(\overline{I_A}^* - \overline{I_B}^*\right)$ (Equation 342)
PhsBC	$\overline{S} = \overline{U_{BC}} \cdot \left(\overline{I_B}^* - \overline{I_C}^*\right)$ (Equation 343)
PhsCA	$\overline{S} = \overline{U_{CA}} \cdot \left(\overline{I_C}^* - \overline{I_A}^*\right)$ (Equation 344)

Table continues on the next page

Measurement mode setting values	Power calculation
PhsA	$\overline{S} = 3 \cdot \overline{U_A} \cdot \overline{I_A}^*$ (Equation 345)
PhsB	$\overline{S} = 3 \cdot \overline{U_B} \cdot \overline{I_B}^*$ (Equation 346)
PhsC	$\overline{S} = 3 \cdot \overline{U_C} \cdot \overline{I_C}^*$ (Equation 347)

Depending upon the set *Measurement mode*, the Power and energy calculation module calculates active power, reactive power and apparent power values from the available set of measurements.

$$P = \mathrm{Re}(\overline{S})$$

(Equation 348)

$$Q = \mathrm{Im}(\overline{S})$$

(Equation 349)

$$S = \left|\overline{S}\right| = \sqrt{P^2 + Q^2}$$

(Equation 350)

$$Cos\varphi = \frac{P}{S}$$

(Equation 351)

The calculated powers are available as function outputs S_INST, P_INST, Q_INST and the power factor angle as PF_INST.

Depending on the unit multiplier selected with *Power unit Mult*, the calculated power values in the monitored data and measurement view are presented in units of kVA/kW/kVAr or in units of MVA/MW/MVAr.

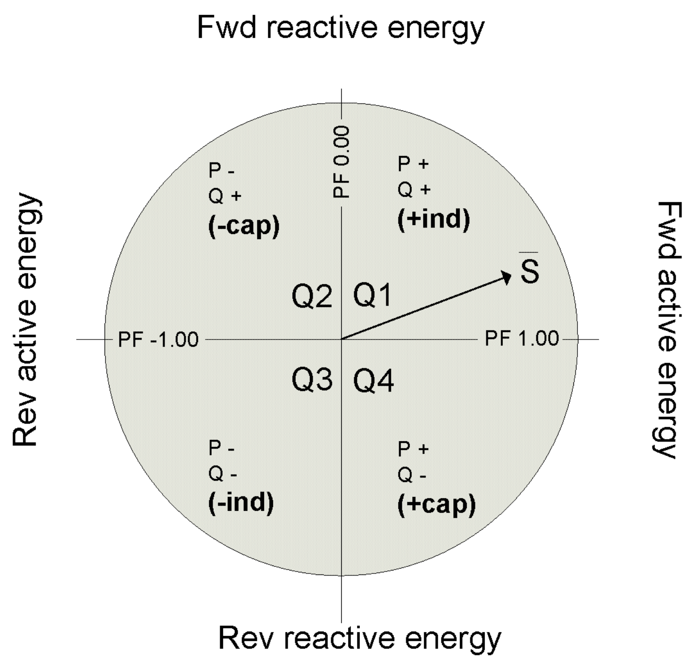


Figure 805: Complex power and power quadrants

Table 1361: Power quadrants

Quadrant	Current	P	Q	PF	Power
Q1	Lagging	+	+	0…+1.00	+ind
Q2	Lagging	-	+	0…-1.00	-cap
Q3	Leading	-	-	0…-1.00	-ind
Q4	Leading	+	-	0…+1.00	+cap

The active power P direction can be selected between forward and reverse with *Active power Dir* and correspondingly the reactive power Q direction can be selected with *Reactive power Dir*. This affects also the accumulated energy directions.

The accumulated energy is calculated separately as forward active (`EA_FWD_ACM`), reverse active (`EA_RV_ACM`), forward reactive (`ER_FWD_ACM`) and reverse reactive (`ER_RV_ACM`). Depending on the value of the unit multiplier selected with *Energy unit Mult*, the calculated power values are presented in units of kWh/kVArh or in units of MWh/MVArh.

When the energy counter reaches its defined maximum value, the counter value is reset and restarted from zero. Changing the value of the *Energy unit Mult* setting resets the accumulated energy values to the initial values, that is, `EA_FWD_ACM` to *Forward Wh Initial*, `EA_RV_ACM` to *Reverse Wh Initial*, `ER_FWD_ACM` to *Forward VArh Initial* and `ER_RV_ACM` to *Reverse VArh Initial*. It is also possible to reset the accumulated energy to initial values through a parameter or with the `RSTACM` input.

Sequence components

The phase-sequence components are calculated using the phase currents and phase voltages. More information on calculating the phase-sequence components can be found in *Chapter 11.7 Calculated measurements* in this manual.

8.1.3 Measurement function applications

The measurement functions are used for power system measurement, supervision and reporting to LHMI, a monitoring tool within PCM600, or to the station level, for example, with IEC 61850. The possibility to continuously monitor the measured values of active power, reactive power, currents, voltages, power factors and so on, is vital for efficient production, transmission, and distribution of electrical energy. It provides a fast and easy overview of the present status of the power system to the system operator. Additionally, it can be used during testing and commissioning of protection and control protection relays to verify the proper operation and connection of instrument transformers, that is, the current transformers (CTs) and voltage transformers (VTs). The proper operation of the protection relay analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the protection relay to other independent meters.

When the zero signal is measured, the noise in the input signal can still produce small measurement values. The zero point clamping function can be used to ignore the noise in the input signal and, hence, prevent the noise to be shown in the user display. The zero clamping is done for the measured analog signals and angle values.

The demand values are used to neglect sudden changes in the measured analog signals when monitoring long time values for the input signal. The demand values are linear average values of the measured signal over a settable demand interval. The demand values are calculated for the measured analog three-phase current signals.

The limit supervision indicates, if the measured signal exceeds or goes below the set limits. Depending on the measured signal type, up to two high limits and up to two low limits can be set for the limit supervision.

The deadband supervision reports a new measurement value if the input signal has gone out of the deadband state. The deadband supervision can be used in value reporting between the measurement point and operation control. When the deadband supervision is properly configured, it helps to keep the communication load to a minimum and yet measurement values are reported frequently enough.

The instantaneous measurement values of several measurement functions are available as primary values for further use in Application Configuration. The current values are in amperes while voltage values are in kilovolts and power values in kilovolt-amperes, watts or volt-amperes reactive.

8.1.4 Three-phase current measurement CMMXU (ANSI IA, IB, IC)

8.1.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase current measurement	CMMXU	3I	IA, IB, IC

8.1.4.2 Function block

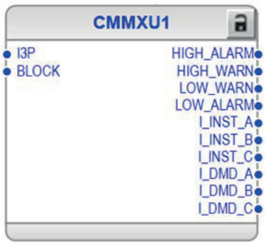


Figure 806: Function block

8.1.4.3 Functionality

The three-phase current measurement function CMMXU provides limit value supervision output (HIGH_ALARM, HIGH_WARN, LOW_WARN, LOW_ALARM). The delay of the activation and deactivation of these outputs can be controlled with setting parameters *On delay time* and *Off delay time*.

Instantaneous phase currents (I_INST_A, I_INST_B and I_INST_C) are provided as outputs in amperes. These can be used in the application configuration.

Phase current demand values (I_DMD_A, I_DMD_B and I_DMD_C) are provided as outputs in amperes. These outputs are dedicated for Load profile recorder (LDPRLRC).

8.1.4.4 Analog channel configuration

CMMXU has one analog group input which must be properly configured.

Table 1362: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.4.5 Signals

CMMXU Input signals

Table 1363: CMMXU Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

CMMXU Output signals

Table 1364: CMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm
I_INST_A	FLOAT32	Phase A current instantaneous value amplitude in amperes
I_INST_B	FLOAT32	Phase B current instantaneous value amplitude in amperes
I_INST_C	FLOAT32	Phase C current instantaneous value amplitude in amperes
I_DMD_A	FLOAT32	Demand value of IL1 current
I_DMD_B	FLOAT32	Demand value of IL2 current
I_DMD_C	FLOAT32	Demand value of IL3 current

8.1.4.6 CMMXU Non group settings

Table 1365: CMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation				1=on	Operation Off / On
Num of phases				1=1 out of 3	Number of phases required by limit supervision
A high high limit	0.00...40.00	xIn	0.01	1.40	High alarm current limit
A high limit	0.00...40.00	xIn	0.01	1.20	High warning current limit
A low limit	0.00...40.00	xIn	0.01	0.00	Low warning current limit

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
A low low limit	0.00...40.00	xIn	0.01	0.00	Low alarm current limit
A deadband	100...100000		1	2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1366: CMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode				2=DFT	Selects used measurement mode
On delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs
Off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs

8.1.4.7 CMMXU Monitored data

Table 1367: CMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
IL1-A:1	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase A
IL2-A:1	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase B
IL3-A:1	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase C
Max demand IL1	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase A
Max demand IL2	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase B
Max demand IL3	FLOAT32	0.00...40.00	xIn	Maximum demand for Phase C
Min demand IL1	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase A
Min demand IL2	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase B
Min demand IL3	FLOAT32	0.00...40.00	xIn	Minimum demand for Phase C
Time max demand IL1	Timestamp			Time of maximum demand phase A
Time max demand IL2	Timestamp			Time of maximum demand phase B
Time max demand IL3	Timestamp			Time of maximum demand phase C
Time min demand IL1	Timestamp			Time of minimum demand phase A
Time min demand IL2	Timestamp			Time of minimum demand phase B
Time min demand IL3	Timestamp			Time of minimum demand phase C

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
BLOCK	BOOLEAN	0=False 1=True		Block signal for all binary outputs
HIGH_ALARM	BOOLEAN	0=False 1=True		High alarm
HIGH_WARN	BOOLEAN	0=False 1=True		High warning
LOW_WARN	BOOLEAN	0=False 1=True		Low warning
LOW_ALARM	BOOLEAN	0=False 1=True		Low alarm
I_INST_A	FLOAT32	0.00...40.00	xIn	IL1 Amplitude, magnitude of instantaneous value
I_ANGL_A	FLOAT32	-180.00...180.00	deg	IL1 current angle
I_DB_A	FLOAT32	0.00...40.00	xIn	IL1 Amplitude, magnitude of deadband value
I_DMD_A	FLOAT32	0.00...40.00	xIn	Demand value of IL1 current
I_RANGE_A	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		IL1 Amplitude range
I_INST_B	FLOAT32	0.00...40.00	xIn	IL2 Amplitude, magnitude of instantaneous value
I_ANGL_B	FLOAT32	-180.00...180.00	deg	IL2 current angle
I_DB_B	FLOAT32	0.00...40.00	xIn	IL2 Amplitude, magnitude of deadband value
I_DMD_B	FLOAT32	0.00...40.00	xIn	Demand value of IL2 current
I_RANGE_B	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		IL2 Amplitude range
I_INST_C	FLOAT32	0.00...40.00	xIn	IL3 Amplitude, magnitude of instantaneous value
I_ANGL_C	FLOAT32	-180.00...180.00	deg	IL3 current angle
I_DB_C	FLOAT32	0.00...40.00	xIn	IL3 Amplitude, magnitude of deadband value
I_DMD_C	FLOAT32	0.00...40.00	xIn	Demand value of IL3 current
I_RANGE_C	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		IL3 Amplitude range

8.1.4.8 Technical data

Table 1368: CMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f_n ±2 Hz
	±0.5 % or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.5 Three-phase voltage measurement VMMXU (ANSI VA, VB, VC)

8.1.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase voltage measurement	VMMXU	3U	VA, VB, VC

8.1.5.2 Function block

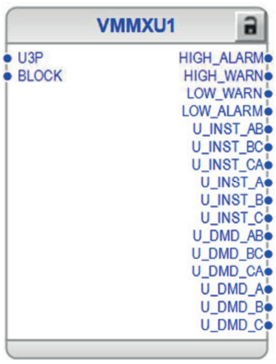


Figure 807: Function block

8.1.5.3 Functionality

The three-phase voltage measurement function VMMXU provides limit value supervision output (HIGH_ALARM, HIGH_WARN, LOW_WARN, LOW_ALARM). Setting parameters *On delay time* and *Off delay time* are used for controlling the activation and the deactivation of alarm and warning outputs.

Instantaneous phase-to-phase and phase-to-earth voltages in volts are available for application configurations through outputs U_INST_AB, U_INST_BC and U_INST_CA and U_INST_A, U_INST_B and U_INST_C, respectively.

Phase current demand values in volts are for connecting to Load profile recorder (LDPRLRC) through outputs `I_DMD_A`, `I_DMD_B` and `I_DMD_C`.

8.1.5.4 Analog channel configuration

VMMXU has one analog group input which must be properly configured.

Table 1369: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1370: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that at least one voltage channel is connected if *Num of start phases* is set to "1 out of 3".
	The function requires that at least two voltage channels are connected if *Num of start phases* is set to "2 out of 3".
	The function requires that all three voltage channels are connected if *Num of start phases* is set to "3 out of 3".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.5.5 Signals

VMMXU Input signals

Table 1371: VMMXU Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

VMMXU Output signals

Table 1372: VMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm
U_INST_AB	FLOAT32	Phase AB voltage instantaneous value amplitude in kV
U_INST_BC	FLOAT32	Phase BC voltage instantaneous value amplitude in kV
U_INST_CA	FLOAT32	Phase CA voltage instantaneous value amplitude in kV
U_INST_A	FLOAT32	Phase A voltage instantaneous value amplitude in kV
U_INST_B	FLOAT32	Phase B voltage instantaneous value amplitude in kV
U_INST_C	FLOAT32	Phase C voltage instantaneous value amplitude in kV
U_DMD_AB	FLOAT32	Demand value of U12 voltage
U_DMD_BC	FLOAT32	Demand value of U23 voltage
U_DMD_CA	FLOAT32	Demand value of U31 voltage
U_DMD_A	FLOAT32	Demand value of UL1 voltage
U_DMD_B	FLOAT32	Demand value of UL2 voltage
U_DMD_C	FLOAT32	Demand value of UL3 voltage

8.1.5.6 VMMXU Settings

Table 1373: VMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
V high high limit	0.00...4.00	xUn	0.01	1.40	High alarm voltage limit
V high limit	0.00...4.00	xUn	0.01	1.20	High warning voltage limit
V low limit	0.00...4.00	xUn	0.01	0.00	Low warning voltage limit
V low low limit	0.00...4.00	xUn	0.01	0.00	Low alarm voltage limit
V deadband	100...100000		1	10000	Deadband configuration value for integral calculation.

Parameter	Values (Range)	Unit	Step	Default	Description
					(percentage of difference between min and max as 0,001 % s)

Table 1374: VMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
On delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs
Off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs

8.1.5.7 VMMXU Monitored data

Table 1375: VMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U12-kV:1	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase AB
U23-kV:1	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase BC
U31-kV:1	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase CA
UL1-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase A
UL2-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase B
UL3-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase C
BLOCK	BOOLEAN	0=False 1=True		Block signal for all binary outputs
HIGH_ALARM	BOOLEAN	0=False 1=True		High alarm
HIGH_WARN	BOOLEAN	0=False 1=True		High warning
LOW_WARN	BOOLEAN	0=False 1=True		Low warning
LOW_ALARM	BOOLEAN	0=False 1=True		Low alarm
U_INST_AB	FLOAT32	0.00...4.00	xUn	U12 amplitude, magnitude of instantaneous value
U_ANGL_AB	FLOAT32	-180.00...180.00	deg	U12 angle
U_DB_AB	FLOAT32	0.00...4.00	xUn	U12 amplitude, magnitude of deadband value

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
U_DMD_AB	FLOAT32	0.00...4.00	xUn	Demand value of U12 voltage
U_RANGE_AB	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U12 amplitude range
U_INST_BC	FLOAT32	0.00...4.00	xUn	U23 amplitude, magnitude of instantaneous value
U_ANGL_BC	FLOAT32	-180.00...180.00	deg	U23 angle
U_DB_BC	FLOAT32	0.00...4.00	xUn	U23 amplitude, magnitude of deadband value
U_DMD_BC	FLOAT32	0.00...4.00	xUn	Demand value of U23 voltage
U_RANGE_BC	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U23 amplitude range
U_INST_CA	FLOAT32	0.00...4.00	xUn	U31 amplitude, magnitude of instantaneous value
U_ANGL_CA	FLOAT32	-180.00...180.00	deg	U31 angle
U_DB_CA	FLOAT32	0.00...4.00	xUn	U31 amplitude, magnitude of deadband value
U_DMD_CA	FLOAT32	0.00...4.00	xUn	Demand value of U31 voltage
U_RANGE_CA	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U31 amplitude range
U_INST_A	FLOAT32	0.00...5.00	xUn	UL1 amplitude, magnitude of instantaneous value
U_ANGL_A	FLOAT32	-180.00...180.00	deg	UL1 angle
U_DMD_A	FLOAT32	0.00...5.00	xUn	Demand value of UL1 voltage
U_INST_B	FLOAT32	0.00...5.00	xUn	UL2 amplitude, magnitude of instantaneous value
U_ANGL_B	FLOAT32	-180.00...180.00	deg	UL2 angle
U_DMD_B	FLOAT32	0.00...5.00	xUn	Demand value of UL2 voltage
U_INST_C	FLOAT32	0.00...5.00	xUn	UL3 amplitude, magnitude of instantaneous value
U_ANGL_C	FLOAT32	-180.00...180.00	deg	UL3 angle
U_DMD_C	FLOAT32	0.00...5.00	xUn	Demand value of UL3 voltage

8.1.5.8 Technical data

Table 1376: VMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × U_n
	±0.5 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.6 Phase voltage measurement VPHMMXU

8.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase voltage measurement	VPHMMXU	3UL	VL

8.1.6.2 Function block

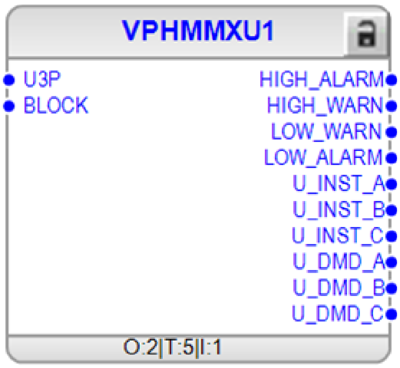


Figure 808: Function block

8.1.6.3 Functionality

The phase voltage measurement function VPHMMXU provides limit value supervision output (HIGH_ALARM, HIGH_WARN, LOW_WARN and LOW_ALARM). Instantaneous phase voltage in volt is available for application configurations through output U_INST_A, U_INST_B and U_INST_C. Phase voltage demand value in volt is for connecting to Load profile recorder (LDPRLRC) through output U_DMD_A, U_DMD_B and U_DMD_C.

8.1.6.4 Analog channel configuration

VPHMMXU has one analog group input which must be properly configured.

Table 1377: Analog inputs

Input	Description
U3P	Three-phase voltage

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1378: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that at least one voltage channel is connected if *Num of start phases* is set to "1 out of 3".
	The function requires that at least two voltage channels are connected if *Num of start phases* is set to "2 out of 3".
	The function requires that at least three voltage channels are connected if *Num of start phases* is set to "3 out of 3".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the content of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.6.5 Signals

VPHMMXU Input signals

Table 1379: VPHMMXU Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

VPHMMXU Output signals

Table 1380: VPHMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm
U_INST_A	FLOAT32	Phase A voltage instantaneous value amplitude in kV

Table continues on the next page

Name	Type	Description
U_INST_B	FLOAT32	Phase B voltage instantaneous value amplitude in kV
U_INST_C	FLOAT32	Phase C voltage instantaneous value amplitude in kV
U_DMD_A	FLOAT32	Demand value of UL1 voltage
U_DMD_B	FLOAT32	Demand value of UL2 voltage
U_DMD_C	FLOAT32	Demand value of UL3 voltage

8.1.6.6 VPHMMXU Settings

Table 1381: VPHMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
V high high limit	0.00...5.00	xUn	0.01	1.40	High alarm voltage limit
V high limit	0.00...5.00	xUn	0.01	1.20	High warning voltage limit
V low limit	0.00...5.00	xUn	0.01	0.00	Low warning voltage limit
V low low limit	0.00...5.00	xUn	0.01	0.00	Low alarm voltage limit
V deadband	100...100000		1	10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1382: VPHMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
On delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs
Off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs

8.1.6.7 VPHMMXU Monitored data

Table 1383: VPHMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
UL1-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to neutral voltage phase A
UL2-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to neutral voltage phase B
UL3-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to neutral voltage phase C
BLOCK	BOOLEAN			Block signal for all binary outputs
HIGH_ALARM	BOOLEAN			High alarm
HIGH_WARN	BOOLEAN			High warning
LOW_WARN	BOOLEAN			Low warning
LOW_ALARM	BOOLEAN			Low alarm
U_INST_A	FLOAT32	0.00...5.00	xUn	UL1 amplitude, magnitude of instantaneous value
U_ANGL_A	FLOAT32	-180.00...180.00	deg	UL1 angle
U_DMD_A	FLOAT32	0.00...5.00	xUn	Demand value of UL1 voltage
U_RANGE_A	Enum			UL1 amplitude range
U_INST_B	FLOAT32	0.00...5.00	xUn	UL2 amplitude, magnitude of instantaneous value
U_ANGL_B	FLOAT32	-180.00...180.00	deg	UL2 angle
U_DMD_B	FLOAT32	0.00...5.00	xUn	Demand value of UL2 voltage
U_RANGE_B	Enum			UL2 amplitude range
U_INST_C	FLOAT32	0.00...5.00	xUn	UL3 amplitude, magnitude of instantaneous value
U_ANGL_C	FLOAT32	-180.00...180.00	deg	UL3 angle
U_DMD_C	FLOAT32	0.00...5.00	xUn	Demand value of UL3 voltage
U_RANGE_C	Enum			UL3 amplitude range

8.1.6.8 Technical data

Table 1384: VPHMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz

Table continues on the next page

Characteristic	Value
	At voltages in range 0.01…1.15 × U_n
	±0.5 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.7 Single-phase voltage measurement VAMMXU (ANSI V_A)

8.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Single-phase voltage measurement	VAMMXU	U_A	V_A

8.1.7.2 Function block

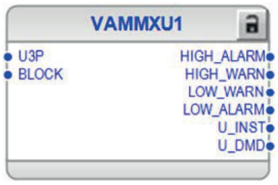


Figure 809: Function block

8.1.7.3 Functionality

The single-phase voltage measurement function VAMMXU provides limit value supervision output (HIGH_ALARM, HIGH_WARN, LOW_WARN, LOW_ALARM).

Instantaneous single-phase voltage in volt is available for application configurations through output U_INST. Phase voltage demand value in volt is for connecting to Load profile recorder (LDPRLRC) through output U_DMD.

8.1.7.4 Analog channel configuration

VAMMXU has one analog group input which must be properly configured.

Table 1385: Analog inputs

Input	Description
U3P	Voltage group signal

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1386: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that the first phase voltage U_A or U_AB is connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.7.5 Signals

VMMXU Input signals

Table 1387: VMMXU Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

VMMXU Output signals

Table 1388: VMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
LOW_WARN	BOOLEAN	Low warning
LOW_ALARM	BOOLEAN	Low alarm
U_INST_AB	FLOAT32	Phase AB voltage instantaneous value amplitude in kV
U_INST_BC	FLOAT32	Phase BC voltage instantaneous value amplitude in kV
U_INST_CA	FLOAT32	Phase CA voltage instantaneous value amplitude in kV
U_INST_A	FLOAT32	Phase A voltage instantaneous value amplitude in kV
U_INST_B	FLOAT32	Phase B voltage instantaneous value amplitude in kV
U_INST_C	FLOAT32	Phase C voltage instantaneous value amplitude in kV
U_DMD_AB	FLOAT32	Demand value of U12 voltage
U_DMD_BC	FLOAT32	Demand value of U23 voltage
U_DMD_CA	FLOAT32	Demand value of U31 voltage
U_DMD_A	FLOAT32	Demand value of UL1 voltage
U_DMD_B	FLOAT32	Demand value of UL2 voltage
U_DMD_C	FLOAT32	Demand value of UL3 voltage

8.1.7.6 VMMXU Settings

Table 1389: VMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Num of phases	1=1 out of 3 2=2 out of 3 3=3 out of 3			1=1 out of 3	Number of phases required by limit supervision
V high high limit	0.00...4.00	xUn	0.01	1.40	High alarm voltage limit
V high limit	0.00...4.00	xUn	0.01	1.20	High warning voltage limit
V low limit	0.00...4.00	xUn	0.01	0.00	Low warning voltage limit
V low low limit	0.00...4.00	xUn	0.01	0.00	Low alarm voltage limit
V deadband	100...100000		1	10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1390: VMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
On delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs
Off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs

8.1.7.7 VMMXU Monitored data

Table 1391: VMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U12-kV:1	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase AB
U23-kV:1	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase BC
U31-kV:1	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase CA
UL1-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase A
UL2-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
UL3-kV:1	FLOAT32	0.00...5.00	xUn	Measured phase to earth voltage amplitude phase C
BLOCK	BOOLEAN	0=False 1=True		Block signal for all binary outputs
HIGH_ALARM	BOOLEAN	0=False 1=True		High alarm
HIGH_WARN	BOOLEAN	0=False 1=True		High warning
LOW_WARN	BOOLEAN	0=False 1=True		Low warning
LOW_ALARM	BOOLEAN	0=False 1=True		Low alarm
U_INST_AB	FLOAT32	0.00...4.00	xUn	U12 amplitude, magnitude of instantaneous value
U_ANGL_AB	FLOAT32	-180.00...180.00	deg	U12 angle
U_DB_AB	FLOAT32	0.00...4.00	xUn	U12 amplitude, magnitude of deadband value
U_DMD_AB	FLOAT32	0.00...4.00	xUn	Demand value of U12 voltage
U_RANGE_AB	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U12 amplitude range
U_INST_BC	FLOAT32	0.00...4.00	xUn	U23 amplitude, magnitude of instantaneous value
U_ANGL_BC	FLOAT32	-180.00...180.00	deg	U23 angle
U_DB_BC	FLOAT32	0.00...4.00	xUn	U23 amplitude, magnitude of deadband value
U_DMD_BC	FLOAT32	0.00...4.00	xUn	Demand value of U23 voltage
U_RANGE_BC	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U23 amplitude range
U_INST_CA	FLOAT32	0.00...4.00	xUn	U31 amplitude, magnitude of instantaneous value
U_ANGL_CA	FLOAT32	-180.00...180.00	deg	U31 angle
U_DB_CA	FLOAT32	0.00...4.00	xUn	U31 amplitude, magnitude of deadband value
U_DMD_CA	FLOAT32	0.00...4.00	xUn	Demand value of U31 voltage
U_RANGE_CA	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		U31 amplitude range

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
U_INST_A	FLOAT32	0.00...5.00	xUn	UL1 amplitude, magnitude of instantaneous value
U_ANGL_A	FLOAT32	-180.00...180.00	deg	UL1 angle
U_DMD_A	FLOAT32	0.00...5.00	xUn	Demand value of UL1 voltage
U_INST_B	FLOAT32	0.00...5.00	xUn	UL2 amplitude, magnitude of instantaneous value
U_ANGL_B	FLOAT32	-180.00...180.00	deg	UL2 angle
U_DMD_B	FLOAT32	0.00...5.00	xUn	Demand value of UL2 voltage
U_INST_C	FLOAT32	0.00...5.00	xUn	UL3 amplitude, magnitude of instantaneous value
U_ANGL_C	FLOAT32	-180.00...180.00	deg	UL3 angle
U_DMD_C	FLOAT32	0.00...5.00	xUn	Demand value of UL3 voltage

8.1.7.8 Technical data

Table 1392: VAMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × U_n
	±0.5 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.8 Residual current measurement RESCMMXU (ANSI IG)

8.1.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual current measurement	RESCMMXU	Io	IG

8.1.8.2 Function block

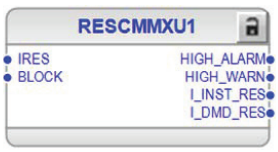


Figure 810: Function block

8.1.8.3 Functionality

The residual current measurement function RESCMMXU provides limit value supervision output (HIGH_ALARM, HIGH_WARN). Setting parameters *On delay time* and *Off delay time* are used for controlling the activation and, respectively, the deactivation of alarm and warning outputs.

Instantaneous residual current in amperes is available for application configurations through output I_INST_RES. The residual current demand value in amperes is for connecting to Load profile recorder (LDPRLRC) through output I_DMD_RES.

8.1.8.4 Analog channel configuration

RESCMMXU has one analog group input which must be properly configured.

Table 1393: Analog inputs

Input	Description
IRES	Residual current (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.8.5 Signals

RESCMMXU Input signals

Table 1394: RESCMMXU Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

RESCMMXU Output signals

Table 1395: RESCMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning

Table continues on the next page

Name	Type	Description
I_INST_RES	FLOAT32	Residual current instantaneous value amplitude in amperes
I_DMD_RES	FLOAT32	Demand value of residual current

8.1.8.6 RESCMMXU Settings

Table 1396: RESCMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
A Hi high limit res	0.00...40.00	xIn	0.01	0.20	High alarm current limit
A high limit res	0.00...40.00	xIn	0.01	0.05	High warning current limit
A deadband res	100...100000		1	2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1397: RESCMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
On delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs
Off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs

8.1.8.7 RESCMMXU Monitored data

Table 1398: RESCMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
Io-A:1	FLOAT32	0.00...40.00	xIn	Residual current
BLOCK	BOOLEAN	0=False 1=True		Block signal for all binary outputs
HIGH_ALARM	BOOLEAN	0=False 1=True		High alarm
HIGH_WARN	BOOLEAN	0=False 1=True		High warning
I_INST_RES	FLOAT32	0.00...40.00	xIn	Residual current Amplitude, magnitude of instantaneous value

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I_ANGL_RES	FLOAT32	-180.00...180.00	deg	Residual current angle
I_DB_RES	FLOAT32	0.00...40.00	xIn	Residual current Amplitude, magnitude of deadband value
I_DMD_RES	FLOAT32	0.00...40.00	xIn	Demand value of residual current
I_RANGE_RES	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Residual current Amplitude range
Max demand Io	FLOAT32	0.00...40.00	xIn	Maximum demand for residual current
Min demand Io	FLOAT32	0.00...40.00	xIn	Minimum demand for residual current
Time max demand Io	Timestamp			Time of maximum demand residual current
Time min demand Io	Timestamp			Time of minimum demand residual current

8.1.8.8 Technical data

Table 1399: RESCMMXU Technical data

Characteristic	Value
Operation accuracy	At the frequency $f = f_n$
	±0.5 % or ±0.002 × I_n (at currents in the range of 0.01...4.00 × I_n)
Suppression of harmonics	DFT: -50 dB at $f = n \times f_n$, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.9 Residual voltage measurement RESVMMXU (ANSI VG/VN)

8.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual voltage measurement	RESVMMXU	Uo	VG/VN

8.1.9.2 Function block

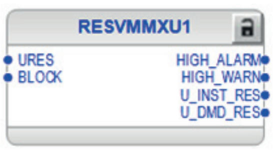


Figure 811: Function block

8.1.9.3 Functionality

The residual voltage measurement function RESVMMXU provides limit value supervision output (HIGH_ALARM, HIGH_WARN). Setting parameters *On delay time* and *Off delay time* are used for controlling the activation and, respectively, the deactivation of alarm and warning outputs.

Instantaneous residual voltage in volt is available for application configurations through output U_INST_RES. The residual voltage demand value in volt is for connecting to Load profile recorder (LDPRLRC) through output U_DMD_RES.

8.1.9.4 Analog channel configuration

RESVMMXU has one analog group input which must be properly configured.

Table 1400: Analog inputs

Input	Description
URES	Residual voltage (measured or calculated)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1401: Special conditions

Condition	Description
URES calculated	The function requires that all three voltage channels are connected to calculate residual voltage. Setting *VT connection* must be "Wye" in that particular UTVTR.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.9.5 Signals

RESVMMXU Input signals

Table 1402: RESVMMXU Input signals

Name	Type	Default	Description
URES	SIGNAL	-	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

RESVMMXU Output signals

Table 1403: RESVMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning
U_INST_RES	FLOAT32	Residual voltage instantaneous value amplitude in kV
U_DMD_RES	FLOAT32	Demand value of residual voltage

8.1.9.6 RESVMMXU Settings

Table 1404: RESVMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
V Hi high limit res	0.00...4.00	xUn	0.01	0.20	High alarm voltage limit
V high limit res	0.00...4.00	xUn	0.01	0.05	High warning voltage limit
V deadband res	100...100000		1	10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1405: RESVMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
On delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs
Off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs

8.1.9.7 RESVMMXU Monitored data

Table 1406: RESVMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
Uo-kV:1	FLOAT32	0.00...4.00	xUn	Residual voltage
BLOCK	BOOLEAN	0=False 1=True		Block signal for all binary outputs
HIGH_ALARM	BOOLEAN	0=False 1=True		High alarm

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
HIGH_WARN	BOOLEAN	0=False 1=True		High warning
U_INST_RES	FLOAT32	0.00...4.00	xUn	Residual voltage Amplitude, magnitude of instantaneous value
U_ANGL_RES	FLOAT32	-180.00...180.00	deg	Residual voltage angle
U_DB_RES	FLOAT32	0.00...4.00	xUn	Residual voltage Amplitude, magnitude of deadband value
U_DMD_RES	FLOAT32	0.00...4.00	xUn	Demand value of residual voltage
U_RANGE_RES	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Residual voltage Amplitude range

8.1.9.8 Technical data

Table 1407: RESVMMXU Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured voltage: f/f_n = ±2 Hz
	±0.5 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,… RMS: No suppression

8.1.10 Frequency measurement FMMXU (ANSI f)

8.1.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency measurement	FMMXU	f	f

8.1.10.2 Function block

Figure 812: Function block

8.1.10.3 Functionality

The frequency measurement range is 35...75 Hz. The measured frequencies outside the measurement range are considered to be out of range and the minimum and maximum values are then shown in parentheses.

There is an extended range of 10...75 Hz in a 50 Hz network and 12...75 Hz in a 60 Hz network. The measured frequencies outside 35...75 Hz are shown in parentheses.

When the frequencies cannot be measured, for example, due to too low voltage amplitude, the default value for frequency measurement can be selected with the *Def frequency Sel* setting parameter. In the “Nominal” mode the frequency is set to 50 Hz (or 60 Hz) and in “Zero” mode the frequency is set to zero and shown in parentheses.

FMMXU provides instantaneous frequency in hertz which is available for application configurations through output `F_INST`.

8.1.10.4 Signals

FMMXU Input signals

Table 1408: FMMXU Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages

FMMXU Output signals

Table 1409: FMMXU Output signals

Name	Type	Description
F_INST	FLOAT32	Frequency, instantaneous value

8.1.10.5 FMMXU Settings

Table 1410: FMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
F high high limit	35.00...75.00	Hz	0.01	60.00	High alarm frequency limit
F high limit	35.00...75.00	Hz	0.01	55.00	High warning frequency limit
F low limit	35.00...75.00	Hz	0.01	45.00	Low warning frequency limit
F low low limit	35.00...75.00	Hz	0.01	40.00	Low alarm frequency limit
F deadband	100...100000		1	1000	Deadband configuration value for integral calculation (percentage of difference between

Parameter	Values (Range)	Unit	Step	Default	Description
					min and max as 0,001 % s)

Table 1411: FMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Def frequency Sel	1=Nominal 2=Zero			1=Nominal	Default frequency selection

8.1.10.6 FMMXU Monitored data

Table 1412: FMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
f-Hz:1	FLOAT32	35.00...75.00	Hz	Measured frequency
F_INST	FLOAT32	35.00...75.00	Hz	Frequency, instantaneous value
F_DB	FLOAT32	35.00...75.00	Hz	Frequency, deadband value
F_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Measured frequency range

8.1.10.7 Technical data

Table 1413: FMMXU Technical data

Characteristic	Value
Operation accuracy	±5 mHz (in measurement range 35...75 Hz)

8.1.11 Sequence current measurement CSMSQI (ANSI I1, I2, I0)

8.1.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence current measurement	CSMSQI	I1, I2, I0	I1, I2, I0

8.1.11.2 Function block

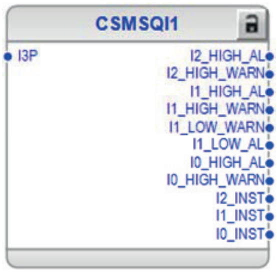


Figure 813: Function block

8.1.11.3 Functionality

The sequence current measurement function CSMSQI provides limit value supervision outputs (`I2_HIGH_AL`, `I2_HIGH_WARN`, `I1_HIGH_AL`, `I1_HIGH_WARN`, `I1_LOW_WRN`, `I1_LOW_AL`, `I0_HIGH_AL`, `I0_HIGH_WARN`). Setting parameters *Ps Seq A on delay time, Ps Seq A off delay time, Ng Seq A on delay time, Ng Seq A off delay time, Zro Seq A on delay time, Zro Seq A off delay time* are used for controlling the activation and the deactivation of alarm and warning outputs.

Instantaneous sequence currents in amperes are available for application configurations through outputs `I2_INST`, `I1_INST` and `I0_INST`.

8.1.11.4 Analog channel configuration

CSMSQI has one analog group input which must be properly configured.

Table 1414: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.11.5 Signals

CSMSQI Input signals

Table 1415: CSMSQI Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents

CSMSQI Output signals

Table 1416: CSMSQI Output signals

Name	Type	Description
I2_HIGH_AL	BOOLEAN	Negative sequence high alarm
I2_HIGH_WARN	BOOLEAN	Negative sequence high warning
I1_HIGH_AL	BOOLEAN	Positive sequence high alarm
I1_HIGH_WARN	BOOLEAN	Positive sequence high warn-ing
I1_LOW_WARN	BOOLEAN	Positive sequence low warn-ing
I1_LOW_AL	BOOLEAN	Positive sequence low alarm
I0_HIGH_AL	BOOLEAN	Zero sequence high alarm
I0_HIGH_WARN	BOOLEAN	Zero sequence high warning
I2_INST	FLOAT32	Negative sequence current amplitude, instantaneous val-ue (A)
I1_INST	FLOAT32	Positive sequence current amplitude, instantaneous val-ue (A)
I0_INST	FLOAT32	Zero sequence current ampli-tude, instantaneous value (A)

8.1.11.6 CSMSQI Settings

Table 1417: CSMSQI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Ps Seq A Hi high Lim	0.00...40.00	xIn	0.01	1.40	High alarm current limit for positive sequence current
Ps Seq A high limit	0.00...40.00	xIn	0.01	1.20	High warning current limit for positive sequence current
Ps Seq A low limit	0.00...40.00	xIn	0.01	0.00	Low warning current limit for positive sequence current
Ps Seq A low low Lim	0.00...40.00	xIn	0.01	0.00	Low alarm current limit for positive sequence current
Ps Seq A deadband	100...100000		1	2500	Deadband configuration value for positive sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Ng Seq A Hi high Lim	0.00...40.00	xIn	0.01	0.20	High alarm current limit for negative sequence current
Ng Seq A High limit	0.00...40.00	xIn	0.01	0.05	High warning current limit for negative sequence current
Ng Seq A low limit	0.00...40.00	xIn	0.01	0.00	Low warning current limit for negative sequence current
Ng Seq A low low Lim	0.00...40.00	xIn	0.01	0.00	Low alarm current limit for negative sequence current
Ng Seq A deadband	100...100000		1	2500	Deadband configuration value for negative sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Zro A Hi high Lim	0.00...40.00	xIn	0.01	0.20	High alarm current limit for zero sequence current
Zro A High limit	0.00...40.00	xIn	0.01	0.05	High warning current limit for zero sequence current
Zro A low limit	0.00...40.00	xIn	0.01	0.00	Low warning current limit for zero sequence current
Zro A low low Lim	0.00...40.00	xIn	0.01	0.00	Low alarm current limit for zero sequence current
Zro A deadband	100...100000		1	2500	Deadband configuration value for zero sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1418: CSMSQI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Ps Seq A on delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs for positive sequence current
Ps Seq A off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs for positive sequence current
Ng Seq A on delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs for negative sequence current
Ng Seq A off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs for negative sequence current
Zro A on delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs for zero sequence current
Zro A off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs for zero sequence current

8.1.11.7 CSMSQI Monitored data

Table 1419: CSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
NgSeq-A:1	FLOAT32	0.00...40.00	xIn	Measured negative sequence current
PsSeq-A:1	FLOAT32	0.00...40.00	xIn	Measured positive sequence current
ZrSeq-A:1	FLOAT32	0.00...40.00	xIn	Measured zero sequence current
I2_HIGH_AL	BOOLEAN	0=False 1=True		Negative sequence high alarm
I2_HIGH_WARN	BOOLEAN	0=False 1=True		Negative sequence high warning
I1_HIGH_AL	BOOLEAN	0=False 1=True		Positive sequence high alarm
I1_HIGH_WARN	BOOLEAN	0=False 1=True		Positive sequence high warning
I1_LOW_WARN	BOOLEAN	0=False 1=True		Positive sequence low warning
I1_LOW_AL	BOOLEAN	0=False 1=True		Positive sequence low alarm
I0_HIGH_AL	BOOLEAN	0=False 1=True		Zero sequence high alarm

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
I0_HIGH_WARN	BOOLEAN	0=False 1=True		Zero sequence high warning
I2_INST	FLOAT32	0.00...40.00	xIn	Negative sequence current amplitude, instantaneous value
I2_ANGL	FLOAT32	-180.00...180.00	deg	Negative sequence current angle
I2_DB	FLOAT32	0.00...40.00	xIn	Negative sequence current amplitude, deadband value
I2_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Negative sequence current amplitude range
I1_INST	FLOAT32	0.00...40.00	xIn	Positive sequence current amplitude, instantaneous value
I1_ANGL	FLOAT32	-180.00...180.00	deg	Positive sequence current angle
I1_DB	FLOAT32	0.00...40.00	xIn	Positive sequence current amplitude, deadband value
I1_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Positive sequence current amplitude range
I0_INST	FLOAT32	0.00...40.00	xIn	Zero sequence current amplitude, instantaneous value
I0_ANGL	FLOAT32	-180.00...180.00	deg	Zero sequence current angle
I0_DB	FLOAT32	0.00...40.00	xIn	Zero sequence current amplitude, deadband value
I0_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Zero sequence current amplitude range

8.1.11.8 Technical data

Table 1420: CSMSQI Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the measured current: f/f_n = ±2 Hz
	±1.0 % or ±0.002 × I_n at currents in the range of 0.01...4.00 × I_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.1.12 Sequence voltage measurement VSMSQI (ANSI V1, V2, V0)

8.1.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence voltage measurement	VSMSQI	U1, U2, U0	V1, V2, V0

8.1.12.2 Function block

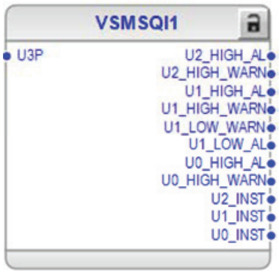


Figure 814: Function block

8.1.12.3 Functionality

The sequence voltage measurement function VSMSQI provides limit value supervision outputs (`U2_HIGH_AL`, `U2_HIGH_WARN`, `U1_HIGH_AL`, `U1_HIGH_WARN`, `U1_LOW_WRN`, `U1_LOW_AL`, `U0_HIGH_AL`, `U0_HIGH_WARN`). Setting parameters *Ps Seq V on delay time*, *Ps Seq V off delay time*, *Ng Seq V on delay time*, *Ng Seq V off delay time*, *Zro Seq V on delay time*, and *Zro Seq V off delay time* are used for controlling the activation and the deactivation of alarm and warning outputs.

Instantaneous sequence voltages in volt are available for application configurations through outputs `U2_INST`, `U1_INST` and `U0_INST`.

8.1.12.4 Analog channel configuration

VSMSQI has one analog group input which must be properly configured.

Table 1421: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1422: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that any two voltage channels are connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.12.5 Signals

VSMSQI Input signals

Table 1423: VSMSQI Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages

VSMSQI Output signals

Table 1424: VSMSQI Output signals

Name	Type	Description
U2_HIGH_AL	BOOLEAN	Negative sequence high alarm
U2_HIGH_WARN	BOOLEAN	Negative sequence high warning
U1_HIGH_AL	BOOLEAN	Positive sequence high alarm
U1_HIGH_WARN	BOOLEAN	Positive sequence high warning
U1_LOW_WARN	BOOLEAN	Positive sequence low warning
U1_LOW_AL	BOOLEAN	Positive sequence low alarm
U0_HIGH_AL	BOOLEAN	Zero sequence high alarm
U0_HIGH_WARN	BOOLEAN	Zero sequence high warning
U2_INST	FLOAT32	Negative sequence voltage amplitude, instantaneous value (kV)

Table continues on the next page

Name	Type	Description
U1_INST	FLOAT32	Positive sequence voltage amplitude, instantaneous value (kV)
U0_INST	FLOAT32	Zero sequence voltage amplitude, instantaneous value (kV)

8.1.12.6 VSMSQI Settings

Table 1425: VSMSQI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Ps Seq V Hi high Lim	0.00...4.00	xUn	0.01	1.40	High alarm voltage limit for positive sequence voltage
Ps Seq V high limit	0.00...4.00	xUn	0.01	1.20	High warning voltage limit for positive sequence voltage
Ps Seq V low limit	0.00...4.00	xUn	0.01	0.00	Low warning voltage limit for positive sequence voltage
Ps Seq V low low Lim	0.00...4.00	xUn	0.01	0.00	Low alarm voltage limit for positive sequence voltage
Ps Seq V deadband	100...100000		1	10000	Deadband configuration value for positive sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Ng Seq V Hi high Lim	0.00...4.00	xUn	0.01	0.20	High alarm voltage limit for negative sequence voltage
Ng Seq V High limit	0.00...4.00	xUn	0.01	0.05	High warning voltage limit for negative sequence voltage
Ng Seq V low limit	0.00...4.00	xUn	0.01	0.00	Low warning voltage limit for negative sequence voltage
Ng Seq V low low Lim	0.00...4.00	xUn	0.01	0.00	Low alarm voltage limit for negative sequence voltage
Ng Seq V deadband	100...100000		1	10000	Deadband configuration value for negative sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Zro V Hi high Lim	0.00...4.00	xUn	0.01	0.20	High alarm voltage limit for zero sequence voltage
Zro V High limit	0.00...4.00	xUn	0.01	0.05	High warning voltage limit for zero sequence voltage
Zro V low limit	0.00...4.00	xUn	0.01	0.00	Low warning voltage limit for zero sequence voltage
Zro V low low Lim	0.00...4.00	xUn	0.01	0.00	Low alarm voltage limit for zero sequence voltage
Zro V deadband	100...100000		1	10000	Deadband configuration value for zero sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)

Table 1426: VSMSQI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Ps Seq V on delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs for positive sequence voltage
Ps Seq V off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs for positive sequence voltage
Ng Seq V on delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs for negative sequence voltage
Ng Seq V off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs for negative sequence voltage
Zro V on delay time	0...1800000	ms	100	0	Delay the activation of the alarm and warning outputs for zero sequence voltage
Zro V off delay time	0...1800000	ms	100	0	Delay the deactivation of the alarm and warning outputs for zero sequence voltage

8.1.12.7 VSMSQI Monitored data

Table 1427: VSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
NgSeq-kV:1	FLOAT32	0.00...4.00	xUn	Measured negative sequence voltage
PsSeq-kV:1	FLOAT32	0.00...4.00	xUn	Measured positive sequence voltage
ZrSeq-kV:1	FLOAT32	0.00...4.00	xUn	Measured zero sequence voltage

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
U2_HIGH_AL	BOOLEAN	0=False 1=True		Negative sequence high alarm
U2_HIGH_WARN	BOOLEAN	0=False 1=True		Negative sequence high warning
U1_HIGH_AL	BOOLEAN	0=False 1=True		Positive sequence high alarm
U1_HIGH_WARN	BOOLEAN	0=False 1=True		Positive sequence high warning
U1_LOW_WARN	BOOLEAN	0=False 1=True		Positive sequence low warning
U1_LOW_AL	BOOLEAN	0=False 1=True		Positive sequence low alarm
U0_HIGH_AL	BOOLEAN	0=False 1=True		Zero sequence high alarm
U0_HIGH_WARN	BOOLEAN	0=False 1=True		Zero sequence high warning
U2_INST	FLOAT32	0.00...4.00	xUn	Negative sequence voltage amplitude, instantaneous value
U2_ANGL	FLOAT32	-180.00...180.00	deg	Negative sequence voltage angle
U2_DB	FLOAT32	0.00...4.00	xUn	Negative sequence voltage amplitude, deadband value
U2_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Negative sequence voltage amplitude range
U1_INST	FLOAT32	0.00...4.00	xUn	Positive sequence voltage amplitude, instantaneous value
U1_ANGL	FLOAT32	-180.00...180.00	deg	Positive sequence voltage angle
U1_DB	FLOAT32	0.00...4.00	xUn	Positive sequence voltage amplitude, deadband value
U1_RANGE	Enum	0=normal 1=high 2=low 3=high-high 4=low-low		Positive sequence voltage amplitude range
U0_INST	FLOAT32	0.00...4.00	xUn	Zero sequence voltage amplitude, instantaneous value
U0_ANGL	FLOAT32	-180.00...180.00	deg	Zero sequence voltage angle
U0_DB	FLOAT32	0.00...4.00	xUn	Zero sequence voltage amplitude, deadband value
U0_RANGE	Enum	0=normal 1=high		Zero sequence voltage amplitude range

Name	Type	Values (Range)	Unit	Description
		2=low 3=high-high 4=low-low		

8.1.12.8 Technical data

Table 1428: VSMSQI Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz At voltages in range 0.01…1.15 × U_n
	±1.0 % or ±0.002 × U_n
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.1.13 Three-phase power and energy measurement PEMMXU (ANSI P, E)

8.1.13.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase power and energy measurement	PEMMXU	P, E	P, E

8.1.13.2 Function block

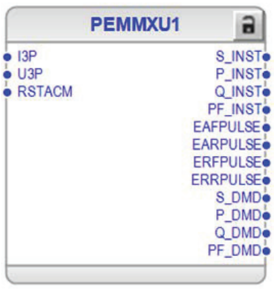


Figure 815: Function block

8.1.13.3 Functionality

The three-phase power and energy measurement function PEMMXU calculates energy and power from the available current and voltage inputs. The function stores the accumulated values of the real and reactive energy in both directions, and presents these values as numerical and pulse outputs.

PEMMXU provides pulse outputs EAFPULSE, EARPULSE, ERFPULSE and ERRPULSE which are activated based on the calculated values of forward and reverse, active and reactive accumulated energy. The activation of the pulse depends on the *Pulse quantity* setting. For example, if *Pulse quantity* is set as "10000" Wh, EAFPULSE is activated every time accumulated energy EA_FWD_ACM increases by 10000 Wh. The pulse-on and -off time duration can be set using the *Pulse on time* and *Pulse off time* settings.

Instantaneous three-phase power and power factor measurements are available for application configurations through output S_INST, P_INST, Q_INST and PF_INST.

Three-phase power and power factor demand values (S_DMD, P_DMD, Q_DMD and PF_DMD) are provided as outputs. These outputs are dedicated for Load profile recorder (LDPRLRC).

8.1.13.4 Analog channel configuration

PEMMXU has two analog group inputs which all must be properly configured.

Table 1429: Analog inputs

Input	Description
I3P	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1430: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with the corresponding one voltage channel connected if *Measurement mode* is set to "PhsAB", "PhsBC" or "PhsCA".
	The function can work with the corresponding two voltage channels connected if *Measurement mode* is set to "PhsA", "PhsB" or "PhsC".
	The function requires that all three voltage channels are connected for the other measurement modes.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

8.1.13.5 Signals

PEMMXU Input signals

Table 1431: PEMMXU Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
RSTACM	BOOLEAN	0=False	Reset of accumulated energy reading

PEMMXU Output signals

Table 1432: PEMMXU Output signals

Name	Type	Description
S_INST	FLOAT32	Apparent power, magnitude of instantaneous value in kVA
P_INST	FLOAT32	Active power, magnitude of instantaneous value in kW
Q_INST	FLOAT32	Reactive power, magnitude of instantaneous value in kvar
PF_INST	FLOAT32	Power factor, magnitude of instantaneous value
EAFPULSE	SIGNAL	Accumulated forward active energy pulse
EARPULSE	SIGNAL	Accumulated reverse active energy pulse
ERFPULSE	SIGNAL	Accumulated forward reac-tive energy pulse
ERRPULSE	SIGNAL	Accumulated reverse reactive energy pulse
S_DMD	FLOAT32	Demand value of apparent power
P_DMD	FLOAT32	Demand value of active pow-er
Q_DMD	FLOAT32	Demand value of reactive power
PF_DMD	FLOAT32	Demand value of power fac-tor

8.1.13.6 PEMMXU Settings

Table 1433: PEMMXU Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			1=on	Operation Off / On

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Power unit Mult	3=k 6=M			3=k	Unit multiplier for presentation of the power related values
Energy unit Mult	3=k 6=M			3=k	Unit multiplier for presentation of the energy related values
Active power Dir	1=Forward 2=Reverse			1=Forward	Direction of active power flow: Forward, Reverse
Reactive power Dir	1=Forward 2=Reverse			1=Forward	Direction of reactive power flow: Forward, Reverse
Power deadband	1000...10000		1	10000	Deadband configuration value for integral calculation. (percentage of Sn as 0,001 % s)
Pulse quantity	1...10000000	Wh/VArh	1	100000	Pulse quantity for the energy pulse outputs

Table 1434: PEMMXU Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Forward Wh Initial	0...999999999		1	0	Preset Initial value for forward active energy
Reverse Wh Initial	0...999999999		1	0	Preset Initial value for reverse active energy
Forward VArh Initial	0...999999999		1	0	Preset Initial value for forward reactive energy
Reverse VArh Initial	0...999999999		1	0	Preset Initial value for reverse reactive energy
Measurement mode	1=PhsA, PhsB, PhsC 2=Arone 3=Pos Seq 4=PhsAB 5=PhsBC 6=PhsCA 7=PhsA 8=PhsB 9=PhsC			1=PhsA, PhsB, PhsC	Selected measurement mode for power calculation
Pulse on time	0.050...60.000	s	0.001	1.000	Energy accumulated pulse ON time in secs
Pulse off time	0.050...60.000	s	0.001	0.500	Energy accumulated pulse OFF time in secs

8.1.13.7 PEMMXU Monitored data

Table 1435: PEMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
S-kVA:1	FLOAT32	-999999.9...999999.9	kVA	Total Apparent Power
P-kW:1	FLOAT32	-999999.9...999999.9	kW	Total Active Power
Q-kVAr:1	FLOAT32	-999999.9...999999.9	kVAr	Total Reactive Power
PF:1	FLOAT32	-1.00...1.00		Average Power factor
RSTACM	BOOLEAN	0=False 1=True		Reset of accumulated energy reading
S_INST	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of instantaneous value
S_DB	FLOAT32	-999999.9...999999.9	kVA	Apparent power, magnitude of deadband value
S_DMD	FLOAT32	-999999.9...999999.9	kVA	Demand value of apparent power
P_INST	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of instantaneous value
P_DB	FLOAT32	-999999.9...999999.9	kW	Active power, magnitude of deadband value
P_DMD	FLOAT32	-999999.9...999999.9	kW	Demand value of active power
Q_INST	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of instantaneous value
Q_DB	FLOAT32	-999999.9...999999.9	kVAr	Reactive power, magnitude of deadband value
Q_DMD	FLOAT32	-999999.9...999999.9	kVAr	Demand value of reactive power
PF_INST	FLOAT32	-1.00...1.00		Power factor, magnitude of instantaneous value
PF_DB	FLOAT32	-1.00...1.00		Power factor, magnitude of deadband value
PF_DMD	FLOAT32	-1.00...1.00		Demand value of power factor
EA_RV_ACM	INT64	0...999999999	kWh	Accumulated reverse active energy value
ER_RV_ACM	INT64	0...999999999	kVArh	Accumulated reverse reactive energy value
EA_FWD_ACM	INT64	0...999999999	kWh	Accumulated forward active energy value
ER_FWD_ACM	INT64	0...999999999	kVArh	Accumulated forward reactive energy value
Max demand S	FLOAT32	-999999.9...999999.9	kVA	Maximum demand value of apparent power
Min demand S	FLOAT32	-999999.9...999999.9	kVA	Minimum demand value of apparent power
Max demand P	FLOAT32	-999999.9...999999.9	kW	Maximum demand value of active power
Min demand P	FLOAT32	-999999.9...999999.9	kW	Minimum demand value of active power
Max demand Q	FLOAT32	-999999.9...999999.9	kVAr	Maximum demand value of reactive power
Min demand Q	FLOAT32	-999999.9...999999.9	kVAr	Minimum demand value of reactive power
Time max dmd S	Timestamp			Time of maximum demand
Time min dmd S	Timestamp			Time of minimum demand

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Time max dmd P	Timestamp			Time of maximum demand
Time min dmd P	Timestamp			Time of minimum demand
Time max dmd Q	Timestamp			Time of maximum demand
Time min dmd Q	Timestamp			Time of minimum demand

8.1.13.8 Technical data

Table 1436: PEMMXU Technical data

Characteristic	Value
Operation accuracy [1]	At all three currents in range 0.10…1.20 × I_n At all three voltages in range 0.50…1.15 × U_n At the frequency f_n ±1 Hz
	±1.5 % for apparent power S ±1.5 % for active power P and active energy [2] ±1.5 % for reactive power Q and reactive energy [3] ±0.015 for power factor
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.2 Disturbance recorder, common functionality RDRE (ANSI DFR)

8.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Disturbance recorder, common functionality	RDRE	DR	DFR

1 *Measurement mode* = "Pos Seq" (default)
2 |PF| >0.5 which equals |cosφ| >0.5
3 |PF| <0.86 which equals |sinφ| >0.5

8.2.2 Function block

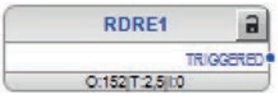


Figure 816: Function block

8.2.3 Functionality

The protection relay is provided with a disturbance recorder featuring up to 24 analog and 64 binary signal channels. The analog channels can be set to record either the waveform or the trend of the currents and voltages measured and they can trigger the recording function when the measured value falls below or exceeds the set values.

The binary signal channels can be set to start a recording either on the rising or the falling edge of the binary signal or on both. By default, the binary channels are set to record external or internal relay signals, for example, the start or trip signals of the relay stages, or external blocking or control signals. Binary relay signals, such as protection start and trip signals, or an external relay control signal via a binary input can be set to trigger the recording. Recorded information is stored in a nonvolatile memory and can be uploaded for subsequent fault analysis.

8.2.3.1 Recorded analog and binary inputs

The relay's analog and binary signals for disturbance recorder can be configured with Application Configuration in PCM600. In addition, each channel of the disturbance recorder can be enabled or disabled by setting the *Operation* parameter of the corresponding channel to "on" or "off".

All channels of the disturbance recorder that are enabled and have a valid signal connected are included in the recording.

8.2.3.2 Triggering alternatives

The recording can be triggered by any of the following alternatives.

- Triggering according to the state change of any of the binary channels of the disturbance recorder. The level sensitivity can be set with the *Level trigger mode* parameter of the corresponding binary channel.
- Triggering on limit violations of the analog channels of the disturbance recorder (high and low limit)
- Manual triggering via the *Trig recording* parameter (LHMI or communication)
- Periodic triggering

Regardless of the triggering type, each recording generates the Recording started and Recording made events. The Recording made event indicates that the recording has been stored to the nonvolatile memory. In addition, every analog channel and binary channel of the disturbance recorder has its own *Channel triggered* parameter. Manual trigger has the *Manual triggering* parameter and periodic trigger has the *Periodic triggering* parameter.

Triggering by binary channels

The input signals for the binary channels of the disturbance recorder can be formed from any of the digital signals that can be dynamically mapped. A change in the status of a monitored signal triggers the recorder according to the configuration and settings. Triggering on the rising edge of a digital input signal means that the recording sequence starts when the input signal is activated. Correspondingly, triggering on the falling edge means that the recording sequence starts when the active input signal resets. It is also possible to trigger from both edges. In addition, the monitored signal can be non-triggering. The trigger setting can be set individually for each binary channel of the disturbance recorder with the *Level trigger mode* parameter of the corresponding binary channel.

Triggering by analog channels

The trigger level can be set for triggering in a limit violation situation. The user can set the limit values with the *High trigger level* and *Low trigger level* parameters of the corresponding analog channel. Both high level and low level violation triggering can be active simultaneously for the same analog channel. If the duration of the limit violation condition exceeds the filter time of approximately 50 ms, the recorder triggers. In case of a low level limit violation, if the measured value falls below approximately 0.05 during the filter time, the situation is considered to be a circuit-breaker operation and therefore, the recorder does not trigger. This is useful especially in undervoltage situations. The filter time of approximately 50 ms is common to all the analog channel triggers of the disturbance recorder. The value used for triggering is the calculated peak-to-peak value. Either high or low analog channel trigger can be disabled by setting the corresponding trigger level parameter to zero.

Frequency cannot be used as a trigger to disturbance recorder.

Manual triggering

The recorder can be triggered manually via the LHMI or via communication by setting the *Trig recording* parameter to "Trig".

Periodic triggering

Periodic triggering means that the recorder automatically makes a recording at certain time intervals. The interval can be adjusted with the *Periodic trig time* parameter. If the value of the parameter is changed, the new setting takes effect when the next periodic triggering occurs. Setting the parameter to zero disables the triggering alternative and the setting becomes valid immediately. If a new non-zero setting needs to be valid immediately, the *Periodic trig time* parameter should first be set to zero and then to the new value. The time remaining to the next triggering can be monitored with the Time to trigger monitored data which counts downwards.

8.2.3.3 Length of recordings

The recording length can be defined with the *Record length* parameter. The length is given as the number of fundamental cycles.

According to the memory available and the number of analog channels used, the disturbance recorder automatically calculates the remaining number of recordings that fit into the available recording memory. This information can be seen with the Rem. amount of rec. monitored data. The fixed memory size allocated to the recorder can fit in two recordings that are ten seconds long. The recordings contain data from all analog and binary channels of the disturbance recorder, at the sample rate of 32 samples per fundamental cycle.

The number of recordings in the memory can be viewed with the Number of recordings monitored data. The used memory space can be viewed with the Rec. memory used monitored data. It is shown as a percentage value.

The maximum number of recordings is 100.

8.2.3.4 Sampling frequencies

The sampling frequency of the disturbance recorder analog channels depends on the set rated frequency. One fundamental cycle always contains the number of samples set with the *Storage rate* parameter. Since the states of the binary channels are sampled once per task execution of the disturbance recorder, the sampling frequency of binary channels is 400 Hz at the rated frequency of 50 Hz and 480 Hz at the rated frequency of 60 Hz.

Table 1437: Sampling frequencies of the disturbance recorder analog and binary channels

Storage rate (samples per fundamental cycle)	Recording length	Rated frequency = 50 Hz		Rated frequency = 60 Hz	
		Sampling frequency of analog channels	Sampling frequency of binary channels	Sampling frequency of analog channels	Sampling frequency of binary channels
32	1 · Record length	1600 Hz	400 Hz	1920 Hz	480 Hz
16	2 · Record length	800 Hz	400 Hz	960 Hz	480 Hz
8	4 · Record length	400 Hz	400 Hz	480 Hz	480 Hz

8.2.3.5 Uploading of recordings

The protection relay stores COMTRADE files to the `C:\COMTRADE` folder. The files can be uploaded with PCM600 or any appropriate computer software that can access the `C:\COMTRADE` folder.

One complete disturbance recording consists of two COMTRADE file types: the configuration file and the data file. The file name is the same for both file types. The configuration file has .CFG and the data file .DAT as the file extension.

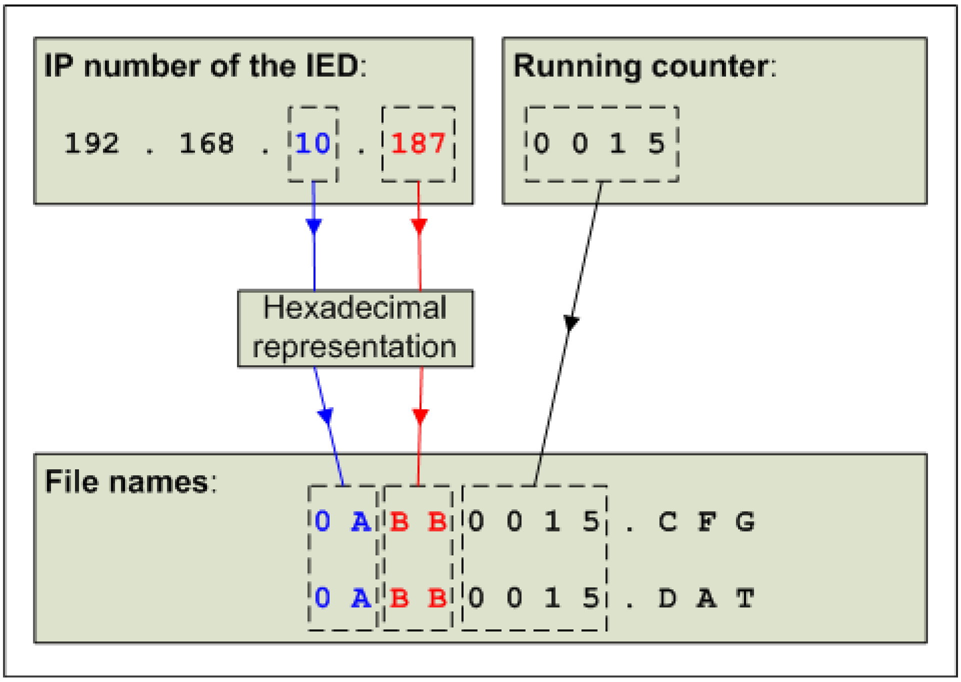


Figure 817: Disturbance recorder file naming

The naming convention of 8+3 characters is used in COMTRADE file naming. The file name is composed of the last two octets of the protection relay's IP number and a running counter, which has a range of 1...9999. A hexadecimal representation is used for the IP number octets. The appropriate file extension is added to the end of the file name.

8.2.3.6 Deletion of recordings

The recordings can be deleted individually or all at once.

Individual disturbance recordings can be deleted with PCM600 or any appropriate computer software, which can access the protection relay's `C:\COMTRADE` folder. The disturbance recording is not removed from the protection relay's memory until both of the corresponding COMTRADE files, .CFG and .DAT, are deleted. Both file types may need to be deleted separately, depending on the software used.

Deleting all disturbance recordings at once is done either with PCM600 or any appropriate computer software, or from the LHMI via the **Clear** > **Disturbance records** menu. Deleting all disturbance recordings at once also clears the pre-trigger recording in progress.

8.2.3.7 Storage mode

The disturbance recorder can capture data in two modes: waveform and trend mode. The storage mode can be set individually for each trigger source with the *Storage mode* parameter of the corresponding analog channel or binary channel, the *Stor. mode manual* parameter for manual trigger and the *Stor. mode periodic* parameter for periodic trigger.

In the waveform mode, the samples are captured according to the *Storage rate* and *Pre-trg length* parameters.

In the trend mode, one value is recorded for each enabled analog channel, once per fundamental cycle. The recorded values are RMS values, which are scaled to peak level. The binary channels of the disturbance recorder are also recorded once per fundamental cycle in the trend mode.

Only post-trigger data is captured in trend mode.

The trend mode enables recording times of 32 * *Record length*.

8.2.3.8 Pre-trigger and post-trigger data

The waveforms of the disturbance recorder analog channels and the states of the disturbance recorder binary channels are constantly recorded into the history memory of the recorder. The percentage of the data duration preceding the triggering, that is, the pre-trigger time, can be adjusted with the *Pre-trg length* parameter. The duration of the data following the triggering, that is, the post-trigger time, is the difference between the recording length and the pre-trigger time. Changing the pre-trigger time resets the history data and the current recording under collection.

8.2.3.9 Operation modes

The disturbance recorder has two operation modes: saturation and overwrite mode. The operation mode of the disturbance recorder can be changed with the *Operation mode* parameter.

Saturation mode

In saturation mode, the captured recordings cannot be overwritten with new recordings. Capturing the data is stopped when the recording memory is full, that is, when the maximum number of recordings is reached. In this case, the event is sent via the state change (TRUE) of the *Memory full* parameter. When there is memory available again, another event is generated via the state change (FALSE) of the *Memory full* parameter.

Overwrite mode

In the overwrite mode, if the recording memory is full, the oldest recording is overwritten with the pre-trigger data collected for the next recording. Each time a recording is overwritten, the event is generated via the state change of the *Overwrite of rec.* parameter.

The overwrite mode is recommended if it is important to have the latest recordings in the memory. The saturation mode is preferred when the oldest recordings are more important.

New triggerings are blocked in both modes until the previous recording is completed, but a new triggering can be accepted before all pre-trigger samples are collected for the new recording. In such a case, the recording is as much shorter as there are pre-trigger samples lacking.

8.2.3.10 Exclusion mode

Exclusion mode is on when the value of the *Exclusion time* parameter is higher than zero. During the exclusion mode, new triggerings are ignored if the triggering reason is the same as in the previous recording. The *Exclusion time* parameter controls how long the exclusion of triggerings of same type is active after a triggering. The exclusion mode applies only to the analog and binary channel triggerings, not to periodic and manual triggerings.

When the value set with the *Exclusion time* parameter is zero, the exclusion mode is disabled and there are no restrictions on the triggering types of the successive recordings.

The exclusion time setting is global for all inputs, but there is an individual counter for each analog and binary channel of the disturbance recorder, counting the remaining exclusion time. The remaining exclusion time can be monitored with the *Exclusion time rem* parameter (only visible via communication, IEC 61850 data ExclTmRmn) of the corresponding analog or binary channel. The *Exclusion time rem* parameter counts downwards.

8.2.4 Configuration

The disturbance recorder can be configured with PCM600 or any tool supporting the IEC 61850 standard.

RDRE1 should always be included in Application Configuration when the disturbance recorder is used.

The disturbance recorder can be enabled or disabled with the *Operation* parameter under the **Configuration** > **Disturbance recorder** > **General** menu.

One analog signal type of the protection relay can be mapped to each of the analog channels of the disturbance recorder. The mapping is done in Application Configuration in PCM600. The name of the analog channel is user-configurable. It can be modified by defining a new name to the *Channel id text* parameter of the corresponding analog channel. *Channel id text* can be edited in Application Configuration by selecting the input channel and defining a new *Instance Name* for the channel in the Object Properties window.

Any external or internal digital signal of the protection relay which can be dynamically mapped can be connected to the binary channels of the disturbance recorder. These signals can be, for example, the start and trip signals from protection function blocks or the external binary inputs of the protection relay. The connection is made with dynamic mapping to the binary channel of the disturbance recorder using, for example, Signal Matrix of PCM600. It is also possible to connect several digital signals to one binary channel of the disturbance recorder. In that case, the signals can be combined with logical functions, for example AND and OR. The name of the binary channel can be modified by defining a new name to the *Channel id text* parameter of the corresponding channel. *Channel id text* can be edited in Application Configuration by selecting the input channel and defining a new *Instance Name* for the channel in the Object Properties window.

The *Channel id text* parameter is used in COMTRADE configuration files as a channel identifier.

The recording always contains all binary channels of the disturbance recorder. If one of the binary channels is disabled, the recorded state of the channel is continuously FALSE and the state changes of the corresponding channel are not recorded. The corresponding channel name for disabled binary channels in the COMTRADE configuration file is Unused BI.

To enable or disable an analog or a binary channel of the disturbance recorder, the *Operation* parameter of the corresponding analog or binary channel is set to "on" or "off".

The states of manual triggering and periodic triggering are not included in the recording, but they create a state change to the *Periodic triggering* and *Manual triggering* status parameters, which in turn create events.

The TRIGGERED output can be used to control the indication LEDs of the protection relay. The triggering of the disturbance recorder sets the TRIGGERED output to TRUE. The output remains in this state until all the data for the corresponding recording has been recorded.

The IP number of the protection relay and the value of the *Bay name* parameter are both included in the COMTRADE configuration file for identification purposes.

8.2.5 Application

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection relays and circuit breakers. It can record both analog and binary signal information. The analog inputs are recorded as instantaneous values and converted to primary peak value units when the protection relay converts the recordings to the COMTRADE format.

COMTRADE is the general standard format used for storing disturbance recordings.

The binary channels are sampled once per task execution of the disturbance recorder. The task execution interval for the disturbance recorder is the same as for the protection functions. During the COMTRADE conversion, the digital status values are repeated so that the sampling frequencies of the analog and binary channels correspond to each other. This is required by the COMTRADE standard.

The disturbance recorder follows the 1999 version of the COMTRADE standard and uses the binary data file format.

8.2.6 Signals

Table 1438: RDRE Output signals

Name	Type	Description
TRIGGERED	BOOLEAN	Recording started

8.2.7 Settings

Table 1439: RDRE Non group general settings (basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off		1	1=on	Disturbance recorder on/off
Record length	10...500	fundamental cycles	1	50	Size of the recording in fundamental cycles
Pre-trg length	0...100	%	1	50	Length of the recording preceding the triggering

Table 1440: RDRE Non group general settings (advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	1=Saturation 2=Overwrite		1	1	Operation mode of the recorder
Exclusion time	0...1 000 000	ms	1	0	The time during which triggerings of same type are ignored
Storage rate	32, 16, 8	samples per fundamental cycle		32	Storage rate of the waveform recording
Periodic trig time	0...604 800	s	10	0	Time between periodic triggerings
Stor. mode periodic	0=Waveform 1=Trend / cycle		1	0	Storage mode for periodic triggering
Stor. mode manual	0=Waveform 1=Trend / cycle		1	0	Storage mode for manual triggering

Table 1441: RDRE Control data (basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Trig recording	0=Cancel 1=Trig			0=Cancel	Trigger the disturbance recording
Clear recordings	0=Cancel 1=Trig			0=Cancel	Clear all recordings currently in memory

8.2.8 Monitored data

Table 1442: RDRE Monitored data

Parameter	Values (Range)	Unit	Step	Default	Description
Number of recordings	0...100				Number of recordings currently in memory
Rem. amount of rec.	0...100				Remaining amount of recordings that

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
					fit into the available recording memory, when current settings are used
Rec. memory used	0...100	%			Storage mode for the binary channel
Time to trigger	0...604 800	s			Time remaining to the next periodic triggering

8.3 Disturbance recorder, analog channels 1...24 A1RADR and A2RADR

8.3.1 Function block

Figure 818: Function block

8.3.2 Signals

The input signal tables for A1RADR and A2RADR are similar except for the channel numbers.

- A1RADR, CH1...CH12
- A2RADR, CH13...CH24

Table 1443: A1RADR Input signals

Name	Type	Default	Description
CH1	SIGNAL		Signal for input 1

Values are the same for each input signal. The channel numbers are shown after the parameter name in the HMI and PCM600.

8.3.3 Settings

Setting tables for all A1RADR and A2RADR channels are similar except for the channel numbers.

Table 1444: A1RADR Non group general settings (basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Analog channel on / off
Channel id text				Analog ch 1 input	Channel identifier text
High trigger level	0.00...60.00		0.01	10	Over limit
Low trigger level	0.00...2.00		0.01	0	Under limit

Table 1445: A1RADR Non group general settings (advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Storage mode	0=Waveform 1=Trend / cycle			0	Storage mode selection (waveform / trend)

8.4 Disturbance recorder, binary channels 1...64 B1RBDR and B2RBDR

8.4.1 Function block

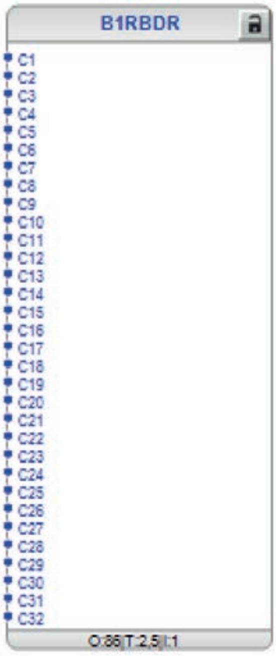


Figure 819: Function block

8.4.2 Signals

The input signal tables for B1RBDR and B2RBDR are similar except for the channel numbers.

- B1RBDR, C1...C32
- B2RBDR, C33...C64

Table 1446: B1RBDR Input signals

Name	Type	Default	Description
C1	BOOLEAN	0=False	Signal for input 1

Values are the same for each input signal. The channel numbers are shown after the parameter name in the HMI and PCM600.

8.4.3 Settings

Setting tables for all B1RBDR and B2RBDR channels are similar except for the channel numbers.

Table 1447: B1RBDR Non group general settings (basic) Parameter Values (Range) Unit Step

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on			5=off	Binary channel on / off

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=off				
Level trigger mode	1=Positive or Rising 2=Negative or Falling 3=Both 4=Level trigger off			1=Positive or Rising	Rising / falling / both / trigger off

Table 1448: B1RBDR Non group general settings (advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Storage mode	0=Waveform 1=Trend / cycle			0=Waveform	Storage mode selection (waveform / trend)
Channel id text				Binary ch 1 input	Channel identifier text

8.5 Tap changer position indication TPOSYLTC (ANSI 84T)

8.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap changer position indication	TPOSYLTC	TPOSM	84T

8.5.2 Function block

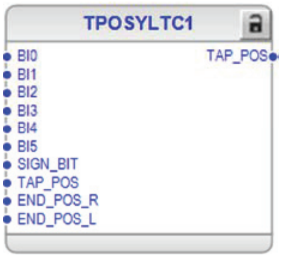


Figure 820: Function block

8.5.3 Functionality

The tap changer position indication function TPOSYLTC is used for transformer tap position supervision. The binary inputs can be used for converting a binary-coded tap changer position to a tap position status indication. The RTD module, available as an option, provides the RTD sensor information to be used and the versatile analog inputs enabling the tap position supervision through mA.

There are three user-selectable conversion modes available for the 7-bit binary inputs where MSB is used as the SIGN bit: the natural binary-coded boolean input to the signed integer output, binary coded decimal BCD input to the signed integer output and binary reflected GRAY coded input to the signed integer output.

8.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". When the function is disabled, the tap position quality information is changed accordingly. When the tap position information is not available, it is recommended to disable this function with the *Operation* setting.

The operation of TPOSYLTC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

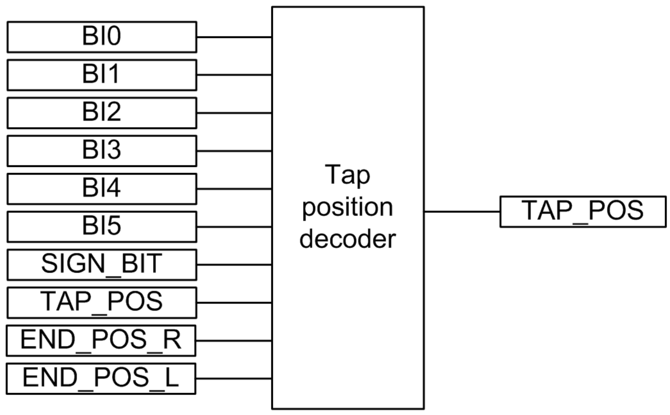


Figure 821: Functional module diagram

Tap position decoder

When there is a wired connection to the `TAP_POS` input connector, the corresponding tap changer position is decoded from the `mA` or `RTD` input. When there is no wired connection to the `TAP_POS` connector, the binary inputs are expected to be used for the tap changer position information. The tap changer position value and quality are internally shared to other functions. The value is available in the Monitored data view or as a `TAP_POS` output signal.

The function has three alternative user selectable operation modes: "NAT2INT", "BCD2INT" and "GRAY2INT". The operation mode is selected with the *Operation mode* setting. Each operation mode can be used to convert a maximum of 6–bit coded input to an 8–bit signed short integer output. For less than 6–bit input, for example 19 positions with 5 bits when the BCD coding is used, the rest of the bits can be set to `FALSE` (0).

The operation mode "NAT2INT" is selected when the natural binary coding is used for showing the position of the transformer tap changer. The basic principle of the natural binary coding is to calculate the sum of the bits set to `TRUE` (1). The LSB has the factor 1. Each following bit has the previous factor multiplied by 2. This is also called dual coding.

The operation mode "BCD2INT" is selected when the binary-coded decimal coding is used for showing the position of the transformer tap changer. The basic principle with the binary-coded decimal coding is to calculate the sum of the bits set to TRUE (1). The four bits nibble (BI3...BI0) have a typical factor to the natural binary coding. The sum of the values should not be more than 9. If the nibble sum is greater than 9, the tap position output validity is regarded as bad.

The operation mode “GRAY2INT” is selected when the binary-reflected Gray coding is used for showing the position of the transformer tap changer. The basic principle of the Gray coding is that only one actual bit changes value with consecutive positions. This function is based on the common binary-reflected Gray code which is used with some tap changers. Changing the bit closest to the right side bit gives a new pattern.

An additional separate input, SIGN_BIT, can be used for negative values. If the values are positive, the input is set to FALSE (0). If the SIGN_BIT is set to TRUE (1) making the number negative, the remaining bits are identical to those of the coded positive number.

The tap position validity is set to good in all valid cases. The quality is set to bad in invalid combinations in the binary inputs. For example, when the “BCD2INT” mode is selected and the input binary combination is “0001101”, the quality is set to bad. For negative values, when the SIGN_BIT is set to TRUE (1) and the input binary combination is “1011011”, the quality is set to bad.

If the tap changer has auxiliary contacts for indicating the extreme positions of the tap changer, their status can be connected to END_POS_R and END_POS_L inputs. The END_POS_R (End position raise or highest allowed tap position reached) status refers to the extreme position that results in the highest number of the taps in the tap changer. Similarly, END_POS_L (End position lower or lowest allowed tap position reached) status refers to the extreme position that results in the lowest number of the taps in the tap changer. TAP_POS output is dedicated for transferring the validated tap position for the functions that need tap position information, for example OL5ATCC and TRxPTDF. It includes both the actual position information and the status of reached end positions, assuming that inputs END_POS_R and END_POS_L are connected.

Table 1449: Truth table of the decoding modes

Inputs							**TAP_POS outputs**		
SIGN_BIT	BI5	BI4	BI3	BI2	BI1	BI0	NAT2INT	BCD2INT	GRAY2INT
...		...		...		...	...	...	...
1	0	0	0	0	1	1	-3	-3	-2
1	0	0	0	0	1	0	-2	-2	-3
1	0	0	0	0	0	1	-1	-1	-1
0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	1	1	1
0	0	0	0	0	1	0	2	2	3
0	0	0	0	0	1	1	3	3	2
0	0	0	0	1	0	0	4	4	7
0	0	0	0	1	0	1	5	5	6
0	0	0	0	1	1	0	6	6	4

Table continues on the next page

Inputs							TAP_POS outputs		
0	0	0	0	1	1	1	7	7	5
0	0	0	1	0	0	0	8	8	15
0	0	0	1	0	0	1	9	9	14
0	0	0	1	0	1	0	10	9	12
0	0	0	1	0	1	1	11	9	13
0	0	0	1	1	0	0	12	9	8
0	0	0	1	1	0	1	13	9	9
0	0	0	1	1	1	0	14	9	11
0	0	0	1	1	1	1	15	9	10
0	0	1	0	0	0	0	16	10	31
0	0	1	0	0	0	1	17	11	30
0	0	1	0	0	1	0	18	12	28
0	0	1	0	0	1	1	19	13	29
0	0	1	0	1	0	0	20	14	24
0	0	1	0	1	0	1	21	15	25
0	0	1	0	1	1	0	22	16	27
0	0	1	0	1	1	1	23	17	26
0	0	1	1	0	0	0	24	18	16
0	0	1	1	0	0	1	25	19	17
0	0	1	1	0	1	0	26	19	19
0	0	1	1	0	1	1	27	19	18
0	0	1	1	1	0	0	28	19	23
0	0	1	1	1	0	1	29	19	22
0	0	1	1	1	1	0	30	19	20
0	0	1	1	1	1	1	31	19	21
0	1	0	0	0	0	0	32	20	63
0	1	0	0	0	0	1	33	21	62
0	1	0	0	0	1	0	34	22	60
0	1	0	0	0	1	1	35	23	61
0	1	0	0	1	0	0	36	24	56
...		...		...		...	...	...	...

8.5.5 Application

TPOSYLTC provides tap position information for other functions as a signed integer value that can be fed to the tap position input.

The position information of the tap changer can be coded in various methods for many applications, for example, the differential protection algorithms. In this function, the binary inputs in the transformer terminal connector are used as inputs to the function. The coding method can be chosen by setting the mode parameter. The available coding methods are BCD, Gray and Natural binary coding. Since the number of binary inputs are limited to seven, the coding functions are limited to seven bits including the sign bit and thus the six bits are used in the coding functions. The position limits for the tap positions at BCD, Gray and Natural binary coding are ±39, ±63 and ±63 respectively.

In this example, the transformer tap changer position indication is wired as a mA signal from the corresponding measuring transducer. The position indication is connected to input 1 (AI_VAL1) of the (RTD) module. The tap changer operating range from the minimum to maximum turns of the tap and a corresponding mA signal for the tap position are set in the RTD module. Since the values of the RTD module outputs are floating point numbers, the float to integer (T_R_TO_I8) conversion is needed before the tap position information can be fed to TPOSYLTC. When there is a wired connection to the TAP_POS connector, the validated tap changer position is presented in the TAP_POS output that is connected to other functions, for example, OL5ATCC1. When there is no wired connection to the TAP_POS connector, the binary inputs are expected to be used for the tap changer position information.

Figure 822: RTD/analog input configuration example

8.5.6 Signals

8.5.6.1 TPOSYLTC Input signals

Table 1450: TPOSYLTC Input signals

Name	Type	Default	Description
BI0	BOOLEAN	0=False	Binary input 1
BI1	BOOLEAN	0=False	Binary input 2
BI2	BOOLEAN	0=False	Binary input 3
BI3	BOOLEAN	0=False	Binary input 4
BI4	BOOLEAN	0=False	Binary input 5
BI5	BOOLEAN	0=False	Binary input 6
SIGN_BIT	BOOLEAN	0=False	Binary input sign bit
END_POS_R	BOOLEAN	0=False	End position raise or highest allowed tap position reached

Table continues on the next page

Name	Type	Default	Description
END_POS_L	BOOLEAN	0=False	End position lower or lowest allowed tap position reached
TAP_POS	INT8	0	Tap position indica-tion

8.5.6.2 TPOSYLTC Output signals

Table 1451: TPOSYLTC Output signals

Name	Type	Description
TAP_POS	INT8-TAPPOS	Tap position indication

8.5.7 TPOSYLTC Settings

Table 1452: TPOSYLTC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=NAT2INT 2=BCD2INT 3=GRAY2INT			2=BCD2INT	Operation mode selection

8.5.8 TPOSYLTC Monitored data

Table 1453: TPOSYLTC Monitored data

Name	Type	Values (Range)	Unit	Description
BI0	BOOLEAN	0=False 1=True		Binary input 1
BI1	BOOLEAN	0=False 1=True		Binary input 2
BI2	BOOLEAN	0=False 1=True		Binary input 3
BI3	BOOLEAN	0=False 1=True		Binary input 4
BI4	BOOLEAN	0=False 1=True		Binary input 5
BI5	BOOLEAN	0=False 1=True		Binary input 6
SIGN_BIT	BOOLEAN	0=False 1=True		Binary input sign bit

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
END_POS_R	BOOLEAN	0=False 1=True		End position raise or highest allowed tap position reached
END_POS_L	BOOLEAN	0=False 1=True		End position lower or lowest allowed tap position reached
TAP_POS	INT8	-63...63		Tap position indication

8.5.9 Technical data

Table 1454: TPOSYLTC Technical data

Description	Value
Response time for binary inputs	Typical 100 ms

9 Control functions

9.1 Circuit breaker control CBXCBR, Disconnector control DCXSWI and Earthing switch control ESXSWI (ANSI 52, 29DS, 29GS)

9.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker control	CBXCBR	I<->O CB	52
Disconnector control	DCXSWI	I<->O DCC	29DS
Earthing switch control	ESXSWI	I<->O ESC	29GS

9.1.2 Function block

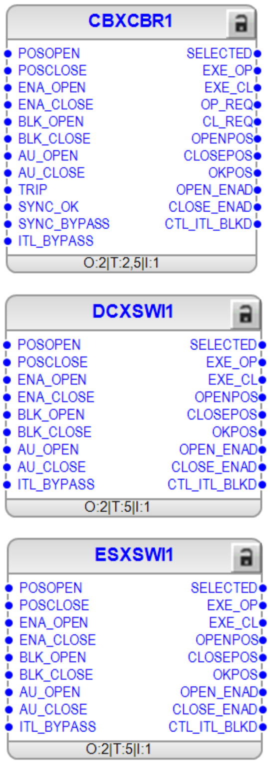


Figure 823: Function block

9.1.3 Functionality

CBXCBR, DCXSWI and ESXSWI are intended for circuit breaker, disconnector and earthing switch control and status information purposes. These functions execute commands and evaluate block conditions and different time supervision conditions. The functions perform an execution command only if all conditions indicate that a switch operation is allowed. If erroneous conditions occur, the functions indicate an appropriate cause value. The functions are designed according to the IEC 61850-7-4 standard with logical nodes CILO, CSWI and XSWI/XCBR.

The circuit breaker, disconnector and earthing switch control functions have an operation counter for closing and opening cycles. The counter value can be read and written remotely from the place of operation or via LHMI.

9.1.4 Operation principle

Status indication and validity check

The object state is defined by two digital inputs, `POSOPEN` and `POSCLOSE`, which are also available as outputs `OPENPOS` and `CLOSEPOS` together with the `OKPOS` according to *Table 1455*. The debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of the digital inputs that indicate the object state is used as additional information in indications and event logging. The reporting of faulty or intermediate position of the apparatus occurs after the *Event delay* setting, assuming that the circuit breaker is still in a corresponding state.

Table 1455: Status indication

Input		Status	Output		
POSOPEN	**POSCLOSE**	**POSITION (Monitored data)**	**OKPOS**	**OPENPOS**	**CLOSEPOS**
1=True	0=False	1=Open	1=True	1=True	0=False
0=False	1=True	2=Closed	1=True	0=False	1=True
1=True	1=True	3=Faulty/Bad (11)	0=False	0=False	0=False
0=False	0=False	0=Intermediate (00)	0=False	0=False	0=False

Enabling and blocking

CBXCBR, DCXSWI and ESXSWI have an enabling and blocking functionality for interlocking and synchrocheck purposes.

Circuit breaker control CBXCBR

Normally, the CB closing is enabled (that is, `CLOSE_ENAD` signal is TRUE) by activating both `ENA_CLOSE` and `SYNC_OK` inputs. Typically, the `ENA_CLOSE` comes from the interlocking, and `SYNC_OK` comes from the synchronism and energizing check. The input ITL_BYPASS can be used for bypassing ENA_CLOSE input, while the SYNC_BYPASS can be used for bypassing SYNC_OK input. However, the BLK_CLOSE input always blocks the CLOSE_ENAD output. The CB opening (OPEN_ENAD) logic is the same as CB closing logic, except that SYNC_OK and SYNC_BYPASS are used only in closing.

The CB opening (OPEN_ENAD) logic is the same as CB closing logic, except that SYNC_OK is used only in closing. The SYNC_ITL_BYP input is used in both CLOSE_ENAD and OPEN_ENAD logics.

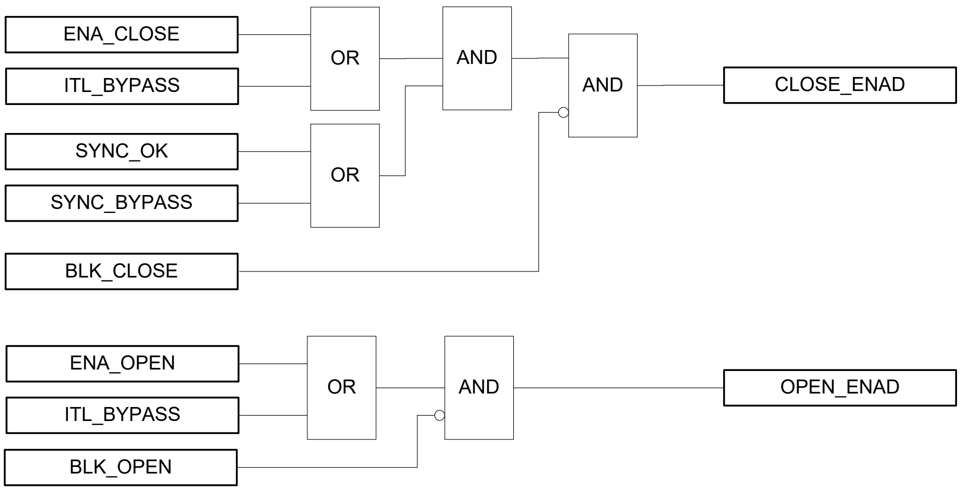


Figure 824: Enabling and blocking logic for CLOSE_ENAD and OPEN_ENAD signals

Disconnector control DCXSWI and earthing switch control ESXSWI

Normally, the switch closing is enabled (that is, the CLOSE_ENAD signal is TRUE) by activating the ENA_CLOSE input. The input ITL_BYPASS can be used for bypassing this control. The ITL_BYPASS input can be used to activate the CLOSE_ENAD discarding the ENA_CLOSE input state. However, the BLK_CLOSE input always blocks the CLOSE_ENAD output.

The CB opening (OPEN_ENAD) logic is identical to CB closing logic. The ITL_BYPASS input is used in both CLOSE_ENAD and OPEN_ENAD logics.

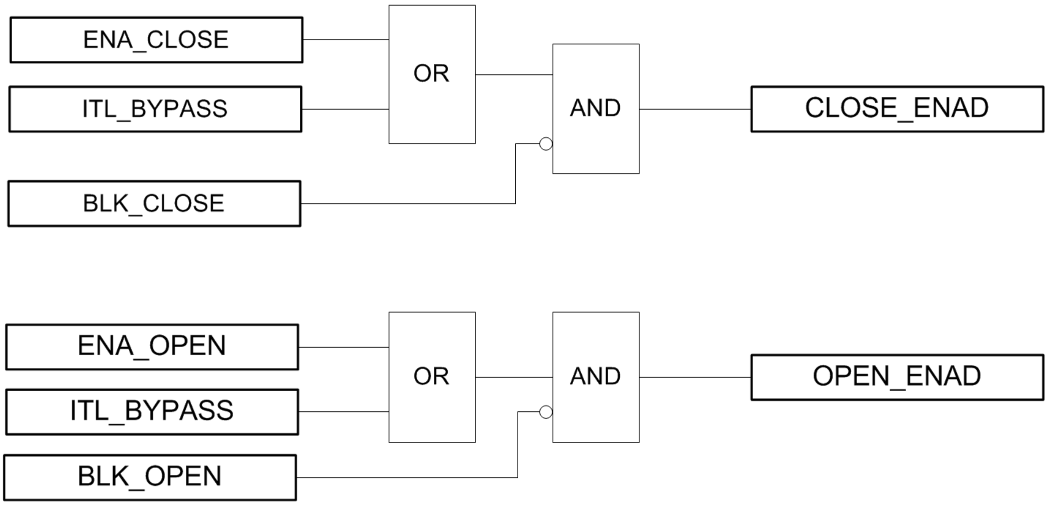


Figure 825: Enabling and blocking logic for CLOSE_ENAD and OPEN_ENAD signals

Opening and closing operations

The opening and closing operations are available via communication, binary inputs or LHMI commands. As a prerequisite for control commands, there are enabling and blocking functionalities for both opening and closing commands (`CLOSE_ENAD` and `OPEN_ENAD` signals). If the control command is executed against the blocking or if the enabling of the corresponding command is not valid, CBXCBR, DCXSWI and ESXSWI generate an error message. If the control is inhibited due to interlocking conditions the pulse output `CTL_ITL_BLKD` is activated. The length of the pulse is defined by the *Interlocking Pls Len* setting.

When close command is given from communication, via LHMI or activating the `AU_CLOSE` input, it is carried out (the `EXE_CL` output) only if `CLOSE_ENAD` is TRUE.

If the SECRSYN function is used in “Command” mode, the `CL_REQ` output can be used in CBXCBR. Initially, the `SYNC_OK` input is FALSE. When the close command given, it activates the `CL_REQ` output, which should be routed to SECRSYN. The close command is then processed only after `SYNC_OK` is received from SECRSYN.

When using SECRSYN in the “Command” mode, the CBXCBR setting *Operation timeout* should be set longer than SECRSYN setting *Maximum Syn time*.

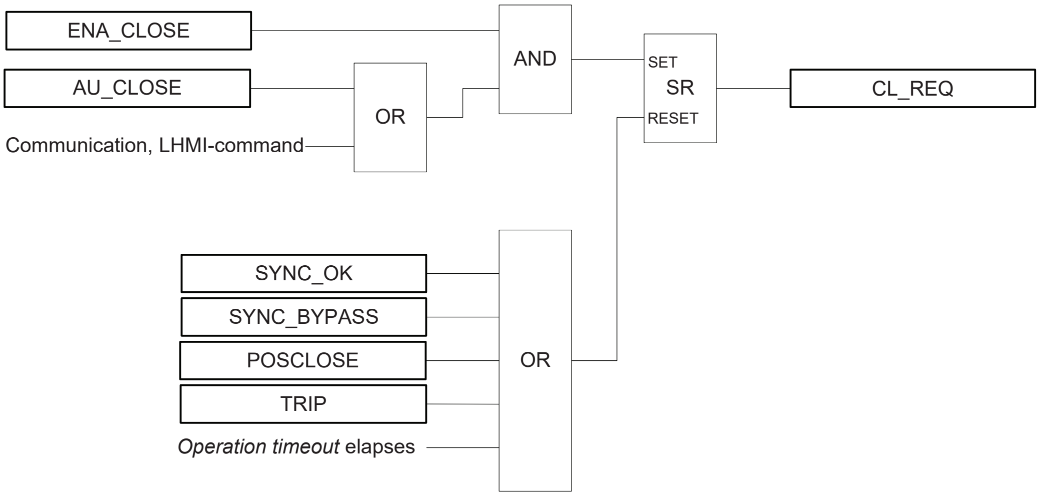


Figure 826: Condition for enabling the close request (CL_REQ) for CBXCBR

When the open command is given from communication, via LHMI or activating the AU_OPEN input, it is processed only if OPEN_ENAD is TRUE. OP_REQ output is also available.

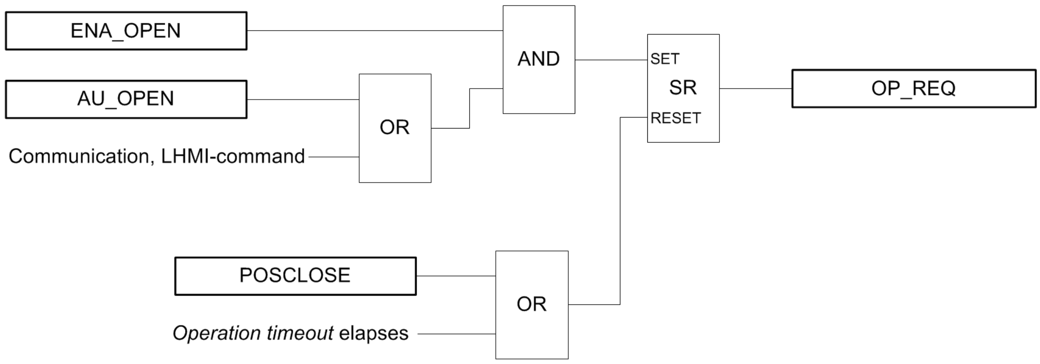


Figure 827: Condition for enabling the open request (OP_REQ) for CBXCBR

OPEN and CLOSE outputs

The EXE_OP output is activated when the open command is given (AU_OPEN, via communication or from LHMI) and OPEN_ENAD signal is TRUE. In addition, the protection trip commands can be routed through the CBXCBR function by using the TRIP input. When the TRIP input is TRUE, the EXE_OP output is activated immediately and bypassing all enabling or blocking conditions.

The EXE_CL output is activated when the close command is given (AU_CLOSE, via communication or from LHMI) and CLOSE_ENAD signal is TRUE. When the TRIP input is “TRUE”, CB closing is not allowed.

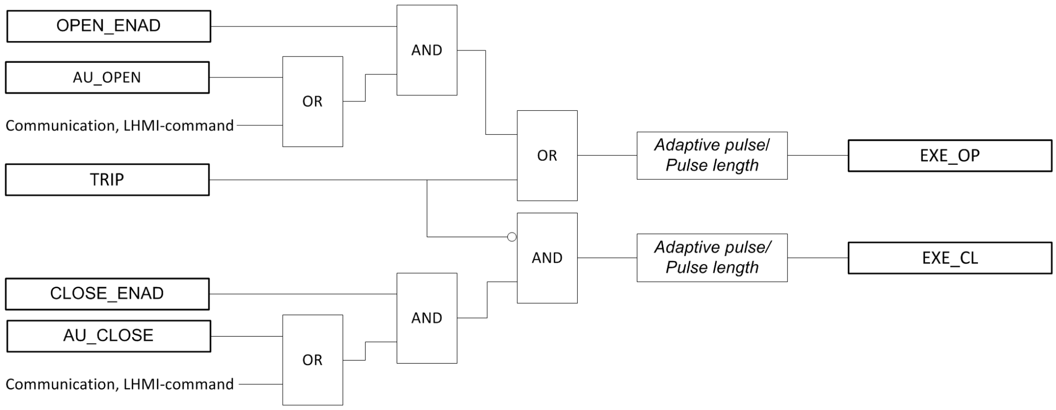


Figure 828: OPEN and CLOSE outputs logic for CBXCBR

Opening and closing pulse widths

The pulse width type can be defined with the *Adaptive pulse* setting. The function provides two modes to characterize the opening and closing pulse widths. When the *Adaptive pulse* is set to “TRUE”, it causes a variable pulse width, which means that the output pulse is deactivated if the object state shows that the apparatus has entered the correct state before the pulse time has elapsed. The pulse will not be extended beyond the maximum pulse width. If apparatus fails to enter the correct state, the output pulse is deactivated after the set *Operation timeout* setting, and an error message is displayed. When the *Adaptive pulse* is set to “FALSE”, the functions always use the maximum pulse width, defined by the user-configurable *Pulse length* setting. The *Pulse length* setting is the same for both the opening and closing commands. When the apparatus already is in the right position, the maximum pulse length is given.

Pulse length setting does not affect the length of the opening pulse when `EXE_OP` is activated via `TRIP` input. `EXE_OP` will remain active as long as `TRIP` input is active.

Control methods

The command execution mode can be set with the *Control model* setting. The alternatives for command execution are direct control and secured object control, which can be used to secure controlling.

The secured object control SBO is an important feature of the communication protocols that support horizontal communication, because the command reservation and interlocking signals can be transferred with a bus. All secured control operations require two-step commands: a selection step and an execution step. The secured object control is responsible for the several tasks.

- Command authority: ensures that the command source is authorized to operate the object
- Mutual exclusion: ensures that only one command source at a time can control the object
- Interlocking: allows only safe commands
- Execution: supervises the command execution
- Command canceling: cancels the controlling of a selected object.

In direct operation, a single message is used to initiate the control action of a physical device. The direct operation method uses less communication network capacity and bandwidth than the SBO method, because the procedure needs fewer messages for accurate operation.

The “status-only” mode means that control is not possible (non-controllable) via communication or from LHMI. However, it is possible to control a disconnector (DCXSWI) from `AU_OPEN` and `AU_CLOSE` inputs.

`AU_OPEN` and `AU_CLOSE` control the object directly regardless of the set *Control model*. These inputs can be used when control is wanted to be implemented purely based on ACT logic and no additional exception handling is needed. However, in case of simultaneous open and close control, the open control is always prioritized.

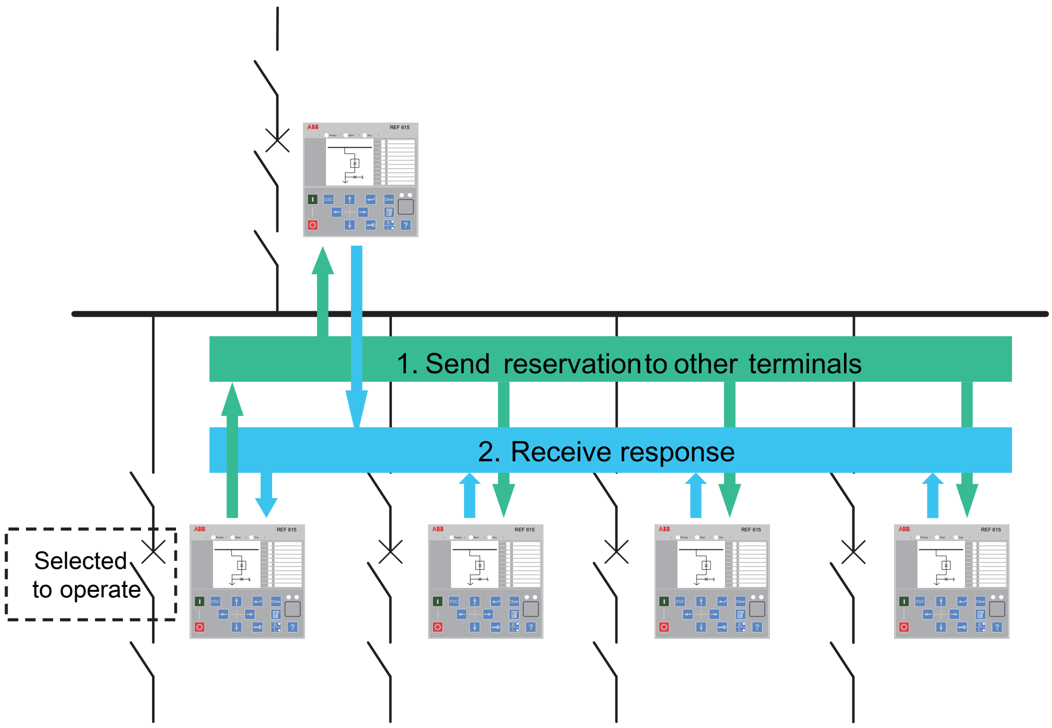


Figure 829: Control procedure in the SBO method

Local/Remote operations

The local/remote selection affects CBXCBR, DCXSWI and ESXSWI.

- Local: the opening and closing via communication is disabled.
- Remote: the opening and closing via LHMI is disabled.
- `AU_OPEN` and `AU_CLOSE` inputs function regardless of the local/remote selection.

9.1.5 Application

In the field of distribution and sub-transmission automation, reliable control and status indication of primary switching components both locally and remotely is in a significant role. They are needed especially in modern remotely controlled substations.

Control and status indication facilities are implemented in the same package with CBXCBR, DCXSWI and ESXSWI. When primary components are controlled in the energizing phase, for example, the correct execution sequence of the control commands must be ensured. This can be achieved, for example, with interlocking based on the status indication of the related primary components. The interlocking on substation level can be applied using the IEC 61850 GOOSE messages between feeders.

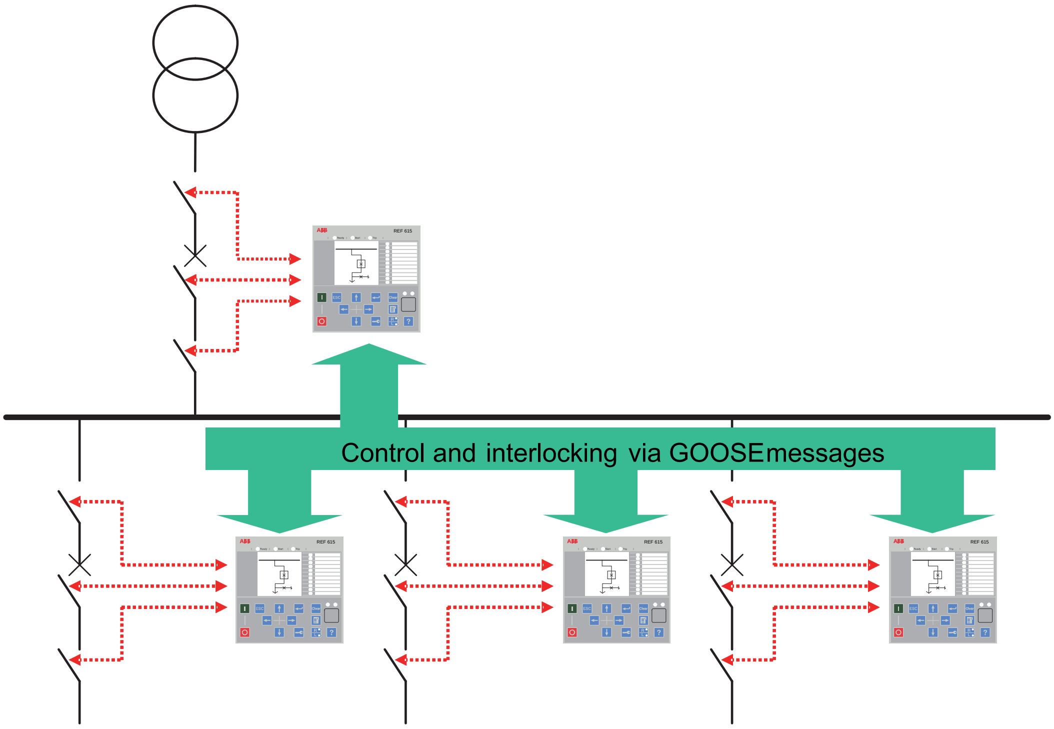


Figure 830: Status indication-based interlocking via the GOOSE messaging

9.1.6 Signals

9.1.6.1 CBXCBR Input signals

Table 1456: CBXCBR Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing

Table continues on the next page

Name	Type	Default	Description
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Auxiliary open
AU_CLOSE	BOOLEAN	0=False	Auxiliary close
TRIP	BOOLEAN	0=False	Trip signal
SYNC_OK	BOOLEAN	1=True	Synchronism-check OK
SYNC_BYPASS	BOOLEAN	0=False	Discards SYNC_OK interlocking when TRUE
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

9.1.6.2 DCXSWI Input signals

Table 1457: DCXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Auxiliary open
AU_CLOSE	BOOLEAN	0=False	Auxiliary close
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

9.1.6.3 ESXSWI Input signals

Table 1458: ESXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O
ENA_OPEN	BOOLEAN	1=True	Enables opening
ENA_CLOSE	BOOLEAN	1=True	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Auxiliary open
AU_CLOSE	BOOLEAN	0=False	Auxiliary close
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

9.1.6.4 CBXCBR Output signals

Table 1459: CBXCBR Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OP_REQ	BOOLEAN	Open request
CL_REQ	BOOLEAN	Close request
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status
CTL_ITL_BLKD	BOOLEAN	Control is blocked due to interlocking

9.1.6.5 DCXSWI Output signals

Table 1460: DCXSWI Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status
CTL_ITL_BLKD	BOOLEAN	Control is blocked due to in-terlocking

9.1.6.6 ESXSWI Output signals

Table 1461: ESXSWI Output signals

Name	Type	Description
SELECTED	BOOLEAN	Object selected
EXE_OP	BOOLEAN	Executes the command for open direction
EXE_CL	BOOLEAN	Executes the command for close direction
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok
OPEN_ENAD	BOOLEAN	Opening is enabled based on the input status
CLOSE_ENAD	BOOLEAN	Closing is enabled based on the input status
CTL_ITL_BLKD	BOOLEAN	Control is blocked due to in-terlocking

9.1.7 Settings

9.1.7.1 CBXCBR Settings

Table 1462: CBXCBR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Pulse length	10...60000	ms	1	200	Open and close pulse length
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Operation timeout	10...6000000	ms	1	500	Timeout for negative termination
Identification				CBXCBR1 switch position	Control Object identification

Table 1463: CBXCBR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter	0...99999		1	0	Nr of opening operations
Adaptive pulse	0=False 1=True			1=True	Deactivate control pulse when apparatus has reached correct position
Event delay	0...10000	ms	1	200	Event delay of the intermediate and faulty position
Interlocking Pls Len	1...10	s	1	2	Pulse length for interlocking violation signal
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.1.7.2 DCXSWI Settings

Table 1464: DCXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation timeout	10...60000	ms	1	30000	Timeout for negative termination
Identification				DCXSWI1 switch position	Control Object identification

Table 1465: DCXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter	0...10000		1	0	Nr of opening operations
Adaptive pulse	0=False 1=True			1=True	Deactivate control pulse when apparatus has reached correct position
Event delay	0...60000	ms	1	10000	Event delay of the intermediate and faulty position
Interlocking Pls Len	1...10	s	1	2	Pulse length for interlocking violation signal
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.1.7.3 ESXSWI Settings

Table 1466: ESXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Operation timeout	10...60000	ms	1	30000	Timeout for negative termination
Identification				ESXSWI1 switch position	Control Object identification

Table 1467: ESXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter	0...10000		1	0	Nr of opening operations
Adaptive pulse	0=False 1=True			1=True	Deactivate control pulse when apparatus has reached correct position
Event delay	0...60000	ms	1	10000	Event delay of the intermediate and faulty position

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Interlocking Pls Len	1...10	s	1	2	Pulse length for interlocking violation signal
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.1.8 Monitored data

9.1.8.1 CBXCBR Monitored data

Table 1468: CBXCBR Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.1.8.2 DCXSWI Monitored data

Table 1469: DCXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.1.8.3 ESXSWI Monitored data

Table 1470: ESXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.1.9 Technical revision history

9.1.9.1 Technical revision history

Table 1471: CBXCBR Technical revision history

Product connectivity level	Technical revision	Change
PCL4	G	Input SYN_ITL_BYPS is devided into two inputs SYN_BYPASS and ITL_BYPASS. New output CTL_ITL_BLKD and pulse timer setting *Interlocking Pls Len* added.

9.1.9.2 Technical revision history

Table 1472: DCXSWI Technical revision history

Product connectivity level	Technical revision	Change
PCL4	E	New output CTL_ITL_BLKD and pulse timer setting *Interlocking Pls Len* added.

9.1.9.3 Technical revision history

Table 1473: ESXSWI Technical revision history

Product connectivity level	Technical revision	Change
PCL4	E	New output CTL_ITL_BLKD and pulse timer setting *Interlocking Pls Len* added.

9.2 Three-state disconnector control P3SXSWI (ANSI 29DS/GS)

9.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-state disconnector control	P3SXSWI	I<->O P3S	29DS/GS

9.2.2 Function block

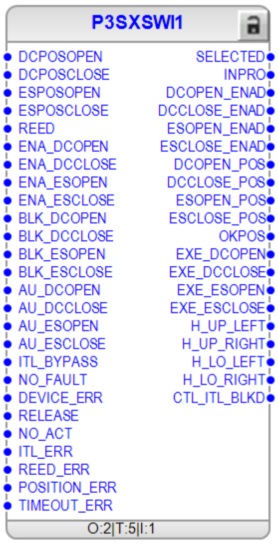


Figure 831: Function block

9.2.3 Functionality

The three-state disconnector control function P3SXSWI is used to control a three-state switch (disconnector closed, both open, earthing switch closed) and to provide status information on the MV air-insulated switchgear (AIS) and gas-insulated switchgear (GIS). P3SXSWI executes commands to RIO600 SCM or directly drives the switchgear motor by direct control of the protection relay’s H-bridge (if available). The function evaluates blocking conditions and different supervision conditions and it performs an execution command only if all conditions are fulfilled. If erroneous conditions occur, the function indicates an appropriate cause value. The function is designed according to the IEC 61850-7-4 standard including logical nodes CILO, CSWI and XSWI.

P3SXSWI has operation counters for disconnector operation and earthing switch operation. The counter values can be read and written remotely from the place of operation or via LHMI.

The function can also be configured to handle only two-position switches (earthing switch or disconnector).

9.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The switch type is determined depending on the connected inputs in Application Configuration.

- If inputs DCPOSOPEN, DCPOSCLOSE, ESPOSOPEN and ESPOSCLOSE are connected, the switch type is three-position switch.
- When only inputs DCPOSOPEN and DCPOSCLOSE are connected, the switch type is disconnector.
- When only inputs ESPOSOPEN and ESPOSCLOSE are connected, the switch type is earthing switch.

Any other connection leads to a configuration error.

The motor control application of the three-position switch can be selected with parameter setting *Control mode*. If "With RIO600 SCM" is selected, the motor control is handled externally by the RIO600 SCM module; the protection relay only supervises the switch position and interlocking but provides commands to RIO600. If "Direct control" is selected, the motor control is handled by the protection relay's H-bridge and no external RIO600 SCM device is needed.

9.2.4.1 Position indication and validity check

Depending on the switch type connection, a three-position switch, disconnector or earthing switch can be configured.

Be aware of the physical switch type and corresponding connections in Application Configuration, both for P3SXSWI and in RIO600 SCM, if used. A wrong connection according to the physical switch type can cause misleading position indication.

In certain three-position switches an additional reed contact is available to indicate safe earthing. The contact is TRUE only when the earthing switch is in closed position. The reed contact is given a short time window to confirm closed earthing switch position, in case of vibrations. If the earthing switch has closed but the reed contact does not close within the time window, faulty position is reported.

Table 1474: Reed contact detection

Control mode	Reed contact detection
Direct control	The availability of the reed contact needs to be set through the *Reed contact* setting by setting it as "Available". The reed contact signal is connected at input REED.
With RIO600 SCM	Reed detection is handled externally by the module. The input ESPOSCLOSE is not indicated TRUE by RIO600 if reed contact closing is not detected. Therefore, unsecure earthing is reported to input REED_ERR so that P3SXSWI can indicate faulty position in this control mode.

The state of the switch is indicated at outputs DCCLOSE_POS, DCOPEN_POS, ESCLOSE_POS and ESOPEN_POS together with the OKPOS information.

Debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering timer can be adjusted separately for each digital input used by the function block. The reporting of faulty or intermediate position of the apparatus occurs after the *Event delay* setting.

Table 1475: Status indication for a three-position switch with auxiliary contacts in direct control mode

Status	Inputs					Outputs				
POSITION	DCPOSCLOSE	DCPOSOPEN	ESPOSCLOSE	ESPOSOPEN	REED	DCCLOSE_POS	DCOPEN_POS	ESCLOSE_POS	ESOPEN_POS	OKPOS
Disconnector closed	1	0	0	1	x	1	0	0	1	1
Disconnector intermediate	0	0	0	1	x	0	0	0	1	0
Both open	0	1	0	1	x	0	1	0	1	1
Earthing switch intermediate	0	1	0	0	x	0	1	0	0	0
Earthing switch closed	0	1	1	0	1 [1]	0	1	1	0	1
Faulty	0	1	1	0	0 [2]	0	1	0	0	0
Faulty	0	1	1	1	x	0	1	0	0	0
Faulty	1	1	0	1	x	0	0	0	1	0
Faulty	1	x	1	x	x	0	0	0	0	0
Faulty	x	0	x	0	x	0	0	0	0	0
x = no difference										

The REED input is only supervised during a short time window when earthing switch has closed and if *Reed contact* setting is set as "Available" in direct control mode.

When a two-position switch type is used, only the corresponding outputs are enabled. For example, if the switch type is disconnector, the status of the two-position switch is based only on the connected inputs DCPOSOPEN and DCPOSCLOSE. Furthermore, the outputs ESOPEN_POS and ESCLOSE_POS are disabled.

Common three-position status is indicated at variable POSITION, regardless of the switch type. For example, if only a disconnector is available, and the disconnector is in open state, the open indication equals “both open”.

[1] REED input has been detected as closed within time-out and earthing switch is indicated as closed.
[2] REED input has not been detected as closed within time-out and faulty position is indicated.

Table 1476: Position indication values based on switch type

Status	Switch type		
POSITION	**Three-position switch**	**Disconnector**	**Earthing switch**
Earthing switch closed	Earthing switch closed and disconnector open	N/A	Earthing switch closed
Earthing switch intermediate	Earthing switch intermediate and disconnector open	N/A	Earthing switch intermediate
Both open	Earthing switch open and disconnector open	Disconnector open	Earthing switch open
Disconnector intermediate	Earthing switch open and disconnector intermediate	Disconnector intermediate	N/A
Disconnector closed	Earthing switch open and disconnector closed	Disconnector closed	N/A
Faulty	Earthing switch faulty or disconnector faulty (or incorrect combination)	Faulty	Faulty

When controlling P3SXSWI with RIO600 SCM, the switch's position information should be made available to the function in the protection relay via GOOSE or binary inputs from RIO600 to reflect correct position and status information.

9.2.4.2 Control of a three-position switch

There are three possible end positions in a three-position switch: earthing switch closed, both open, and disconnector closed. Additionally, there are two intermediate states: earthing switch intermediate and disconnector intermediate. The function follows the command order in cyclic order as shown in *Figure 832*. For example, at disconnector close state only disconnector open command can be executed. Similarly, when the state is both open, both disconnector close and earth close commands can be executed. When the switch indicates earthing switch or disconnector intermediate position (for example, the motor has stopped due to timeout), a specified open command is allowed only.

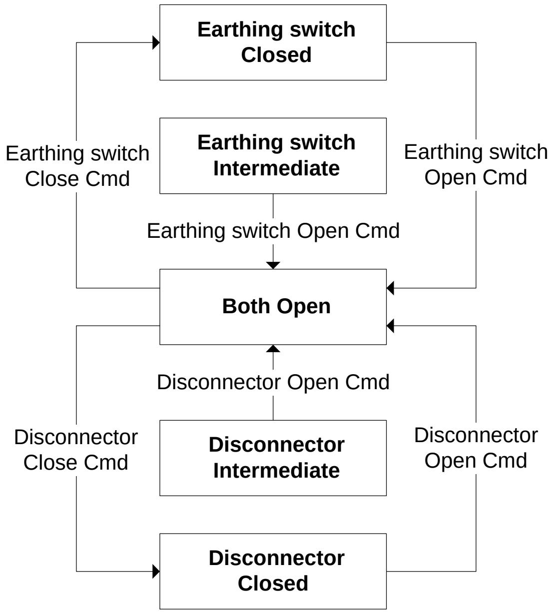


Figure 832: Control of a three-position switch by commands

9.2.4.3 Blocking

The function has a blocking functionality to prevent human errors that can cause injuries to the operator and damages to the system components.

The control operations are allowed if the interlocking signals for the operations are TRUE. These signals are ENA_DCOPEN, ENA_DCCLOSE, ENA_ESOPEN and ENA_ESCLOSE.

In addition, the function provides a general interlocking bypass input ITL_BYPASS. When ITL_BYPASS is TRUE, the apparatus can be controlled by discarding the ENA_DCOPEN, ENA_DCCLOSE, ENA_ESOPEN and ENA_ESCLOSE input states.

However, the BLK_DCOPEN, BLK_DCCLOSE, BLK_ESOPEN and BLK_ESCLOSE input signals are not bypassed with the interlocking bypass functionality since they always have higher priority.

In *Table 1477* the interlocking condition is switch-specific by row.

Table 1477: Interlocking conditions for enabling the closing/opening command

Inputs			Outputs
ITL_BYPASS	ENA_DCCLOSE	BLK_DCCLOSE	DCCLOSE_ENAD
	ENA_DCOPEN	BLK_DCOPEN	DCOPEN_ENAD
	ENA_ESCLOSE	BLK_ESCLOSE	ESCLOSE_ENAD
	ENA_ESOPEN	BLK_ESOPEN	ESOPEN_ENAD
0 = False	0 = False	0 = False	0 = False
0 = False	0 = False	1 = True	0 = False
0 = False	1 = True	0 = False	1 = True

Table continues on the next page

Inputs			Outputs
ITL_BYPASS	ENA_DCCLOSE	BLK_DCCLOSE	DCCLOSE_ENAD
	ENA_DCOPEN	BLK_DCOPEN	DCOPEN_ENAD
	ENA_ESCLOSE	BLK_ESCLOSE	ESCLOSE_ENAD
	ENA_ESOPEN	BLK_ESOPEN	ESOPEN_ENAD
0 = False	1 = True	1 = True	0 = False
1 = True	0 = False	0 = False	1 = True
1 = True	0 = False	1 = True	0 = False
1 = True	1 = True	0 = False	1 = True
1 = True	1 = True	1 = True	0 = False

However, the enabled outputs also depend on the actual position of the switch, according to *Figure 832* and if any motor operation is ongoing. Internal blocking based on switch position or motor in progress always overrides the enabled output regardless of the status of enable, block and interlock bypass inputs.

For two-position switches, the enabling outputs of the opposite switch type are disabled regardless of the input status. For example, if the switch type is earthing switch, DCCLOSE_ENAD and DCOPEN_ENAD are forced to FALSE.

Operation of the three-position switch is permitted only when the circuit breaker is in open position. The closed circuit breaker information can be connected to the BLK inputs in Application Configuration.

9.2.4.4 Various operations

The required operation command is available via communication, binary inputs or LHMI. As a prerequisite for control commands, there are enabling and blocking functionalities for all the operations. If the control command is executed against the blocking or if the enabling of the corresponding command is not valid, the function generates an error message. If the control is inhibited due to interlocking conditions the pulse output CTL_ITL_BLKD is activated. The length of the pulse is defined by the *Interlocking Pls Len* setting. The command operations are requested through binary inputs AU_DCOPEN, AU_DCCLOSE, AU_ESOPEN and AU_ESCLOSE. The requested operation is possible provided the apparatus is not blocked by the interlocking logic and no other previous request is active.

When the function block is selected for performing any of the operations locally from the HMI, the output SELECTED is activated. Once the function is selected, the command for execution of operation should be issued before *Select timeout* time lapses.

The function contains two operation counters: disconnector counter *Operation counter DC* and earthing switch counter *Operation counter ES*. The first one indicates each disconnector opening state and the latter one indicates each earthing switch opening state. The counter values are resettable and writable and stored in a nonvolatile memory.

Output INPRO indicates any active motor operation, including braking and pause operation.

9.2.4.5 Control of three-position switch using RIO600 smart control module

When using RIO600 smart control module (SCM) for controlling a three-position switch, the setting *Control mode* should be set as "With RIO600 SCM".

SCM is available with RIO600 to be able to drive a three-position switch. The motor of the three-position switch is directly driven by the RIO600 SCM. RIO600 sends the status information to the protection relay by GOOSE communication, and the switch position is indicated on the HMI on the protection relay. When a three-position switch operation is requested and enabled by the protection relay, it generates commands via EXE_DCOPEN, EXE_DCCLOSE, EXE_ESOPEN or EXE_ESCLOSE, which are transmitted to RIO600 over GOOSE communication. Though the command handling is pre-checked by P3SXSWI, RIO600 SCM further checks for command priority and if the requested command is allowed. The commands are always checked on rising edge by the RIO600 SCM.

In RIO600 SCM control mode, the operation timeouts in P3SXSWI are not available due to external motor handling by the SCM module. Status feedback from the module is returned to the protection relay via GOOSE. The inputs for P3SXSWI shown in *Figure 833* must be connected by GOOSE status signals from SCM. Input REED remains unconnected in this control mode.

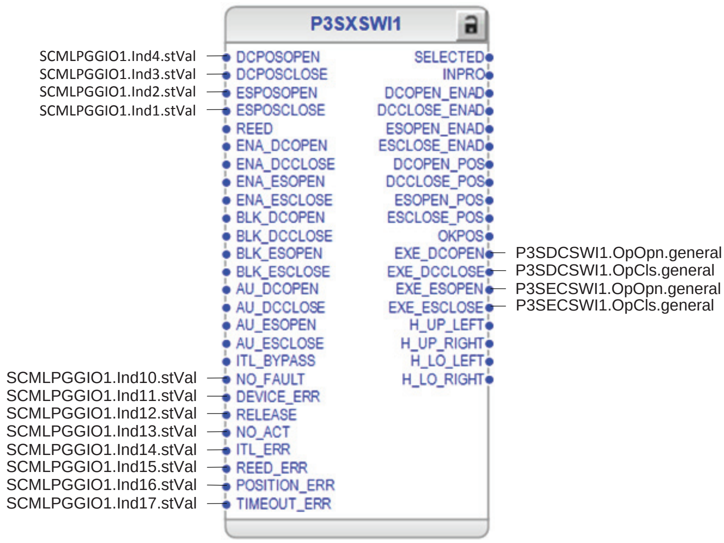


Figure 833: Connections in P3SXSWI when using RIO600 SCM for a threeposition switch

See the RIO600 and SCM manual when using RIO600 SCM for threeposition switch motor control. All the signals from RIO600 must be connected to the P3SXSWI function block as in *Figure 833*.

9.2.4.6 Control of three-position switch using H-bridge with static outputs of the protection relay

When using the protection relay for direct motor control of the three-position switch, the setting *Control mode* must be set as "Direct control".

If the protection relay is equipped with static power outputs, the three-position switch's driving motor can be controlled with an H-bridge. The function has four outputs for motor control.

- H-bridge upper-left: `H_UP_LEFT`
- H-bridge upper-right: `H_UP_RIGHT`
- H-bridge lower-left: `H_LO_LEFT`
- H-bridge lower-right: `H_LO_RIGHT`

These outputs must be connected to the static outputs of the protection relay. With the H-bridge functionality it is possible to drive the motor to left or to right, and brake the motor. The auxiliary voltage (U_{aux}) connected to the H-bridge has to match the voltage of the motor.

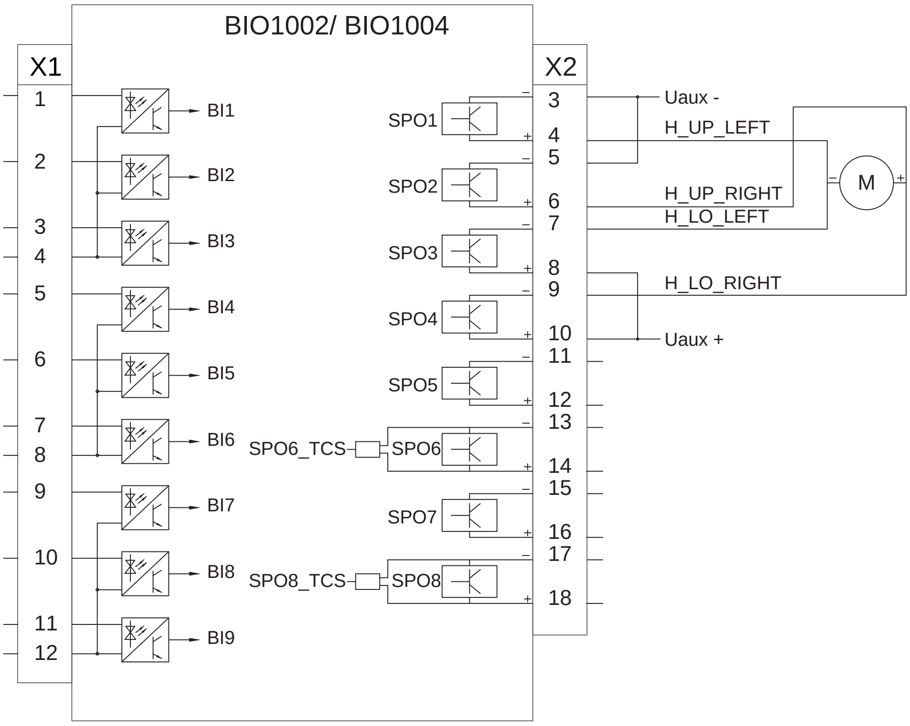


Figure 834: H-bridge motor control for a protection relay equipped with BIO1002 module

Table 1478: H-bridge motor operation depending on active outputs

Motor direction	Static outputs			
	H_UP_LEFT	H_UP_RIGHT	H_LO_LEFT	H_LO_RIGHT
Motor right	1	0	0	1
Motor left	0	1	1	0
Motor brake	1	1	0	0
Motor brake	0	0	1	1
Motor free	0	0	0	0

Be aware of the motor polarity so that a correct connection between the motor and the H-bridge is established. The H-bridge needs to be properly connected to the static outputs of the protection relay in Application Configuration. Wrong connections affect the motor functionality and may cause personal injury or damage to the equipment.

Motor logic and parameters

To prevent damage to the motor, the motor is protected by several settable timeouts. With setting parameter *Motor start timeout*, the maximum start time for the motor to recognize a position indication change is defined. If a position indication change is not recognized during this time, the motor is stopped. If *Motor start timeout* is set to zero, the motor start timeout is disabled.

With timeout *Operation timeout DC*, the maximum time for the disconnector to go from one state to another is defined.

With timeout *Operation timeout ES*, the maximum time for the earthing switch to go from one state to another is defined. If a state change is not fulfilled within this time, the motor is stopped.

If an unexpected position is detected based on the requested command, in other words the motor is running in the wrong direction, or if faulty position of the switch is detected, the motor is immediately stopped. Additionally, an activated block input that corresponds to the active command stops the running motor immediately.

If any of the cases above occur, the specific event is displayed on the HMI or reported via communication.

When the motor operates and reaches the final destination, the motor brakes if the *Motor braking* setting is selected as "True". The braking time of the motor is selectable with the *Motor brake time* parameter. After the motor has braked and stopped, the motor is in a free state, meaning that the switch is mechanically operable by hand-crank. A successful operation is also displayed on the HMI or reported via communication.

After each operation the motor is paused for one second before any new control command can pass through.

9.2.4.7 Control methods

The command execution mode can be set with the *Control model* setting. The alternatives for command execution are direct control and secured object control, which can be used to secure controlling.

The secured object control SBO is an important feature of the communication protocols that support horizontal communication, because the command reservation and interlocking signals can be transferred with a bus. All secured control operations require two-step commands: a selection step and an execution step. The secured object control is responsible for several tasks.

- Command authority: ensures that the command source is authorized to operate the object.
- Mutual exclusion: ensures that only one command source at a time can control the object.
- Interlocking: allows only safe commands.
- Execution: supervises the command execution.
- Command canceling: cancels the controlling of a selected object.

In direct operation, a single message is used to initiate the control action of a physical device. The direct operation method uses less communication network capacity and bandwidth than the SBO method, because the procedure needs fewer messages for accurate operation.

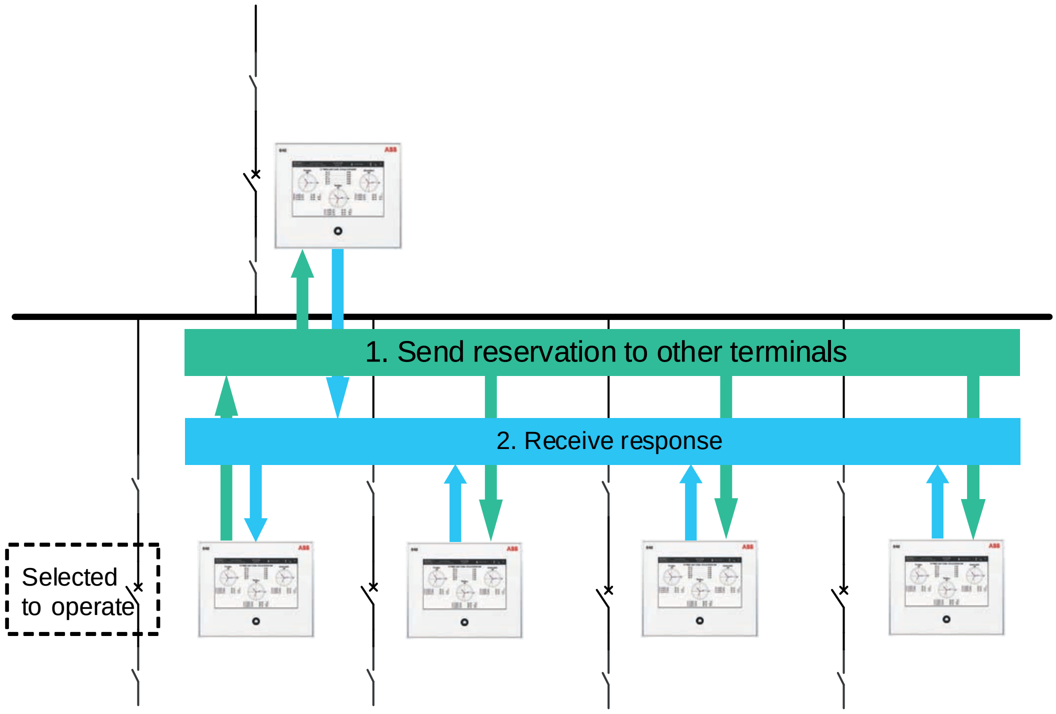


Figure 835: Control procedure in the SBO method

9.2.5 Application

In the field of distribution and sub-transmission, automatic, reliable control and status indication of primary switching components, both locally and remotely, are of significant importance. They are needed especially in modern remotely controlled substations.

P3SXSWI is designed to be used for the control of two- (open, closed) and three-state (earthing switch closed, disconnector closed and both open) switches. The function also handles user-defined interlocking logics and provides commands.

Control and status indication facilities are implemented in the same package with P3SXSWI. When primary components are controlled in the energizing phase, for example, the correct execution sequence of the control command must be ensured. This can be achieved, for example, with interlocking based on the status indication of the related primary components.

The interlocking on the substation level can be applied using the IEC 61850 GOOSE message between feeders.

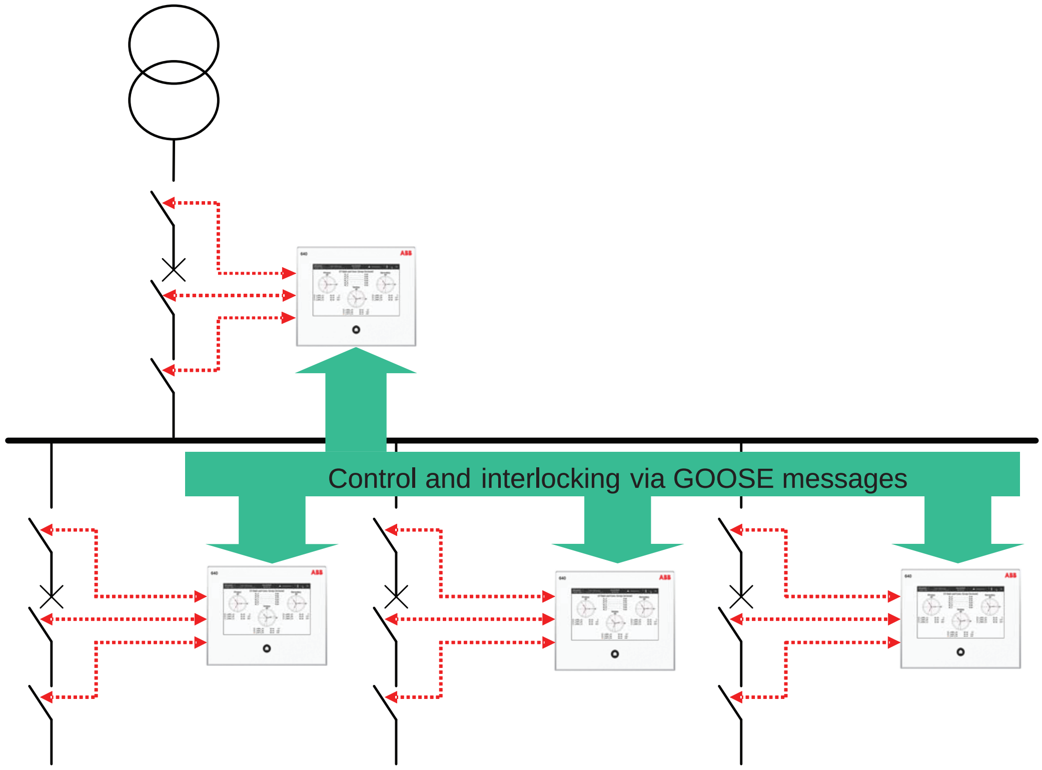


Figure 836: Status indication-based interlocking via the GOOSE messaging

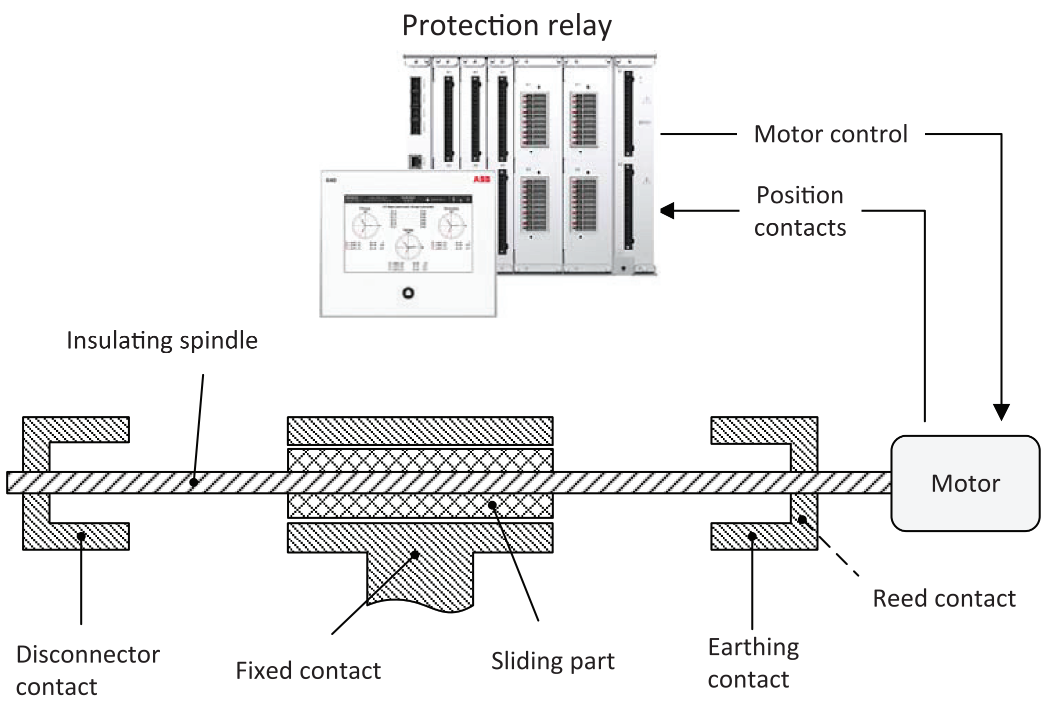


Figure 837: Connection diagram for direct control of a three-position switchgear motor

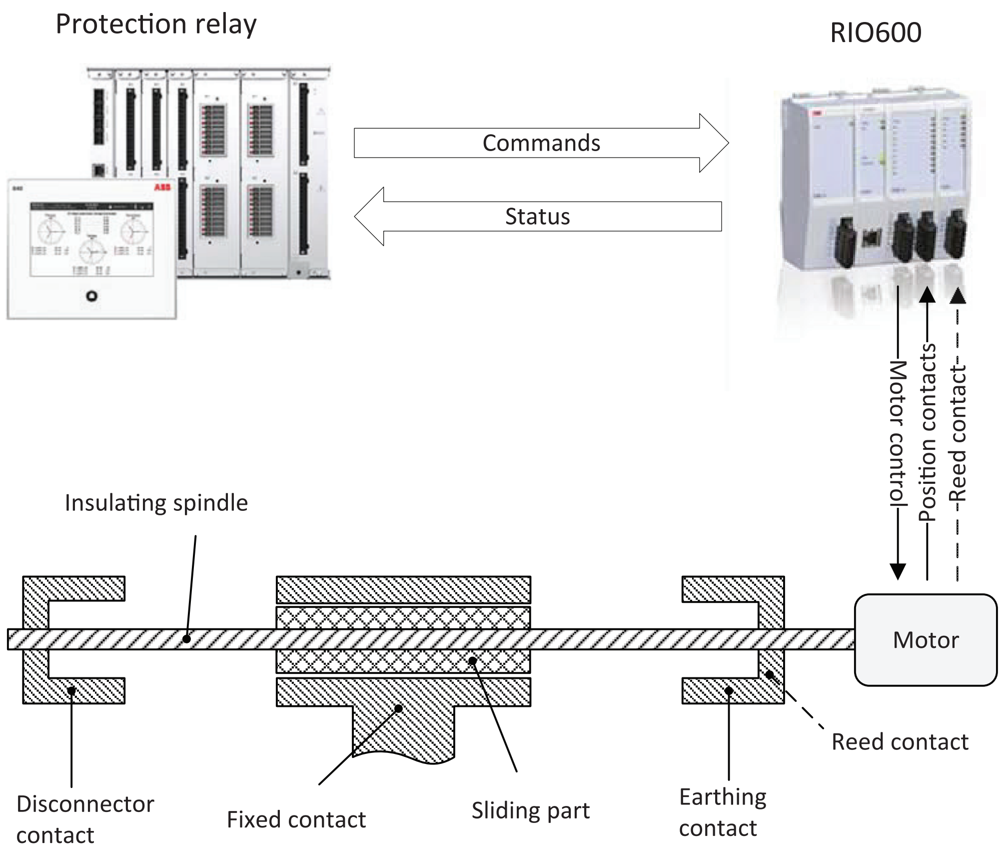


Figure 838: Connection diagram for RIO600 control of a three-position switchgear motor

When the RIO600 SCM module is selected as control mode, outputs `EXE_DCCLOSE`, `EXE_DCOPEN`, `EXE_ESCLOSE` and `EXE_ESOPEN` are connected in Application Configuration. When direct motor control is selected as control mode, static outputs `H_UP_LEFT`, `H_UP_RIGHT`, `H_LO_LEFT` and `H_LO_RIGHT` are connected in Application Configuration.

9.2.6 Signals

9.2.6.1 P3SXSWI Input signals

Table 1479: P3SXSWI Input signals

Name	Type	Default	Description
DCPOSOPEN	BOOLEAN	0=False	Signal for open position of disconnector
DCPOSCLOSE	BOOLEAN	0=False	Signal for close position of disconnector

Table continues on the next page

Name	Type	Default	Description
ESPOSOPEN	BOOLEAN	0=False	Signal for open position of earthing switch
ESPOSCLOSE	BOOLEAN	0=False	Signal for close position of earthing switch
REED	BOOLEAN	0=False	Signal for close position of reed contact
ENA_DCOPEN	BOOLEAN	1=True	Enables opening command for disconnector
ENA_DCCLOSE	BOOLEAN	1=True	Enables closing command for disconnector
ENA_ESOPEN	BOOLEAN	1=True	Enables opening command for earthing switch
ENA_ESCLOSE	BOOLEAN	1=True	Enables closing command for earthing switch
BLK_DCOPEN	BOOLEAN	0=False	Blocks opening of disconnector
BLK_DCCLOSE	BOOLEAN	0=False	Blocks closing of disconnector
BLK_ESOPEN	BOOLEAN	0=False	Blocks opening of earthing switch
BLK_ESCLOSE	BOOLEAN	0=False	Blocks closing of earthing switch
AU_DCOPEN	BOOLEAN	0=False	Auxiliary open disconnector
AU_DCCLOSE	BOOLEAN	0=False	Auxiliary close disconnector
AU_ESOPEN	BOOLEAN	0=False	Auxiliary open earthing switch
AU_ESCLOSE	BOOLEAN	0=False	Auxiliary close earthing switch
ITL_BYPASS	BOOLEAN	0=False	Discards enable interlocking when TRUE
NO_FAULT	BOOLEAN	1=True	RIO600 SCM no fault
DEVICE_ERR	BOOLEAN	0=False	RIO600 SCM device error
RELEASE	BOOLEAN	0=False	RIO600 SCM release information
NO_ACT	BOOLEAN	1=True	RIO600 SCM no motor action

Table continues on the next page

Name	Type	Default	Description
ITL_ERR	BOOLEAN	0=False	RIO600 SCM inter-locking error
REED_ERR	BOOLEAN	0=False	RIO600 SCM reed er-ror
POSITION_ERR	BOOLEAN	0=False	RIO600 SCM position error
TIMEOUT_ERR	BOOLEAN	0=False	RIO600 SCM timeout error

9.2.6.2 P3SXSWI Output signals

Table 1480: P3SXSWI Output signals

Name	Type	Description
SELECTED	BOOLEAN	Obejct selected
INPRO	BOOLEAN	Motor operation in progress
DCOPEN_ENAD	BOOLEAN	Disconnector opening is ena-bled
DCCLOSE_ENAD	BOOLEAN	Disconnector closing is ena-bled
ESOPEN_ENAD	BOOLEAN	Earthing switch opening is enabled
ESCLOSE_ENAD	BOOLEAN	Earthing switch closing is en-abled
DCOPEN_POS	BOOLEAN	Disconnector in open posi-tion
DCCLOSE_POS	BOOLEAN	Disconnector in closed posi-tion
ESOPEN_POS	BOOLEAN	Earthing switch in open posi-tion
ESCLOSE_POS	BOOLEAN	Earthing switch in closed po-sition
OKPOS	BOOLEAN	Apparatus position is ok
EXE_DCOPEN	BOOLEAN	Command to RIO600 SCM for opening disconnector
EXE_DCCLOSE	BOOLEAN	Command to RIO600 SCM for closing disconnector
EXE_ESOPEN	BOOLEAN	Command to RIO600 SCM for opening earthing switch
EXE_ESCLOSE	BOOLEAN	Command to RIO600 SCM for closing earthing switch
H_UP_LEFT	BOOLEAN	H-bridge output upper left
H_UP_RIGHT	BOOLEAN	H-bridge output upper right

Table continues on the next page

Name	Type	Description
H_LO_LEFT	BOOLEAN	H-bridge output lower left
H_LO_RIGHT	BOOLEAN	H-bridge output lower right
CTL_ITL_BLKD	BOOLEAN	Control is blocked due to interlocking

9.2.7 P3SXSWI Settings

Table 1481: P3SXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Control mode	1=Direct control 2=With RIO600 SCM			1=Direct control	Direct control or RIO600 SCM control
Reed contact	0=Not available 1=Available			0=Not available	Availability of reed contact
Select timeout	10000...300000	ms	10000	30000	Select timeout in ms
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Operation timeout DC	10...60000	ms	1	30000	Timeout for negative termination for disconnector
Operation timeout ES	10...60000	ms	1	30000	Timeout for negative termination for earthing switch
Motor braking	0=False 1=True			1=True	Motor braking on/off selection
Identification				P3SXSWI1 switch position	Control object identification

Table 1482: P3SXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation counter DC	0...10000		1	0	Disconnector operation cycles
Operation counter ES	0...10000		1	0	Earthing switch operation cycles
Event delay	0...60000	ms	1	10000	Event delay of intermediate or faulty position
Motor start timeout	0...32000	ms	100	0	Timeout for motor to start
Motor brake time	10...500	ms	1	100	Motor brake time
Interlocking Pls Len	1...10	s	1	2	Pulse length for interlocking violation signal
Vendor				0	External equipment vendor

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Serial number				0	External equipment serial number
Model				0	External equipment model

9.2.8 P3SXSWI Monitored data

Table 1483: P3SXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Enum	0=earthing switch closed 1=earthing switch intermediate 2=both open 3=disconnector intermediate 4=disconnector closed 5=faulty		3-position switch position
POSITION_DC	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Disconnector position
POSITION_ES	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Earthing switch position
SWTYPE	Enum	1=3-position switch 2=Disconnector 3=Earthing switch 4=Unknown		Switch type

9.2.9 Technical revision history

Table 1484: P3SXSWI Technical revision history

Product connectivity level	Technical revision	Change
PCL4	B	New output `CTL_ITL_BLKD` and pulse timer setting *Interlocking Pls Len* added.

9.3 Three-state disconnector position indication P3SSXSWI (ANSI 29DS/GS)

9.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-state disconnector position indication	P3SSXSWI	I<->O P3SS	29DS/GS

9.3.2 Function block

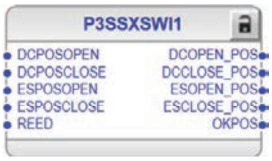


Figure 839: Function block

9.3.3 Functionality

The three-state disconnector position indication function P3SSXSWI provides status information on three-state switches: MV air-insulated switchgear (AIS) and gas-insulated switchgear (GIS). The function is designed according to the IEC 61850-7-4 standard including logical nodes CSWI and XSWI.

9.3.4 Operation principle

Position indication

In certain three-position switches an additional reed contact is available to indicate safe earthing. The contact is TRUE only when the earthing switch is in closed position. The reed contact is given a short time window to confirm closed earthing switch position, in case of vibrations. If the earthing switch has closed but the reed contact does not close within the time window, faulty position is reported. The availability of the reed contact needs to be set through *Reed contact* setting by setting it as "Available". The reed contact signal is connected at input REED in this control mode.

The state of the switch is indicated at outputs DCCLOSE_POS, DCOPEN_POS, ESCLOSE_POS and ESOPEN_POS together with the OKPOS information.

Debouncing and short disturbances in an input are eliminated by filtering. The binary input filtering timer can be adjusted separately for each digital input used by the function block. The reporting of faulty or intermediate position of the apparatus occurs after the *Event delay* setting. A common three-position status is indicated at variable POSITION.

Table 1485: Status indication for a three-position switch based on auxiliary contacts

Status	Inputs					Outputs				
POSITION	**DCPOSCLOSE**	**DCPOSOPEN**	**ESPOSCLOSE**	**ESPOSOPEN**	**REED**	**DCCLOSE_POS**	**DCOPEN_POS**	**ESCLOSE_POS**	**ESOPEN_POS**	**OKPOS**
Disconnector closed	1	0	0	1	x	1	0	0	1	1
Disconnector intermediate	0	0	0	1	x	0	0	0	1	0
Both open	0	1	0	1	x	0	1	0	1	1
Earthing switch intermediate	0	1	0	0	x	0	1	0	0	0
Earthing switch closed	0	1	1	0	1 [1]	0	1	1	0	1
Faulty	0	1	1	0	0 [2]	0	1	0	0	0
Faulty	0	1	1	1	x	0	1	0	0	0
Faulty	1	1	0	1	x	0	0	0	1	0
Faulty	1	x	1	x	x	0	0	0	0	0
Faulty	x	0	x	0	x	0	0	0	0	0
x = no difference										

The REED input is only supervised during a short time window when earthing switch has closed and if *Reed contact* setting is set as "Available".

9.3.5 Application

In the field of distribution and sub-transmission automatic, reliable control and status indication of primary switching components both locally and remotely is of significant importance. They are needed especially in modern remotely controlled substations.

P3SSXSWI is designed to be used for status indication of a three-state (earthing switch closed, disconnector closed and both open) switch.

9.3.6 Signals

[1] REED input has been detected as closed within time-out and earthing switch is indicated as closed.

[2] REED input has not been detected as closed within time-out and faulty position is indicated.

9.3.6.1 P3SSXSWI Input signals

Table 1486: P3SSXSWI Input signals

Name	Type	Default	Description
DCPOSOPEN	BOOLEAN	0=False	Signal for open position of disconnector
DCPOSCLOSE	BOOLEAN	0=False	Signal for close position of disconnector
ESPOSOPEN	BOOLEAN	0=False	Signal for open position of earthing switch
ESPOSCLOSE	BOOLEAN	0=False	Signal for close position of earthing switch
REED	BOOLEAN	0=False	Signal for close position of reed contact

9.3.6.2 P3SSXSWI Output signals

Table 1487: P3SSXSWI Output signals

Name	Type	Description
DCOPEN_POS	BOOLEAN	Disconnector in open position
DCCLOSE_POS	BOOLEAN	Disconnector in closed position
ESOPEN_POS	BOOLEAN	Earthing switch in open position
ESCLOSE_POS	BOOLEAN	Earthing switch in closed position
OKPOS	BOOLEAN	Apparatus position is ok

9.3.7 P3SSXSWI Settings

Table 1488: P3SSXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Reed contact	0=Not available 1=Available			0=Not available	Availability of reed contact
Identification				P3SSXSWI1 switch position	Control object identification

Table 1489: P3SSXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Event delay	0...60000	ms	1	10000	Event delay of intermediate or faulty position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.3.8 P3SSXSWI Monitored data

Table 1490: P3SSXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Enum	0=earthing switch closed 1=earthing switch intermediate 2=both open 3=disconnector intermediate 4=disconnector closed 5=faulty		3-position switch position
POSITION_DC	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Disconnector position
POSITION_ES	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Earthing switch position

9.4 Disconnector position indicator DCSXSWI and Earthing switch position indication ESSXSWI (ANSI 29DS, 29GS)

9.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Disconnector position indication	DCSXSWI	I<->O DC	29DS
Earthing switch indication	ESSXSWI	I<->O ES	29GS

9.4.2 Function block

Figure 840: Function block

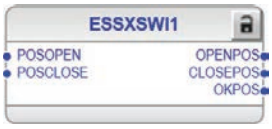


Figure 841: Function block

9.4.3 Functionality

The functions DCSXSWI and ESSXSWI indicate remotely and locally the open, close and undefined states of the disconnector and earthing switch. The functionality of both is identical, but each one is allocated for a specific purpose visible in the function names. For example, the status indication of disconnectors or circuit breaker truck can be monitored with the DCSXSWI function.

The functions are designed according to the IEC 61850-7-4 standard with the logical node XSWI.

9.4.4 Operation principle

Status indication and validity check

The object state is defined by the two digital inputs POSOPEN and POSCLOSE, which are also available as outputs OPENPOS and CLOSEPOS together with the OKPOS according to *Table 1491*. The debounces and short disturbances in an input are eliminated by filtering. The binary input filtering time can be adjusted separately for each digital input used by the function block. The validity of digital inputs that indicate the object state is used as additional information in indications and event logging.

Table 1491: Status indication

Input		**Status**	**Output**		
POSOPEN	**POSCLOSE**	**POSITION (Monitored data)**	**OKPOS**	**OPENPOS**	**CLOSEPOS**
1=True	0=False	1=Open	1=True	1=True	0=False
0=False	1=True	2=Closed	1=True	0=False	1=True
1=True	1=True	3=Faulty/Bad (11)	0=False	0=False	0=False
0=False	0=False	0=Intermedi-ate (00)	0=False	0=False	0=False

9.4.5 Application

In the field of distribution and sub-transmission automation, the reliable control and status indication of primary switching components both locally and remotely is in a significant role. These features are needed especially in modern remote controlled substations. The application area of DCSXSWI and ESSXSWI functions covers remote and local status indication of, for example, disconnectors, air-break switches and earthing switches, which represent the lowest level of power switching devices without short-circuit breaking capability.

9.4.6 Signals

9.4.6.1 DCSXSWI Input signals

Table 1492: DCSXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O

9.4.6.2 ESSXSWI Input signals

Table 1493: ESSXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O
POSCLOSE	BOOLEAN	0=False	Signal for close position of apparatus from I/O

9.4.6.3 DCSXSWI Output signals

Table 1494: DCSXSWI Output signals

Name	Type	Description
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok

9.4.6.4 ESSXSWI Output signals

Table 1495: ESSXSWI Output signals

Name	Type	Description
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok

9.4.7 Settings

9.4.7.1 DCSXSWI Settings

Table 1496: DCSXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Identification				DCSXSWI1 switch position	Control Object identification

Table 1497: DCSXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Event delay	0...60000	ms	1	30000	Event delay of the intermediate and faulty position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.4.7.2 ESSXSWI Settings

Table 1498: ESSXSWI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Identification				ESSXSWI1 switch position	Control Object identification

Table 1499: ESSXSWI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Event delay	0...60000	ms	1	30000	Event delay of the intermediate and faulty position
Vendor				0	External equipment vendor
Serial number				0	External equipment serial number
Model				0	External equipment model

9.4.8 Monitored data

9.4.8.1 DCSXSWI Monitored data

Table 1500: DCSXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.4.8.2 ESSXSWI Monitored data

Table 1501: ESSXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.5 Synchronism and energizing check SECRSYN (ANSI 25)

9.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Synchronism and energizing check	SECRSYN	SYNC	25

9.5.2 Function block

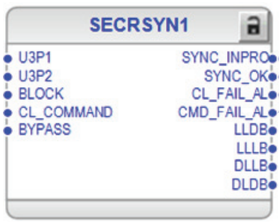


Figure 842: Function block

9.5.3 Functionality

The synchronism and energizing check function SECRSYN checks the condition across the circuit breaker from separate power system parts and gives the permission to close the circuit breaker. SECRSYN includes the functionality of synchrocheck and energizing check.

Asynchronous operation mode is provided for asynchronously running systems. The main purpose of the asynchronous operation mode is to provide a controlled closing of circuit breakers when two asynchronous systems are connected.

The synchrocheck operation mode checks that the voltages on both sides of the circuit breaker are perfectly synchronized. It is used to perform a controlled reconnection of two systems which are divided after islanding and it is also used to perform a controlled reconnection of the system after reclosing.

The energizing check function checks that at least one side is dead to ensure that closing can be done safely.

The function contains a blocking functionality. It is possible to block function outputs and timers.

9.5.4 Analog channel configuration

SECRSYN has two analog group inputs which must be properly configured.

Table 1502: Analog inputs

Input	Description
U3P1	Three-phase voltages (bus side)
U3P2	Three-phase voltages (line side)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1503: Special conditions

Condition	Description
U3P1 connected to real measurements	The function requires that at least two voltage channels from the bus side are connected.
U3P2 connected to real measurements	The function requires that one voltage channel from the line side is connected to channel 1 or any two voltage channels from the line side.

When a single voltage channel is connected on the line side, the *VT connection* setting of the U3P2 source UTVTR defines whether ph-to-earth or ph-to-ph voltages are used from both sides in checking the conditions. If at least two voltage channels are connected on line side, ph-to-ph voltages are used from both sides in checking the conditions regardless of the *VT connection* settings of the source UTVTRs.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings.

For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

9.5.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

SECRSYN has two parallel functionalities, the synchro check and energizing check functionality. The operation of SECRSYN can be described using a module diagram. All the modules in the diagram are explained in the next sections.

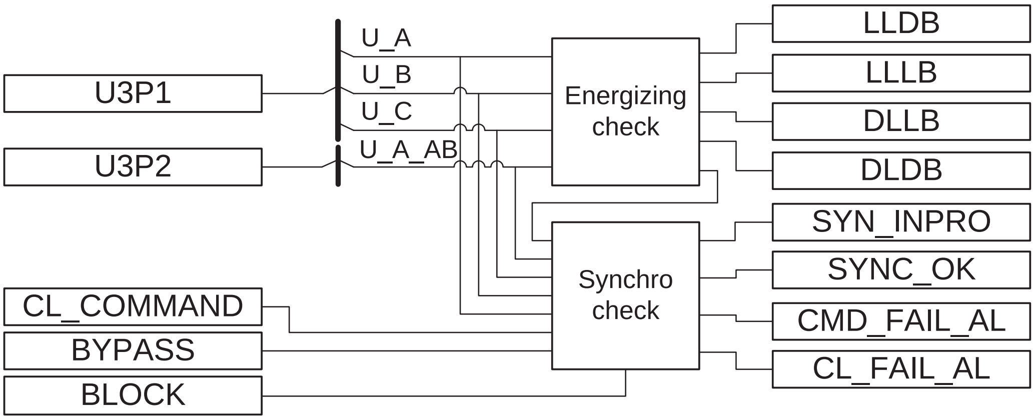


Figure 843: Functional module diagram

If Energizing check is passed, no further conditions need to be fulfilled to permit closing. Otherwise, Synchro check function can operate either with the U_AB or U_A voltages. The selection of used voltages is defined with the *VT connection* setting of the line voltage general parameters.

By default, voltages U_BUS and U_LINE are connected as presented in *Figure 852*. If necessary, connections can be switched by setting *Voltage source switch* to “True”.

Energizing check

The Energizing check function checks the energizing direction. Energizing is defined as a situation where a dead network part is connected to an energized section of the network. The conditions of the network sections to be controlled by the circuit breaker, that is, which side has to be live and which side dead, are determined by the setting. A situation where both sides are dead is possible as well. The actual value for defining the dead line or bus is given with the *Dead bus value* and *Dead line value* settings. Similarly, the actual values of live line or bus are defined with the *Live bus value* and *Live line value* settings.

Table 1504: *Live dead mode* of operation under which switching can be carried out

Live dead mode	Description
Both Dead	Both line and bus de-energized
Live L, Dead B	Bus de-energized and line energized
Dead L, Live B	Line de-energized and bus energized
Dead Bus, L Any	Both line and bus de-energized or bus de-energized and line energized
Dead L, Bus Any	Both line and bus de-energized or line de-energized and bus energized
One Live, Dead	Bus de-energized and line energized or line de-energized and bus energized
Not Both Live	Both line and bus de-energized or bus de-energized and line energized or line de-energized and bus energized

When the energizing direction corresponds to the settings, the situation has to be constant for a time set with the *Energizing time* setting before the circuit breaker closing is permitted. The purpose of this time delay is to ensure that the dead side remains de-energized and also that the situation is not caused by a temporary interference. If the conditions do not persist for a specified operation time, the timer is reset and the procedure is restarted when the conditions allow. The circuit breaker closing is not permitted if the measured voltage on the live side is greater than the set value of *Max energizing V*.

The measured energized state is available as a monitored data value ENERG_STATE and as four function outputs `LLDB` (live line / dead bus), `LLLB` (live line / live bus), `DLLB` (dead line / live bus) and `DLDB` (dead line / dead bus), of which only one can be active at a time. It is also possible that the measured energized state indicates “Unknown” if at least one of the measured voltages is between the limits set with the dead and live setting parameters.

Synchro check

The Synchro check function measures the difference between the line voltage and bus voltage. The function permits the closing of the circuit breaker when certain conditions are simultaneously fulfilled.

- The measured line and bus voltages are higher than the set values of *Live bus value* and *Live line value* (ENERG_STATE equals to "Both Live").
- The measured bus and line frequency are both within the range of 95 to 105 percent of the value of f_n.
- The measured voltages for the line and bus are less than the set value of *Max energizing V*.

In case *Syncro check mode* is set to "Syncronous", the additional conditions must be fulfilled.

- In the synchronous mode, the closing is attempted so that the phase difference at closing is close to zero.
- The synchronous mode is only possible when the frequency slip is below 0.1 percent of the value of f_n.
- The voltage difference must not exceed the 1 percent of the value of U_n.

In case *Syncro check mode* is set to “Asyncronous”, the additional conditions must be fulfilled.

- The measured difference of the voltages is less than the set value of *Difference voltage*.
- The measured difference of the phase angles is less than the set value of *Difference angle*.
- The measured difference in frequency is less than the set value of *Frequency difference*.
- The estimated breaker closing angle is decided to be less than the set value of *Difference angle*.

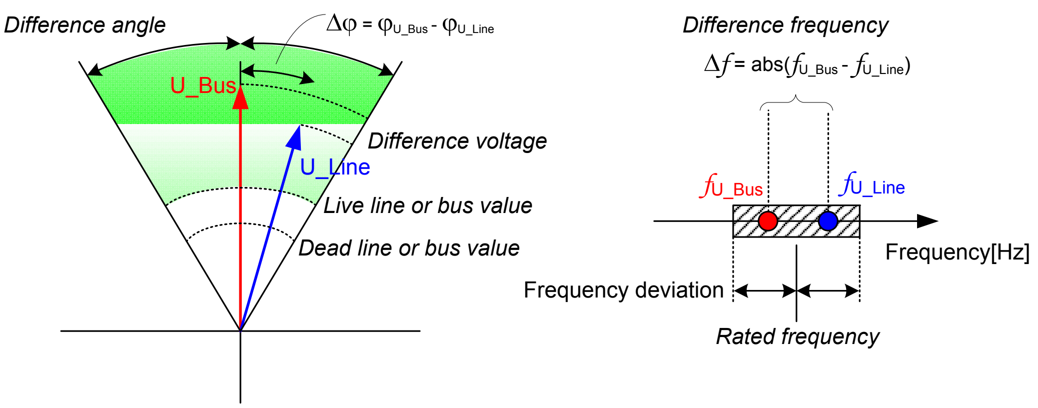


Figure 844: Conditions to be fulfilled when detecting synchronism between systems

When the frequency, phase angle and voltage conditions are fulfilled, the duration of the synchronism conditions is checked so as to ensure that they are still met when the condition is determined on the basis of the measured frequency and phase difference. Depending on the circuit breaker and the closing system, the delay from the moment the closing signal is given until the circuit breaker finally closes is about 50...250 ms. The selected *Closing time of CB* informs the function how long the conditions have to persist. The Synchro check function compensates for the measured slip frequency and the circuit breaker closing delay. The phase angle advance is calculated continuously with the formula.

$$Closing\ angle = \left|(\angle U_{Bus} - \angle U_{Line})^{\circ} + ((f_{Bus} - f_{line}) \times (T_{CB} + T_{PL}) \times 360^{\circ})\right|$$

(Equation 352)

$\angle U_{Bus}$	Measured bus voltage phase angle
$\angle U_{Line}$	Measured line voltage phase angle
f_{Bus}	Measured bus frequency
f_{line}	Measured line frequency
T_{CB}	Total circuit breaker closing delay, including the delay of the protection relay output contacts defined with the *Closing time of CB* setting parameter value
T_{PL}	Output type dependent delay according to *Table 1505*

Table 1505: Typical delays for different output types

Output type	Recommended value for T_{PL}
Semiconductor output (HSO, SPO)	0 ms
Mechanical relay output (POSP, PODP, PO)	6 ms

The closing angle is the estimated angle difference after the breaker closing delay.

The *Minimum Syn time* setting time can be set, if required, to demand the minimum time within which conditions must be simultaneously fulfilled before the SYNC_OK output is activated.

The measured voltage, frequency and phase angle difference values between the two sides of the circuit breaker are available as monitored data values U_DIFF_MEAS, FR_DIFF_MEAS and PH_DIFF_MEAS. Also, the indications of the conditions that are not fulfilled and thus preventing the breaker closing permission are available as monitored data values U_DIFF_SYNC, PH_DIF_SYNC and FR_DIFF_SYNC. These monitored data values are updated only when the Synchro check is enabled with the *Synchro check mode* setting and the measured ENERG_STATE is "Both Live".

Continuous mode

The continuous mode is activated by setting the parameter *Control mode* to "Continuous". In the continuous control mode, Synchro check is continuously checking the synchronism. When synchronism is detected (according to the settings), the SYNC_OK output is set to TRUE (logic '1') and it stays TRUE as long as the conditions are fulfilled. The command input is ignored in the continuous control mode.

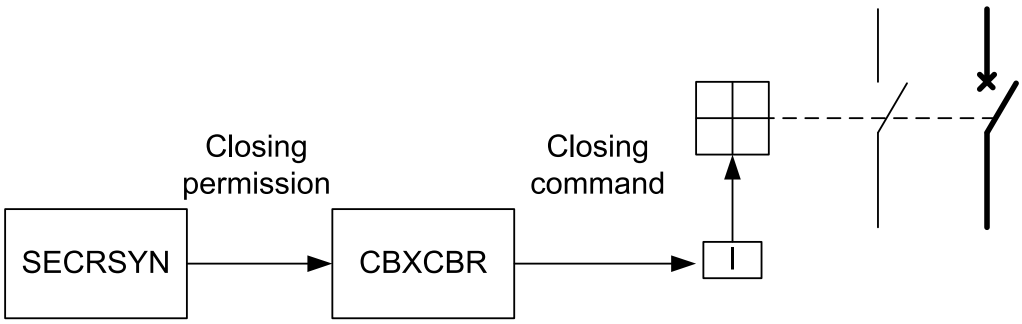


Figure 845: A simplified block diagram of the Synchro check function in the continuous mode operation

Command mode

If *Control mode* is set to "Command", the purpose of the Synchro check functionality in the command mode is to find the instant when the voltages on both sides of the circuit breaker are in synchronism. The conditions for synchronism are met when the voltages on both sides of the circuit breaker have the same frequency and are in phase with a magnitude that makes the concerned busbars or lines such that they can be regarded as live.

In the command mode operation, an external command signal CL_COMMAND (initiated by the breaker function CBXCBR output CL_REQ), in addition to the normal closing conditions, is needed for delivering the SYNC_OK signal for the breaker function input SYNC_OK. If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, the Synchro check function delivers a SYNC_OK signal to the circuit breaker function after the command signal is delivered for closing.

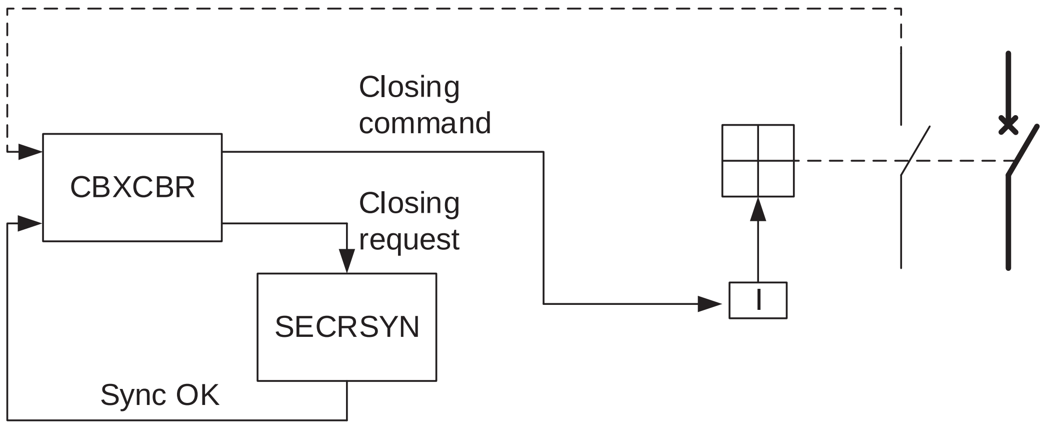


Figure 846: A simplified block diagram of SECRSYN in the command mode operation

The SYNC_OK signal is delivered only once for each activated external closing command signal. The pulse length of the delivered SYNC_OK is set with the *Close pulse* setting.

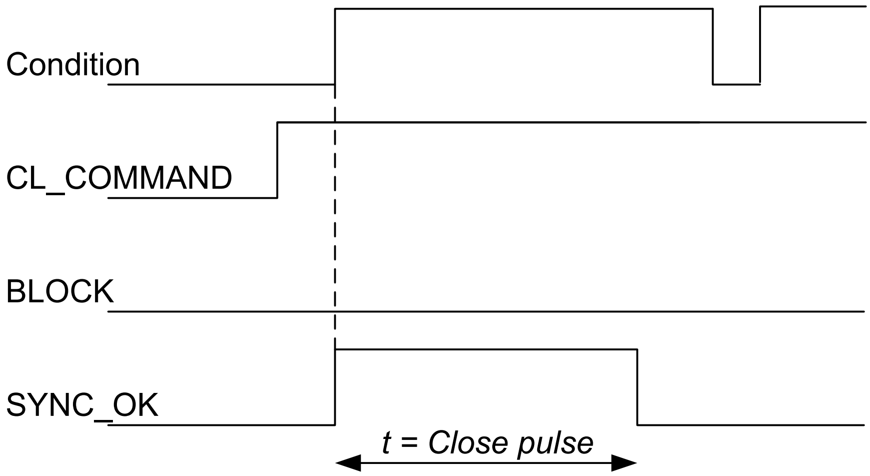


Figure 847: Determination of the pulse length of the closing signal

In the command control mode operation, there are alarms for a failed closing attempt (CL_FAIL_AL) and for a command signal that remains active too long (CMD_FAIL_AL).

If the conditions for closing are not fulfilled within the set time of *Maximum Syn time*, a failed closing attempt alarm is given. The CL_FAIL_AL alarm output signal is pulse-shaped and the pulse length is 500 ms. If the external command signal is removed too early, that is, before conditions are fulfilled and the closing pulse is given, the alarm timer is reset.

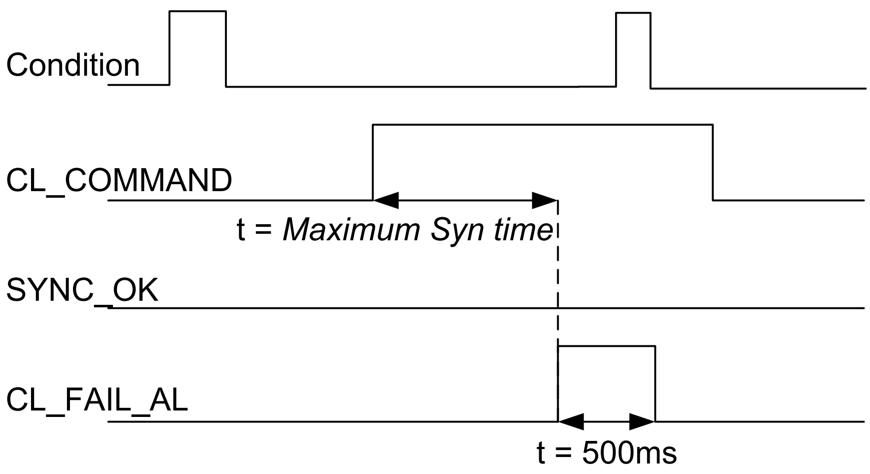


Figure 848: Determination of the checking time for closing

CBXCBR receives information about the circuit breaker status and thus is able to adjust the command signal to be delivered to the Synchro check function. If the external command signal CL_COMMAND is kept active longer than necessary, the CMD_FAIL_AL alarm output is activated. The alarm indicates that the control module has not removed the external command signal after the closing operation. To avoid unnecessary alarms, the duration of the command signal should be set in such a way that the maximum length of the signal is always below *Maximum Syn time* + 5s.

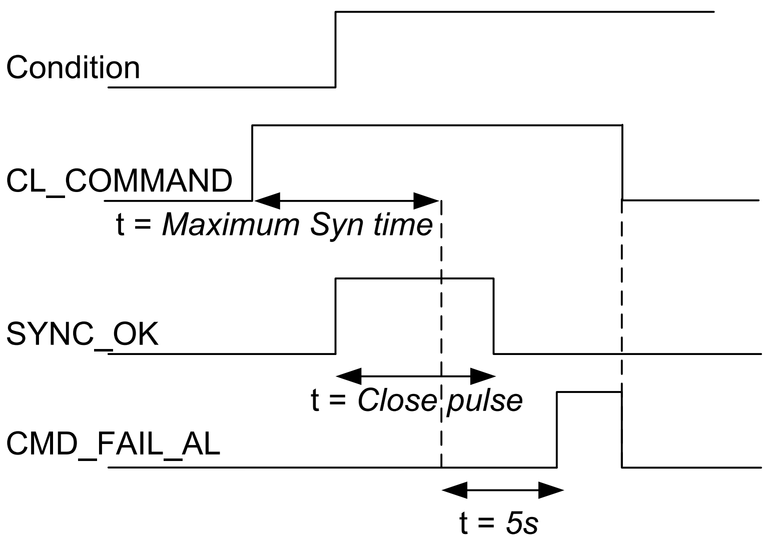


Figure 849: Determination of the alarm limit for a still-active command signal

Closing is permitted during *Maximum Syn time*, starting from the moment the external command signal CL_COMMAND is activated. The CL_COMMAND input must be kept active for the whole time that the closing conditions are waited to be fulfilled. Otherwise, the procedure is cancelled. If the closing-command conditions are fulfilled during *Maximum Syn time*, a SYNC_OK pulse is delivered to the circuit breaker function. If the closing conditions are not fulfilled during the checking time, the alarm CL_FAIL_AL is activated as an indication of a failed closing attempt. The SYNC_OK pulse is not delivered if the closing conditions become valid after *Maximum Syn time* has elapsed. The closing pulse is delivered only once for each activated external command signal, and a new closing-command sequence cannot be started until the external command signal is reset and reactivated. The SYNC_INPRO output is active when the closing-command sequence is in progress and it is reset when the CL_COMMAND input is reset or *Maximum Syn time* has elapsed.

Bypass mode

SECRSYN can be set to the bypass mode by setting the parameters *Synchrocheck mode* and *Live dead mode* to "Off" or alternatively by activating the BYPASS input.

In the bypass mode, the closing conditions are always considered to be fulfilled by SECRSYN. Otherwise, the operation is similar to the normal mode.

Voltage angle difference adjustment

In application where the power transformer is located between the voltage measurement and the vector group connection gives phase difference to the voltages between the high- and low-voltage sides, the angle adjustment can be used to meet synchronism.

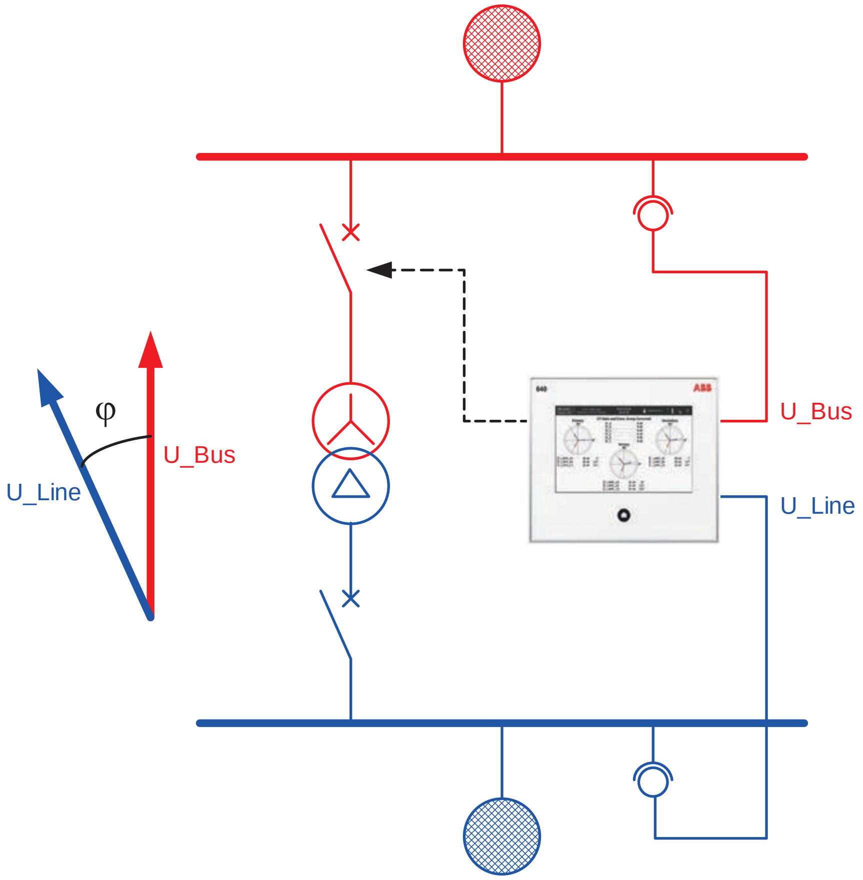


Figure 850: Angle difference when power transformer is in sychrocheck zone

The vector group of the power transformer is defined with clock numbers, where the value of the hour pointer defines the low-voltage-side phasor and the high-voltage-side phasor is always fixed to the clock number 12, which is same as zero. The angle between clock numbers is 30 degrees. When comparing phase angles, the U_BUS input is always the reference. This means that when the Yd11 power transformer is used, the low-voltage-side voltage phasor leads by 30 degrees or lags by 330 degrees the high-voltage-side phasor. The rotation of the phasors is counterclockwise.

The generic rule is that a low-voltage-side phasor lags the high-voltage-side phasor by clock number * 30º. This is called angle difference adjustment and can be set for SECRSYN with the *Phase shift* setting.

9.5.6 Application

The main purpose of the synchrocheck function is to provide control over the closing of the circuit breakers in power networks to prevent the closing if the conditions for synchronism are not detected. This function is also used to prevent the reconnection of two systems which are divided after islanding and a three-pole reclosing.

The Synchro check function block includes both the synchronism check function and the energizing function to allow closing when one side of the breaker is dead.

Network and the generator running in parallel with the network are connected through the line AB. When a fault occurs between A and B, the protection relay protection opens the circuit breakers A and B, thus isolating the faulty section from the network and making the arc that caused the fault extinguish. The first attempt to recover is a delayed autoreclosure made a few seconds later. Then, the autoreclose function DARREC gives a command signal to the synchrocheck function to close the circuit breaker A. SECRSYN performs an energizing check, as the line AB is de-energized (`U_BUS`> *Live bus value*, `U_LINE`< *Dead line value*) . After verifying the line AB is dead and the energizing direction is correct, the protection relay energizes the line (`U_BUS` -> `U_LINE`) by closing the circuit breaker A. The PLC of the power plant discovers that the line has been energized and sends a signal to the other synchrocheck function to close the circuit breaker B. Since both sides of the circuit breaker B are live (`U_BUS` > *Live bus value*, `U_LINE` > *Live bus value*), the synchrocheck function controlling the circuit breaker B performs a synchrocheck and, if the network and the generator are in synchronism, closes the circuit breaker.

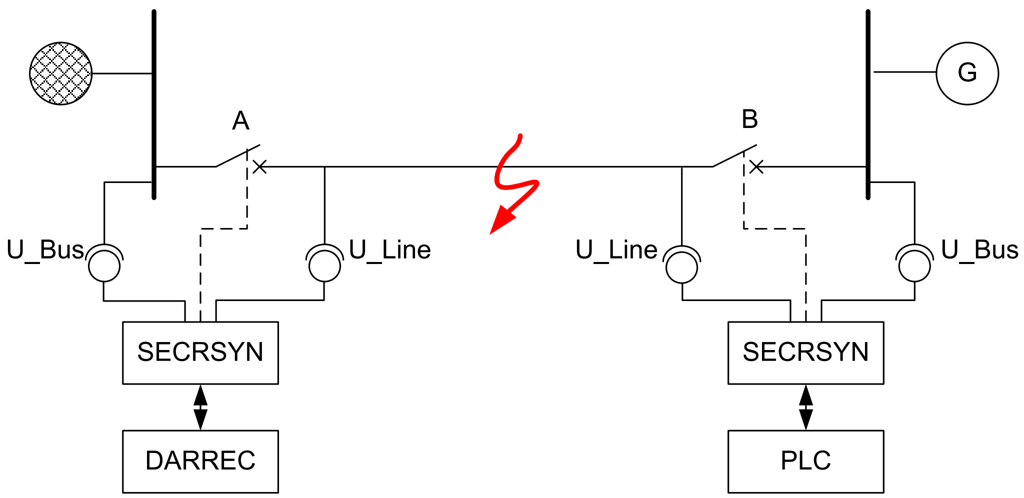


Figure 851: Synchrocheck function SECRSYN checking energizing conditions and synchronism

Connections

A special attention is paid to the connection of the protection relay. Furthermore it is checked that the primary side wiring is correct.

A faulty wiring of the voltage inputs of the protection relay causes a malfunction in the synchrocheck function. If the wires of an energizing input have changed places, the polarity of the input voltage is reversed (180°). In this case, the protection relay permits the circuit breaker closing in a situation where the voltages are in opposite phases. This can damage the electrical devices in the primary circuit. Therefore, it is extremely important that the wiring from the voltage transformers to the terminals on the rear of the protection relay is consistent regarding the energizing inputs U_BUS (bus voltage) and U_LINE (line voltage).

The wiring should be verified by checking the reading of the phase difference measured between the U_BUS and U_LINE voltages. The phase difference measured by the protection relay has to be close to zero within the permitted accuracy tolerances. The measured phase differences are indicated in the LHMI. At the same time, it is recommended to check the voltage difference and the frequency differences presented in the monitored data view. These values should be within the permitted tolerances, that is, close to zero.

Figure 852 shows an example where the synchrocheck is used for the circuit breaker closing between a busbar and a line. The phase-to-phase voltages are measured from the busbar and also one phase-to-phase voltage from the line is measured.

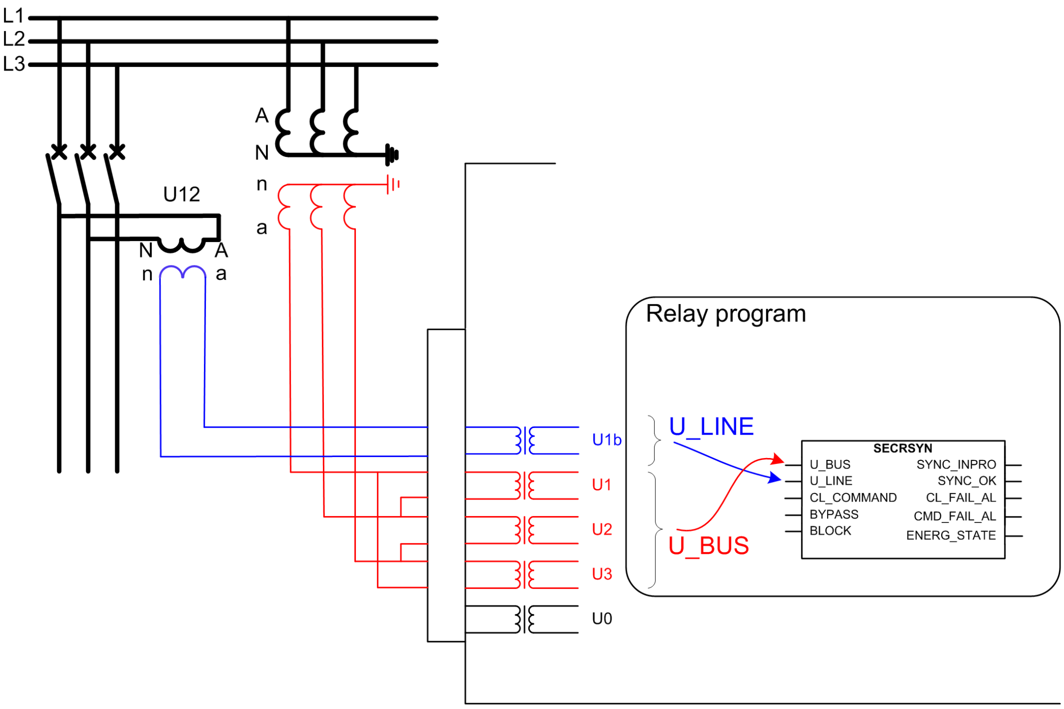


Figure 852: Connection of voltages for the protection relay and signals used in synchrocheck

9.5.7 Signals

9.5.7.1 SECRSYN Input signals

Table 1506: SECRSYN Input signals

Name	Type	Default	Description
U3P1	SIGNAL	-	Three-phase voltages 1
U3P2	SIGNAL	-	Three-phase voltages 2
BLOCK	BOOLEAN	0=False	Blocking signal of the synchro check and voltage check function
CL_COMMAND	BOOLEAN	0=False	External closing request
BYPASS	BOOLEAN	0=False	Request to bypass synchronism check and voltage check

9.5.7.2 SECRSYN Output signals

Table 1507: SECRSYN Output signals

Name	Type	Description
SYNC_INPRO	BOOLEAN	Synchronizing in progress
SYNC_OK	BOOLEAN	Systems in synchronism
CL_FAIL_AL	BOOLEAN	CB closing failed
CMD_FAIL_AL	BOOLEAN	CB closing request failed
LLDB	BOOLEAN	Live Line, Dead Bus
LLLB	BOOLEAN	Live Line, Live Bus
DLLB	BOOLEAN	Dead Line, Live Bus
DLDB	BOOLEAN	Dead Line, Dead Bus

9.5.8 SECRSYN Settings

Table 1508: SECRSYN Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Live dead mode	-1=Off 1=Both Dead 2=Live L, Dead B 3=Dead L, Live B 4=Dead Bus, L Any 5=Dead L, Bus Any 6=One Live, Dead			1=Both Dead	Energizing check mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	7=Not Both Live				
Difference voltage	0.01...0.50	xUn	0.01	0.05	Maximum voltage difference limit
Difference frequency	0.0002...0.1000	xFn	0.0001	0.0010	Maximum frequency difference limit
Difference angle	5...90	deg	1	5	Maximum angle difference limit

Table 1509: SECRSYN Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Synchro check mode	1=Off 2=Synchronous 3=Asynchronous			3=Asynchronous	Synchro check operation mode
Dead line value	0.1...0.8	xUn	0.1	0.2	Voltage low limit line for energizing check
Live line value	0.2...1.0	xUn	0.1	0.8	Voltage high limit line for energizing check
Dead bus value	0.1...0.8	xUn	0.1	0.2	Voltage low limit bus for energizing check
Live bus value	0.2...1.0	xUn	0.1	0.5	Voltage high limit bus for energizing check
Max energizing V	0.50...1.15	xUn	0.01	1.05	Maximum voltage for energizing

Table 1510: SECRSYN Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Control mode	1=Continuous 2=Command			1=Continuous	Selection of synchro check command or Continuous control mode
Close pulse	200...60000	ms	10	200	Breaker closing pulse duration
Phase shift	-180...180	deg	1	0	Correction of phase difference between measured U_BUS and U_LINE
Minimum Syn time	0...60000	ms	10	0	Minimum time to accept synchronizing
Maximum Syn time	100...6000000	ms	10	2000	Maximum time to accept synchronizing
Energizing time	100...60000	ms	10	100	Time delay for energizing check
Closing time of CB	40...250	ms	10	60	Closing time of the breaker
Voltage source switch	0=False 1=True			0=False	Voltage source switch

9.5.9 SECRSYN Monitored data

Table 1511: SECRSYN Monitored data

Name	Type	Values (Range)	Unit	Description
ENERG_STATE	Enum	0=Unknown 1=Both Live 2=Live L, Dead B 3=Dead L, Live B 4=Both Dead		Energization state of Line and Bus
U_DIFF_MEAS	FLOAT32	-3.00...3.00	xUn	Calculated voltage amplitude difference
FR_DIFF_MEAS	FLOAT32	-1.500...1.500	xFn	Calculated voltage frequency difference
PH_DIFF_MEAS	FLOAT32	-180.00...180.00	deg	Calculated voltage phase angle difference
U_DIFF_SYNC	BOOLEAN	0=False 1=True		Voltage difference out of limit for synchronizing
PH_DIF_SYNC	BOOLEAN	0=False 1=True		Phase angle difference out of limit for synchronizing
FR_DIFF_SYNC	BOOLEAN	0=False 1=True		Frequency difference out of limit for synchronizing
SECRSYN	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.5.10 Technical data

Table 1512: SECRSYN Technical data

Characteristic	Value
Operation accuracy	Depending on the frequency of the voltage measured: f_n ±1 Hz
	Voltage: ±3.0 % of the set value or ±0.01 × U_n Frequency: ±10 mHz Phase angle: ±3°
Reset time	<50 ms
Reset ratio	Typically 0.96
Operate time accuracy in definite time mode	±1.0 % of the set value or ±20 ms

9.6 Autosynchronizer for generator breaker ASGCSYN (ANSI 25AUTOSYNCG)

9.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autosynchronizer for generator breaker	ASGCSYN	AUTOSYNCG	25AUTOSYNCG

9.6.2 Function block

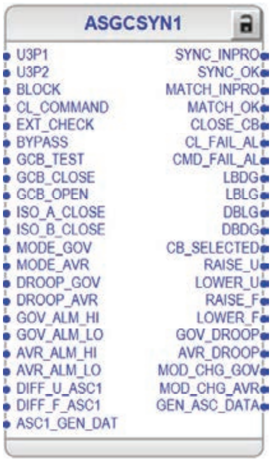


Figure 853: Function block

9.6.3 Functionality

The autosynchronizer for generator breaker function ASGCSYN checks the conditions across the circuit breaker from generator and bus side and issues the pulse commands to the automatic voltage regulator (AVR) and prime mover governor to match the voltage and frequency conditions if required. Once the synchronization check and close CB conditions are fulfilled, the function gives permission to close the circuit breaker. ASGCSYN includes the functionality of energizing check, synchronization check and voltage and frequency matching.

The energizing check function checks that bus side is dead to ensure that breaker closing can be done safely. The synchronization check function checks that the voltages and frequency on both sides of the circuit breaker are within the predefined setting. It is used to perform a controlled reconnection of two systems.

Depending on the selected control mode, the synchronization process is fully automatic or it requires operator action for breaker closing and voltage and frequency matching. In all of the modes, the synchronization check prevents breaker closing if the set limit values are not met.

The voltage and frequency matching function issues raise or lower pulse commands to AVR and the governor to match the voltage and frequency, based on the calculated voltage and frequency difference across the circuit breaker to be synchronized. ASGCSYN also participates in voltage and frequency matching for network breaker synchronization.

9.6.4 Analog channel configuration

ASGCSYN has two analog group inputs which must be properly configured.

Table 1513: Analog inputs

Input	Description
U3P1	Three-phase voltages (generator side)
U3P2	Three-phase voltages (bus side)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1514: Special conditions

Condition	Description
U3P1 and U3P2 connected to real measurements	When one voltage channel from the generator side is connected to channel 1 of `U3P1` and one voltage channel from the bus side is connected to channel 1 of `U3P2`, the function can only work if UTVTR's *VT connection* settings on the generator and bus sides are similar.
	The function can work if one voltage channel from the generator side is connected to channel 1 of `U3P1` and three voltage channels from the bus side are connected to `U3P2`.
	The function can work if one voltage channel from the generator side is connected to channel 1 of `U3P1` and two voltage channels along with the residual voltage from the bus side are connected to `U3P2`.
	The function can work if three voltage channels from the generator side are connected to `U3P1` and one voltage channel from the bus side is connected to channel 1 of `U3P2`.
	The function can work if two voltage channels and the residual voltage from the generator side are connected to `U3P1` and one voltage channel from the bus side is connected to channel 1 of `U3P2`.
Dissimilar VT connection settings for UTVTR on the generator and bus sides	The function requires that all three voltage channels or two voltage channels and the residual voltage are connected to either `U3P1` or `U3P2`.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

9.6.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of ASGCSYN can be described with a module diagram. All the modules in the diagram are explained in the next sections.

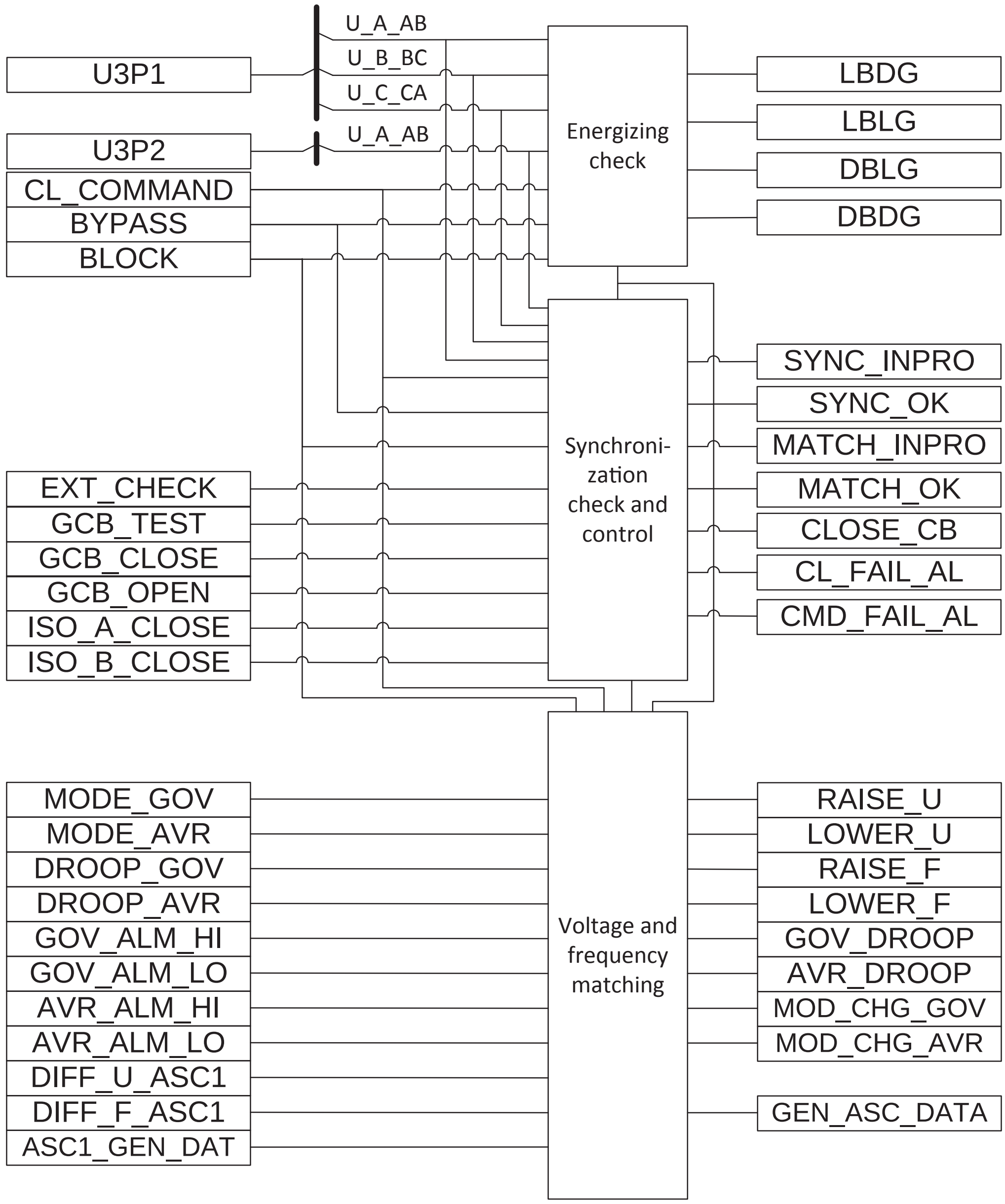


Figure 854: Functional module diagram

ASGCSYN can operate either with the U_AB or U_A voltages. The selection of used voltages is defined with the *VT connection* setting of the voltage measurement parameters.

9.6.5.1 Energizing check

The Energizing check module checks the energizing direction. Energizing is the situation where a dead network part is connected to an energized section of the network. The conditions of the network sections to be controlled by the circuit breaker, that is, which side has to be live and which side dead, are determined by the setting *Live dead mode*.

Live dead mode can be set in two ways: either through settings or through the command control.

If the *Live dead mode* parameter under the Setting menu is set as "Command", then *Live dead mode Ctl* parameter under the Control menu can be used to select the values in *Table 1515*. Otherwise, the *Live dead mode* parameter under the Setting menu is used to select the values in *Table 1515*.

Table 1515: Live dead mode of operation when switching can be carried out

Live dead mode	Description
Off	Live dead mode setting is in off status
Both Dead	Both bus and generator de-energized
Live G, Dead B	Bus de-energized and generator energized
Dead B, G Any	Bus de-energized and generator energized or de-energized

The actual value for defining the dead bus or generator is given with the *Dead voltage value* setting. Similarly, the actual values of live bus or generator are defined with the *Live voltage value* setting.

When the energizing direction corresponds to the settings, the situation has to be constant for a time set with the *Energizing time* setting before the circuit breaker closing is permitted. This time delay ensures that the dead side remains de-energized and that the situation is not caused by a temporary interference. If the conditions do not persist for a specified operate time, the timer is reset and the procedure is restarted when the conditions allow it. The circuit breaker does not close if the measured voltage on the live side is greater than the set value of *Maximum voltage*.

The measured energized state is available as a monitored data value ENERG_STATE and as four function outputs LBLG (“Both Live”), LBDG (“Live B, Dead G”), DBLG (“Dead B, Live G”) and DBDG (“Both Dead”), of which only one can be active at a time. The measured energized state indicates “Unknown” if at least one of the measured voltages is between the limits set with the dead and live setting parameters.

9.6.5.2 Synchronization check and control

The operation of Synchronization check and control modes can be described with a module diagram.

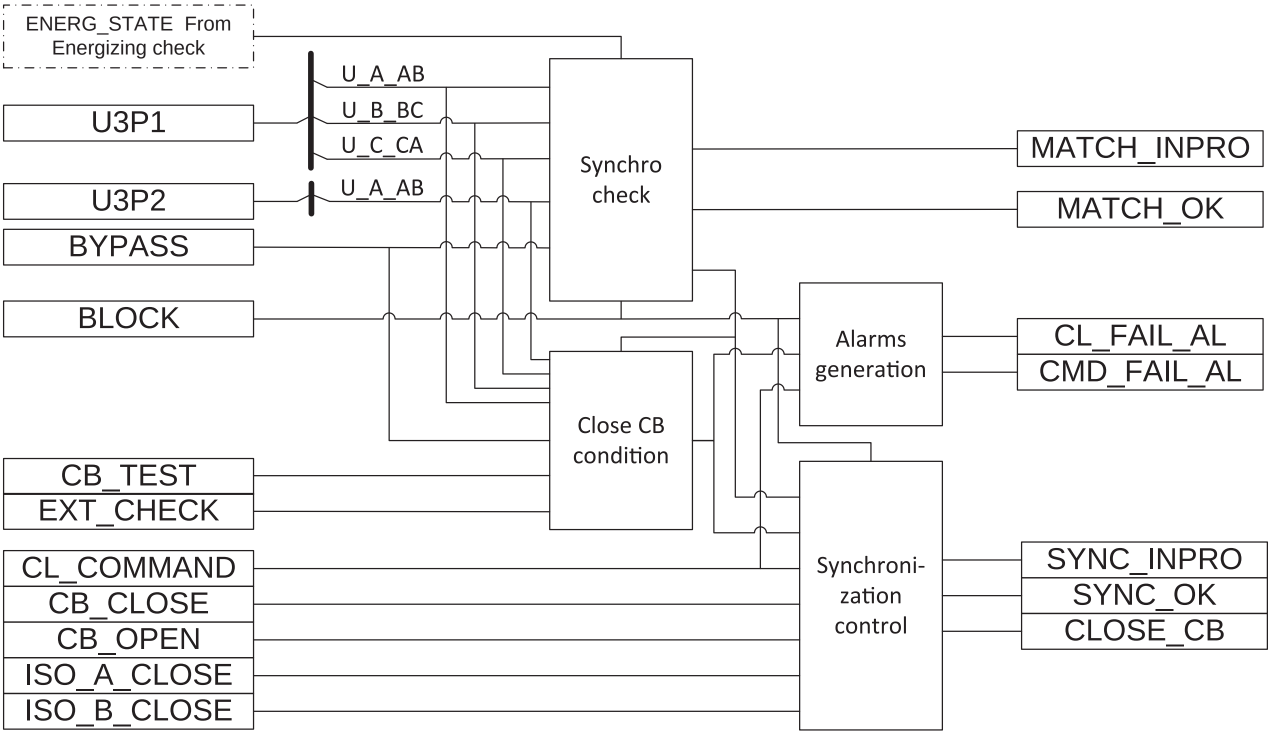


Figure 855: Module diagram for Synchronization check and control

Synchro check

The function measures the voltage difference U_DIFF_MEAS, frequency difference FR_DIFF_MEAS and phase angle difference PH_DIFF_MEAS between the bus voltage and generator voltage. In the calculation of PH_DIFF_MEAS, setting *Phase shift* is used to compensate the angle shift caused if a power transformer is located between the voltage measurements. Offset correction due to different channel measurements (for voltage and frequency values) can be done using *Voltage offset* and *Frequency offset*. The user can select the direction of generator synchronization using the setting *Synchronization Dir*.

$$U\_DIFF\_MEAS = U_{Gen} - U_{Bus} - Voltage\ offset$$

(Equation 353)

U_{Bus}	Measured bus side voltage
U_{Gen}	Measured generator side voltage
Voltage offset	Setting *Voltage offset*

$$FR\_DIFF\_MEAS = f_{Gen} - f_{Bus} - Frequency\ offset$$

(Equation 354)

f_{Bus}	Measured bus side frequency
f_{Gen}	Measured generator side frequency
Frequency offset	Setting *Frequency offset*

$$PH\_DIFF\_MEAS = \angle U_{Gen} - \angle U_{Bus} - Phase\ shift$$

(Equation 355)

$\angle U_{Bus}$	Measured bus side voltage phase angle
$\angle U_{Gen}$	Measured generator side voltage phase angle
Phase shift	Setting *Phase shift*

The synchronism conditions are checked according to several criteria.

- The measured bus and generator voltages are higher than the set value of *Live voltage value* (ENERG_STATE equals “Both Live”).
- The measured bus and generator frequencies are both within the range of 95...105 percent of the nominal frequency (fn).
- The measured bus and generator voltages are lower than the set value of *Maximum voltage*.

If the *Synchrocheck mode* parameter under the Setting menu is set as "Command", then the *SynchroChk Mod Ctl* parameter under the Control menu is used to set values "OFF/Asynchronous". Otherwise, the *Synchrocheck mode* parameter under the Setting menu is used to set the values "Off/Asynchronous".

Some additional conditions must also be fulfilled as per the set *Synchrocheck mode*.

Table 1516: Additional conditions for the Synchro check

Measurements	Synchrocheck mode “Asynchronous”
U_DIFF_MEAS	< Voltage Diff Ov Ex and > -Voltage Diff Un Ex
PH_DIFF_MEAS	< Angle Diff positive and > - Angle Diff negative
FR_DIFF_MEAS	< Freq Diff OV Synch and > -Freq Diff sub Synch
Closing angle	< Angle Diff positive and >- Angle Diff negative

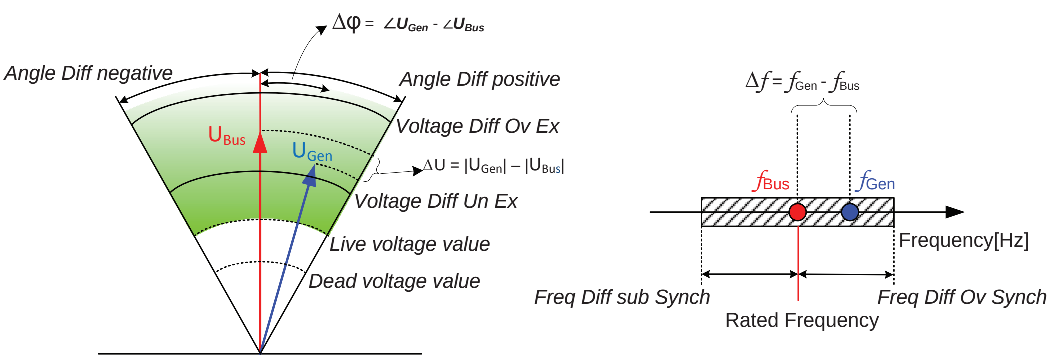


Figure 856: Conditions to be fulfilled when detecting synchronism between systems

When the measured differences in voltage and frequency are within the synchro check limits, the output `MATCH_OK` is activated. The output `MATCH_INPRO` is active while the voltage and frequency matching is in progress.

When the frequency, phase angle and voltage conditions are fulfilled, the duration of the synchronism conditions is checked to ensure that they are still met when the condition is determined on the basis of the measured frequency and phase difference. Depending on the circuit breaker and the closing system, the delay between the closing signal and the circuit breaker closing is about 50...250 ms. The selected *Closing time of CB* informs the function how long the conditions have to persist. The value covers both circuit breaker closing delay and output type dependent delay. The synchro check function compensates for the measured slip frequency and the circuit breaker closing delay. The closing angle advance is calculated continuously:

$$Closing\ angle = \left| (\angle U_{Gen} - \angle U_{Bus})^{\circ} + \left((f_{Gen} - f_{Bus}) \cdot \left(\frac{TCB}{1000} \right) \cdot 360^{\circ} \right) \right|$$

(Equation 356)

$\angle U_{Bus}$	Measured generator voltage phase angle
$\angle U_{Gen}$	Measured bus voltage phase angle
TCB	Parameter *Closing time of CB* to be set as in *Equation 357*

$$TCB = t_{CB} + T_{PL} + x$$

(Equation 357)

t_{CB}	Circuit breaker closing delay in ms
T_{PL}	Output type dependent delay in ms (see *Table 1517*)
x	Hardware delays between the protection relay and CB in ms; delays due to, for example, auxiliary relays and contactors, if used

Table 1517: Typical delays for different output types

Output type	Recommended value for T_{PL}	
	Generator voltage measurement: Non-Adaptive Bus voltage measurement: Non-Adaptive	Generator voltage measurement: Adaptive Bus voltage measurement: Non-Adaptive
Semiconductor output (SPO)	16 ms	7 ms
Mechanical relay output (POSP, PODP)	23 ms	13 ms

The *Minimum Syn time* setting defines the minimum time for which synchro check conditions must be simultaneously fulfilled.

ASGCSYN can be set to the bypass mode by setting the parameters *Synchrocheck mode* and *Live dead mode* to "Off" or, alternatively, by activating the `BYPASS` input. In the bypass mode, the synchro check conditions are always fulfilled. Otherwise, the operation is similar to the normal mode.

The frequency slip acceleration (ds/dt) FR_SLIP_ACCL is the average value of frequency slip difference (Δs) calculated over a time period of 0.5 s.

$$Frequency\ slip(s) = \frac{(f_{Gen} - f_{Bus})}{f_{Bus}}$$

(Equation 358)

The measured bus voltage (U_{Bus}), bus frequency (f_{Bus}), generator voltage (U_{Gen}), generator frequency (f_{Gen}) and phase angle difference values between the two sides of the circuit breaker are available as monitored data values U_BUS_MEAS, FR_BUS_MEAS, U_GEN_MEAS, FR_GEN_MEAS, U_DIFF_MEAS, FR_DIFF_MEAS and PH_DIFF_MEAS. The calculated frequency slip acceleration (ds/dt) is available as monitored data value FR_SLIP_ACCL. Also, the indications of the conditions that are not fulfilled and thus preventing the breaker closing permission are available as monitored data values U_DIFF_SYNC, PH_DIF_SYNC and FR_DIFF_SYNC. These monitored data values are updated only when the setting *Synchrocheck mode* is set to "Asynchronous" and the measured ENERG_STATE is "Both Live".

The measured voltage, frequency are updated in the monitored data irrespective of any condition.

Close CB condition

When *Synchrocheck mode* is set to "Asynchronous", the close CB condition is generated as explained below.

From the frequency slip s, the acceleration ds/dt, the bus frequency FR_BUS_MEAS (f_{Bus}) and the set *Closing time of CB*, the function calculates the necessary lead angle (α_{Lead}) by which the close CB command is shifted forward in time so that the main contacts close on phase coincidence.

$$\alpha_{Lead} = \left(360 \cdot f_{Bus} \cdot \left(s + \frac{\frac{TCB}{2} \cdot \frac{ds}{dt}}{1000} \right) \cdot \frac{TCB}{1000} \right)$$

(Equation 359)

f_{Bus}	Bus side frequency
s	Frequency slip
ds/dt	Frequency slip acceleration
TCB	Setting *Closing time of CB*

ASGCSYN can be set to the bypass mode by setting the parameters *Synchrocheck mode* and *Live dead mode* to "Off" or, alternatively, by activating the BYPASS input. In the bypass mode, the close CB conditions are always fulfilled. Otherwise, the operation is similar to the normal mode.

If the parameter *Synchronization Dir* is “Both directions”, function issues CLOSE_CB output direct-ly when the measured frequency difference is zero and the measured phase difference is less than 5 degrees for duration set by *Minimum Syn time*.

If the parameter *Synchronization Dir* is “Always over-synchronous”, closing signal is blocked when the measured frequency difference is between 0 and 1/3*Freq Diff Ov Synch*.

The monitored data CB_CL_BLKD depends on the inputs GCB_TEST and EXT_CHECK, and also on IED test mode as described in *Table 1518*. CB_CL_BLKD is available in the Monitored data view.

Table 1518: Monitored data CB_CL_BLKD activation based on the inputs

IED test mode	Inputs		Monitored data
	GCB_TEST	**EXT_CHECK**	**CB_CL_BLKD**
TRUE	TRUE	TRUE	1 (“Unblocked”)
FALSE	FALSE		
TRUE	TRUE	FALSE	2 (“Ext Check Fail”)
FALSE	FALSE		
TRUE	FALSE	N/A	3 (“IED Test CB Service”)
FALSE	TRUE	N/A	4 (“IED Service CB Test”)

The close CB condition is blocked if the CB_CL_BLKD status is 2(“Ext Check Fail”), 3(“IED Test CB Service”) or 4(“IED Service CB Test”).

In case for BYPASS input activation,

- If GCB_TEST is activated, CLOSE_CB is activated.
- If GCB_TEST is deactivated, and the bus and generator terminal voltages are both live or one side live, CLOSE_CB is not activated.

Synchronization control

The general bus bar arrangement for a generator bus is shown in *Figure 857*. The bus to which the generator is connected is determined based on the circuit breaker and isolator position inputs (GCB_OPEN, GCB_CLOSE, ISO_A_CLOSE and ISO_B_CLOSE). The generator's bus connection status is shared with the autosynchronizer co-ordinator function ASCGAPC as part of the GEN_ASC_DATA output.

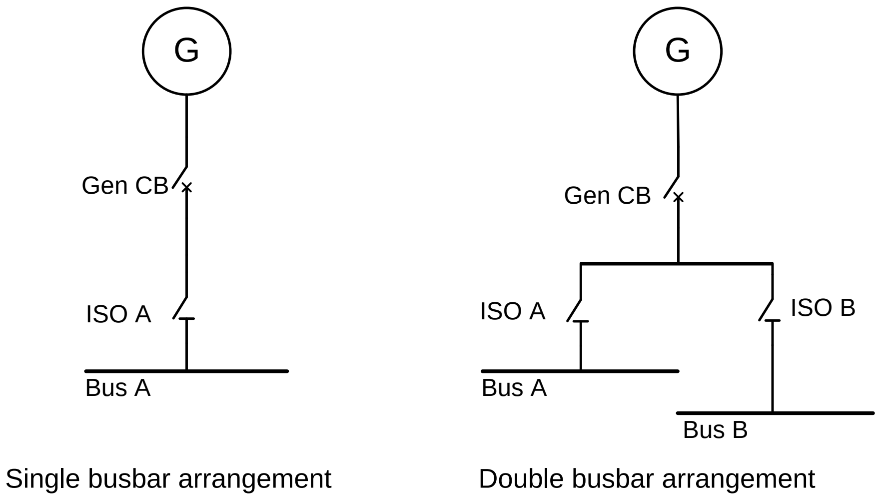


Figure 857: Different bus bar arrangements for a generator bus

Auto synchronization mode

In this mode, the closing signal is delivered if either the command *Synchronize CB* or the input CL_COMMAND is set to TRUE. The relay should be in the local mode if synchronization is initiated with the Synchronize CB command.

If the setting *Auto Syn mode* is set as "Manual mode" or "Semi-automatic synchronising mode", the additional command Manual CB release should be active for the closing signal CLOSE_CB to be activated. If the setting *Auto Syn mode* is set as "Automatic synchronising mode", no additional command is required to activate the closing signal CLOSE_CB.

In this auto synchronization mode, once all the closing conditions are satisfied within the set *Maximum Syn time*, the outputs SYNC_OK and CLOSE_CB become TRUE and remain active as long as the closing conditions are fulfilled. If *Multiple command* is set to "Off", then only CLOSE_CB outputs are delivered once for each activated input signal as shown in *Figure 858*. If *Multiple command* is set to "On", then CLOSE_CB outputs are delivered each time the conditions are satisfied as shown in *Figure 859*.

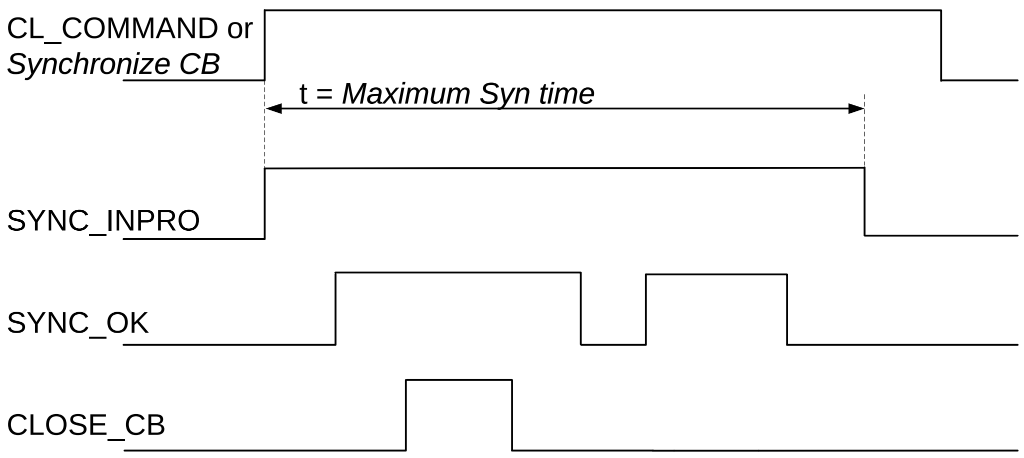


Figure 858: Determination of closing signal CLOSE_CB when Multiple command is set to "Off"

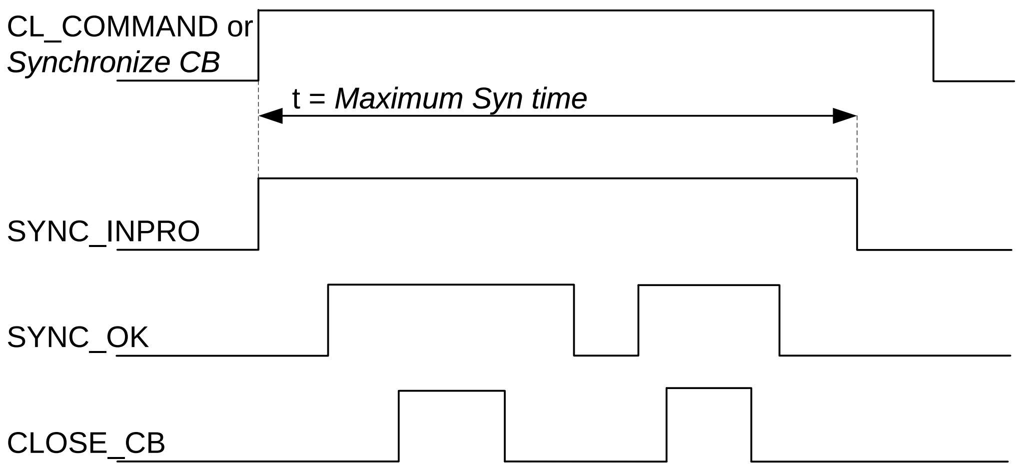


Figure 859: Determination of closing signal CLOSE_CB when Multiple command is set to "On"

The SYNC_INPRO output is active when the close command (CL_COMMAND or *Synchronize CB*) is in progress and it is reset when the close command is reset or *Maximum Syn time* has elapsed.

If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, ASGCSYN gives synchro check permission to the breaker control function block after the closing command signal is delivered. The simplified configuration block diagram of ASGCSYN with CLOSE_CB to the breaker control function block is shown in *Figure 860*.

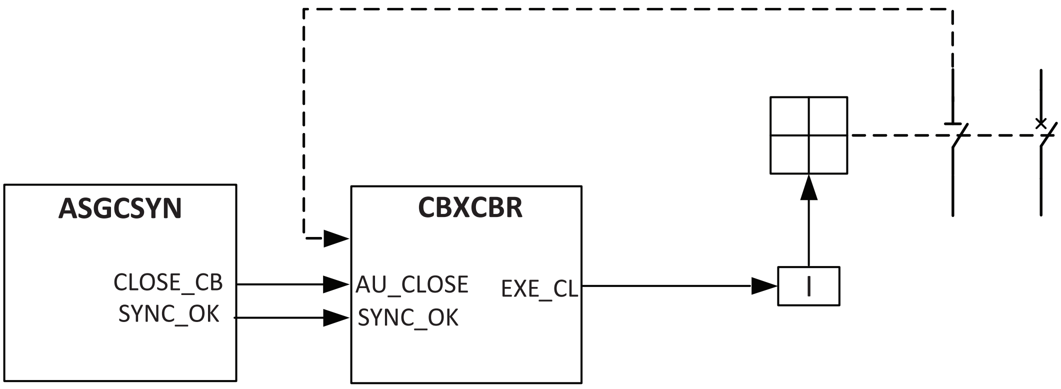


Figure 860: Simplified configuration block diagram of ASGCSYN in auto synchronization mode operation

Alarms generation

In the synchro check command and auto synchronization control mode operation, there are alarms for failed closing attempt (CL_FAIL_AL) and for a command signal that remains active too long (CMD_FAIL_AL).

In the auto synchronization control mode, the closing command generation is activated either by the command input CL_COMMAND or by the command parameter *Synchronize CB*.

From the closing command activation, if the conditions for closing CB are not fulfilled within the set time of *Maximum Syn time*, a failed closing attempt alarm is given. The CL_FAIL_AL alarm output signal is pulse-shaped and the pulse length is 500 ms.

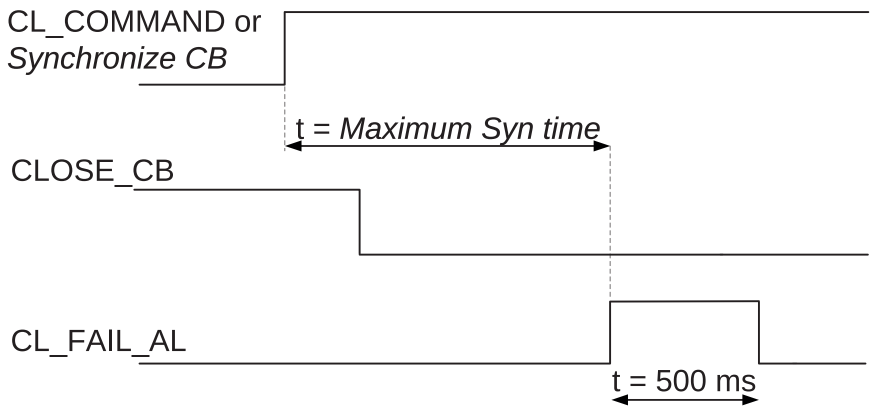


Figure 861: Determination of checking time for closing

CB closing is permitted during *Maximum Syn time*, starting from the moment the close command is activated. The close command must be active while the closing conditions are fulfilled, otherwise the procedure is cancelled. If the closing conditions are fulfilled during *Maximum Syn time*, a closing pulse output is delivered to the circuit breaker. If the closing conditions are not fulfilled during the checking time, the alarm CL_FAIL_AL is activated as an indication of a failed closing attempt. The closing pulse is not delivered if the closing conditions become valid after *Maximum Syn time* has elapsed. The closing pulse is delivered only once for each activated close command, and a new closing command sequence cannot be started until the close command is reset and reactivated.

The circuit breaker control function block receives information about the circuit breaker status and thus is able to adjust the command signal to be delivered to ASGCSYN. If the closing command is active longer than necessary, the CMD_FAIL_AL alarm output is activated. To avoid unnecessary alarms, the maximum length of the closing command signal should be below *Maximum Syn time* + 5 s.

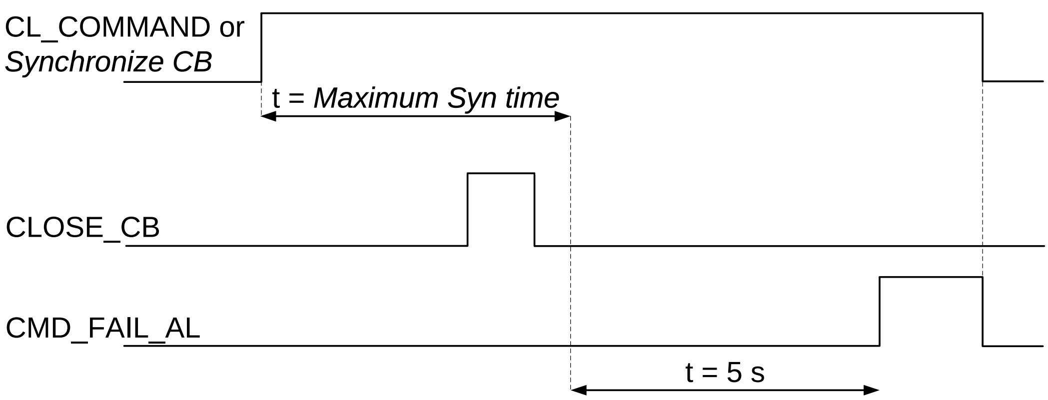


Figure 862: Determination of the alarm limit for a still-active command signal

9.6.5.3 Voltage and frequency matching

The operation of the Voltage and frequency matching module can be described with a module diagram. All the modules in the diagram are explained in the next sections.

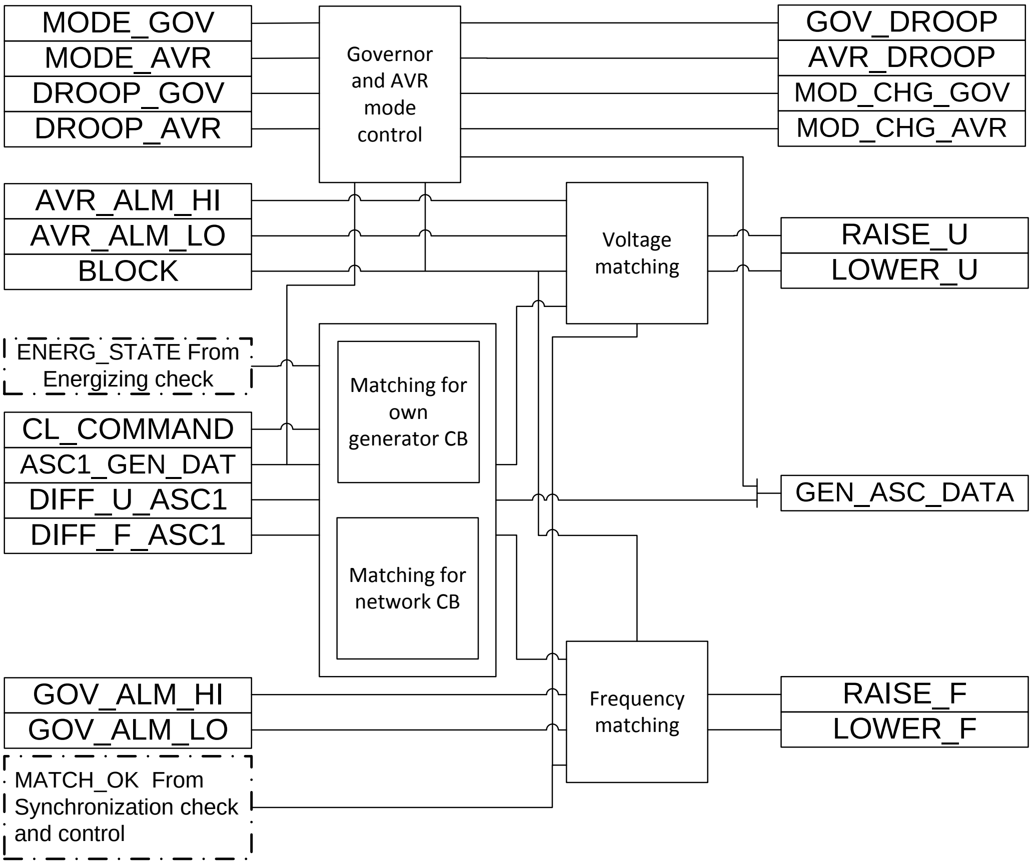


Figure 863: Module diagram for Voltage and frequency matching

The voltage and frequency matching is activated automatically during the “Autosynchronization” mode.

Governor and AVR mode control

If the setting *Central PMS present* is set to "Yes", then the governor and AVR mode is decided based on the inputs MODE_GOV and MODE_AVR, respectively. If the setting *Central PMS present* is set to "No", then the governor and AVR mode is decided based on the inputs DROOP_GOV and DROOP_AVR, respectively.

For the matching of frequency and voltage, the governor or AVR mode must be 1(“Droop”) or 2(“Fixed MW’). Otherwise, the MOD_CHG_GOV or MOD_CHG_AVR output is used for the mode change request.

When the setting *Central PMS present* is set to "Yes" and the Governor or AVR mode is not 1(“Droop”) or 2(“Fixed MW’), then the function sets MOD_CHG_GOV or MOD_CHG_AVR output to (“Droop”) or (“Fixed MW’). Otherwise, the function sets MOD_CHG_GOV or MOD_CHG_AVR output to “No change”.

When the setting *Central PMS present* is set to "No" and the Governor or AVR mode is not Droop mode, then the function activates the binary output GOV_DROOP or AVR_DROOP by using the input DROOP_GOV or DROOP_AVR.

The governor and AVR modes can also be changed through the command parameters *Gov mode change* and *AVR mode change*, respectively. If the command parameter *Gov mode change* is set to "Droop" or "Fixed MW", the function activates the binary output GOV_DROOP and sets integer output MOD_CHG_GOV to 1(“Droop”) or 2(“Fixed MW’), respectively. If the command parameter *AVR mode change* is set to "Droop" or "Fixed MVAr", the function activates the binary output AVR_DROOP and sets integer output MOD_CHG_AVR to 9(“Droop”) or 11(“Fixed MVAr”), respectively.

Matching for own generator CB

If the command ‘Synchronize CB’ is set to “TRUE” or input CL_COMMAND is TRUE, the generator CB is selected for synchronizing. For the voltage and frequency matching to start, the generator CB should be in open position and *Synchrocheck mode* should be set to "Asynchronous".

The measured voltage difference U_DIFF_MEAS is used for generating AVR raise or lower pulses to match the voltages across the CB. The measured frequency difference FR_DIFF_MEAS is used for generating governor raise or lower pulses to match the frequencies across the CB. The voltage and frequency matching starts only when the ENERG_STATE is “Both Live”.

Voltage difference (ΔU) = U_DIFF_MEAS

Frequency difference (ΔF) = FR_DIFF_MEAS

Matching for network CB

The generator is ready for network CB matching only when the generator CB is closed, the protection relay is in remote mode and the generator is requested for matching from non-source function.

After receiving the acknowledgement from ASGCSYN, the autosynchronizer coordinator function ASCGAPC gives permission to participate in the voltage and frequency matching across the CB to be synchronized in the network. ASCGAPC also shares the information about how many generators participate in the voltage matching (NgV) and frequency matching (NgF). Depending on the number of participating generators, the voltage and frequency difference is divided among the generators.

The voltage and frequency difference calculated for generating raise or lower pulses for AVR and governor are

Voltage difference (ΔU) = DIFF_U_ASC1 / NgV

Frequency difference (ΔF) = DIFF_F_ASC1 / NgF

The sign bit for voltage difference and frequency difference is decided based on the data received from ASCGAPC. The calculated voltage difference and frequency difference are available in the Monitored data view U_DIFF_NTW and FR_DIFF_NTW, respectively.

Voltage matching

Working range of the voltage matcher

If the bus voltage U_BUS is between settings *Minimum voltage* and *Maximum voltage* and the generator voltage U_GEN is greater than the setting *Dead voltage value*, the adjusting commands are released. The direction of the adjusting commands depends on the polarity of ΔU. As an additional condition, both frequencies must be in the range f_n ±5 Hz.

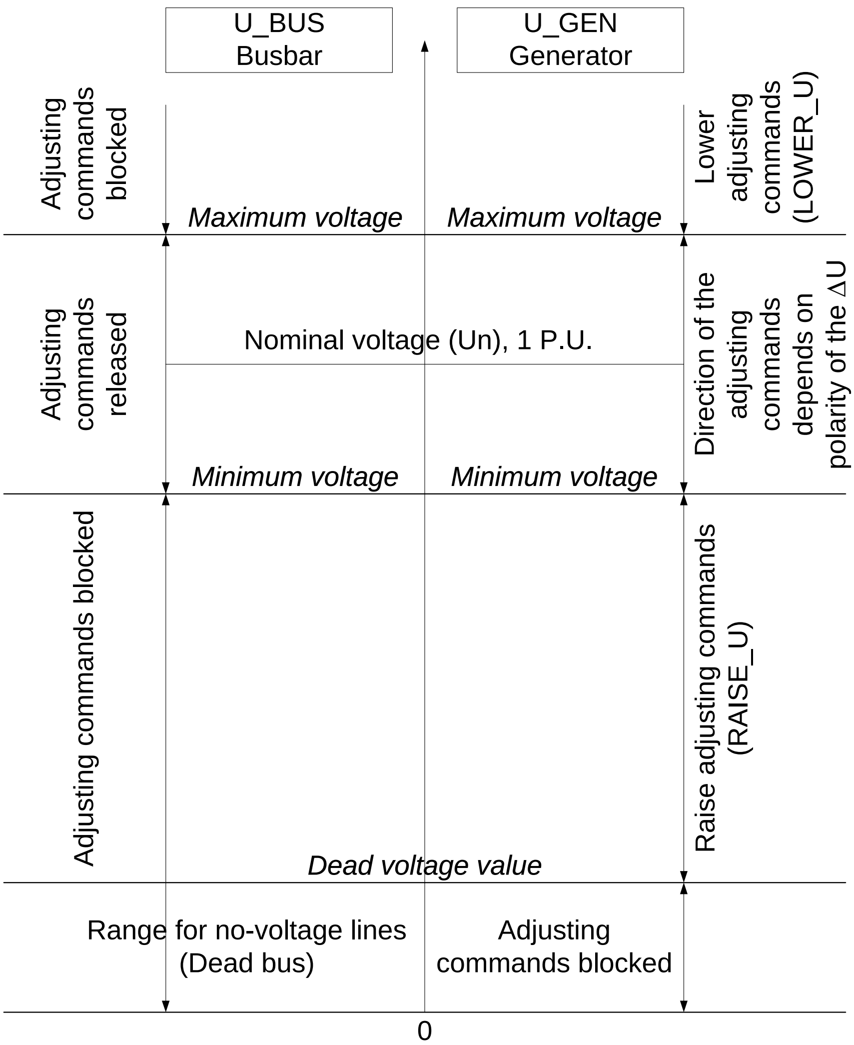


Figure 864: Working range of the voltage matcher

If *Auto Syn mode* is set to either "Semi-automatic synchronizing mode" or "Automatic synchronizing mode", the voltage raise or lower command pulses are generated from the function based on the voltage difference across the breaker and AVR response characteristics. If the voltage difference (ΔU) is negative, it means the reference side voltage is greater than the running side voltage. So the voltage matching generates the voltage raise command pulse `RAISE_U`. If the voltage difference (ΔU) is positive, it means the reference side voltage is lower than the running side voltage. So the voltage matching generates the voltage lower command pulse `LOWER_U`.

The length of the voltage raise and lower command pulse (tpU) and the pulse off interval (tsU) are calculated based on the setting *Voltage match mode*.

Voltage matching in manual mode

If *Auto Syn mode* is set to "Manual mode", the voltage raise or lower command pulses are generated manually from the function's user commands.

If the command *AVR voltage raise* is set to "RAISE", the function activates the voltage raise command pulse RAISE_U. If the command *AVR voltage lower* is set to "LOWER", the function activates the voltage lower command pulse LOWER_U.

The lengths of these generated pulses tpU and pulse off interval tsU are based on the settings as: tpU = *Volt pulse Min Dur*; tsU = *Volt pulse off Intv*.

Voltage matching with variable command pulse lengths

When the setting *Voltage match mode* is set to "Variable Pulse", the voltage matching is done with variable command pulse lengths.

The voltage matcher issues a command with a length proportional to the voltage difference. The proportionality factor setting *Volt rate of change* (dU/dt) can be adapted to the voltage regulator. The voltage matcher aims at a value in the middle of the set tolerance band.

The adjusting voltage command pulse length tpU is calculated as

$$tpU = \frac{\Delta U - \left(\dfrac{+\Delta U\max - \left| -\Delta U\max \right|}{2} \right)}{\dfrac{dU}{dt}}$$

(Equation 360)

ΔU	Measured voltage difference across the CB to be synchronized
+ΔUmax	Setting *Voltage Diff Ov Ex*
-ΔUmax	Setting *Voltage Diff Un Ex*
dU/dt	Setting *Volt rate of change*

The adjusting pulse is discontinued as soon as the voltage difference exceeds the target value. The command length does not fall below a settable minimum value *Volt pulse Min Dur*. After an adjusting command, the system waits for the set *Volt pulse off Intv* (tsU) so that the actual values can stabilize to the new set point.

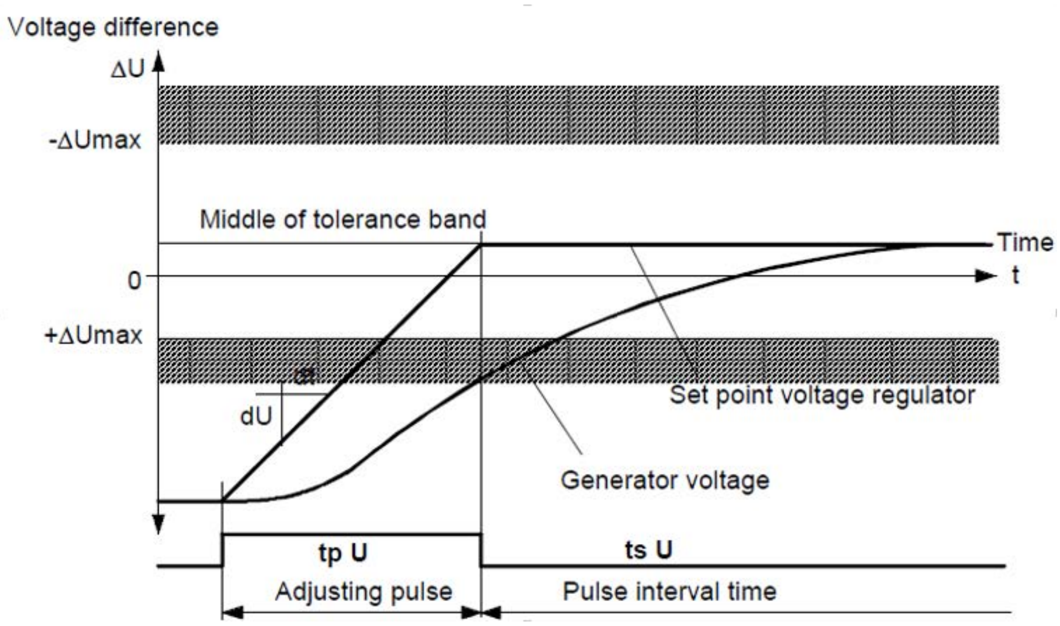


Figure 865: Voltage matching pulse generation with variable command pulse length

Voltage matching with variable command pulse off intervals

When the setting *Voltage match mode* is set to "Variable Interval", the voltage matching is done with variable command pulse off intervals.

The voltage match command pulses are now the same length, but the intervals are inversely proportional to the voltage difference.

Pulse length (tpU): adjustable with the setting *Volt pulse Min Dur* (tpUmin)

Pulse off interval (tsU): adjustable with the setting *Volt pulse off Intv*, and also dependent on settings *Voltage Diff Ov Ex* and *Voltage Diff Un Ex* as per *Equation 361*.

$$tsU = Volt\ pulse\ off\ Intv \cdot \left(1 - 0.325 \cdot \left(\Delta U - \frac{(+\Delta U\max + |-\Delta U\max|)}{2}\right)\right) \geq 0$$

(Equation 361)

ΔU	Measured voltage difference across the CB to be synchronized
+ΔUmax	Setting *Voltage Diff Ov Ex*
-ΔUmax	Setting *Voltage Diff Un Ex*

Reset of voltage raise and lower command pulses

The generated voltage raise and lower command pulses RAISE_U and LOWER_U are immediately reset if any of the following conditions is met.

- During matching of its own CB synchronization
  - If AVR lower limit alarm AVR_ALM_LO is TRUE, it resets the voltage lower command LOWER_U. If AVR high limit alarm AVR_ALM_HI is TRUE, it resets the voltage raise command RAISE_U.
  - If the output MATCH_OK is TRUE, the raise and lower commands are reset.

- If the voltage difference reaches the target value with a hysteresis band that is in the middle of the tolerance band specified by the settings *Voltage Diff Ov Ex* and *Voltage Diff Un Ex*, the raise and lower commands are reset.

• During matching of network CB synchronization
  - If either of the AVR limit alarms AVR_ALM_LO and AVR_ALM_HI is TRUE, it resets the voltage raise and lower commands.
  - When the generator is selected for fine tuning, if the voltage difference is within the limits of tolerance band specified by the settings *Voltage Diff Ov Ex* and *Voltage Diff Un Ex*, the raise and lower commands are reset.
  - When the generator is selected for coarse tuning, if the voltage difference reaches within the limits of *Coarse Volt Diff Ov* and *Coarse Volt Diff Un*, the raise and lower commands are reset.

Voltage rate of change tuning

When the control command parameter *Tune V and F match* is set to "Volt match rate", the function calculates the generator voltage matching rate (dU/dt). The calculated voltage matching rate is stored to the nonvolatile memory output VOLT_CHG_RTE and is available in the Monitored data view. Once stored, the value from the output VOLT_CHG_RTE can be used to set the setting *Volt rate of change*.

This tuned voltage matching rate proceeds as follows:

1. The generator voltage is adjusted until it lies in the range of 95...97 % of the line voltage, then the adjusting pulse is discontinued.
2. Ten seconds after the first adjusting pulse, the voltage difference ΔU0 is measured, then a voltage raise command RAISE_U lasting 5 s is given. Ten seconds after the end of the pulse, the voltage difference ΔU is measured and dU/ dt calculated according to the following formula:

$$\frac{dU}{dt} = \frac{\Delta U - \Delta U_0}{5}$$

(Equation 362)

3. With this dU/dt value, the generator voltage is brought back to approximately 96 %.

Ten seconds later, the generator voltage is brought to approximately 100 % with the same dU/dt value. After ten seconds, dU/dt is calculated again and shown as monitored data output VOLT_CHG_RTE.

Frequency matching

Working range of the frequency matcher

No adjustment takes place between 1/3 and 2/3 of smax. The adjusting pulse is discontinued as soon as the slip passes through zero. The command length does not fall below a settable *Freq pulse Min Dur*. After an adjusting command, the system waits for the set *Freq pulse off Intv* so that the actual values can stabilize to the new set point.

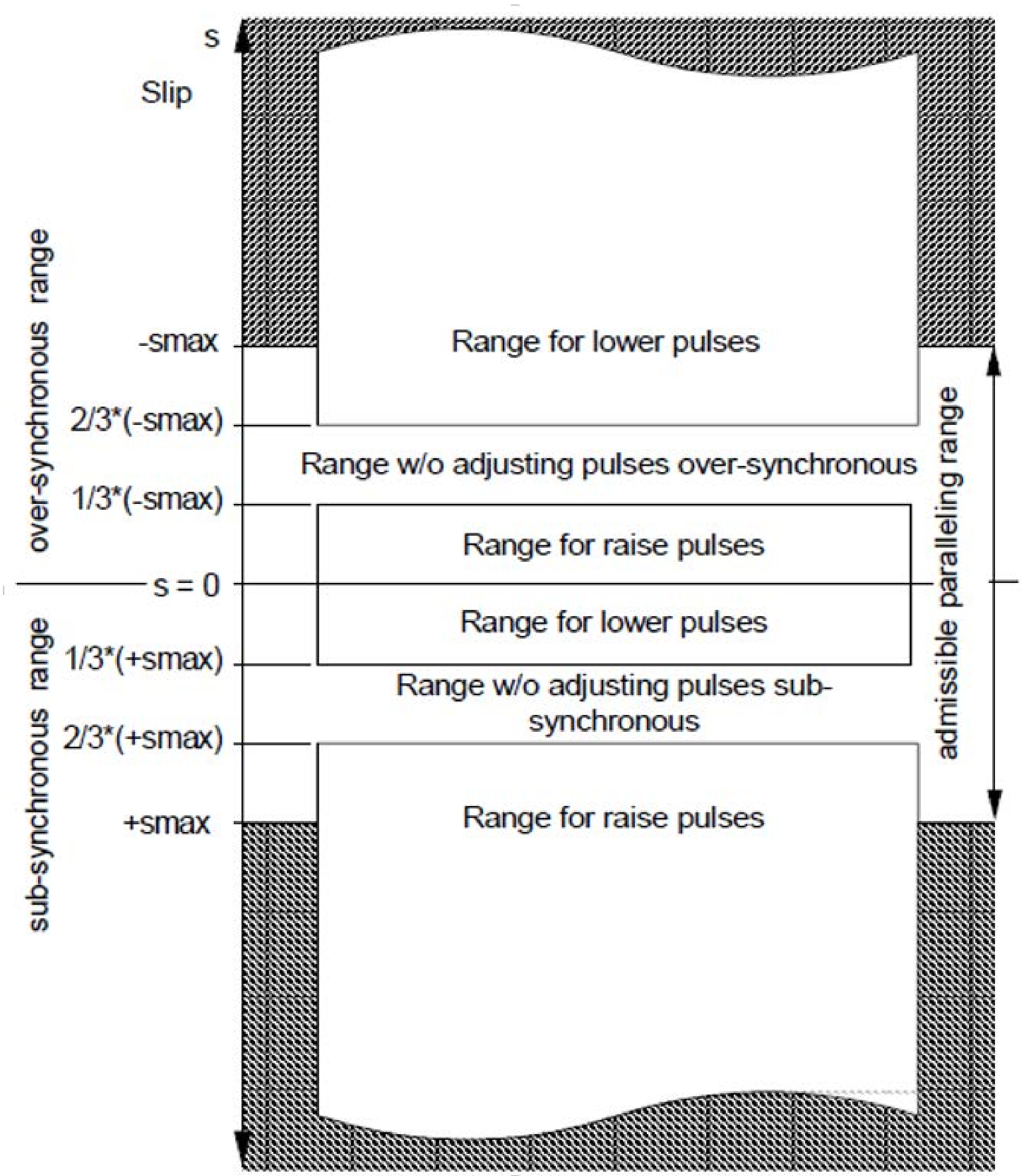


Figure 866: Working range of the frequency matcher

If *Auto Syn mode* is set to either "Semi-automatic synchronizing mode" or "Automatic synchronizing mode", the frequency raise or lower command pulses are generated from the function based on the frequency difference across the CB and governor response characteristics.

If the frequency difference (DF) is negative, the reference side frequency is greater than the running side frequency. So the frequency matching generates frequency raise command pulse `RAISE_F`.

If the frequency difference (DF) is positive, it means the reference side frequency is lower than the running side frequency. So the frequency matching generates frequency lower command pulse `LOWER_F`.

The length of the frequency raise and lower command pulses (tpf) and pulse off interval (tsf) are calculated based on the setting *Frequency match mode*.

Frequency matching in manual mode

If *Auto Syn mode* is set to "Manual mode", the frequency raise or lower command pulses are generated manually from the function's user commands.

If the command Gov frequency raise is set to “RAISE”, the function activates the frequency raise command pulse RAISE_F. If the command Gov frequency lower is set to “LOWER”, the function activates the frequency lower command pulse LOWER_F.

The length of these generated pulses tpf and pulse off interval tsf are based on the settings as: tpf = *Freq pulse Min Dur*; tsf = *Freq pulse off Intv*.

Frequency matching with variable command pulse lengths

When the setting *Frequency match mode* is set to "Variable Pulse", the frequency matching is done with variable command pulse lengths.

The frequency matcher issues a command with a length proportional to the current slip. The proportionality factor df/dt can be adapted to the governor. The frequency matcher aims at a value midway between the nearer slip limit and zero.

The adjusting frequency command pulse length tpf is calculated as

$$tpf = \frac{\left|\pm s\right| - \frac{\left|\pm s\max\right|}{2}}{\frac{df}{dt}}$$

(Equation 363)

s	Measured frequency difference across the CB to be synchronized
+smax	Setting *Freq Diff Ov Synch*
-smax	Setting *Freq Diff sub Synch*
df/dt	Setting *Freq rate of change*

The command length does not fall below a settable minimum value *Freq pulse Min Dur*. After an adjusting command, the system waits for the set *Freq pulse off Intv* (tsf) so that the actual values can stabilize to the new set point.

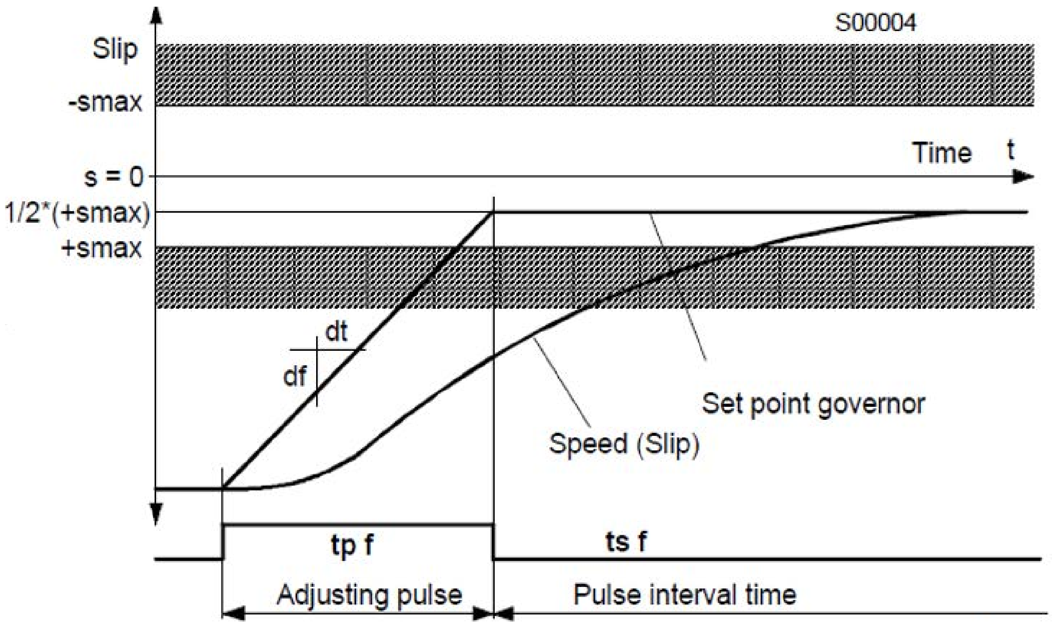


Figure 867: Frequency matching pulses generation with variable command pulse length

Frequency matching with variable command pulse off intervals

When the setting *Frequency match mode* is set to "Variable Interval", the frequency matching is done with variable command pulse off intervals.

The voltage match command pulses are now the same length, but the intervals are inversely proportional to the frequency slip.

Pulse length (tpf): adjustable with the setting *Freq pulse Min Dur* (tpfmin)

Pulse off interval (tsf): calculated as

$$tsf = \frac{1}{f_{Gen} - f_{Bus}} = \frac{1}{f_{Gen}|s|} \leq 30\ [Sec]$$

(Equation 364)

s	Measured frequency slip across the CB to be synchronized
f_{Gen}	Measured generator side frequency
f_{Bus}	Measured bus side frequency

Reset of frequency raise and lower command pulses

The generated frequency raise and lower command pulses RAISE_F and LOWER_F are immediately reset if any of the following conditions is met.

- During matching of its own CB synchronization
  - If governor lower limit alarm GOV_ALM_LO is TRUE, it resets the frequency lower command LOWER_F. If governor high limit alarm GOV_ALM_HI is TRUE, it resets the frequency raise command RAISE_F.
  - If the output MATCH_OK is TRUE, the raise and lower commands are reset.

- If the frequency difference reaches the target value "± Smax/2" with the hysteresis band specified by the settings *Freq Diff Ov Synch* and *Freq Diff sub Synch*, the raise and lower commands are reset.

- During matching of network CB synchronization
  - If any of the governor limit alarms GOV_ALM_HI or GOV_ALM_LO is TRUE, the raise and lower commands are reset.
  - When the generator is selected for fine tuning, if the frequency difference reaches to target value "± Smax/2" with the hysteresis band specified by the settings *Freq Diff Ov Synch* and *Freq Diff sub Synch*, the raise and lower commands are reset.
  - When the generator is selected for coarse tuning, if the frequency difference reaches within the limits of *Coarse Freq Diff Ov* and *Coarse Freq Diff sub*, the raise and lower commands are reset.

When the matching is done for its own CB synchronization, the output MATCH_OK is activated if the measured voltage and frequency differences are within the set synchro check limits. The MATCH_INPRO output is active while the matching is in progress.

When the matching is done for network CB synchronization, the monitored data NTWMATCH_OK is activated if the network breaker voltage and frequency differences are within the set match limits. NTWMATCH_PRO is active while the matching is in progress. NTWMATCH_OK and NTWMATCH_PRO are available in the Monitored data view.

Frequency rate of change tuning

When the control command parameter *Tune V and F match* is set to "Freq match rate", the function calculates the generator frequency matching rate (dF/dt). The calculated frequency matching rate is stored to the nonvolatile memory output FREQ_CHG_RTE and is available in the Monitored data view. Once stored, the value from FREQ_CHG_RTE can be used to set the setting *Freq rate of change*.

This tune frequency matching rate proceeds as follows:

1. The slip is adjusted until this lies in the range of +1...+3 %, then the adjusting pulse is discontinued.
2. Ten seconds after the first adjusting pulse, the slip s0 is measured, then a frequency raise command RAISE_F lasting 3 s is given. Ten seconds after the end of the pulse, the slip s is measured and df/dt is calculated according to the formula

$$\frac{df}{dt} = \frac{s - s0}{3}$$

(Equation 365)

3. With this df/dt value, the slip is brought back to approximately +2 %.

Ten seconds later, the slip is brought to 0 % with the same df/dt value. After ten seconds, df/dt is calculated again and shown as monitored data output FREQ_CHG_RTE.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all binary outputs, binary monitored data and resets the internal timers.

9.6.6 Application

A circuit breaker is used to connect two different power networks. It is essential to ensure that these power networks are synchronized before closing the circuit breaker, otherwise it may lead to disturbances in the power system, causing stress and damage to the connected equipment.

ASGCSYN controls the closing of the generator circuit breakers in power networks; it enables the closing after matching the voltage and frequency conditions to achieve synchronism. ASGCSYN also participates in matching voltage and frequency conditions for the network breaker synchronization.

ASGCSYN includes both the synchronization check function and the energizing function to allow closing when one side of the breaker is dead.

The participation of ASGCSYN in matching of voltage and frequency conditions for the network breaker synchronization is described via one of the typical application example as shown in *Figure 868*.

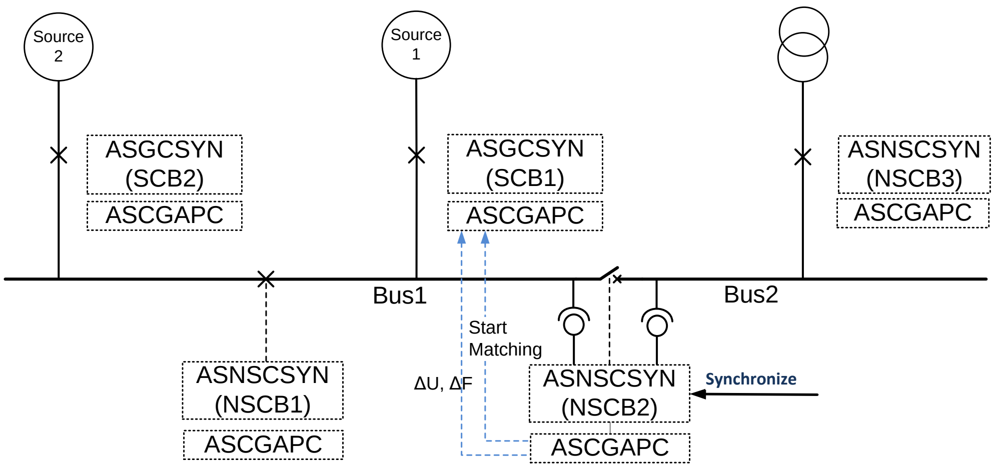


Figure 868: ASGCSYN participation in matching of V, F during network breaker synchronization

In this application example, breaker NSCB2 must be closed, so the synchronizing conditions between the Bus1 and Bus2 power systems are checked by the autosynchronizer for network breaker function ASNSCSYN. If the synchro check conditions are not met, then ASNSCSYN sends the auto synchronization request and voltage and frequency difference (ΔU, ΔF) between Bus1 and Bus2 to the autosynchronizer co-ordinator function ASCGAPC.

ASCGAPC transfers the voltage and frequency difference sent by ASNSCSYN to the ASCGAPC of the generator1 ASGCSYN function. It also sends permission to the generator to start matching the voltage and frequency. The generator's ASGCSYN function gives the raise or lower pulses to AVR and governor to raise or lower their voltage and frequency on Bus2. The matching process is carried out so that the voltage and frequency difference between Bus1 and Bus2 measured by ASNSCSYN reduces and comes within the synchro check limits. This satisfies the synchro check conditions for breaker NSCB2 which can then be synchronized by ASNSCSYN.

Voltage angle difference adjustment

In applications where the power transformer is located between the voltage measurement and the generator circuit breaker, the vector group connection gives phase difference to the voltages between the high- and low-voltage sides. The angle adjustment can be used to meet synchronism.

The vector group of the power transformer is defined with clock numbers, where the value of the hour pointer defines the low-voltage side phasor and the high-voltage side phasor is always fixed to the clock number 12, which is the same as zero. The angle between clock numbers is 30º. When comparing phase angles, the `U_BUS` input is always the reference. This means that when the Yd11 power transformer is used, the low-voltage side voltage phasor leads the high-voltage side phasor by 30º or lags by 330º. The rotation of the phasors is counterclockwise.

The generic rule is that a low-voltage side phasor lags the high-voltage side phasor by clock number · 30º. This is called angle difference adjustment and can be set for ASGCSYN with the *Phase shift* setting.

9.6.7 Signals

9.6.7.1 ASGCSYN Input signals

Table 1519: ASGCSYN Input signals

Name	Type	Default	Description
U3P1	SIGNAL	-	Three-phase voltages (generator side)
U3P2	SIGNAL	-	Three-phase voltages (bus side)
BLOCK	BOOLEAN	0=False	Blocking signal of the auto synchronization function
CL_COMMAND	BOOLEAN	0=False	External closing re-quest
EXT_CHECK	BOOLEAN	0=False	External permissive check for CB close
BYPASS	BOOLEAN	0=False	Request to bypass synchronism check and voltage check
GCB_TEST	BOOLEAN	0=False	Circuit breaker test position status
GCB_CLOSE	BOOLEAN	0=False	Circuit breaker close status
GCB_OPEN	BOOLEAN	0=False	Circuit breaker open status
ISO_A_CLOSE	BOOLEAN	0=False	Isolator A close sta-tus
ISO_B_CLOSE	BOOLEAN	0=False	Isolator B close sta-tus

Table continues on the next page

Name	Type	Default	Description
MODE_GOV	Enum	1=Droop	Governor working mode
MODE_AVR	Enum	9=Droop	AVR working mode
DROOP_GOV	BOOLEAN	0=False	Governor droop mode status
DROOP_AVR	BOOLEAN	0=False	AVR droop mode sta-tus
GOV_ALM_HI	BOOLEAN	0=False	Governor alarm due to high limits
GOV_ALM_LO	BOOLEAN	0=False	Governor alarm due to low limits
AVR_ALM_HI	BOOLEAN	0=False	AVR alarm due to high limits
AVR_ALM_LO	BOOLEAN	0=False	AVR alarm due to low limits
DIFF_U_ASC1	FLOAT32	0.00	Network breaker volt-age difference from ASCGAPC1
DIFF_F_ASC1	FLOAT32	0.000	Network breaker fre-quency difference from ASCGAPC1
ASC1_GEN_DAT	INT32	0	Integer weighted in-put data from ASC-GAPC1

9.6.7.2 ASGCSYN Output signals

Table 1520: ASGCSYN Output signals

Name	Type	Description
SYNC_INPRO	BOOLEAN	Auto synchronization in pro-gress
SYNC_OK	BOOLEAN	Systems in synchronism
MATCH_INPRO	BOOLEAN	Voltage and frequency matching in progress
MATCH_OK	BOOLEAN	Voltage and frequency of the systems matched
CLOSE_CB	BOOLEAN	CB close signal
CL_FAIL_AL	BOOLEAN	CB closing failed
CMD_FAIL_AL	BOOLEAN	CB closing request failed
LBDG	BOOLEAN	Live bus, dead generator
LBLG	BOOLEAN	Live bus, live generator
DBLG	BOOLEAN	Dead bus, live generator

Table continues on the next page

Name	Type	Description
DBDG	BOOLEAN	Dead bus, dead generator
CB_SELECTED	BOOLEAN	CB selected for synchroniza-tion
RAISE_U	BOOLEAN	Raise voltage pulse
LOWER_U	BOOLEAN	Lower voltage pulse
RAISE_F	BOOLEAN	Raise frequency pulse
LOWER_F	BOOLEAN	Lower frequency pulse
GOV_DROOP	BOOLEAN	Command for governor mode change to droop
AVR_DROOP	BOOLEAN	Command for AVR mode change to droop
MOD_CHG_GOV	Enum	MOD_CHG_GOV
MOD_CHG_AVR	Enum	MOD_CHG_AVR
GEN_ASC_DATA	INT32	Integer weighted output data to ASCGAPC

9.6.8 ASGCSYN Settings

Table 1521: ASGCSYN Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Live dead mode	-1=Off -2=Command 1=Both Dead 4=Dead B, G Any 2=Live G, Dead B			-1=Off	Live dead mode
Freq Diff Ov Synch	0.000...0.060	xFn	0.001	0.004	Over synchronous limit for admissible paralleling range
Freq Diff sub Synch	0.000...0.060	xFn	0.001	0.004	Sub synchronous limit for admissible paralleling range
Coarse Freq Diff Ov	0.000...0.060	xFn	0.001	0.005	Over synchronous limit during gener-ator coarse match-ing
Coarse Freq Diff sub	0.000...0.060	xFn	0.001	0.005	Sub synchronous limit during gener-ator coarse match-ing
Voltage Diff Ov Ex	0.00...0.40	xUn	0.01	0.03	Maximum voltage difference limit allowed during matching
Voltage Diff Un Ex	0.00...0.40	xUn	0.01	0.03	Maximum voltage difference limit allowed during matching
Coarse Volt Diff Ov	0.00...0.40	xUn	0.01	0.03	Maximum voltage difference limit allowed during matching

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Coarse Volt Diff Un	0.00...0.40	xUn	0.01	0.03	Maximum voltage difference limit allowed during matching
Angle Diff positive	5...90	deg	1	5	Maximum angle difference limit
Angle Diff negative	5...90	deg	1	5	Maximum angle difference limit
Volt rate of change	0.001...0.050	xUn/s	0.001	0.003	dU/dt adapted to AVR for voltage matching pulses
Freq rate of change	0.001...0.050	xFn/s	0.001	0.002	dF/dt adapted to governor for frequency matching pulses

Table 1522: ASGCSYN Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase shift	-180...180	deg	1	0	Correction of phase difference between measured voltages
Closing time of CB	40...250	ms	1	60	Closing time of the breaker
Multiple command	0=Off 1=On			0=Off	Multiple command generation
Synchronization Dir	1=Always over synchronous 2=Both direction			2=Both direction	Synchronization direction
Voltage offset	-0.100...0.100	xUn	0.001	0.000	Voltage offset
Frequency offset	-0.010...0.010	xFn	0.001	0.000	Frequency offset

Table 1523: ASGCSYN Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Synchrocheck mode	1=Off 3=Asynchronous 4=Command			3=Asynchronous	Synchrocheck operation mode
Dead voltage value	0.10...0.80	xUn	0.10	0.20	Voltage low limit for energizing check
Live voltage value	0.20...1.00	xUn	0.10	0.50	Voltage high limit for energizing check
Maximum voltage	0.50...1.30	xUn	0.01	1.05	Maximum voltage above which no paralleling takes place
Minimum voltage	0.50...0.95	xUn	0.01	0.80	Minimum voltage below which no paralleling takes place
Voltage match mode	1=Off 2=Variable Pulse 3=Variable Interval			2=Variable Pulse	Voltage matcher mode
Frequency match mode	1=Off			2=Variable Pulse	Frequency matcher mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Variable Pulse 3=Variable Interval				
Auto Syn mode	-1=Semi-automatic synchronising mode 1=Automatic synchronising mode 3=Manual mode			3=Manual mode	Auto synchronization operation mode

Table 1524: ASGCSYN Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Minimum Syn time	0...60000	ms	10	0	Minimum time to accept synchronizing
Maximum Syn time	100...6000000	ms	10	60000	Maximum time to accept synchronizing
Energizing time	100...60000	ms	10	100	Time delay for energizing check
Central PMS present	1=No 2=Yes			1=No	Centralized Power Management System present
Volt pulse off Intv	1000...20000	ms	10	2000	Set voltage pulse off interval time
Volt pulse Min Dur	50...2000	ms	10	50	Set voltage pulse minimum duration
Freq pulse off Intv	1000...120000	ms	10	20000	Set frequency pulse off interval time
Freq pulse Min Dur	50...2000	ms	10	50	Set frequency pulse minimum duration

9.6.9 ASGCSYN Monitored data

Table 1525: ASGCSYN Monitored data

Name	Type	Values (Range)	Unit	Description
ENERG_STATE	Enum	0=Unknown 1=Both Live 2=Live G, Dead B 3=Dead G, Live B 4=Both Dead		Energization state of bus and generator
U_DIFF_MEAS	FLOAT32	-3.00...3.00	xUn	Calculated voltage amplitude difference
FR_DIFF_MEAS	FLOAT32	-1.500...1.500	xFn	Calculated voltage frequency difference
PH_DIFF_MEAS	FLOAT32	-180.00...180.00	deg	Calculated voltage phase angle difference
U_BUS_MEAS	FLOAT32	0.00...5.00	xUn	Calculated bus voltage amplitude
U_GEN_MEAS	FLOAT32	0.00...5.00	xUn	Calculated generator voltage amplitude
FR_BUS_MEAS	FLOAT32	35.00...75.00	Hz	Calculated bus frequency
FR_GEN_MEAS	FLOAT32	35.00...75.00	Hz	Calculated generator frequency

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
FR_SLIP_ACCL	FLOAT32	0.000...5.000	xFn/s	Calculated rate of change of frequency slip
U_DIFF_SYNC	BOOLEAN	0=False 1=True		Voltage difference out of limit for synchronizing
FR_DIFF_SYNC	BOOLEAN	0=False 1=True		Frequency difference out of limit for synchronizing
PH_DIF_SYNC	BOOLEAN	0=False 1=True		Phase angle difference out of limit for synchronizing
CB_CL_BLKD	Enum	1=Unblocked 2=Ext Check Fail 3=IED Test CB Service 4=IED Service CB Test		CB close blocked status
VOLT_CHG_RTE	FLOAT32	0.000...0.050	xUn/s	Calculated generator matching voltage rate of change
FREQ_CHG_RTE	FLOAT32	0.000...0.050	xFn/s	Calculated generator matching frequency rate of change
U_DIFF_NTW	FLOAT32	-3.00...3.00	xUn	Voltage amplitude difference of the network breaker
FR_DIFF_NTW	FLOAT32	-1.500...1.500	xFn	Voltage frequency difference of the network breaker
NTWMATCH_PRO	BOOLEAN	0=False 1=True		Matching in progress for network breaker synchronization
NTWMATCH_OK	BOOLEAN	0=False 1=True		Voltage, frequency across the network breaker systems matched
SYNCCHK_STS	Enum	1=Off 3=Asynchronous		Synchro check mode status
LIVEDEAD_STS	Enum	-1=Off 1=Both Dead 2=Live G, Dead B 4=Dead B, G Any		Live dead mode status
ASGCSYN	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.6.10 Technical data

Table 1526: ASGCSYN Technical data

Characteristic	Value
Measurement accuracy	At the frequency f = f_n
	Voltage difference: ±1.0 % or ±0.004 × U_n Frequency difference: ±10 mHz Phase angle difference: ±1° (±2.5° when f = f_n ±2 Hz)
Operation accuracy	MATCH_OK for voltage: ±0.001 × U_n MATCH_OK for frequency: ±10 mHz
Operation time accuracy	Raise/Lower output pulse width: ±1.0 % of the set value or ±20 ms *Energizing time* for dead-bus closing: ±1.0 % of the set value or ±35 ms *Minimum Syn time* for SYNC_OK: ±1.0 % of the set value or ±60 ms
Reset time	Typically 20 ms
Closing angle accuracy	±1°

9.7 Autosynchronizer for network breaker ASNSCSYN (ANSI 25AUTOSYNCBT/T)

9.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autosynchronizer for network breaker	ASNSCSYN	AUTOSYNCBT/T	25AUTO-SYNCBT/T

9.7.2 Function block

Figure 869: Function block

9.7.3 Functionality

The autosynchronizer function for network breaker ASNSCSYN can be used for synchronized closing of a non-generator circuit breaker such as a bus sectionalizer, a bus coupler or an incoming feeder. ASNSCSYN includes functionalities for autosynchronization, synchrocheck and energizing check.

ASNSCSYN checks the power system conditions between both networks across the circuit breaker. The energizing check is used to check that at least one side is dead to ensure that closing can be done safely.

In case of a synchronous system, the closing command is issued after considering the function modes, essential checks, CB closing time and the paralleling conditions. In case of asynchronous systems, the function initiates the matching of voltage and frequency with the help of available generators through Autosynchronizer co-ordinator ASCGAPC.

The function contains a blocking functionality. It is possible to block function outputs.

9.7.4 Analog input configuration

ASNSCSYN has two analog group inputs which must be properly configured.

Table 1527: Analog inputs

Input	Description
U3P1	Three-phase voltages (Bus B side)
U3P2	Three-phase voltages (Bus A side)

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1528: Special conditions

Condition	Description
U3P1 and U3P2 connected to real measurements	When one voltage channel from the Bus B side is connected to channel 1 of `U3P1` and one voltage channel from the Bus A side is connected to channel 1 of `U3P2`, the function can only work if UTVTR's VT connection settings on the Bus A and Bus B sides are similar.
	The function can work if one voltage channel from the Bus B side is connected to channel 1 of `U3P1` and three voltage channels from the Bus A side are connected to `U3P2`.
	The function can work if one voltage channel from the Bus B side is connected to channel 1 of `U3P1` and two voltage channels along with the residual voltage from the Bus A side are connected to `U3P2`.
	The function can work if three voltage channels from the Bus B side are connected to `U3P1` and one voltage channel from the Bus A side is connected to channel 1 of `U3P2`.
	The function can work if two voltage channels along with the residual voltage from the Bus B side are connected to `U3P1` and one voltage channel from the Bus A side is connected to channel 1 of `U3P2`.
Dissimilar VT connection settings for UTVTR on the Bus A and Bus B sides	The function requires that all three voltage channels or two voltage channels along with the residual voltage are connected to either `U3P1` or `U3P2`.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

9.7.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of ASNSCSYN can be described with a module diagram. All the modules in the diagram are explained in the next sections.

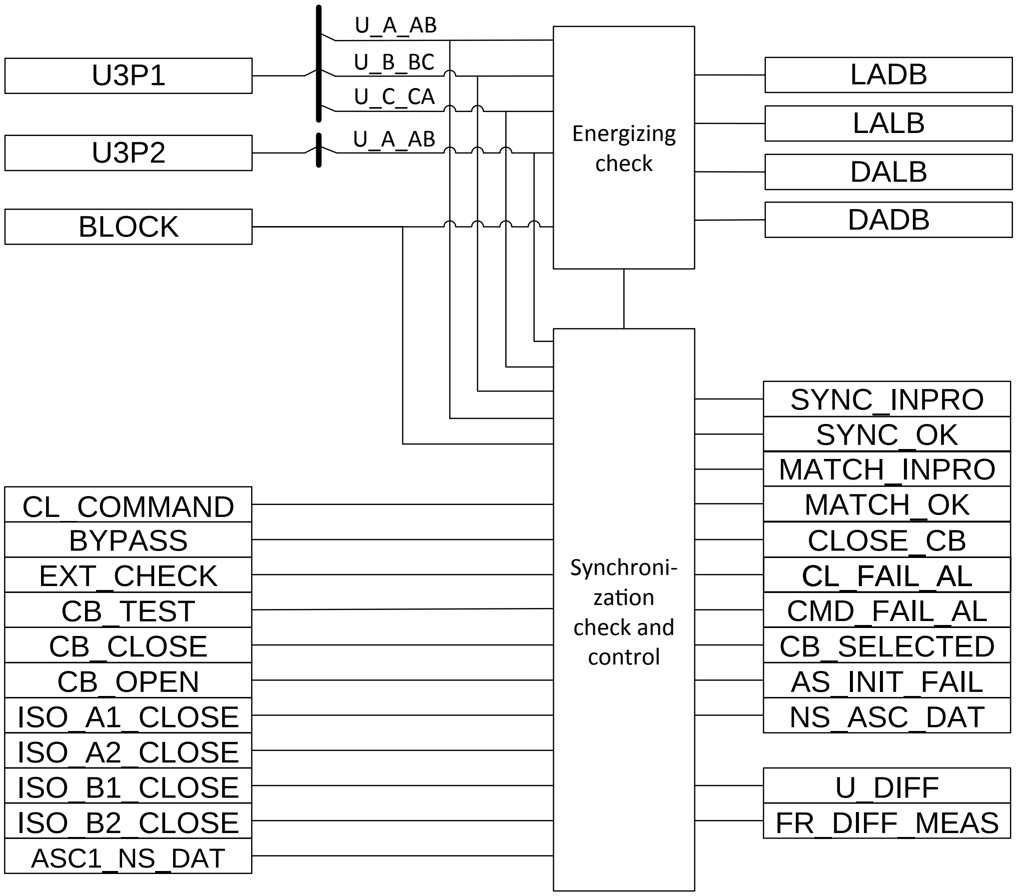


Figure 870: Functional module diagram

This function can operate either with the U_AB or U_A voltages. The selection of used voltages is defined with the *VT connection* of the line voltage general parameters.

9.7.5.1 Energizing check

The Energizing check module checks the energizing direction. Energizing is the situation where a dead network part is connected to an energized section of the network. The *Live dead mode* setting is used to set the energized condition of the bus section across the CB, that is, whether the bus section across the CB is live or dead..

When the *Live dead mode* setting parameter is set to "Command", then then the energized condition (see *Table 1529*) of bus sections across the CB can be set using the *Live dead mode Ctl* control command only. If the *Live dead mode* setting parameter is not set to "Command", then the *Live dead mode* setting parameter is used to set the energized condition (see *Table 1529*) of the bus section across the CB.

Table 1529: Live dead mode of operation when switching can be carried out

Live dead mode	Description
Command	The *Live dead mode* setting uses *Live dead mode Ctl* control command.
Off	*Live dead mode* is set to "Off".
Both Dead	Both Bus A and Bus B de-energized
Live B, Dead A	Bus B energized and Bus A de-energized
Dead B, Live A	Bus B de-energized and Bus A energized
Dead A , B Any	Bus A de-energized and Bus B energized or deenergized
Dead B, A Any	Bus B de-energized and Bus A energized or deenergized
One Live, Dead	Bus A de-energized and Bus B energized or Bus B de-energized and Bus A energized
Not Both Live	Both Bus A and B de-energized or Bus A deenergized and Bus B energized or Bus B deenergized and Bus A energized

When the energizing direction corresponds to the settings, the situation has to be constant for a time set with the *Energizing time* setting before the CB closing is permitted. This time delay ensures that the dead side remains de-energized and that the situation is not caused by a temporary interference. If the conditions do not persist for a specified operation time, the timer is reset and the procedure is restarted when the conditions allow it. The CB does not close if the measured voltage on the live side is greater than the set value of *Max energizing V*.

The measured energized state is available as a monitored data value ENERG_STATE and as four function outputs `LADB` (live bus A and dead bus B), `LALB` (live bus A and live bus B), `DALB` (dead bus A and live bus B) and `DADB` (dead bus A and dead bus B), of which only one can be active at a time. The measured energized state indicates “Unknown” if at least one of the measured voltages is between the limits set with the dead and live setting parameters.

9.7.5.2 Synchronization check and control

The operation of Synchronization check and control can be described with a module diagram. All the modules in the diagram are explained in the next sections.

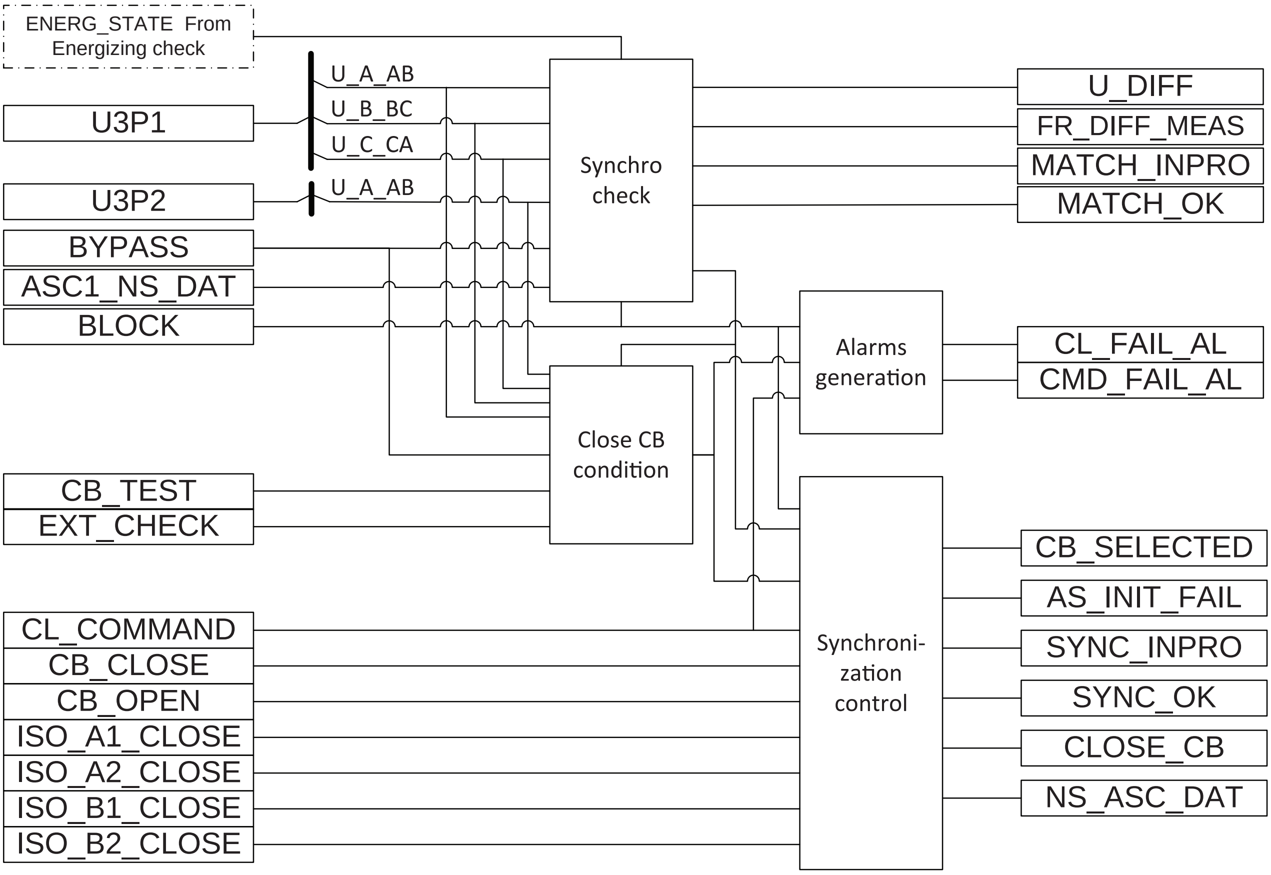


Figure 871: Module diagram for Synchronization check and control

Synchro check

The function measures the voltage difference U_DIFF_MEAS, frequency difference FR_DIFF_MEAS and phase angle difference PH_DIFF_MEAS between the two bus sides.

$$U\_DIFF\_MEAS = U_{BusA} - U_{BusB} + Voltage\ offset$$

(Equation 366)

U_{BusA}	Measured bus A side voltage
U_{BusB}	Measured bus B side voltage
Voltage offset	Setting *Voltage offset*

$$FR\_DIFF\_MEAS = f_{BusA} - f_{BusB} + Frequency\ offset$$

(Equation 367)

f_{BusA}	Measured bus A side frequency
f_{BusB}	Measured bus B side frequency
Frequency offset	Setting *Frequency offset*

$$PH\_DIFF\_MEAS = \angle U_{BusA} - \angle U_{BusB} + Phase\ shift$$

(Equation 368)

$\angle U_{BusA}$	Measured bus A side voltage phase angle
$\angle U_{BusB}$	Measured bus B side voltage phase angle
Phase shift	Setting *Phase shift*

The calculated voltage and phase angle difference values between these voltages are available as monitored data U_DIFF_MEAS and PH_DIFF_MEAS. The setting *Phase shift* is used to compensate the angle shift caused if a power transformer is located between the voltage measurements.

The synchronism condition and CB closing instance are checked according to several criteria.

- The measured bus A and bus B voltages are higher than the set value of *Live bus voltage* (ENERG_STATE equals “Both Live”).
- The measured bus A and bus B frequencies are both within the range of 95...105 % of the value of the nominal frequency (f_n).
- The measured bus A and bus B voltages are lower than the set value of *Max energizing V*.

When the *Synchrocheck mode* setting parameter is set to "Command", then the “Synchronous”, “Asynchronous” or “Off” condition of the network across the CB can be set using the *SynchroChk Mod Ctl* control command only. If the *Synchrocheck mode* setting parameter is not set to "Command", then the *Synchrocheck mode* setting parameter is used to set the “Synchronous”, “Asynchronous” or “Off” condition of the network across the CB.

Some additional conditions must be fulfilled according to the set *Synchrocheck mode*.

Table 1530: Additional conditions for the synchro check

Measurements	Synchrocheck mode	
	“Synchronous”	“Asynchronous”
U_DIFF_MEAS	< 0.01 x Nominal voltage (U_n)	< Difference voltage
PH_DIFF_MEAS	< 5 degree	< Difference angle
FR_DIFF_MEAS	< 0.001 x Nominal frequency (f_n)	< Frequency difference
Estimated closing angle	N/A	< Difference angle

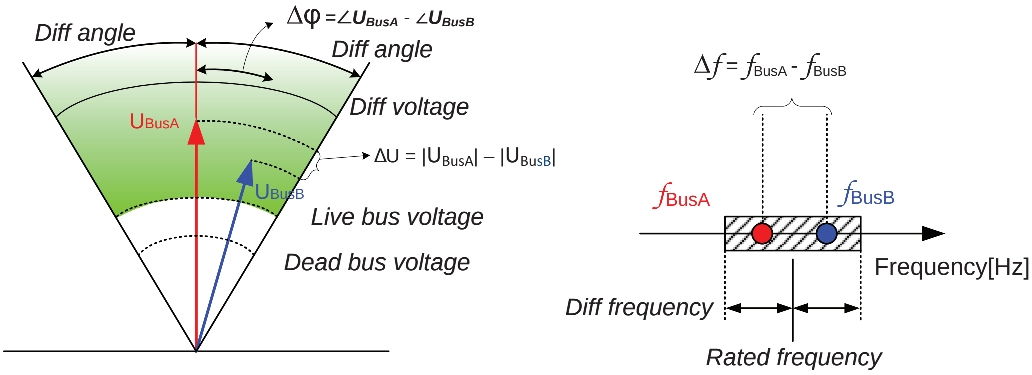


Figure 872: Conditions to be fulfilled when detecting synchronism between systems

When the measured difference of voltages (U_DIFF_MEAS) and measured difference in frequency (FR_DIFF_MEAS) are within the synchro check limits given in *Table 1530*, the output `MATCH_OK` is activated. The output `MATCH_INPRO` is activated when the voltage and frequency matching is in progress. The matching status input is received via `ASC1_NS_DAT` signal from ASCGAPC.

When the frequency, phase angle and voltage conditions are fulfilled, the duration of the synchronism conditions is checked to ensure that they are still met when the condition is determined on the basis of the measured frequency and phase difference. Depending on the CB and the closing system, the delay between the closing signal and the CB closing is about 50...250 ms. The selected *Closing time of CB* informs the function how long the conditions have to persist. The value covers both the CB closing delay and the output type dependent delay. The synchro check function compensates for the measured slip frequency and the CB closing delay.

The closing angle advance is calculated continuously:

$$Closing\ angle = \left| (\angle U_{BusA} - \angle U_{BusB})° + \left((f_{BusA} - f_{BusB}) \cdot \left(\frac{TCB}{1000} \right) \cdot 360° \right) \right|$$

(Equation 369)

$\angle U_{BusA}$	Measured bus A voltage phase angle
$\angle U_{BusB}$	Measured bus B voltage phase angle
TCB	Parameter *Closing time of CB* to be set as in *Equation 370*

$$TCB = t_{CB} + T_{PL} + x$$

(Equation 370)

t_{CB}	CB closing delay in ms
T_{PL}	Output type dependent delay in ms (see *Table 1531*)
x	Hardware delays between the protection relay and CB in ms; delays due to, for example, auxiliary relays and contactors, if used

Table 1531: Typical delays for different output types

Output type	Recommended value for T_{PL}	
	Both Bus side voltage measurements: Non-Adaptive or Both Bus side voltage measurements: Adaptive	Any one of the Bus side voltage measurement: Adaptive, The other Bus side voltage measurement: Non Adaptive
Semiconductor output (SPO)	16 ms	7 ms
Mechanical relay output (POSP, PODP)	23 ms	13 ms

The *Minimum Syn time* setting defines the minimum time for which synchro check conditions must be simultaneously fulfilled.

The frequency slip acceleration (ds/dt) SLIP_ACCL is the average value of frequency slip difference (Δs) calculated over a time period of 0.5 s.

$$Frequency\ slip(s) = \frac{\left(f_{BusA} - f_{BusB}\right)}{f_{BusA}}$$

(Equation 371)

The measured bus A voltage (U_{BusA}), bus A frequency (f_{BusA}), measured bus B voltage (U_{BusB}), bus B frequency (f_{BusB}) and phase angle difference (PH_DIFF_MEAS) values between the two sides of the CB are available as monitored data values.

If the measured U_DIFF_MEAS does not fulfill the condition given in *Table 1530* and thus synchronism is prevented, the monitored data U_DIFF_SYNC is activated. Similarly PH_DIF_SYNC and FR_DIFF_SYNC are activated based on the measurements PH_DIFF_MEAS and FR_DIFF_MEAS, respectively. These monitored data values are updated only when the setting *Synchrocheck mode* is set to either "Synchronous" or "Asynchronous" and the measured ENERG_STATE is "Both Live". The outputs `U_DIFF` and `FR_DIFF_MEAS` give the calculated phaseto- phase voltage difference and the frequency difference values, respectively. These `U_DIFF` and `FR_DIFF_MEAS` outputs are sent to ASCGAPC.

The monitored data ACT_ASC_CB indicates the ASCGAPC CB number. The CB number of the protection relay's ASCGAPC is received via `ASC1_NS_DAT` signal.

Close CB condition

If *Synchrocheck mode* is set to "Asynchronous", the CB close command is generated as explained below.

From the frequency slip s, the acceleration ds/dt, the bus frequency FR_BUS_MEAS (f_{Bus}) and the set *Closing time of CB*, the function calculates the necessary lead angle (α_{Lead}) by which the close CB command is shifted forward in time so that the main contacts close on phase coincidence.

$$\alpha_{Lead} = \left(360 \cdot f_{BusA} \cdot \left(s + \frac{\frac{TCB}{2} \cdot \frac{ds}{dt}}{1000} \right) \cdot \frac{TCB}{1000} \right)$$

(Equation 372)

f_{BusA}	Bus A side frequency
s	Frequency slip
ds/dt	Frequency slip acceleration
TCB	Setting *Closing time of CB*

The breaker closes only when the measured phase-angle difference across the breaker (PH_DIFF_MEAS) equals the calculated lead angle (α_{Lead}) and all synchronization check conditions are fulfilled.

If *Synchrocheck mode* is set to "Synchronous", a zero-passage of the phase-angle difference is not necessary and CB closing is permitted as soon as all the synchrocheck conditions are fulfilled. Similarly for dead bus synchronization, CB closing is possible when the energizing check permits.

The CB closing signal can be blocked based on the inputs CB_TEST and EXT_CHECK and IED test mode as described in *Table 1532*. This blocking status is available in the monitored data CB_CL_BLKD.

Table 1532: CB_CL_BLKD status based on the inputs

IED test mode	Inputs		Monitored data
	CB_TEST	EXT_CHECK	CB_CL_BLKD
TRUE	TRUE	TRUE	1 (“Unblocked”)
FALSE	FALSE		
TRUE	TRUE	FALSE	2 (“Ext Check Fail”)
FALSE	FALSE		
TRUE	FALSE	N/A	3 (“IED Test CB Serv-ice”)
FALSE	TRUE	N/A	4 (“IED Service CB Test”)

ASNSCSYN can be set to the bypass mode by setting the parameters *Synchrocheck mode* and *Live dead mode* to "Off" or, alternatively, by activating the BYPASS input. In the bypass mode, the closing conditions are always considered to be fulfilled by ASNSCSYN.

Synchronization control

The general bus bar arrangement for a non-source CB bus is shown in *Figure 873*. The bus to which the generator is connected is determined based on the circuit breaker and isolator position inputs (CB_OPEN, CB_CLOSE, ISO_A1_CLOSE, ISO_A2_CLOSE, ISO_B1_CLOSE and ISO_B2_CLOSE). The generator's bus connection status is shared with ASCGAPCs as part of the NS_ASC_DATA output.

The equipment which is capable of voltage and frequency adjustment, that is, the generator, is referred to as source and the rest as nonsource. Hence the generator's CB is referred to as source CB and the bus coupler or tie feeder CB as non-source CB. The non-source CB is not directly related to a generator although its closing has to be handled using synchronization.

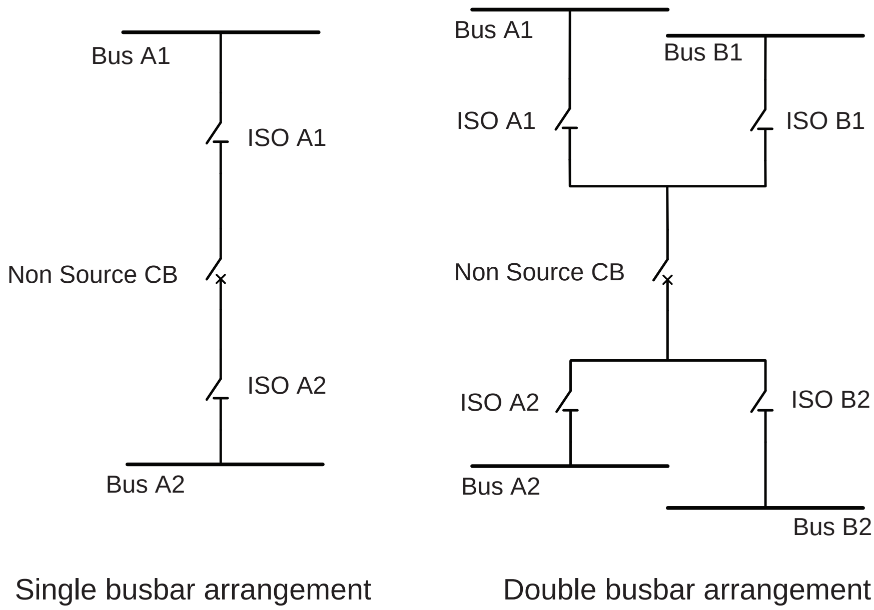


Figure 873: Different busbar arrangement for a non-source CB

Auto synchronization mode

In this mode, the closing signal is delivered if either the command *Synchronize CB* or the input CL_COMMAND is set to TRUE. The device should be in local mode if synchronization is initiated with the *Synchronize CB* command.

If the setting *Auto Syn mode* is set as "Manual mode" or "Semi-automatic synchronising mode", the additional command Manual CB release should be active for the closing signal CLOSE_CB to be activated. If the setting *Auto Syn mode* is set as "Automatic synchronising mode", no additional command is required to activate the closing signal CLOSE_CB.

In this auto synchronization mode, once all the closing conditions are satisfied within the set *Maximum Syn time*, the outputs SYNC_OK and CLOSE_CB become TRUE and remain active as long as the closing conditions are fulfilled. If *Multiple command* is set to "Off", then only CLOSE_CB outputs are delivered once for each activated input signal as shown in *Figure 874*. If *Multiple command* is set to "On", then CLOSE_CB outputs are delivered each time the conditions are satisfied as shown in *Figure 875*. In this auto synchronization mode, once all the closing conditions are satisfied within the set *Maximum Syn time*, the outputs SYNC_OK and CLOSE_CB become TRUE. These outputs remain active as long as the respective conditions are fulfilled. If *Multiple command* is set to "Off", then only CLOSE_CB outputs are delivered only once for each activated input signal as shown in *Figure 874*. If *Multiple command* is set to "On", then CLOSE_CB outputs are delivered each time the conditions are satisfied as shown in *Figure 875*.

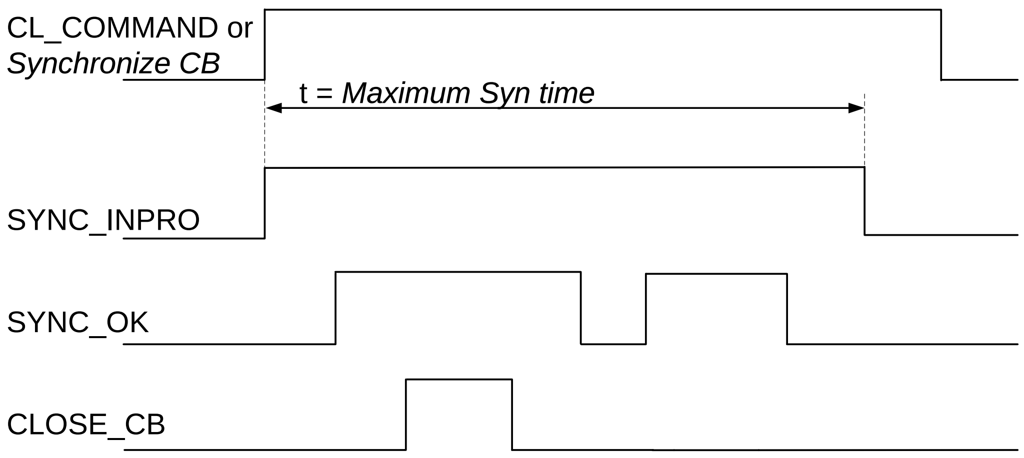


Figure 874: Determination of closing signal CLOSE_CB when Multiple command is set to "Off"

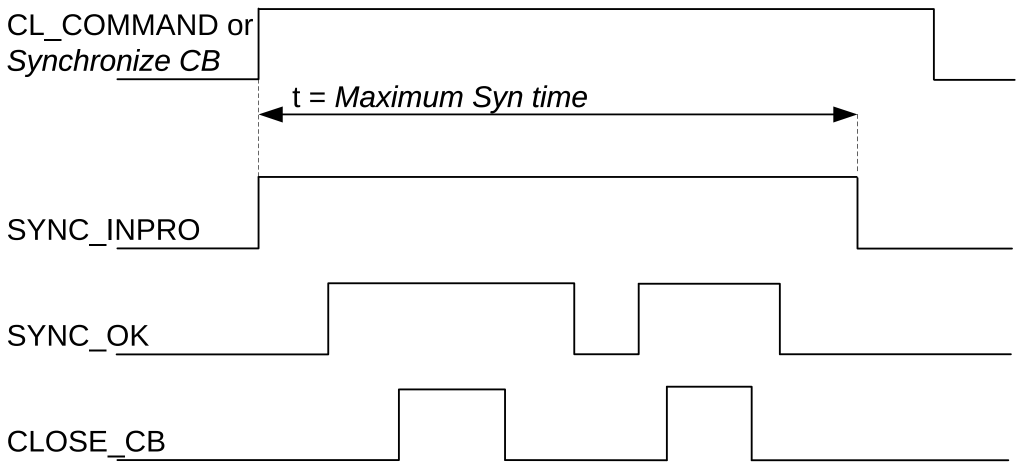


Figure 875: Determination of closing signal CLOSE_CB when Multiple command is set to "On"

The SYNC_INPRO output is active when the close command (CL_COMMAND or *Synchronize CB*) is in progress and it is reset when the close command is reset or *Maximum Syn time* has elapsed. In this automatic mode the closing signal CLOSE_CB is activated automatically once all the closing conditions are satisfied.

If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, ASNSCSYN gives synchro check permission to the circuit-breaker control CBXCBR after the closing command signal is delivered. The simplified configuration block diagram of ASNSCSYN with CLOSE_CB to CBXCBR is shown in *Figure 876*.

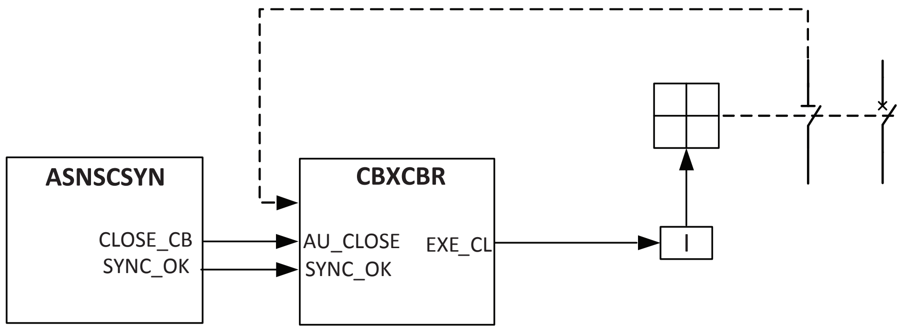


Figure 876: Simplified configuration block diagram of ASNSCSYN in auto synchronization mode operation

Alarms generation

In auto synchronization control mode, the closing command generation is activated either by the command input CL_COMMAND or by command parameter *Synchronize CB*.

After the closing command activation, if the conditions for closing CB are not fulfilled within the set time of *Maximum Syn time*, a failed closing attempt alarm is given. The CL_FAIL_AL alarm output signal is pulse-shaped and the pulse length is 500 ms.

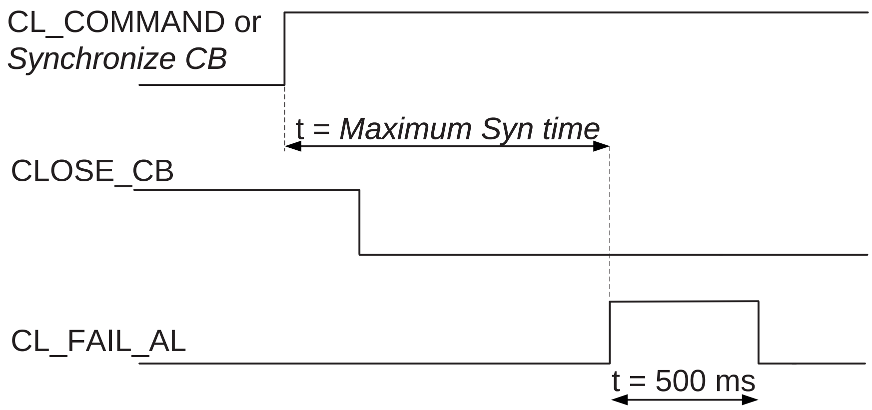


Figure 877: Determination of checking time for closing

CB closing is permitted during *Maximum Syn time*, starting from the moment the close command is activated. The close command must be active while the closing conditions are fulfilled, otherwise the procedure is cancelled. If the closing conditions are fulfilled during *Maximum Syn time*, a closing pulse output is delivered to the CB. If the closing conditions are not fulfilled during the checking time, the alarm CL_FAIL_AL is activated as an indication of a failed closing attempt. The closing pulse is not delivered if the closing conditions become valid after *Maximum Syn time* has elapsed. The closing pulse is delivered only once for each activated close command, and a new closing command sequence cannot be started until the close command is reset and reactivated.

CBXCBR receives information about the CB status and thus is able to adjust the command signal to be delivered to ASNSCSYN. If the closing command is active longer than necessary, the CMD_FAIL_AL alarm output is activated. To avoid unnecessary alarms, the maximum length of the closing command signal should be below *Maximum Syn time* + 5 s.

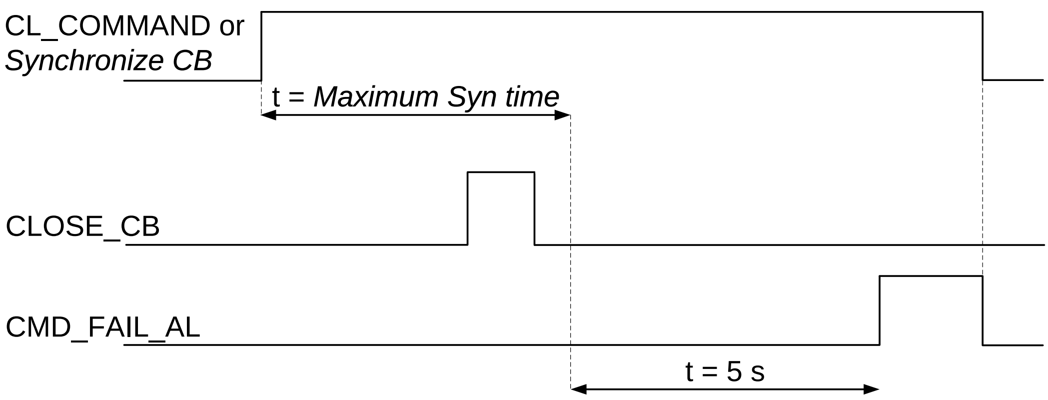


Figure 878: Determination of the alarm limit for a still-active command signal

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all binary outputs and resets the internal timers.

9.7.6 Application

A circuit breaker is used to connect two different power networks. It is essential to ensure that these power networks are synchronized before closing the CB, otherwise it may lead to disturbances in the power system, causing stress and damage to the connected equipment.

ASNSCSYN can be used for the synchronized closing of a non-generator circuit breaker such as a bus sectionalizer, a bus coupler or an incoming feeder. It checks for the synchronization conditions across the CB and releases the CB closing command. If these conditions are not fulfilled, the sources in the power network connected across this bus coupler or tie feeder CB have to change their operating points to meet the requirements. This is achieved with Autosynchronizer co-ordinator ASCGAPC available with the source (ASGCSYN) function and non-source (ASNSCSYN) function.

ASCGAPC assists in the participating sources selection based on the network topology and interacts with the sources to initiate the voltage and frequency matching for the bus coupler or tie feeder CB to be synchronized. When any non-source circuit breaker (NSCB) is selected for synchronization, a synchronization procedure is started. ASCGAPC located in the NSCB relay starts communicating with ASCGAPCs of possible source circuit breaker (SCB) relays for matching the voltage and frequency difference. Both ASCGAPCs pass the required information to the participating sources. A non-source CB synchronization is described with one typical example in *Figure 879*.

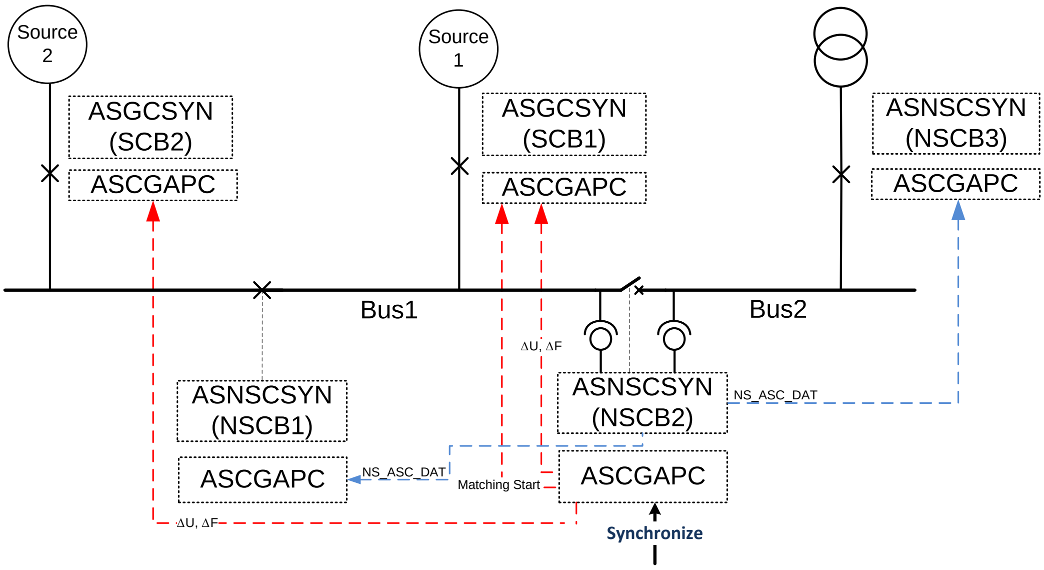


Figure 879: NSCB2 synchronization

In this application example, breaker NSCB2 must be closed. So the synchronizing conditions between Bus1 and Bus2 are checked by ASNSCSYN. ASNSCSYN sends the auto synchronization request and the voltage and frequency difference (ΔU, ΔF) between Bus1 and Bus2 to ASCGAPC.

ASCGAPC transfers the voltage and frequency difference sent by ASNSCSYN to the selected ASCGAPC function of source 1 ASGCSYN function. It also sends the permission to the source to start matching the voltage and frequency. The matching process is carried out so that the voltage and frequency difference between Bus1 and Bus2 measured by ASNSCSYN reduces and comes within the synchro check limits. This satisfies the synchro check conditions for breaker NSCB2 which can then be synchronized by ASNSCSYN. Similarly, the synchronization of NSCB1 and NSCB3 having ASCGAPC is done as shown in *Figure 880* and *Figure 881*.

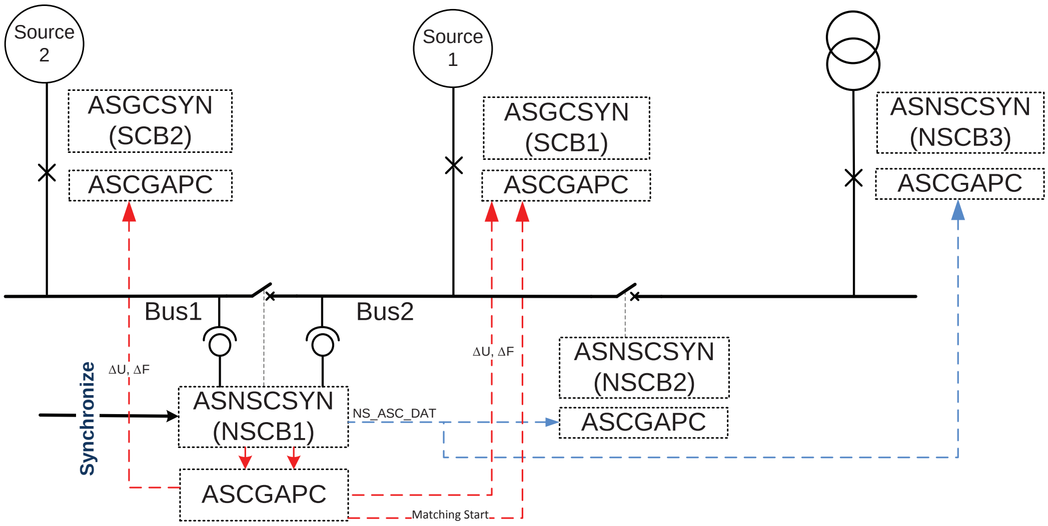


Figure 880: NSCB1 synchronization

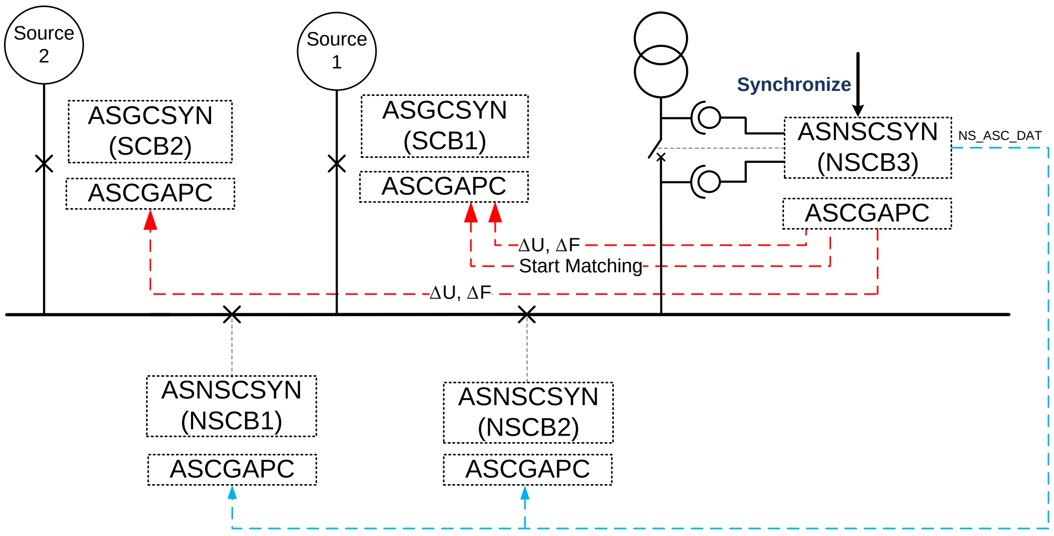


Figure 881: NSCB3 synchronization

This function supports manual, semi-automatic and automatic synchronizing, which adds flexibility in the user operation. In the manual synchronization, the matching is done manually and the closing command is released from the function on user request. In the semi-automatic synchronization, the matching is done automatically with coordination from ASCGAPC and the closing command is released from the function on user request. In the automatic synchronization, the matching is done automatically with coordination from ASCGAPC and the subsequent closing command is released from the function without user intervention.

This function output can be used to block the other functions in the power network to ensure that only one CB is synchronized at a time. This logic has to be developed outside the function block.

Voltage angle difference adjustment

In applications where the power transformer is located between the voltage measurement and the CB, the vector group connection gives phase difference to the voltages between the high- and low-voltage sides. The angle adjustment can be used to meet synchronism.

The vector group of the power transformer is defined with clock numbers, where the value of the hour pointer defines the low-voltage-side phasor and the high-voltage-side phasor is always fixed to the clock number 12, which is the same as zero. The angle between clock numbers is 30°. When comparing phase angles, the U_BUS_A input is always the reference. This means that when the Yd11 power transformer is used, the low-voltage-side voltage phasor leads the high-voltage-side phasor by 30º or lags by 330º. The rotation of the phasors is counterclockwise.

The generic rule is that a low-voltage-side phasor lags the high-voltage-side phasor by clock number · 30º. This is called angle difference adjustment and can be set for ASNSCSYN with the *Phase shift* setting.

9.7.7 Signals

9.7.7.1 ASNSCSYN Input signals

Table 1533: ASNSCSYN Input signals

Name	Type	Default	Description
U3P1	SIGNAL	-	Three-phase voltages (Bus B side)
U3P2	SIGNAL	-	Three-phase voltages (Bus A side)
BLOCK	BOOLEAN	0=False	Blocking signal of the auto synchronization function
BYPASS	BOOLEAN	0=False	Bypass for synchro-nization and closing conditions check
CL_COMMAND	BOOLEAN	0=False	External closing re-quest
EXT_CHECK	BOOLEAN	0=False	External permissive check for CB close
CB_TEST	BOOLEAN	0=False	Circuit breaker test position status
CB_OPEN	BOOLEAN	0=False	Circuit breaker open status
CB_CLOSE	BOOLEAN	0=False	Circuit breaker close status
ISO_A1_CLOSE	BOOLEAN	0=False	Isolator A1 close sta-tus
ISO_B1_CLOSE	BOOLEAN	0=False	Isolator B1 close sta-tus
ISO_A2_CLOSE	BOOLEAN	0=False	Isolator A2 close sta-tus
ISO_B2_CLOSE	BOOLEAN	0=False	Isolator B2 close sta-tus
ASC1_NS_DAT	INT32	0	Coded integer data from ASCGAPC1

9.7.7.2 ASNSCSYN Output signals

Table 1534: ASNSCSYN Output signals

Name	Type	Description
CL_FAIL_AL	BOOLEAN	CB closing failed
CMD_FAIL_AL	BOOLEAN	CB closing request failed
AS_INIT_FAIL	BOOLEAN	Synchronization not initiated
CLOSE_CB	BOOLEAN	CB close signal

Table continues on the next page

Name	Type	Description
SYNC_OK	BOOLEAN	Systems in synchronism
MATCH_OK	BOOLEAN	Voltage and frequency of the systems matched
MATCH_INPRO	BOOLEAN	Voltage and frequency matching in progress
SYNC_INPRO	BOOLEAN	Synchronization in progress
LADB	BOOLEAN	Live bus A, dead bus B
LALB	BOOLEAN	Live bus A, live bus B
DALB	BOOLEAN	Dead bus A, live bus B
DADB	BOOLEAN	Dead bus A, dead bus B
U_DIFF	FLOAT32	Line voltage difference across synchronizing CB
FR_DIFF_MEAS	FLOAT32	Calculated voltage frequency difference
CB_SELECTED	BOOLEAN	CB selected for synchroniza-tion
NS_ASC_DAT	INT32	Integer weighted output data to ASCGAPC

9.7.8 ASNSCSYN Settings

Table 1535: ASNSCSYN Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Live dead mode	-2=Command -1=Off 1=Both Dead 2=Live B, Dead A 3=Dead B, Live A 4=Dead A, B Any 5=Dead B, A Any 6=One Live, Dead 7=Not Both Live			1=Both Dead	Live dead mode
Diff voltage	0.01...0.50	xUn	0.01	0.05	Maximum voltage difference limit
Diff frequency	0.001...0.060	xFn	0.001	0.001	Maximum frequen-cy difference limit
Diff angle	5...90	deg	1	5	Maximum angle difference limit

Table 1536: ASNSCSYN Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Multiple command	0=Off 1=On			0=Off	Multiple command to the circuit break-er
Voltage offset	-0.100...0.100	xUn	0.001	0.000	Voltage offset
Frequency offset	-0.010...0.010	xFn	0.001	0.000	Frequency offset

Table 1537: ASNSCSYN Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Synchrocheck mode	1=Off 2=Synchronous 3=Asynchronous 4=Command			3=Asynchronous	Synchrocheck operation mode
Dead bus voltage	0.1...0.8	xUn	0.1	0.2	Voltage low limit for energizing check
Live bus voltage	0.2...1.0	xUn	0.1	0.5	Voltage high limit for energizing check
Max energizing V	0.50...1.30	xUn	0.01	1.05	Maximum voltage above which no paralleling takes place
Auto Syn mode	-1=Semi-automatic synchronising mode 1=Automatic synchronising mode 3=Manual mode			3=Manual mode	Autosynchronization operation mode

Table 1538: ASNSCSYN Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase shift	-180...180	deg	1	0	Phase difference correction between bus A and bus B voltages
Minimum Syn time	0...60000	ms	10	0	Minimum time to accept synchronizing
Maximum Syn time	100...6000000	ms	10	60000	Maximum time to accept synchronizing
Energizing time	100...60000	ms	10	100	Time delay for energizing check
Closing time of CB	40...250	ms	1	60	Closing time of the breaker

9.7.9 ASNSCSYN Monitored data

Table 1539: ASNSCSYN Monitored data

Name	Type	Values (Range)	Unit	Description
ENERG_STATE	Enum	0=Unknown 1=Both Live 2=Live Bus B, Dead Bus A 3=Dead Bus B, Live Bus A 4=Both Dead		Energization state of bus A and bus B
U_DIFF_MEAS	FLOAT32	-3.00...3.00	xUn	Calculated voltage amplitude difference

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
PH_DIFF_MEAS	FLOAT32	-180.00...180.00	deg	Calculated voltage phase angle difference
U_BUSA_MEAS	FLOAT32	0.00...5.00	xUn	Calculated bus A voltage amplitude
U_BUSB_MEAS	FLOAT32	0.00...5.00	xUn	Calculated bus B voltage amplitude
FR_BUSA_MEAS	FLOAT32	35.00...75.00	Hz	Calculated bus A frequency
FR_BUSB_MEAS	FLOAT32	35.00...75.00	Hz	Calculated bus B frequency
U_DIFF_SYNC	BOOLEAN	0=False 1=True		Voltage difference out of limit for synchronizing
FR_DIFF_SYNC	BOOLEAN	0=False 1=True		Frequency difference out of limit for synchronizing
PH_DIF_SYNC	BOOLEAN	0=False 1=True		Phase angle difference out of limit for synchronizing
SLIP_ACCL	FLOAT32	0.000...5.000	xFn/s	Calculated rate of change of frequency slip
ACT_ASC_CB	INT32	0...2147483647		Active ASCGAPC host circuit breaker number
CB_CL_BLKD	Enum	1=Unblocked 2=Ext Check Fail 3=IED Test CB Service 4=IED Service CB Test		CB close blocked status
SYNCCHK_STS	Enum	1=Off 2=Synchronous 3=Asynchronous		Synchro check mode status
LIVEDEAD_STS	Enum	-1=Off 1=Both Dead 2=Live B, Dead A 3=Dead B, Live A 4=Dead A, B Any 5=Dead B, A Any 6=One Live, Dead 7=Not Both Live		Live dead mode status
ASNSCSYN	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.7.10 Technical data

Table 1540: ASNSCSYN Technical data

Characteristic	Value
Measurement accuracy	Depending on the frequency of the voltage measured: f_n ±2 Hz
	Voltage difference: ±1.0 % or ±0.004 × U_n Frequency difference: ±10 mHz Phase angle difference: ±1°
Operation accuracy	MATCH_OK for voltage: ±0.001 × U_n MATCH_OK for frequency: ±10 mHz
Operation time accuracy	*Energizing time* for dead-bus closing: ±1.0 % of the set value or ±35 ms *Minimum Syn time* for SYNC_OK: ±1.0 % of the set value or ±60 ms
Reset time	Typically 20 ms
Closing angle accuracy	±1°

9.8 Autosynchronizer co-ordinator ASCGAPC (ANSI 25AUTOSYNC)

9.8.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autosynchronizer co-ordinator	ASCGAPC	AUTOSYNC	25AUTOSYNC

9.8.2 Function block

Figure 882: Function block

9.8.3 Functionality

The autosynchronizer co-ordinator function ASCGAPC can be used as a coordinator for the synchronization of any bus coupler or grid transformer incomer breakers in the power network. ASCGAPC must be present on the relay configuration together with the bus coupler or grid transformer autosynchronization functions (ASNSCSYN) as well as in generator autosynchronization functions (ASGCSYN).

ASCGAPC performs the network topology determination to identify the subnetworks within the whole network. It routes the voltage and frequency difference values from the synchronizing CB to all the generator sources. It also identifies the sources which are eligible to participate in matching the voltage and frequency difference. ASCGAPC allows to select sources for synchronization and gives permission for matching to the selected sources after essential checks.

ASCGAPC allows autosynchronization of only one non-source circuit breaker at a time. It also provides the voltage and frequency matching status for the synchronization in progress.

9.8.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off".

The operation of ASCGAPC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

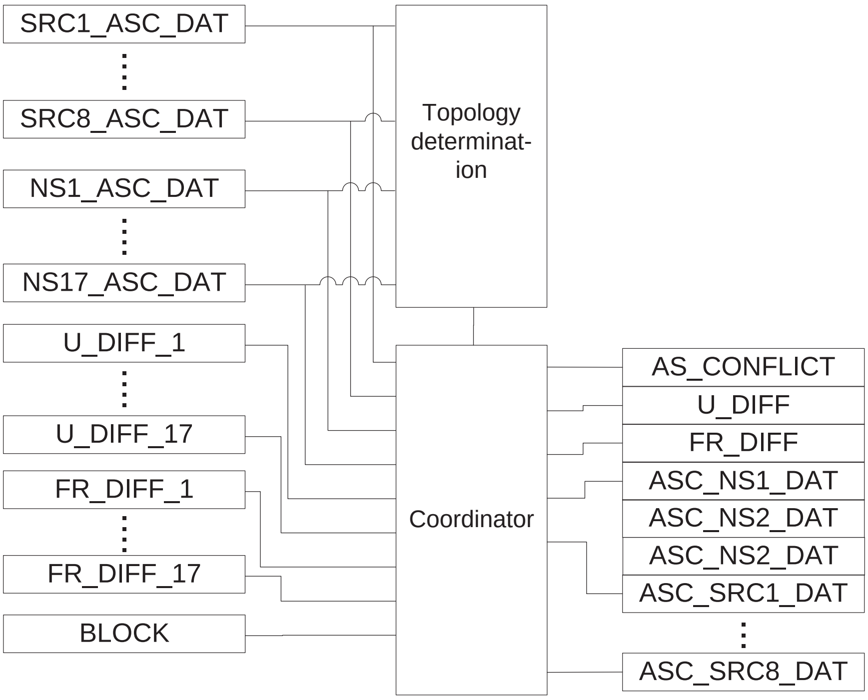


Figure 883: Functional module diagram

9.8.4.1 Topology determination

This module identifies the group of busbars, power sources and network circuit breakers electrically connected together and calculates the subnetwork number for each group. It also identifies the sources and buses which are electrically connected to the external network. The maximum network configuration considered is 8 sources, 8 source CBs (SCB), 15 busbars and 17 non-source CBs (NSCB).

The equipment which is capable of voltage and frequency adjustment, that is, the generator, is referred to as source and the rest as non-source. Hence the generator CB is referred to as source CB and the bus coupler or tie feeder CB as non-source CB. Also, any bus or system, external to this network is referred to as grid.

The general busbar arrangement across any NSCB is shown in Figure 884. For each NSCB, the numbers for Bus A1, Bus A2, Bus B1 and Bus B2 must be set. These bus numbers for non-source CB 1 are set in *NonSrc1 bus A1 Num*, *NonSrc1 bus A2 Num*, *NonSrc1 bus B1 Num* and *NonSrc1 bus B2 Num*, respectively. Each of these settings can be set to values "Bus 1"..."Bus 15" or to "Not Configured".

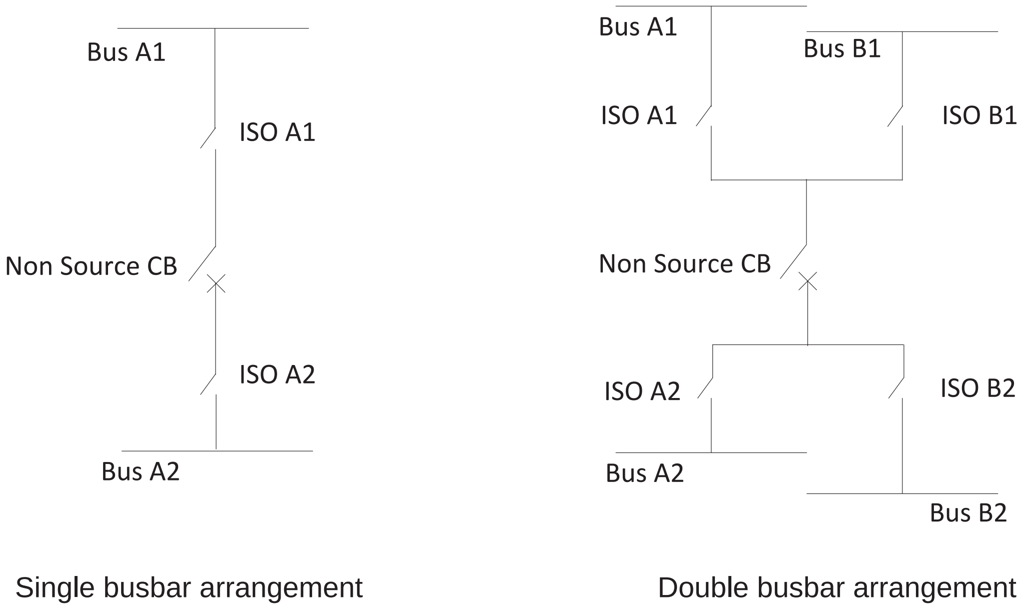


Figure 884: Different busbar arrangement across any non-source CB

The general busbar arrangement across any SCB is shown in Figure 885. For each source CB, the Bus A and Bus B numbers are to be set. These bus numbers for source CB 1 are set in *Src1 bus A Num* and *Src1 bus B Num*, respectively. Each of these settings can be set to values "Bus 1"..."Bus 15" or to "Not Configured".

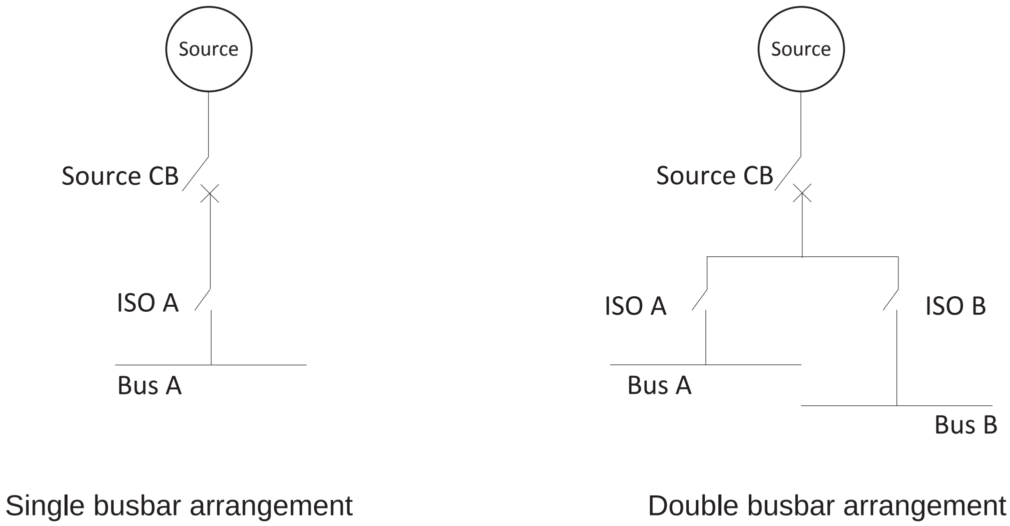


Figure 885: Different busbar arrangement for any source CB

The subnetwork group identification is based on the set busbar arrangement across each CB and the connection status input received from the corresponding

ASGCSYN via SRC1_ASC_DAT...SRC8_ASC_DAT or from the corresponding ASNSCSYN via signals NS1_ASC_DAT...NS17_ASC_DAT.

An example of the subnetwork group identification is shown in *Figure 886*. Since NSCB 2 connects bus bar 1 and bus bar 2, then setting *NonSrc2 bus A1 Num* is set to "Bus 1" and *NonSrc2 bus A2 Num* is set as "Bus 2". Based on the bus connection status received via the input NS2_ASC_DAT, this module determines that Bus 1, Bus 2 and NSCB 2 are electrically connected. Similarly for SCB 2, *Src2 bus A Num* is set as "Bus 2" and the source CB closed status input is received via SRC1_ASC_DAT. So SCB 2 is electrically connected to Bus 2. Hence it is determined that SCB 2, Bus 2, Bus 1 and NSCB 2 are electrically connected to each other.

Two subnetworks are identified in *Figure 886*. The first comprises Bus 1, Bus 2, NSCB 1, NSCB 2, SCB 2 and source 2. The second comprises Bus 3, Bus 4, NSCB 4, SCB 3 and source 3. Each network group is assigned a subnetwork number which is the lowest bus bar number in the subgroup. Hence the first group is assigned subnetwork number 1 and the second group is assigned subnetwork number 3.

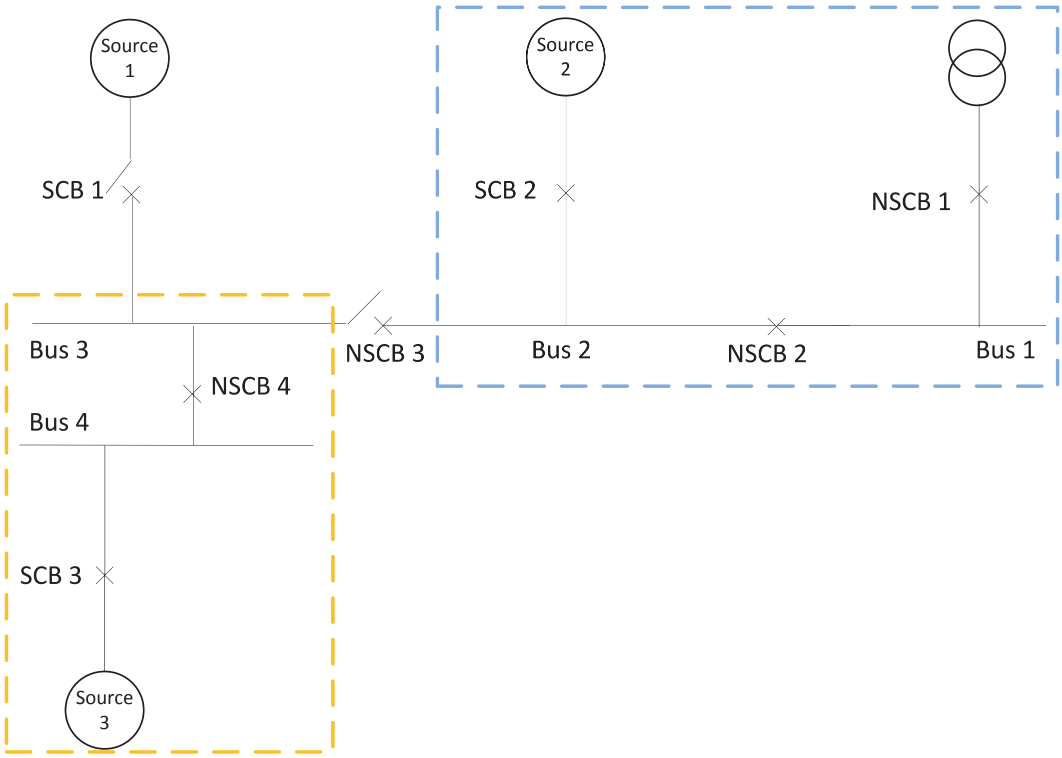


Figure 886: An example of subnetwork group identification

Table 1541: ASCGAPC settings of NSCB1 for given example

Settings	Suggested values	Description
ASC CB Num1	Non source CB 1	ASC1 host circuit breaker number 1
Number of sources	3	Total number of sources present in the system
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system
Src1 bus A Num	Bus 3	Source1 CB connected bus A number

Table continues on the next page

Settings	Suggested values	Description
Src2 bus A Num	Bus 2	Source1 CB connected bus A number
Src3 bus A Num	Bus 4	Source1 CB connected bus A number
NonSrc1 bus A1 Num	Bus 1	Non-source CB1 connected bus A1 number
NonSrc1 bus A2 Num	Grid	Non-source CB1 connected bus A2 number
NonSrc2 bus A1 Num	Bus 1	Non-source CB2 connected bus A1 number
NonSrc2 bus A2 Num	Bus 2	Non-source CB2 connected bus A2 number
NonSrc3 bus A1 Num	Bus 3	Non-source CB3 connected bus A1 number

Table 1542: Settings of ASCGAPC of NSCB2 for given example

Settings	Suggested values	Description
ASC CB Num1	Non source CB 2	ASC1 host circuit breaker number 2
Number of sources	3	Total number of sources present in the sys-tem
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system
Src1 bus A Num	Bus 3	Source1 CB connected bus A number
Src2 bus A Num	Bus 2	Source1 CB connected bus A number
Src3 bus A Num	Bus 4	Source1 CB connected bus A number
NonSrc1 bus A1 Num	Bus 1	Non-source CB1 connected bus A1 number
NonSrc1 bus A2 Num	Grid	Non-source CB1 connected bus A2 number
NonSrc2 bus A1 Num	Bus 1	Non-source CB2 connected bus A1 number
NonSrc2 bus A2 Num	Bus 2	Non-source CB2 connected bus A2 number
NonSrc3 bus A1 Num	Bus 2	Non-source CB3 connected bus A1 number

Table 1543: Settings of ASCGAPC of NSCB3 for given example

Settings	Suggested values	Description
ASC CB Num1	Non source CB 3	ASC1 host circuit breaker number 3
Number of sources	3	Total number of sources present in the sys-tem
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system
Src1 bus A Num	Bus 3	Source1 CB connected bus A number
Src2 bus A Num	Bus 2	Source1 CB connected bus A number
Src3 bus A Num	Bus 4	Source1 CB connected bus A number
NonSrc1 bus A1 Num	Bus 1	Non-source CB1 connected bus A1 number
NonSrc1 bus A2 Num	Grid	Non-source CB1 connected bus A2 number
NonSrc2 bus A1 Num	Bus 1	Non-source CB2 connected bus A1 number
NonSrc2 bus A2 Num	Bus 2	Non-source CB2 connected bus A2 number
NonSrc3 bus A1 Num	Bus 2	Non-source CB3 connected bus A1 number

Table 1544: Settings of ASCGAPC of NSCB4 for given example

Settings	Suggested values	Description
ASC CB Num1	Non source CB 4	ASC1 host circuit breaker number 4
Number of sources	3	Total number of sources present in the sys-tem
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system
Src1 bus A Num	Bus 3	Source1 CB connected bus A number
Src2 bus A Num	Bus 2	Source1 CB connected bus A number
Src3 bus A Num	Bus 4	Source1 CB connected bus A number
NonSrc1 bus A1 Num	Bus 1	Non-source CB1 connected bus A1 number
NonSrc1 bus A2 Num	Grid	Non-source CB1 connected bus A2 number
NonSrc2 bus A1 Num	Bus 1	Non-source CB2 connected bus A1 number
NonSrc2 bus A2 Num	Bus 2	Non-source CB2 connected bus A2 number
NonSrc3 bus A1 Num	Bus 2	Non-source CB3 connected bus A1 number
NonSrc3 bus A2 Num	Bus 3	Non-source CB3 connected bus A2 number
NonSrc4 bus A1 Num	Bus 3	Non-source CB4 connected bus A1 number
NonSrc4 bus A2 Num	Bus 4	Non-source CB4 connected bus A2 number

Table 1545: Settings of ASCGAPC of SCB1 for given example

Settings	Suggested values	Description
ASC CB Num1	Source CB 1	ASC1 host circuit breaker number 1
Number of sources	3	Total number of sources present in system
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system

Table 1546: Settings of ASCGAPC of SCB2 for given example

Settings	Suggested values	Description
ASC CB Num1	Source CB 2	ASC1 host circuit breaker number 2
Number of sources	3	Total number of sources present in system
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system

Table 1547: Settings of ASCGAPC of SCB3 for given example

Settings	Suggested values	Description
ASC CB Num1	Source CB 3	ASC1 host circuit breaker number 3
Number of sources	3	Total number of sources present in system
Number of NonSrc CB	4	Number of bus coupler or grid transformer CB in the system

The subnetwork numbers of eight power sources are available in monitored data SBNW_SRC1...SBNW_SRC8. The subnetwork numbers of NSCBs are available in monitored data SBNW_NSCB1...SBNW_NSCB17. The subnetwork numbers of busbars are available in monitored data SBNW_BB1...SBNW_BB15.

The monitored data SRC1_GRI_CON...SRC8_GRI_CON give the grid connection status of source 1...source 8. In *Figure 886*, source 2 is electrically connected to the grid, so the monitored data SRC2_GRI_CON is TRUE. Also, zero subnetwork number is assigned to all the open CBs. Hence SCB 1 and NSCB3 are assigned zero as subnetwork number.

The CB status is assumed uncertain in abnormal conditions (communication failure, bad quality of the data received from any ASGCSYN or ASNSCSYN) or when the CB status inhibit input is received via `SRC1_ASC_DAT`...`SRC8_ASC_DAT` or `NS1_ASC_DAT`...`NS17_ASC_DAT` signal. When the status of the CB is uncertain, the group including this CB or the groups connected across this CB are assigned zero as the subnetwork number. For example, if the SCB1 status is uncertain, then source 1, source 3, SCB1, SCB3, NSCB4, Bus 3 and Bus 4 are assigned zero as subnetwork number.

All subnetwork numbers are displayed as zero when ASC CB Num1 = "Sourcex", x= 1...8.

9.8.4.2 Coordinator

Three instances of ASNSCSYN can be configured for the synchronization of three NSCBs in a single relay. The CB number can be set using settings *ASC CB Num1*, *ASC CB Num2* and *ASC CB Num3*. The function allows only NSCBs to be synchronized at a time. If synchronization is initiated for one of the three breakers, Coordinator sends the synchronized status to all the sources via `ASC_SRC1_DAT`...`ASC_SRC8_DAT` signal and to all the non-sources via `ASC_NS_DAT` signal. The rest of the operation is explained in *Figure 887*.

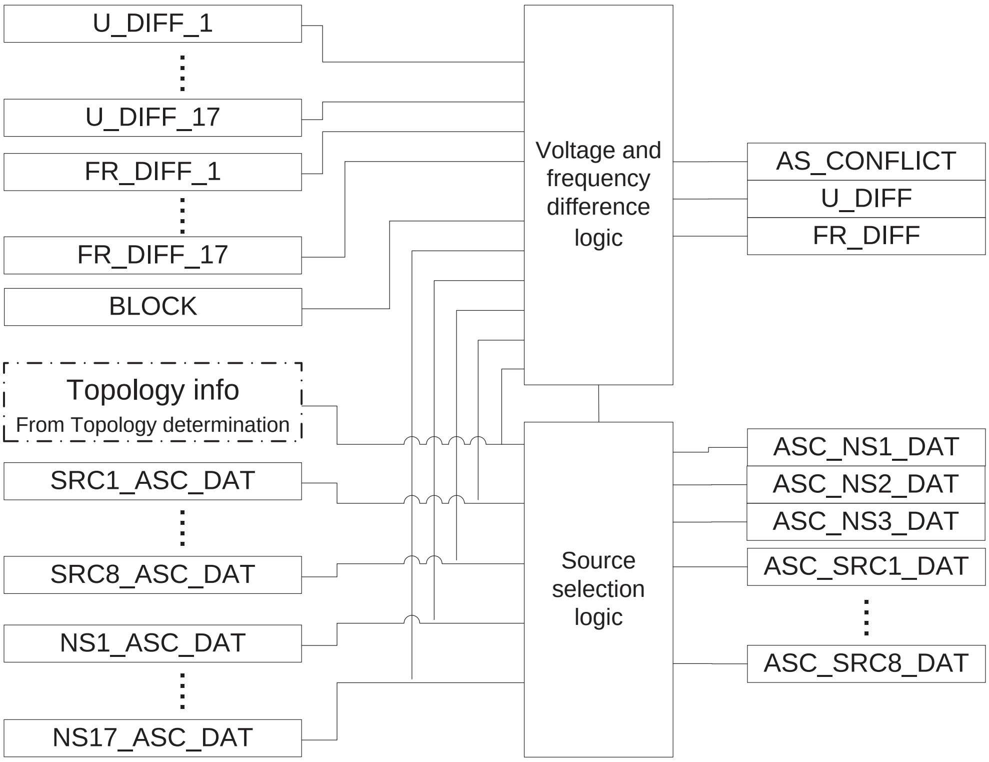


Figure 887: Module diagram of Coordinator

Voltage and frequency difference logic

This module sends the voltage and frequency difference values received from the NSCB to be synchronized to all the sources with appropriate sign according to the topology.

Of the two busbars connected across any NSCB, the voltage transformer (VT) from the lower-number busbar should be connected to bus A voltage channel (U_BUS_A) and the other to bus B voltage channel (U_BUS_B).

If these VT connections are interchanged physically, then the correction can be done in function using *NonSrc1 VT Conn*...*NonSrc17 VT Conn* for NSCB 1...NSCB 17. When the coordinator is active and NSCB 1 is selected for synchronization, the corresponding voltage and frequency difference inputs `U_DIFF_1` and `FR_DIFF_1` are available as outputs `U_DIFF` and `FR_DIFF`, respectively, with their sign adjusted according to the setting *NonSrc1 VT Conn*. If set as "No Change", the sign of `U_DIFF` and `FR_DIFF` remains the same. If set as "Reverse", the sign is reversed. Similarly, when any of the NSCB 2...NSCB 17 is selected for synchronization, the corresponding inputs `U_DIFF_2`...`U_DIFF_17` and `FR_DIFF_2`...`FR_DIFF_17` are passed as the outputs `U_DIFF` and `FR_DIFF`, respectively.

The output `AS_CONFLICT` is active in any of the following conditions:

- If more than one NSCB are selected for synchronization at the same time.
- If a NSCB is selected for synchronization while source synchronization is in progress.
- If more than one source are in synchronization.

When `AS_CONFLICT` is TRUE, then the Coordinator module stops the ongoing coordination activities till a new synchronization request is received from any NSCB.

This conflict status is available in the monitored data CONFL_STATUS as given in *Table 1548*.

Table 1548: States of CONFL_STATUS

Monitored data	Value
CONFL_STATUS	1 (“No conflict”)
	2 (“Multiple NSCB sync”)
	3 (“Multiple SCB sync”)
	4 (“NSCB and SCB sync”)

Source selection logic

Source selection logic is responsible for the selection and coordination of the sources for the voltage and frequency matching. It is enabled only when the autosynchronization function of the selected NSCB is in “Semiautomatic” or “Automatic” mode.

A source is available for participation in the voltage and frequency matching if the corresponding autosynchronization function is in “Semi-automatic” or “Automatic” mode and the host protection relay is in remote mode. This information is received from the corresponding source via input signals SRC1_ASC_DAT...SRC8_ASC_DAT.

All the sources in the network can be divided into nine participation groups based on topology and their availability for participation.

Table 1549: Groups for source participation (monitored data SRC1_PTC_GRP...SRC8_PTC_GRP)

Source participation group	Description
Group 1	All the sources which are unavailable for participation, are electrically connected to the grid or are not part of either subnetwork which must be synchronized by the selected CB.
Group 2	The sources which do not belong to Group 1 and are part of the subnetwork which includes the lower-number busbar of the two busbars connected across the selected CB.
Group 3	The sources which do not belong to Group 1 and are part of the other subnetwork, which includes the higher-number busbar.
Group 4	The sources in Group 2 which are not ready for participation in matching.
Group 5	The sources which are part of Group 3, but not ready for participation in matching.
Group 6	The sources which are part of Group 2 or Group 3, but the network is internally connected and setting *Synchrocheck mode* in ASNSCSYN is "Synchronous"
Group 7	The sources which are part of Group 2 or Group 3, but the network is internally connected and the setting *Synchro-check mode* in ASNSCSYN is "Asynchronous".
Group 8	The sources which are part of Group 2 or Group 3, but the network is internally asynchronous and setting *Synchrocheck mode* in ASNSCSYN is "Synchronous".
Group 9	The sources which are part of Group 2 or Group 3, but setting *Synchrocheck mode* in ASNSCSYN is "Off".

The participation group number for source 1...source 9 is available in the monitored output SRC1_PTC_GRP...SRC8_PTC_GRP.

Any source can be nominated for participation in voltage and frequency matching from the command parameter *Source1 selected*...*Source8 selected*. This selection is confirmed from the command parameter *Confirm source Sel*. The selected participation group information is available in monitored data SELECTED_GRP.

ASCGAPC allows multiple sources to participate in the voltage and frequency matching simultaneously, but all the sources nominated for matching should belong to either participation Group 2 or participation Group 3.

One of the participating sources (set with *Tuning source*) is used for the fine tuning of voltage and frequency. This information is sent to the corresponding source via the respective output signal ASC_SRC1_DAT...ASC_SRC8_DAT.

Table 1550: States of MATCH STATUS

Value	Description
1 (“No request”)	No NSCB is selected for synchronization.
2 (“Request received”)	Synchronization request is received.
3 (“No source selection”)	The request is received and the command parameter *Confirm source Sel* is "FALSE".
4 (“Correct Src selection”)	The synchronization request is received, the command parameter *Confirm source Sel* is "TRUE", and the nominated sources belong to either Group 2 or Group 3.
5 (“Wrong source selection”)	The synchronization request is received, the command parameter *Confirm source Sel* is "FALSE", and the nominated sources do not belong to Group 2 or all belong to Group 3.
6 (“Wrong tuning Src Sel”)	The source selected for fine tuning is not among the nominated sources.
8 (“Source ready”)	Any of the selected sources are ready for matching.
9 (“GOV-AVR modes not OK”)	Any source is selected for matching and the governor and AVR of all the participating sources are not in droop mode and non-participating sources are not in “Fixed MW” and “Fixed MVAr” mode. The governor and Automatic Voltage Regulator (AVR) modes corresponding to each source are received via the corresponding input signal SRC1_ASC_DAT...SRC8_ASC_DAT. If modes are different, then mode change request is sent to the sources via the corresponding output signal ASC_SRC1_DAT...ASC_SRC8_DAT.
10 (“GOV-AVR modes OK”)	Any source is selected for matching, and its governor and AVR are in droop mode and nonparticipating sources are in “Fixed MW” and “Fixed MVAr” mode.
11 (“Matching in progress”)	All the selected sources are issued the permission for matching.
12 (“Matching done”)	Matching is complete according to the NSCB under synchronization.
13 (“Matching not done”)	Matching is not done within the set *Max matching time*.
14 (“Int Connect,set Sync”)	The network is internally connected and setting *Synchrocheck mode* in ASNSCSYN is "Synchronous".

Table continues on the next page

Value	Description
15 (“Int Connect,set Async”)	The network is internally connected and setting *Synchro-check mode* in ASNSCSYN is "Asynchronous".
16 (“Externally connected”)	The network is externally connected.
17 (“Int Async,set Sync”)	The network is internally asynchronous and setting *Synchro-check mode* in ASNSCSYN is "Synchronous".

Internally connected

A network where Bus1 is connected to Bus3, Bus2 is connected to Bus4 and CB1 is closed is seen as an internally connected network by CB2.

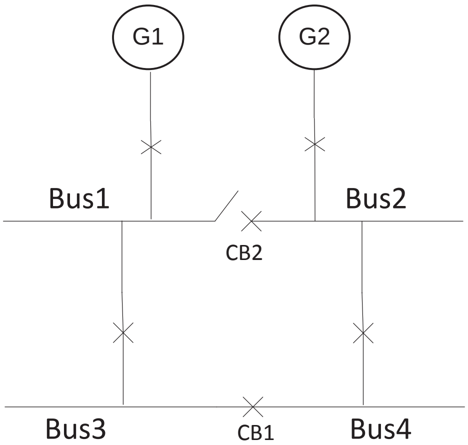


Figure 888: Example of an internally connected network

Externally connected

A network where both Bus3 and Bus4 are connected to the grid across CB1 is considered an externally connected network.

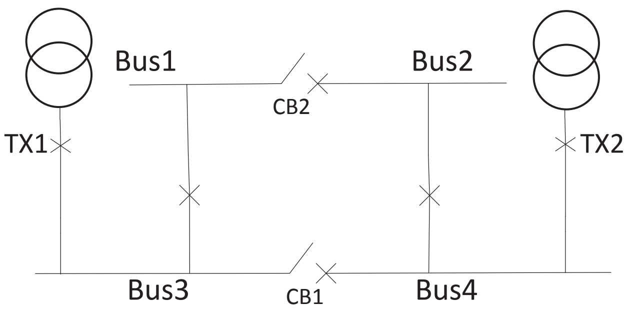


Figure 889: Example of an externally connected network

The number of sources active in the voltage and frequency matching is shared to sources via the corresponding output signal ASC_SRC1_DAT...ASC_SRC8_DAT.

The binary input BLOCK can be used to block the function. The activation of the BLOCK input deactivates all binary outputs and resets the internal timers.

9.8.5 Application

A circuit breaker is used to connect two different power networks. It is essential to ensure that these power networks are synchronized before closing the CB, otherwise it may lead to disturbances in the power system, causing stress and damage to the connected equipment.

The synchronization of any bus coupler or tie feeder is not feasible if the voltage and frequency differences across the circuit breaker are not within the allowed limits. In this case, the sources which are part of the power network connected across this bus coupler or tie feeder CB have to adjust their voltage and frequency. ASCGAPC can be used as coordinator for selection and coordination with the sources, during the synchronization of any bus coupler or tie feeder circuit breaker. The function allows the synchronization of only one circuit breaker at a time. In case of any conflict, the synchronization process is stopped.

As a coordinator the function assists in the participating sources selection based on the network topology and interacts with the sources to initiate the voltage and frequency matching for the bus coupler or tie feeder CB to be synchronized.

When selected for synchronization, any NSCB communicates with ASCGAPC for matching of voltage and frequency difference. ASCGAPC passes the required information to the participating sources along with their active status. An NSCB synchronization is described with one typical example in *Figure 890*.

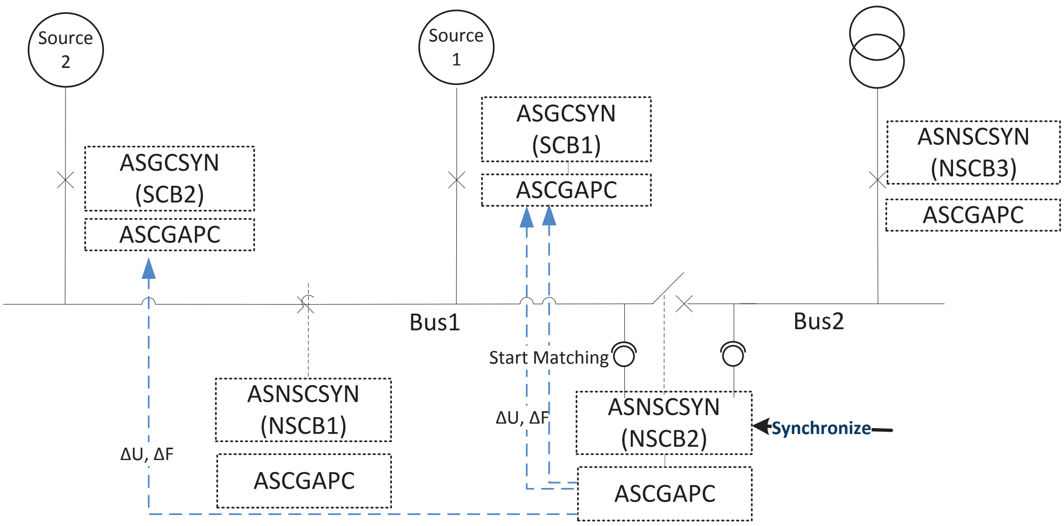


Figure 890: NSCB2 synchronization

In this application example, breaker NSCB2 must be closed so the synchronizing conditions between Bus1 and Bus2 are checked by ASNSCSYN. ASNSCSYN sends the autosynchronization request and voltage and frequency difference (ΔU, ΔF) between the Bus1 and Bus2 to the Autosynchronization coordinator functions ASCGAPC.

ASCGAPC transfers the voltage and frequency difference sent by ASNSCSYN to the ASCGAPC of source 1 ASGCSYN function as well as to the ASCGAPC of source 2 ASGCSYN function. It also sends the permission to the source to start matching the voltage and frequency. The matching process is carried out so that the voltage and frequency difference between Bus1 and Bus2 measured by ASNSCSYN reduces and comes within the synchrocheck limits. This satisfies the synchrocheck conditions for breaker NSCB2 which can then be synchronized by ASNSCSYN.

9.8.6 Signals

9.8.6.1 ASCGAPC Input signals

Table 1551: ASCGAPC Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Blocking output signal of the function
SRC1_ASC_DAT	INT32	0	Input data from source number 1
SRC2_ASC_DAT	INT32	0	Input data from source number 2
SRC3_ASC_DAT	INT32	0	Input data from source number 3
SRC4_ASC_DAT	INT32	0	Input data from source number 4
SRC5_ASC_DAT	INT32	0	Input data from source number 5
SRC6_ASC_DAT	INT32	0	Input data from source number 6
SRC7_ASC_DAT	INT32	0	Input data from source number 7
SRC8_ASC_DAT	INT32	0	Input data from source number 8
NS1_ASC_DAT	INT32	0	Input data from non-source CB number 1
NS2_ASC_DAT	INT32	0	Input data from non-source CB number 2
NS3_ASC_DAT	INT32	0	Input data from non-source CB number 3
NS4_ASC_DAT	INT32	0	Input data from non-source CB number 4
NS5_ASC_DAT	INT32	0	Input data from non-source CB number 5
NS6_ASC_DAT	INT32	0	Input data from non-source CB number 6
NS7_ASC_DAT	INT32	0	Input data from non-source CB number 7
NS8_ASC_DAT	INT32	0	Input data from non-source CB number 8
NS9_ASC_DAT	INT32	0	Input data from non-source CB number 9

Table continues on the next page

Name	Type	Default	Description
NS10_ASC_DAT	INT32	0	Input data from non-source CB number 10
NS11_ASC_DAT	INT32	0	Input data from non-source CB number 11
NS12_ASC_DAT	INT32	0	Input data from non-source CB number 12
NS13_ASC_DAT	INT32	0	Input data from non-source CB number 13
NS14_ASC_DAT	INT32	0	Input data from non-source CB number 14
NS15_ASC_DAT	INT32	0	Input data from non-source CB number 15
NS16_ASC_DAT	INT32	0	Input data from non-source CB number 16
NS17_ASC_DAT	INT32	0	Input data from non-source CB number 17
U_DIFF_1	FLOAT32	0.00	Voltage difference from non-source CB 1
U_DIFF_2	FLOAT32	0.00	Voltage difference from non-source CB 2
U_DIFF_3	FLOAT32	0.00	Voltage difference from non-source CB 3
U_DIFF_4	FLOAT32	0.00	Voltage difference from non-source CB 4
U_DIFF_5	FLOAT32	0.00	Voltage difference from non-source CB 5
U_DIFF_6	FLOAT32	0.00	Voltage difference from non-source CB 6
U_DIFF_7	FLOAT32	0.00	Voltage difference from non-source CB 7
U_DIFF_8	FLOAT32	0.00	Voltage difference from non-source CB 8
U_DIFF_9	FLOAT32	0.00	Voltage difference from non-source CB 9
U_DIFF_10	FLOAT32	0.00	Voltage difference from non-source CB 10
U_DIFF_11	FLOAT32	0.00	Voltage difference from non-source CB 11
U_DIFF_12	FLOAT32	0.00	Voltage difference from non-source CB 12

Table continues on the next page

Name	Type	Default	Description
U_DIFF_13	FLOAT32	0.00	Voltage difference from non-source CB 13
U_DIFF_14	FLOAT32	0.00	Voltage difference from non-source CB 14
U_DIFF_15	FLOAT32	0.00	Voltage difference from non-source CB 15
U_DIFF_16	FLOAT32	0.00	Voltage difference from non-source CB 16
U_DIFF_17	FLOAT32	0.00	Voltage difference from non-source CB 17
FR_DIFF_1	FLOAT32	0.000	Frequency difference from non-source CB 1
FR_DIFF_2	FLOAT32	0.000	Frequency difference from non-source CB 2
FR_DIFF_3	FLOAT32	0.000	Frequency difference from non-source CB 3
FR_DIFF_4	FLOAT32	0.000	Frequency difference from non-source CB 4
FR_DIFF_5	FLOAT32	0.000	Frequency difference from non-source CB 5
FR_DIFF_6	FLOAT32	0.000	Frequency difference from non-source CB 6
FR_DIFF_7	FLOAT32	0.000	Frequency difference from non-source CB 7
FR_DIFF_8	FLOAT32	0.000	Frequency difference from non-source CB 8
FR_DIFF_9	FLOAT32	0.000	Frequency difference from non-source CB 9
FR_DIFF_10	FLOAT32	0.000	Frequency difference from non-source CB 10
FR_DIFF_11	FLOAT32	0.000	Frequency difference from non-source CB 11
FR_DIFF_12	FLOAT32	0.000	Frequency difference from non-source CB 12
FR_DIFF_13	FLOAT32	0.000	Frequency difference from non-source CB 13

Table continues on the next page

Name	Type	Default	Description
FR_DIFF_14	FLOAT32	0.000	Frequency difference from non-source CB 14
FR_DIFF_15	FLOAT32	0.000	Frequency difference from non-source CB 15
FR_DIFF_16	FLOAT32	0.000	Frequency difference from non-source CB 16
FR_DIFF_17	FLOAT32	0.000	Frequency difference from non-source CB 17

9.8.6.2 ASCGAPC Output signals

Table 1552: ASCGAPC Output signals

Name	Type	Description
AS_CONFLICT	BOOLEAN	Auto synchronization conflict
U_DIFF	FLOAT32	Voltage difference across the synchronizing CB
FR_DIFF	FLOAT32	Frequency difference across the synchronizing CB
ASC_NS1_DAT	INT32	Output data to non-source CB 1
ASC_NS2_DAT	INT32	Output data to non-source CB 2
ASC_NS3_DAT	INT32	Output data to non-source CB 3
ASC_SRC1_DAT	INT32	Output data to source num-ber 1
ASC_SRC2_DAT	INT32	Output data to source num-ber 2
ASC_SRC3_DAT	INT32	Output data to source num-ber 3
ASC_SRC4_DAT	INT32	Output data to source num-ber 4
ASC_SRC5_DAT	INT32	Output data to source num-ber 5
ASC_SRC6_DAT	INT32	Output data to source num-ber 6
ASC_SRC7_DAT	INT32	Output data to source num-ber 7
ASC_SRC8_DAT	INT32	Output data to source num-ber 8

9.8.7 ASCGAPC Settings

Table 1553: ASCGAPC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Number of sources	1...8		1	8	Total number of sources present in the system
Number of NonSrc CB	1...17		1	17	Number of bus coupler or grid transformer CB in the system

Table 1554: ASCGAPC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Src1 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 1 CB connected bus A number
Src1 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 1 CB connected bus B number
Src2 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3			0=Not Configured	Source 2 CB connected bus A number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15				
Src2 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 2 CB connected bus B number
Src3 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 3 CB connected bus A number
Src3 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4			0=Not Configured	Source 3 CB connected bus B number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15				
Src4 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 4 CB connected bus A number
Src4 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 4 CB connected bus B number
Src5 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5			0=Not Configured	Source 5 CB connected bus A number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15				
Src5 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 5 CB connected bus B number
Src6 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 6 CB connected bus A number
Src6 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6			0=Not Configured	Source 6 CB connected bus B number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15				
Src7 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 7 CB connected bus A number
Src7 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 7 CB connected bus B number
Src8 bus A Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7			0=Not Configured	Source 8 CB connected bus A number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15				
Src8 bus B Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15			0=Not Configured	Source 8 CB connected bus B number
NonSrc1 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB1 connected bus A1 number
NonSrc1 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7			0=Not Configured	Non-source CB1 connected bus A2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc1 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB1 connected bus B1 number
NonSrc1 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB1 connected bus B2 number
NonSrc2 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5			0=Not Configured	Non-source CB2 connected bus A1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc2 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB2 connected bus A2 number
NonSrc2 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB2 connected bus B1 number
NonSrc2 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3			0=Not Configured	Non-source CB2 connected bus B2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc3 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB3 connected bus A1 number
NonSrc3 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB3 connected bus A2 number
NonSrc3 bus B1 Num	0=Not Configured 1=Bus 1			0=Not Configured	Non-source CB3 connected bus B1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc3 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB3 connected bus B2 number
NonSrc4 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB4 connected bus A1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
NonSrc4 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB4 connected bus A2 number
NonSrc4 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB4 connected bus B1 number
NonSrc4 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14			0=Not Configured	Non-source CB4 connected bus B2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	15=Bus 15 21=Grid				
NonSrc5 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB5 connected bus A1 number
NonSrc5 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB5 connected bus A2 number
NonSrc5 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12			0=Not Configured	Non-source CB5 connected bus B1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc5 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB5 connected bus B2 number
NonSrc6 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB6 connected bus A1 number
NonSrc6 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10			0=Not Configured	Non-source CB6 connected bus A2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc6 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB6 connected bus B1 number
NonSrc6 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB6 connected bus B2 number
NonSrc7 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8			0=Not Configured	Non-source CB7 connected bus A1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc7 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB7 connected bus A2 number
NonSrc7 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB7 connected bus B1 number
NonSrc7 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6			0=Not Configured	Non-source CB7 connected bus B2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc8 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB8 connected bus A1 number
NonSrc8 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB8 connected bus A2 number
NonSrc8 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4			0=Not Configured	Non-source CB8 connected bus B1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc8 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB8 connected bus B2 number
NonSrc9 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB9 connected bus A1 number
NonSrc9 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2			0=Not Configured	Non-source CB9 connected bus A2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc9 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB9 connected bus B1 number
NonSrc9 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB9 connected bus B2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
NonSrc10 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB10 connected bus A1 number
NonSrc10 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB10 connected bus A2 number
NonSrc10 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14			0=Not Configured	Non-source CB10 connected bus B1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	15=Bus 15 21=Grid				
NonSrc10 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB10 connected bus B2 number
NonSrc11 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB11 connected bus A1 number
NonSrc11 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12			0=Not Configured	Non-source CB11 connected bus A2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc11 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB11 connected bus B1 number
NonSrc11 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB11 connected bus B2 number
NonSrc12 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10			0=Not Configured	Non-source CB12 connected bus A1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc12 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB12 connected bus A2 number
NonSrc12 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB12 connected bus B1 number
NonSrc12 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8			0=Not Configured	Non-source CB12 connected bus B2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc13 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB13 connected bus A1 number
NonSrc13 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB13 connected bus A2 number
NonSrc13 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6			0=Not Configured	Non-source CB13 connected bus B1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc13 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB13 connected bus B2 number
NonSrc14 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB14 connected bus A1 number
NonSrc14 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4			0=Not Configured	Non-source CB14 connected bus A2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc14 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB14 connected bus B1 number
NonSrc14 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB14 connected bus B2 number
NonSrc15 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2			0=Not Configured	Non-source CB15 connected bus A1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc15 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB15 connected bus A2 number
NonSrc15 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB15 connected bus B1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
NonSrc15 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB15 connected bus B2 number
NonSrc16 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB16 connected bus A1 number
NonSrc16 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14			0=Not Configured	Non-source CB16 connected bus A2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	15=Bus 15 21=Grid				
NonSrc16 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB16 connected bus B1 number
NonSrc16 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB16 connected bus B2 number
NonSrc17 bus A1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12			0=Not Configured	Non-source CB17 connected bus A1 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc17 bus A2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB17 connected bus A2 number
NonSrc17 bus B1 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10 11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid			0=Not Configured	Non-source CB17 connected bus B1 number
NonSrc17 bus B2 Num	0=Not Configured 1=Bus 1 2=Bus 2 3=Bus 3 4=Bus 4 5=Bus 5 6=Bus 6 7=Bus 7 8=Bus 8 9=Bus 9 10=Bus 10			0=Not Configured	Non-source CB17 connected bus B2 number

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	11=Bus 11 12=Bus 12 13=Bus 13 14=Bus 14 15=Bus 15 21=Grid				
NonSrc1 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB1
NonSrc2 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB2
NonSrc3 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB3
NonSrc4 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB4
NonSrc5 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB5
NonSrc6 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB6
NonSrc7 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB7
NonSrc8 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB8
NonSrc9 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB9
NonSrc10 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB10
NonSrc11 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB11
NonSrc12 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB12
NonSrc13 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB13
NonSrc14 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB14
NonSrc15 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB15
NonSrc16 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB16
NonSrc17 VT Conn	2=No Change 3=Reverse			2=No Change	Voltage transformer connection type for non-source CB17

Table 1555: ASCGAPC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
ASC CB Num1	1=Non source CB 1 2=Non source CB 2 3=Non source CB 3 4=Non source CB 4 5=Non source CB 5 6=Non source CB 6 7=Non source CB 7 8=Non source CB 8 9=Non source CB 9 10=Non source CB 10 11=Non source CB 11 12=Non source CB 12 13=Non source CB 13 14=Non source CB 14 15=Non source CB 15 16=Non source CB 16 17=Non source CB 17 18=Source CB 1 19=Source CB 2 20=Source CB 3 21=Source CB 4 22=Source CB 5 23=Source CB 6 24=Source CB 7 25=Source CB 8			1=Non source CB 1	ASC host circuit breaker number 1
ASC CB Num2	0=Not Configured 1=Non source CB 1 2=Non source CB 2 3=Non source CB 3 4=Non source CB 4 5=Non source CB 5 6=Non source CB 6 7=Non source CB 7 8=Non source CB 8 9=Non source CB 9 10=Non source CB 10 11=Non source CB 11 12=Non source CB 12			0=Not Configured	ASC host circuit breaker number 2

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	13=Non source CB 13 14=Non source CB 14 15=Non source CB 15 16=Non source CB 16 17=Non source CB 17				
ASC CB Num3	0=Not Configured 1=Non source CB 1 2=Non source CB 2 3=Non source CB 3 4=Non source CB 4 5=Non source CB 5 6=Non source CB 6 7=Non source CB 7 8=Non source CB 8 9=Non source CB 9 10=Non source CB 10 11=Non source CB 11 12=Non source CB 12 13=Non source CB 13 14=Non source CB 14 15=Non source CB 15 16=Non source CB 16 17=Non source CB 17			0=Not Configured	ASC host circuit breaker number 3

Table 1556: ASCGAPC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Max matching time	100...6000000	ms	1	60000	Maximum time to complete the voltage and frequency matching
Central PMS present	1=No 2=Yes			1=No	Centralized power management system present
Double busbar	0=False 1=True			0=False	Double busbar present in the system

9.8.8 ASCGAPC Monitored data

Table 1557: ASCGAPC Monitored data

Name	Type	Values (Range)	Unit	Description
SBNW_SRC1	INT32	0...99		Source 1 subnetwork number
SBNW_SRC2	INT32	0...99		Source 2 subnetwork number
SBNW_SRC3	INT32	0...99		Source 3 subnetwork number
SBNW_SRC4	INT32	0...99		Source 4 subnetwork number
SBNW_SRC5	INT32	0...99		Source 5 subnetwork number
SBNW_SRC6	INT32	0...99		Source 6 subnetwork number
SBNW_SRC7	INT32	0...99		Source 7 subnetwork number
SBNW_SRC8	INT32	0...99		Source 8 subnetwork number
SBNW_NSCB1	INT32	0...99		Non-source CB 1 sub-network number
SBNW_NSCB2	INT32	0...99		Non-source CB 2 sub-network number
SBNW_NSCB3	INT32	0...99		Non-source CB 3 sub-network number
SBNW_NSCB4	INT32	0...99		Non-source CB 4 sub-network number
SBNW_NSCB5	INT32	0...99		Non-source CB 5 sub-network number
SBNW_NSCB6	INT32	0...99		Non-source CB 6 sub-network number
SBNW_NSCB7	INT32	0...99		Non-source CB 7 sub-network number
SBNW_NSCB8	INT32	0...99		Non-source CB 8 sub-network number
SBNW_NSCB9	INT32	0...99		Non-source CB 9 sub-network number
SBNW_NSCB10	INT32	0...99		Non-source CB 10 sub-network number
SBNW_NSCB11	INT32	0...99		Non-source CB 11 sub-network number
SBNW_NSCB12	INT32	0...99		Non-source CB 12 sub-network number
SBNW_NSCB13	INT32	0...99		Non-source CB 13 sub-network number
SBNW_NSCB14	INT32	0...99		Non-source CB 14 sub-network number
SBNW_NSCB15	INT32	0...99		Non-source CB 15 sub-network number
SBNW_NSCB16	INT32	0...99		Non-source CB 16 sub-network number
SBNW_NSCB17	INT32	0...99		Non-source CB 17 sub-network number
SBNW_BB1	INT32	0...99		Bus 1 subnetwork num-ber
SBNW_BB2	INT32	0...99		Bus 2 subnetwork num-ber
SBNW_BB3	INT32	0...99		Bus 3 subnetwork num-ber
SBNW_BB4	INT32	0...99		Bus 4 subnetwork num-ber
SBNW_BB5	INT32	0...99		Bus 5 subnetwork num-ber

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
SBNW_BB6	INT32	0...99		Bus 6 subnetwork number
SBNW_BB7	INT32	0...99		Bus 7 subnetwork number
SBNW_BB8	INT32	0...99		Bus 8 subnetwork number
SBNW_BB9	INT32	0...99		Bus 9 subnetwork number
SBNW_BB10	INT32	0...99		Bus 10 subnetwork number
SBNW_BB11	INT32	0...99		Bus 11 subnetwork number
SBNW_BB12	INT32	0...99		Bus 12 subnetwork number
SBNW_BB13	INT32	0...99		Bus 13 subnetwork number
SBNW_BB14	INT32	0...99		Bus 14 subnetwork number
SBNW_BB15	INT32	0...99		Bus 15 subnetwork number
SRC1_GRI_CON	BOOLEAN	0=False 1=True		Source 1 grid connection status
SRC2_GRI_CON	BOOLEAN	0=False 1=True		Source 2 grid connection status
SRC3_GRI_CON	BOOLEAN	0=False 1=True		Source 3 grid connection status
SRC4_GRI_CON	BOOLEAN	0=False 1=True		Source 4 grid connection status
SRC5_GRI_CON	BOOLEAN	0=False 1=True		Source 5 grid connection status
SRC6_GRI_CON	BOOLEAN	0=False 1=True		Source 6 grid connection status
SRC7_GRI_CON	BOOLEAN	0=False 1=True		Source 7 grid connection status
SRC8_GRI_CON	BOOLEAN	0=False 1=True		Source 8 grid connection status
ASC ACTIVE	BOOLEAN	0=False 1=True		ASC active status
MATCH STATUS	Enum	1=No request 2=Request received 3=No source selection 4=Correct Src selection 5=Wrong source selection 6=Wrong tuning Src Sel 8=Source ready 9=GOV-AVR modes not OK 10=GOV-AVR modes OK 11=Matching in progress		Matching status

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		12=Matching done 13=Matching not done 14=Int Connect,set Sync 15=Int Connect,set Async 16=Externally connec-ted 17=Int Async,set Sync		
SRC1_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 1 participation group
SRC2_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 2 participation group
SRC3_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 3 participation group
SRC4_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 4 participation group
SRC5_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4		Source 5 participation group

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		
SRC6_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 6 participation group
SRC7_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 7 participation group
SRC8_PTC_GRP	Enum	1=Group 1 2=Group 2 3=Group 3 4=Group 4 5=Group 5 6=Group 6 7=Group 7 8=Group 8 9=Group 9		Source 8 participation group
SELECTED_GRP	Enum	1=Group 1 2=Group 2 3=Group 3		Selected source participation group
CONFL_STATUS	Enum	1=No conflict 2=Multiple NSCB sync 3=Multiple SCB sync 4=NSCB and SCB sync		Autosynchronization conflict status
NSCB_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Operation mode of non-source CB undergoing synchronization

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
SRC1_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 1
SRC2_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 2
SRC3_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 3
SRC4_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 4
SRC5_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 5
SRC6_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 6
SRC7_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem		Synchronization operation mode of source 7

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		5=AS Auto Relay Loc 6=AS Auto Relay Rem		
SRC8_SYN_MOD	Enum	0=Invalid 1=AS Man Relay Loc 2=AS Man Relay Rem 3=AS Semi Relay Loc 4=AS Semi Relay Rem 5=AS Auto Relay Loc 6=AS Auto Relay Rem		Synchronization operation mode of source 8
NSCB_UND_SYN	INT32	0...99		Non-source CB undergoing synchronization
SRC1_PTC_ST	BOOLEAN	0=False 1=True		Source 1 participation status
SRC2_PTC_ST	BOOLEAN	0=False 1=True		Source 2 participation status
SRC3_PTC_ST	BOOLEAN	0=False 1=True		Source 3 participation status
SRC4_PTC_ST	BOOLEAN	0=False 1=True		Source 4 participation status
SRC5_PTC_ST	BOOLEAN	0=False 1=True		Source 5 participation status
SRC6_PTC_ST	BOOLEAN	0=False 1=True		Source 6 participation status
SRC7_PTC_ST	BOOLEAN	0=False 1=True		Source 7 participation status
SRC8_PTC_ST	BOOLEAN	0=False 1=True		Source 8 participation status
ASCGAPC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.9 Autoreclosing DARREC (ANSI 79)

9.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autoreclosing	DARREC	O -> I	79

9.9.2 Function block

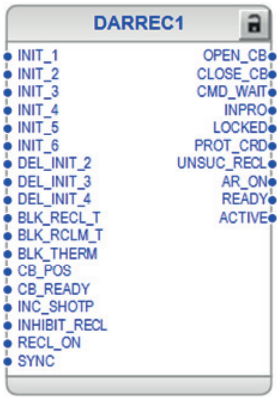


Figure 891: Function block

9.9.3 Functionality

About 80 to 85 percent of faults in the MV overhead lines are transient and automatically cleared with a momentary de-energization of the line. The rest of the faults, 15 to 20 percent, can be cleared by longer interruptions. The de-energization of the fault location for a selected time period is implemented through automatic reclosing, during which most of the faults can be cleared.

In case of a permanent fault, the automatic reclosing is followed by final tripping. A permanent fault must be located and cleared before the fault location can be re-energized.

The autoreclosing function DARREC can be used with any circuit breaker suitable for autoreclosing. The function provides five programmable autoreclosing shots which can perform one to five successive autoreclosings of desired type and duration, for instance one high-speed and one delayed autoreclosing.

When the reclosing is initiated with starting of the protection function, the autoreclosing function can execute the final trip of the circuit breaker in a short operate time, provided that the fault still persists when the last selected reclosing has been carried out.

9.9.3.1 Protection signal definition

The *Control line* setting defines which of the initiation signals are protection start and trip signals and which are not. With this setting, the user can distinguish the blocking signals from the protection signals. The *Control line* setting is a bit mask, that is, the lowest bit controls the `INIT_1` line and the highest bit the `INIT_6` line. Some example combinations of the *Control line* setting are as follows:

Table 1558: Control line setting definition

Control line setting	INIT_1	INIT_2 DEL_INIT _2	INIT_3 DEL_INIT _3	INIT_4 DEL_INIT _4	INIT_5	INIT_6
0	other	other	other	other	other	other
1	prot	other	other	other	other	other
2	other	prot	other	other	other	other
3	prot	prot	other	other	other	other
4	other	other	prot	other	other	other
5	prot	other	prot	other	other	other
...63	prot	prot	prot	prot	prot	prot

prot =	protection signal
other =	non-protection signal

When the corresponding bit or bits in both the *Control line* setting and the INIT_X line are TRUE:

- The CLOSE_CB output is blocked until the protection is reset
- If the INIT_X line defined as the protection signal is activated during the discrimination time, the AR function goes to lockout
- If the INIT_X line defined as the protection signal stays active longer than the time set by the *Max trip time* setting, the AR function goes to lockout (long trip)
- The UNSUC_RECL output is activated after a pre-defined two minutes (alarming earth-fault).

9.9.3.2 Zone coordination

Zone coordination is used in the zone sequence between local protection units and downstream devices. At the falling edge of the INC_SHOTP line, the value of the shot pointer is increased by one, unless a shot is in progress or the shot pointer already has the maximum value.

The falling edge of the INC_SHOTP line is not accepted if any of the shots are in progress.

9.9.3.3 Master and slave scheme

With the cooperation between the AR units in the same protection relay or between protection relays, sequential reclosings of two breakers at a line end in a 1½-breaker, double breaker or ring-bus arrangement can be achieved. One unit is defined as a master and it executes the reclosing first. If the reclosing is successful and no trip takes place, the second unit, that is the slave, is released to complete the reclose shot. With persistent faults, the breaker reclosing is limited to the first breaker.

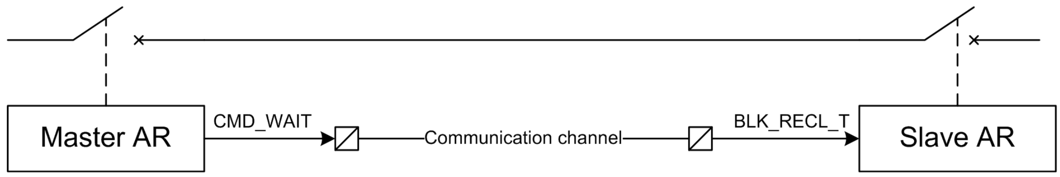


Figure 892: Master and slave scheme

If the AR unit is defined as a master by setting its terminal priority to high:

- The unit activates the CMD_WAIT output to the low priority slave unit whenever a shot is in progress, a reclosing is unsuccessful or the BLK_RCLM_T input is active
- The CMD_WAIT output is reset one second after the reclose command is given or if the sequence is unsuccessful when the reclaim time elapses.

If the AR unit is defined as a slave by setting its terminal priority to low:

- The unit waits until the master releases the BLK_RECL_T input (the CMD_WAIT output in the master). Only after this signal has been deactivated, the reclose time for the slave unit can be started.
- The slave unit is set to a lockout state if the BLK_RECL_T input is not released within the time defined by the *Max wait time* setting , which follows the initiation of an autoreclosing shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

9.9.3.4 Thermal overload blocking

An alarm or start signal from the thermal overload protection (T1PTTR) can be routed to the input BLK_THERM to block and hold the reclose sequence. The BLK_THERM signal does not affect the starting of the sequence. When the reclose time has elapsed and the BLK_THERM input is active, the shot is not ready until the BLK_THERM input deactivates. Should the BLK_THERM input remain active longer than the time set by the setting *Max Thm block time*, the AR function goes to lockout.

If the BLK_THERM input is activated when the auto wait timer is running, the auto wait timer is reset and the timer restarted when the BLK_THERM input deactivates.

9.9.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". Setting *Operation* to "Off" resets non-volatile counters.

The reclosing operation can be enabled and disabled with the *Reclosing operation* setting. This setting does not disable the function, only the reclosing functionality. The setting has three parameter values: “On”, “External Ctl” and ”Off”. The setting value “On” enables the reclosing operation and “Off” disables it. When the setting value “External Ctl” is selected, the reclosing operation is controlled with the RECL_ON input. AR_ON is activated when reclosing operation is enabled.

The operation of DARREC can be described using a module diagram. All the modules in the diagram are explained in the next sections.

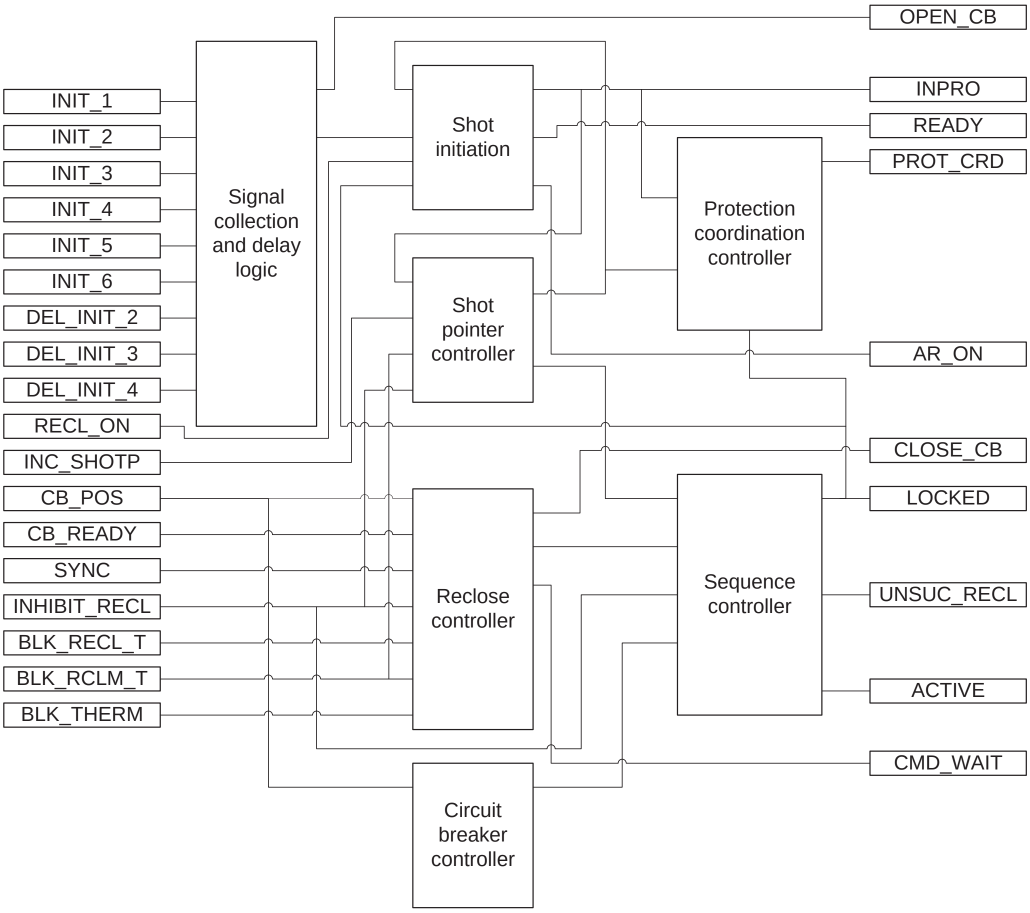


Figure 893: Functional module diagram

9.9.4.1 Signal collection and delay logic

When the protection trips, the initiation of autoreclosing shots is in most applications executed with the `INIT_1...6` inputs. The `DEL_INIT2...4` inputs are not used. In some countries, starting the protection stage is also used for the shot initiation. This is the only time when the `DEL_INIT` inputs are used.

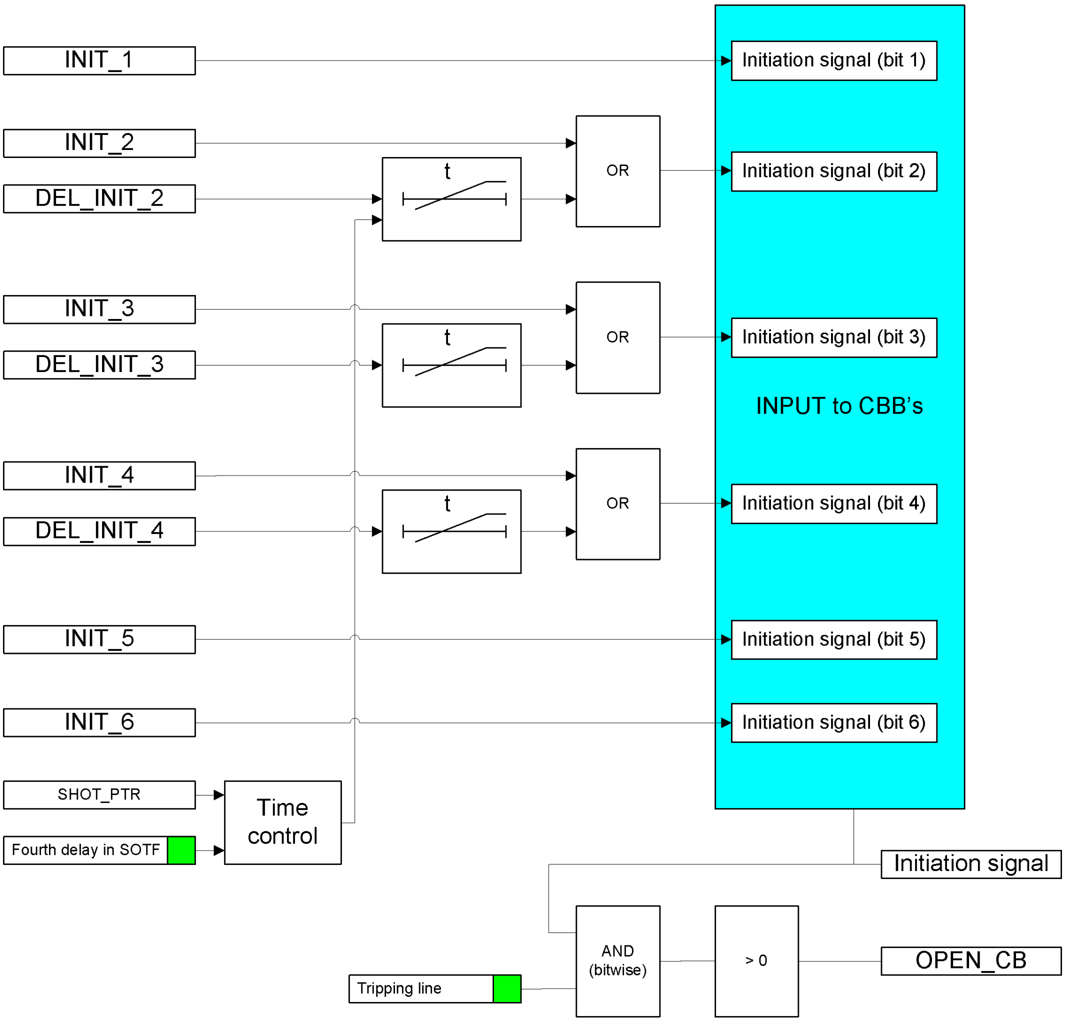


Figure 894: Schematic diagram of delayed initiation input signals

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the autoreclosing shots. These lines are divided into two types of channels. In three of these channels, the signal to the AR function can be delayed, whereas the other three channels do not have any delaying capability.

Each channel that is capable of delaying a start signal has four time delays. The time delay is selected based on the shot pointer in the AR function. For the first reclose attempt, the first time delay is selected; for the second attempt, the second time delay and so on. For the fourth and fifth attempts, the time delays are the same.

Time delay settings for the `DEL_INIT_2` signal

- *Str 2 delay shot 1*
- *Str 2 delay shot 2*
- *Str 2 delay shot 3*
- *Str 2 delay shot 4*

Time delay settings for the `DEL_INIT_3` signal

- *Str 3 delay shot 1*
- *Str 3 delay shot 2*
- *Str 3 delay shot 3*

- *Str 3 delay shot 4*

Time delay settings for the DEL_INIT_4 signal

- *Str 4 delay shot 1*
- *Str 4 delay shot 2*
- *Str 4 delay shot 3*
- *Str 4 delay shot 4*

Normally, only two or three reclosing attempts are made. The third and fourth attempts are used to provide the so-called fast final trip to lockout.

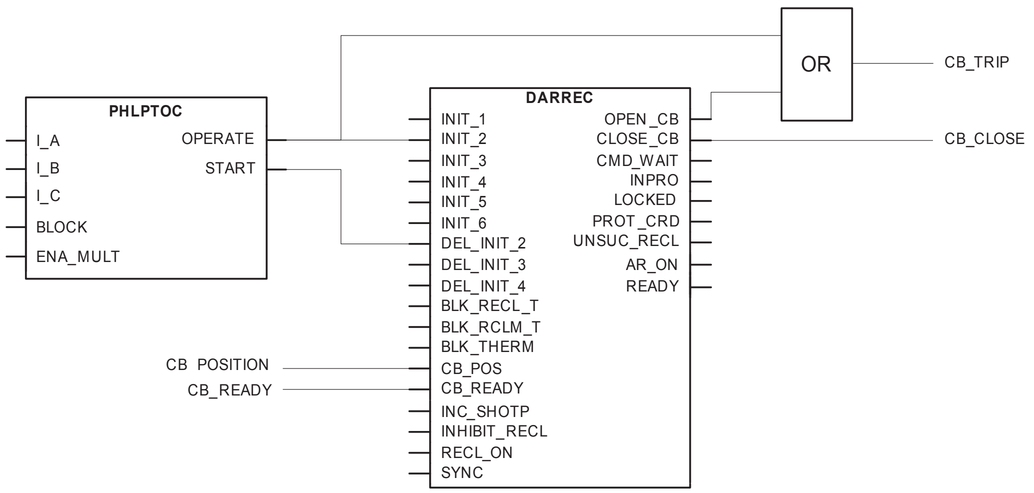


Figure 895: Autoreclosing configuration example

Delayed DEL_INIT_2...4 signals are used only when the autoreclosing shot is initiated with the start signal of a protection stage. After a start delay, the AR function opens the circuit breaker and an autoreclosing shot is initiated. When the shot is initiated with the trip signal of the protection, the protection function trips the circuit breaker and simultaneously initiates the autoreclosing shot.

If the circuit breaker is manually closed against the fault, that is, if SOTF is used, the fourth time delay can automatically be taken into use. This is controlled with the internal logic of the AR function and the *Fourth delay in SOTF* parameter.

A typical autoreclose situation is where one autoreclosing shot has been performed after the fault was detected. There are two types of such cases: operation initiated with protection start signal and operation initiated with protection trip signal. In both cases, the autoreclosing sequence is successful: the reclaim time elapses and no new sequence is started.

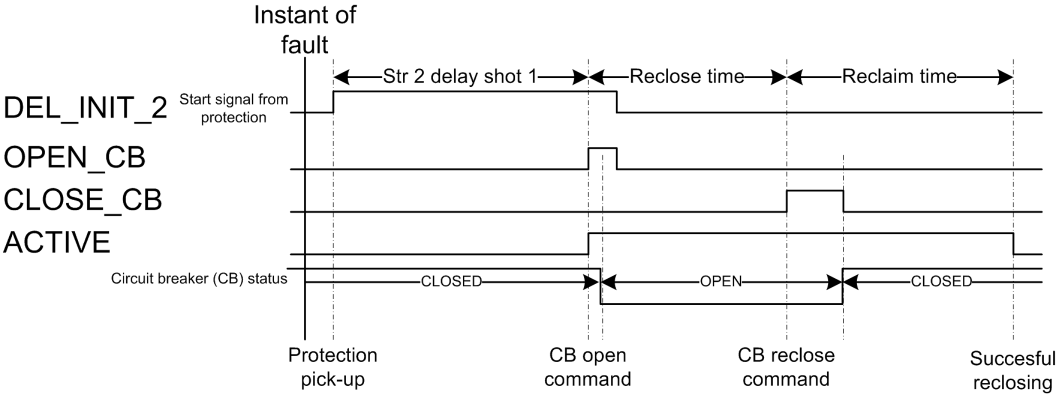


Figure 896: Signal scheme of autoreclosing operation initiated with protection start signal

The autoreclosing shot is initiated with a start signal of the protection function after the start delay time has elapsed. The autoreclosing starts when the *Str 2 delay shot 1* setting elapses.

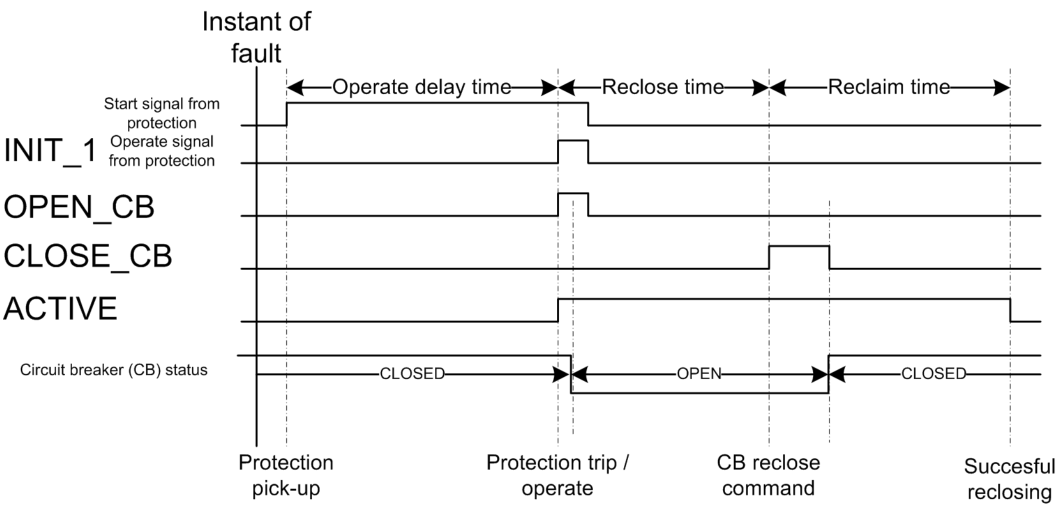


Figure 897: Signal scheme of autoreclosing operation initiated with protection operate signal

The autoreclosing shot is initiated with a trip signal of the protection function. The autoreclosing starts when the protection operate delay time elapses.

Normally, all trip and start signals are used to initiate an autoreclosing shot and trip the circuit breaker. ACTIVE output indicates reclosing sequence in progress. If any of the input signals INIT_X or DEL_INIT_X are used for blocking, the corresponding bit in the *Tripping line* setting must be FALSE. This is to ensure that the circuit breaker does not trip from that signal, that is, the signal does not activate the OPEN_CB output. The default value for the setting is "63", which means that all initiation signals activate the OPEN_CB output. The lowest bit in the *Tripping line* setting corresponds to the INIT_1 input, the highest bit to the INIT_6 line.

9.9.4.2 Shot initiation

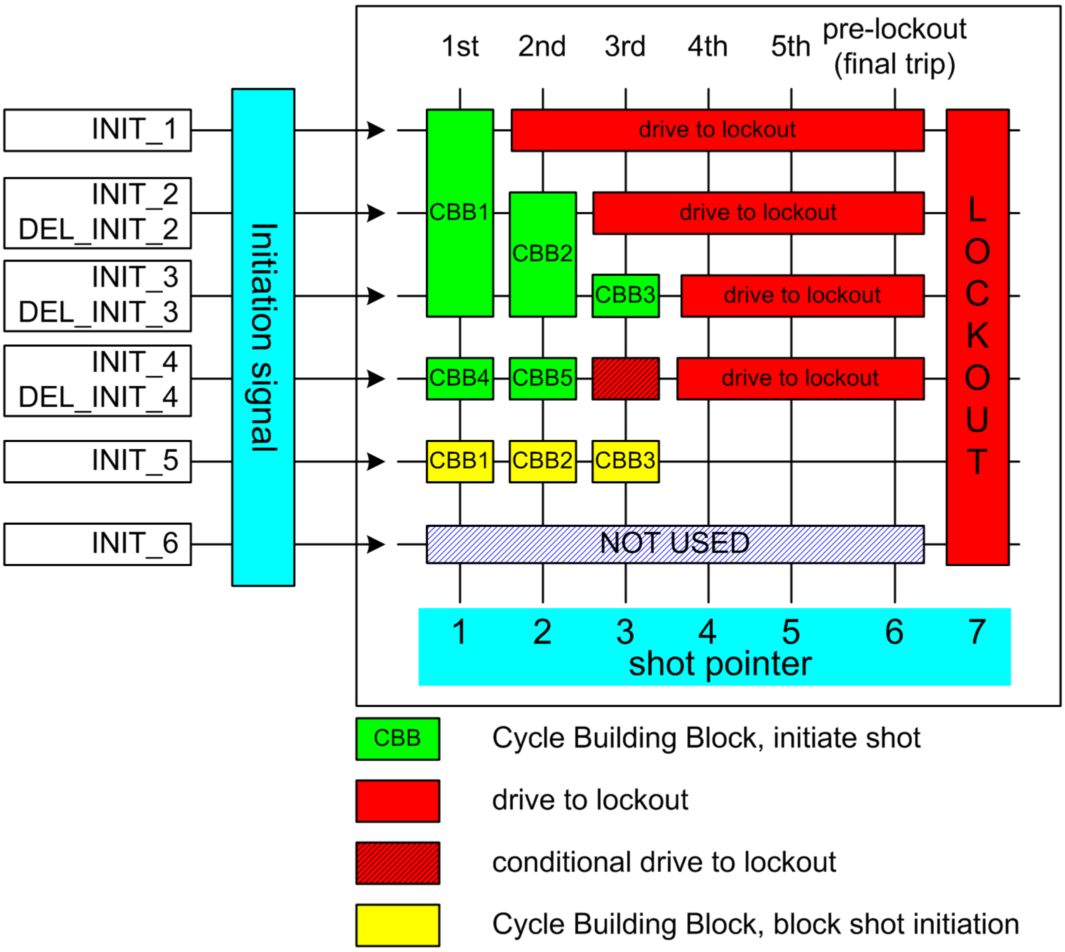


Figure 898: Example of an autoreclosing program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1…CBB7*
- *Blk signals CBB1…CBB7*
- *Shot number CBB1…CBB7*

The reclose time defines the open and dead times, that is, the time between the `OPEN_CB` and the `CLOSE_CB` commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1…CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 111000 = 7)
- *Blk signals CBB1* = 16 (the fifth bit: 000010 = 16)

- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 011000 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 001000 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 000100 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the INIT_1 line, only one shot is allowed before lockout. If a shot is initiated from the INIT_3 line, three shots are allowed before lockout.

A sequence initiation from the INIT_4 line leads to a lockout after two shots. In a situation where the initiation is made from both the INIT_3 and INIT_4 lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the INIT_2 and INIT_3 lines, an immediate lockout occurs.

The INIT_5 line is used for blocking purposes. If the INIT_5 line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.

If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the INIT_2 and INIT_4 lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a CLOSE_CB command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the autoreclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

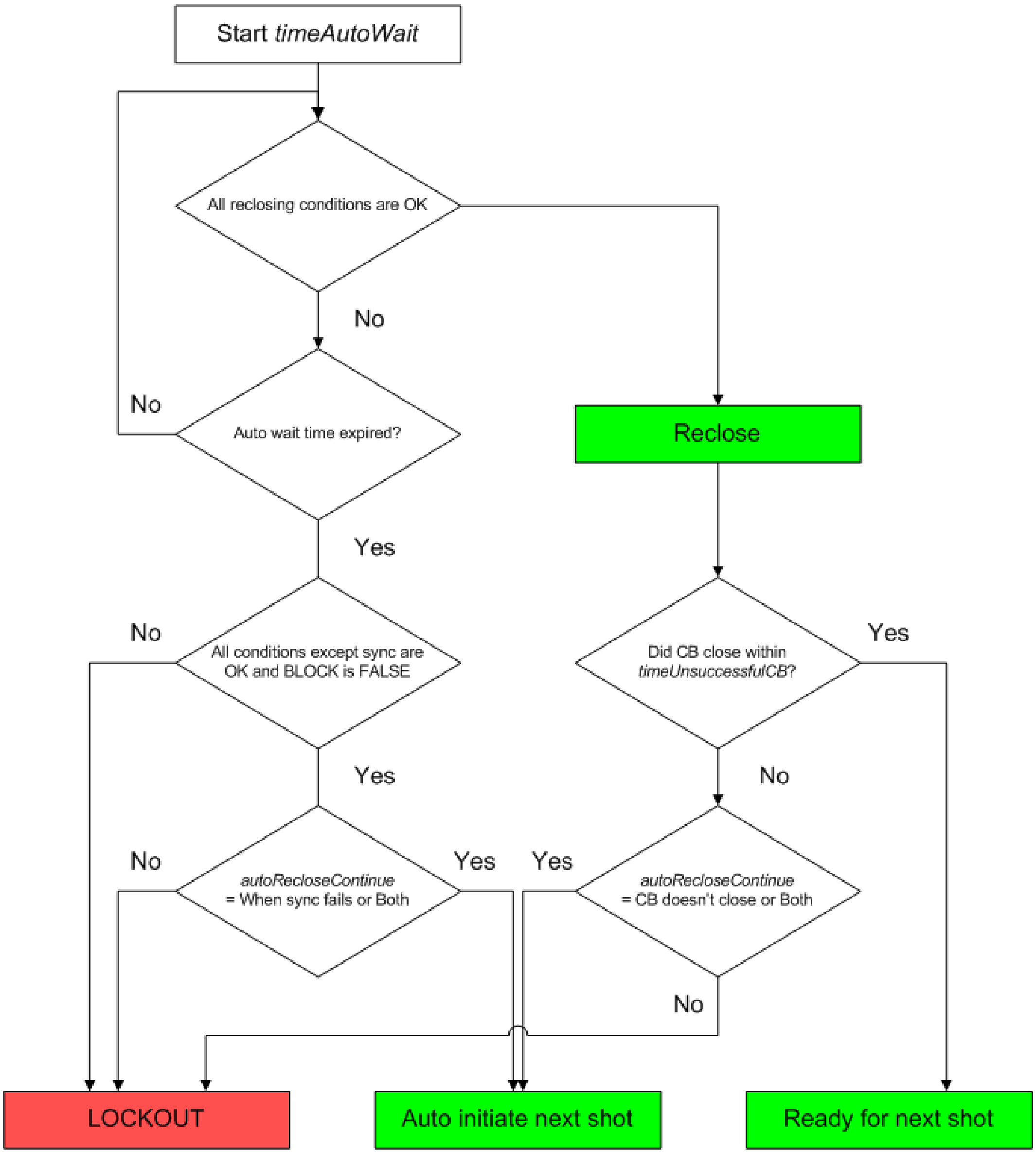


Figure 899: Logic diagram of auto-initiation sequence detection

Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed
- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.

The *Auto init* parameter defines which `INIT_X` lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.

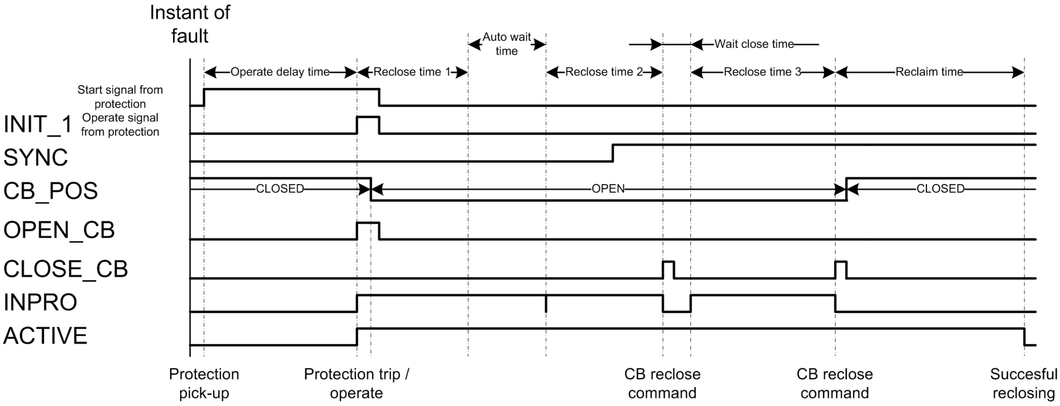


Figure 900: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

In the first shot, the synchronization condition is not fulfilled (SYNC is FALSE). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

9.9.4.3 Shot pointer controller

The execution of a reclose sequence is controlled by a shot pointer. It can be adjusted with the SHOT_PTR monitored data.

The shot pointer starts from an initial value "1" and determines according to the settings whether or not a certain shot is allowed to be initiated. After every shot, the shot pointer value increases. This is carried out until a successful reclosing or lockout takes place after a complete shot sequence containing a total of five shots.

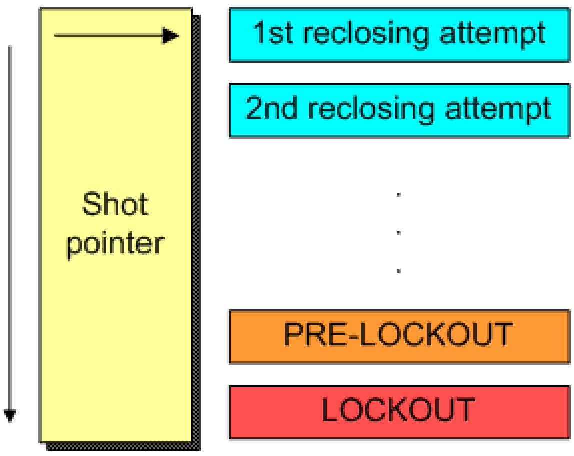


Figure 901: Shot pointer function

Every time the shot pointer increases, the reclaim time starts. When the reclaim time ends, the shot pointer sets to its initial value, unless no new shot is initiated.

The shot pointer increases when the reclose time elapses or at the falling edge of the INC_SHOTP signal.

When SHOT_PTR has the value six, the AR function is in a so called pre-lockout state. If a new initiation occurs during the pre-lockout state, the AR function goes to lockout. Therefore, a new sequence initiation during the pre-lockout state is not possible.

The AR function goes to the pre-lockout state in the following cases:

- During SOTF
- When the AR function is active, it stays in a pre-lockout state for the time defined by the reclaim time
- When all five shots have been executed
- When the frequent operation counter limit is reached. A new sequence initiation forces the AR function to lockout.

9.9.4.4 Reclose controller

The reclose controller calculates the reclose, discrimination and reclaim times. The reclose time is started when the INPRO signal is activated, that is, when the sequence starts and the activated CBB defines the reclose time.

When the reclose time has elapsed, the CLOSE_CB output is not activated until the following conditions are fulfilled:

- The SYNC input must be TRUE if the particular CBB requires information about the synchronism
- All AR initiation inputs that are defined protection lines (using the *Control line* setting) are inactive
- The circuit breaker is open
- The circuit breaker is ready for the close command, that is, the CB_READY input is TRUE. This is indicated by active READY output.

If at least one of the conditions is not fulfilled within the time set with the *Auto wait time* parameter, the autoreclose sequence is locked.

The synchronism requirement for the CBBs can be defined with the *Synchronisation set* setting, which is a bit mask. The lowest bit in the *Synchronisation set* setting is related to CBB1 and the highest bit to CBB7. For example, if the setting is set to "1", only CBB1 requires synchronism. If the setting is it set to "7", CBB1, CBB2 and CBB3 require the SYNC input to be TRUE before the reclosing command can be given.

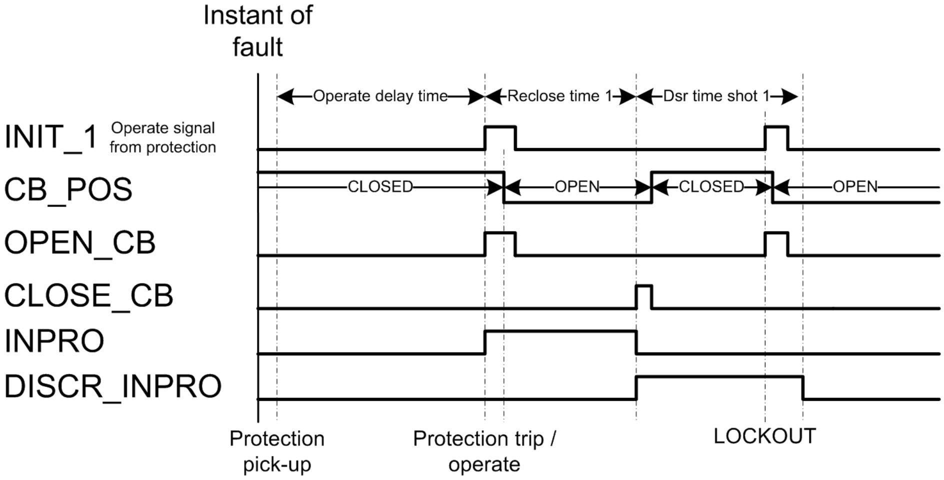


Figure 902: Initiation during discrimination time - AR function goes to lockout

The discrimination time starts when the close command `CLOSE_CB` has been given. If a start input is activated before the discrimination time has elapsed, the AR function goes to lockout. The default value for each discrimination time is zero. The discrimination time can be adjusted with the *Dsr time shot 1…4* parameter.

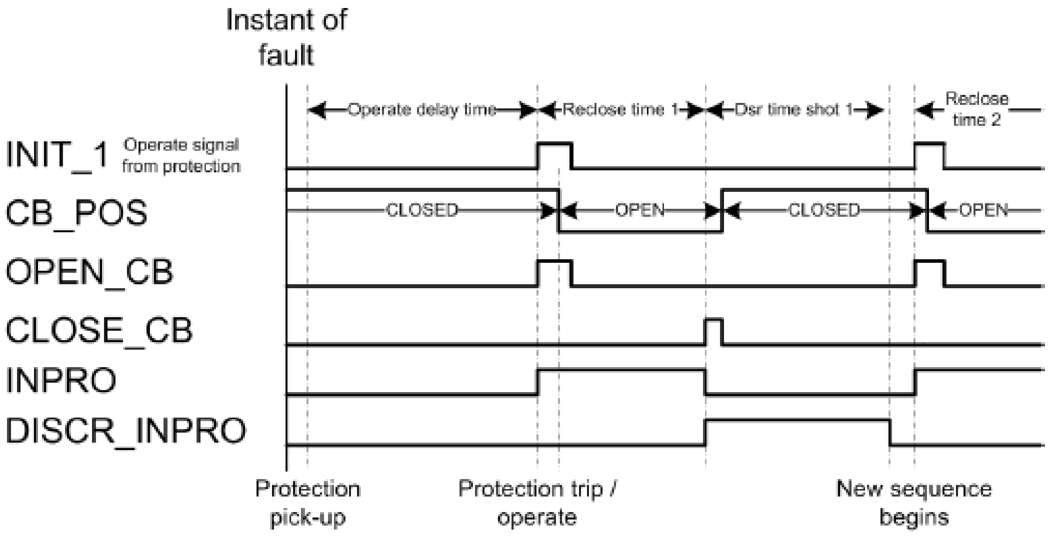


Figure 903: Initiation after elapsed discrimination time - new shot begins

9.9.4.5 Sequence controller

When the `LOCKED` output is active, the AR function is in lockout. This means that new sequences cannot be initialized, because AR is insensitive to initiation commands. It can be released from the lockout state in the following ways.

- The function is reset through communication with the *RecRs* parameter. The same functionality can also be found in the Clear menu (DARREC1 reset).
- The lockout is automatically reset after the reclaim time, if the *Auto lockout reset* setting is in use.

If the *Auto lockout reset* setting is not in use, the lockout can be released only with the *RecRs* parameter.

The AR function can go to lockout for many reasons.

- The INHIBIT_RECL input is active.
- All shots have been executed and a new initiation is made (final trip).
- The time set with the *Auto wait time* parameter expires and the automatic sequence initiation is not allowed because of a synchronization failure.
- The time set with the *Wait close time* parameter expires, that is, the circuit breaker does not close or the automatic sequence initiation is not allowed due to a closing failure of the circuit breaker.
- A new shot is initiated during the discrimination time.
- The time set with the *Max wait time* parameter expires, that is, the master unit does not release the slave unit.
- The frequent operation counter limit is reached and new sequence is initiated. The lockout is released when the recovery timer elapses.
- The protection trip signal has been active longer than the time set with the *Max wait time* parameter since the shot initiation.
- The circuit breaker is closed manually during an autoreclosing sequence and the manual close mode is FALSE.

9.9.4.6 Protection coordination controller

The PROT_CRD output is used for controlling the protection functions. In several applications, such as fuse-saving applications involving down-stream fuses, tripping and initiation of shot 1 should be fast (instantaneous or short-time delayed). The tripping and initiation of shots 2, 3 and definite tripping time should be delayed.

In this example, two overcurrent elements PHLPTOC and PHIPTOC are used. PHIPTOC is given an instantaneous characteristic and PHLPTOC is given a time delay.

The PROT_CRD output is activated, if the SHOT_PTR value is the same or higher than the value defined with the *Protection crd limit* setting and all initialization signals have been reset. The PROT_CRD output is reset under the following conditions:

- If the cut-out time elapses
- If the reclaim time elapses and the AR function is ready for a new sequence
- If the AR function is in lockout or disabled, that is, if the value of the *Protection crd mode* setting is "AR inoperative" or "AR inop, CB man".

The PROT_CRD output can also be controlled with the *Protection crd mode* setting. The setting has the following modes:

- "no condition": the PROT_CRD output is controlled only with the *Protection crd limit* setting
- "AR inoperative": the PROT_CRD output is active, if the AR function is disabled or in the lockout state, or if the INHIBIT_RECL input is active
- "CB close manual": the PROT_CRD output is active for the reclaim time if the circuit breaker has been manually closed, that is, the AR function has not issued a close command
- "AR inop, CB man": both the modes "AR inoperative" and "CB close manual" are effective

- "always": the PROT_CRD output is constantly active

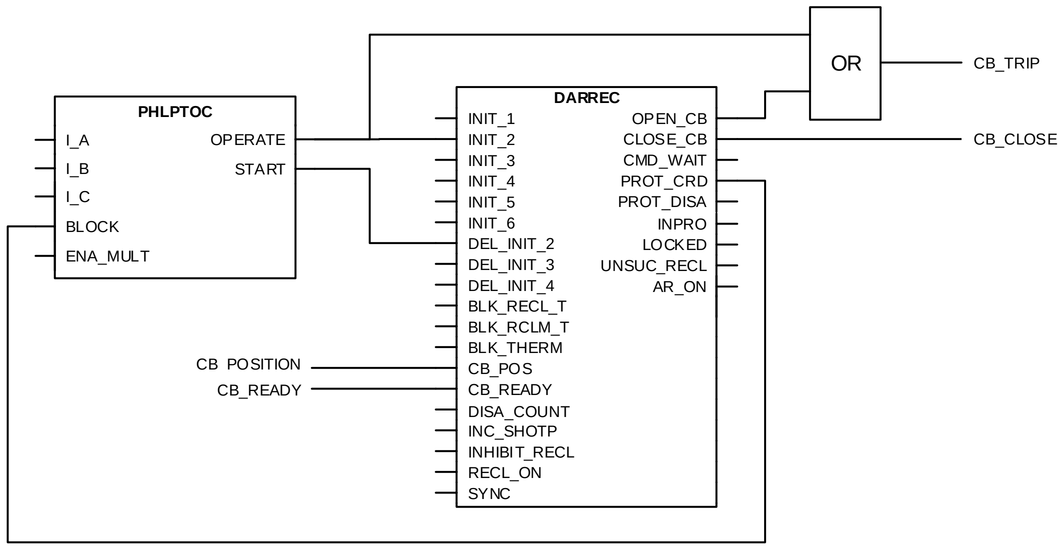


Figure 904: Configuration example of using the PROT_CRD output for protection blocking

If the *Protection crd limit* setting has the value "1", the instantaneous three-phase overcurrent protection function PHIPTOC is disabled or blocked after the first shot.

9.9.4.7 Circuit breaker controller

Circuit breaker controller contains two features: SOTF and frequent-operation counter. SOTF protects the AR function in permanent faults.

The circuit breaker position information is controlled with the *CB closed Pos status* setting. The setting value "TRUE” means that when the circuit breaker is closed, the CB_POS input is TRUE. When the setting value is “FALSE”, the CB_POS input is FALSE, provided that the circuit breaker is closed. The reclose command pulse time can be controlled with the *Close pulse time* setting: the CLOSE_CB output is active for the time set with the *Close pulse time* setting. The CLOSE_CB output is deactivated also when the circuit breaker is detected to be closed, that is, when the CB_POS input changes from open state to closed state. The *Wait close time* setting defines the time after the CLOSE_CB command activation, during which the circuit breaker should be closed. If the closing of circuit breaker does not happen during this time, the autoreclosing function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for autoreclosing to begin with is the assumption that the fault is temporary by nature, and that a momentary de-energizing of the power line and an automatic reclosing restores the power supply. However, when the power line is manually energized and an immediate protection trip is detected, it is very likely that the fault is of a permanent type. A permanent fault is, for example, energizing a power line into a forgotten earthing after a maintenance work along the power line. In such cases, SOTF is activated, but only for the reclaim time after energizing the power line and only when the circuit breaker is closed manually and not by the AR function.

SOTF disables any initiation of an autoreclosing shot. The energizing of the power line is detected from the CB_POS information.

SOTF is activated when the AR function is enabled or when the AR function is started and the SOTF should remain active for the reclaim time.

When SOTF is detected, the parameter *SOTF* is active.

If the *Manual close mode* setting is set to FALSE and the circuit breaker has been manually closed during an autoreclosing shot, the AR unit goes to an immediate lockout.

If the *Manual close mode* setting is set to TRUE and the circuit breaker has been manually closed during an autoreclosing shot (the INPRO is active), the shot is considered as completed.

When SOTF starts, reclaim time is restarted, provided that it is running.

The frequent-operation counter is intended for blocking the autoreclosing function in cases where the fault causes repetitive autoreclosing sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are autoreclosing shots within a few minutes interval during a stormy night. These types of faults can easily damage the circuit breaker if the AR function is not locked by a frequent-operation counter.

The frequent-operation counter has three settings:

- *Frq Op counter limit*
- *Frq Op counter time*
- *Frq Op recovery time*

The *Frq Op counter limit* setting defines the number of reclose attempts that are allowed during the time defined with the *Frq Op counter time* setting. If the set value is reached within a pre-defined period defined with the *Frq Op counter time* setting, the AR function goes to lockout when a new shot begins, provided that the counter is still above the set limit. The lockout is released after the recovery time has elapsed. The recovery time can be defined with the *Frq Op recovery time* setting .

If the circuit breaker is manually closed during the recovery time, the reclaim time is activated after the recovery timer has elapsed.

9.9.5 Counters

The AR function contains six counters. Their values are stored in a semi-retain memory. The counters are increased at the rising edge of the reclosing command. The counters count the following situations.

- COUNTER: counts every reclosing command activation
- CNT_SHOT1: counts reclosing commands that are executed from shot 1
- CNT_SHOT2: counts reclosing commands that are executed from shot 2
- CNT_SHOT3: counts reclosing commands that are executed from shot 3
- CNT_SHOT4: counts reclosing commands that are executed from shot 4
- CNT_SHOT5: counts reclosing commands that are executed from shot 5

The counters are disabled through communication with the *DsaCnt* parameter. When the counters are disabled, the values are not updated.

The counters are reset through communication with the *CntRs* parameter. The same functionality can also be found in the clear menu (DARREC1 counters).

9.9.6 Application

Modern electric power systems can deliver energy to users very reliably. However, different kind of faults can occur. Protection relays play an important role in detecting failures or abnormalities in the system. They detect faults and give commands for corresponding circuit breakers to isolate the defective element before excessive damage or a possible power system collapse occurs. A fast isolation also limits the disturbances caused for the healthy parts of the power system.

The faults can be transient, semi-transient or permanent. Permanent fault, for example in power cables, means that there is a physical damage in the fault location that must first be located and repaired before the network voltage can be restored.

In overhead lines, the insulating material between phase conductors is air. The majority of the faults are flash-over arcing faults caused by lightning, for example. Only a short interruption is needed for extinguishing the arc. These faults are transient by nature.

A semi-transient fault can be caused for example by a bird or a tree branch falling on the overhead line. The fault disappears on its own if the fault current burns the branch or the wind blows it away.

Transient and semi-transient faults can be cleared by momentarily de-energizing the power line. Using the auto-reclose function minimizes interruptions in the power system service and brings the power back on-line quickly and effortlessly.

The basic idea of the auto-reclose function is simple. In overhead lines, where the possibility of self-clearing faults is high, the auto-reclose function tries to restore the power by reclosing the breaker. This is a method to get the power system back into normal operation by removing the transient or semi-transient faults. Several trials, that is, autoreclose shots are allowed. If none of the trials is successful and the fault persists, definite final tripping follows.

The auto-reclose function can be used with every circuit breaker that has the ability for a reclosing sequence. In DARREC auto-reclose function the implementing method of auto-reclose sequences is patented by ABB.

Table 1559: Important definitions related to auto-reclosing

Autoreclose shot	An operation where after a preset time the breaker is closed from the breaker tripping caused by protection.
Autoreclose sequence	A predefined method to do reclose attempts (shots) to restore the power system.
SOTF	If the protection detects a fault immediately after an open circuit breaker has been closed, it indicates that the fault was already there. It can be, for example, a forgotten earthing after maintenance work. Such closing of the circuit breaker is known as switch on to fault. Autoreclosing in such conditions is prohibited.
Final trip	Occurs in case of a permanent fault, when the circuit breaker is opened for the last time after all programmed autoreclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip.

9.9.6.1 Shot initiation

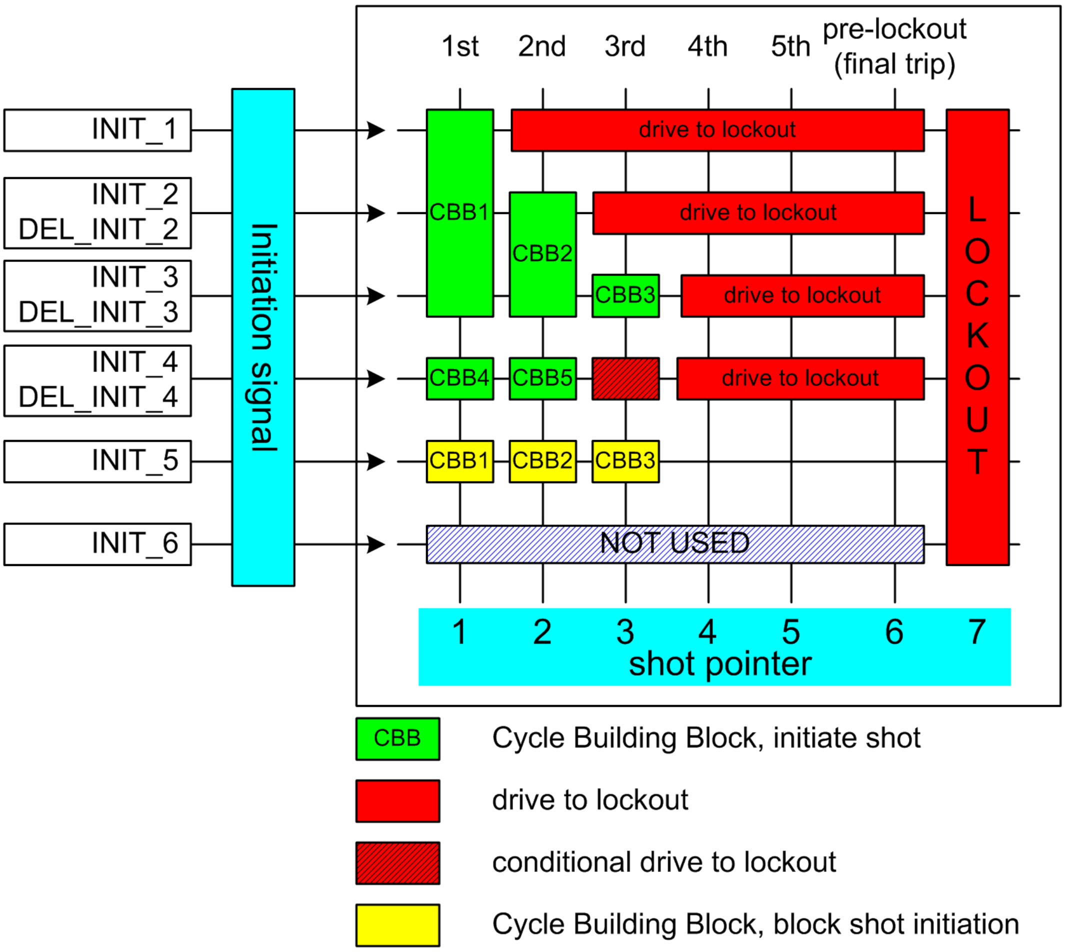


Figure 905: Example of an autoreclosing program with a reclose scheme matrix

In the AR function, each shot can be programmed to locate anywhere in the reclose scheme matrix. The shots are like building blocks used to design the reclose program. The building blocks are called CBBs. All blocks are alike and have settings which give the attempt number (columns in the matrix), the initiation or blocking signals (rows in the matrix) and the reclose time of the shot.

The settings related to CBB configuration are:

- *First...Seventh reclose time*
- *Init signals CBB1…CBB7*
- *Blk signals CBB1…CBB7*
- *Shot number CBB1…CBB7*

The reclose time defines the open and dead times, that is, the time between the OPEN_CB and the CLOSE_CB commands. The *Init signals CBBx* setting defines the initiation signals. The *Blk signals CBBx* setting defines the blocking signals that are related to the CBB (rows in the matrix). The *Shot number CBB1…CBB7* setting defines which shot is related to the CBB (columns in the matrix). For example, CBB1 settings are:

- *First reclose time* = 1.0s
- *Init signals CBB1* = 7 (three lowest bits: 111000 = 7)

- *Blk signals CBB1* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB1* = 1

CBB2 settings are:

- *Second reclose time* = 10s
- *Init signals CBB2* = 6 (the second and third bits: 011000 = 6)
- *Blk signals CBB2* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB2* = 2

CBB3 settings are:

- *Third reclose time* = 30s
- *Init signals CBB3* = 4 (the third bit: 001000 = 4)
- *Blk signals CBB3* = 16 (the fifth bit: 000010 = 16)
- *Shot number CBB3* = 3

CBB4 settings are:

- *Fourth reclose time* = 0.5s
- *Init signals CBB4* = 8 (the fourth bit: 000100 = 8)
- *Blk signals CBB4* = 0 (no blocking signals related to this CBB)
- *Shot number CBB4* = 1

If a shot is initiated from the `INIT_1` line, only one shot is allowed before lockout. If a shot is initiated from the `INIT_3` line, three shots are allowed before lockout.

A sequence initiation from the `INIT_4` line leads to a lockout after two shots. In a situation where the initiation is made from both the `INIT_3` and `INIT_4` lines, a third shot is allowed, that is, CBB3 is allowed to start. This is called conditional lockout. If the initiation is made from the `INIT_2` and `INIT_3` lines, an immediate lockout occurs.

The `INIT_5` line is used for blocking purposes. If the `INIT_5` line is active during a sequence start, the reclose attempt is blocked and the AR function goes to lockout.

If more than one CBBs are started with the shot pointer, the CBB with the smallest individual number is always selected. For example, if the `INIT_2` and `INIT_4` lines are active for the second shot, that is, the shot pointer is 2, CBB2 is started instead of CBB5.

Even if the initiation signals are not received from the protection functions, the AR function can be set to continue from the second to the fifth reclose shot. The AR function can, for example, be requested to automatically continue with the sequence when the circuit breaker fails to close when requested. In such a case, the AR function issues a `CLOSE_CB` command. When the wait close time elapses, that is, the closing of the circuit breaker fails, the next shot is automatically started. Another example is the embedded generation on the power line, which can make the synchronism check fail and prevent the reclosing. If the auto-reclose sequence is continued to the second shot, a successful synchronous reclosing is more likely than with the first shot, since the second shot lasts longer than the first one.

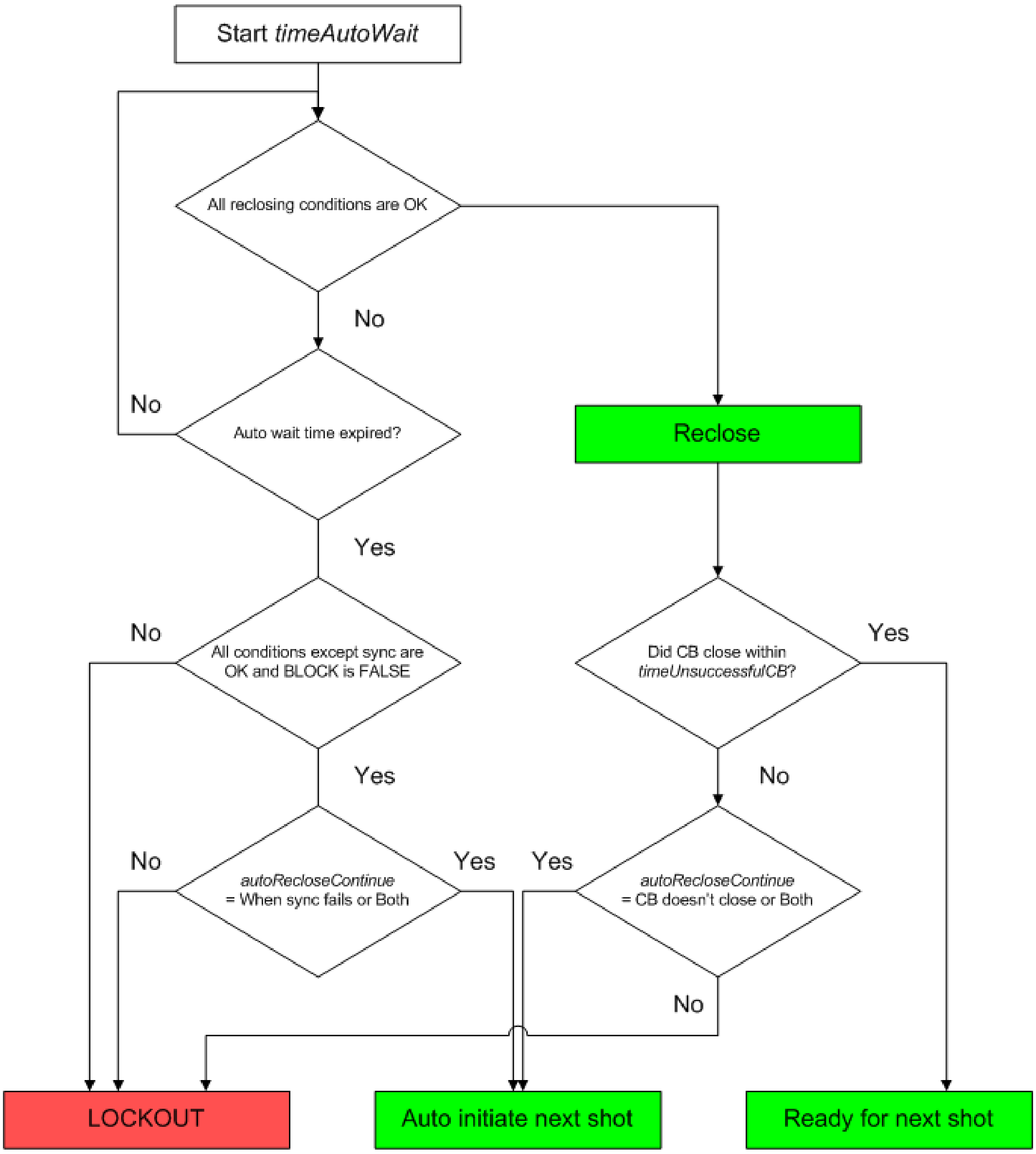


Figure 906: Logic diagram of auto-initiation sequence detection

Automatic initiation can be selected with the *Auto initiation Cnd* setting to be the following:

- Not allowed: no automatic initiation is allowed
- When the synchronization fails, the automatic initiation is carried out when the auto wait time elapses and the reclosing is prevented due to a failure during the synchronism check
- When the circuit breaker does not close, the automatic initiation is carried out if the circuit breaker does not close within the wait close time after issuing the reclose command
- Both: the automatic initiation is allowed when synchronization fails or the circuit breaker does not close.

The *Auto init* parameter defines which `INIT_X` lines are activated in the auto-initiation. The default value for this parameter is "0", which means that no auto-initiation is selected.

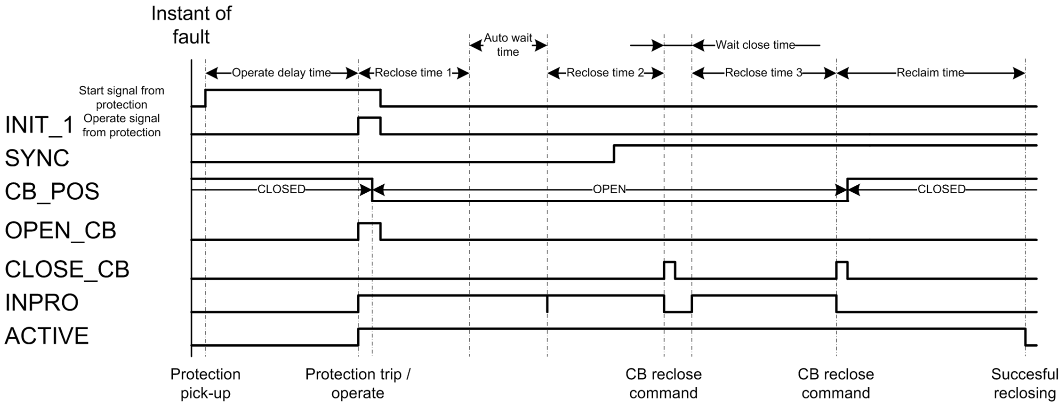


Figure 907: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

In the first shot, the synchronization condition is not fulfilled (`SYNC` is FALSE). When the auto wait timer elapses, the sequence continues to the second shot. During the second reclosing, the synchronization condition is fulfilled and the close command is given to the circuit breaker after the second reclose time has elapsed.

After the second shot, the circuit breaker fails to close when the wait close time has elapsed. The third shot is started and a new close command is given after the third reclose time has elapsed. The circuit breaker closes normally and the reclaim time starts. When the reclaim time has elapsed, the sequence is concluded successful.

9.9.6.2 Sequence

The auto reclose sequence is implemented by using CBBs. The highest possible amount of CBBs is seven. If the user wants to have, for example, a sequence of three shots, only the first three CBBs are needed. Using building blocks instead of fixed shots gives enhanced flexibility, allowing multiple and adaptive sequences.

Each CBB is identical. The *Shot number CBB_* setting defines at which point in the auto-reclose sequence the CBB should be performed, that is, whether the particular CBB is going to be the first, second, third, fourth or fifth shot.

During the initiation of a CBB, the conditions of initiation and blocking are checked. This is done for all CBBs simultaneously. Each CBB that fulfils the initiation conditions requests an execution.

The function also keeps track of shots already performed, that is, at which point the auto-reclose sequence is from shot 1 to lockout. For example, if shots 1 and 2 have already been performed, only shots 3 to 5 are allowed.

Additionally, the *Enable shot jump* setting gives two possibilities:

- Only such CBBs that are set for the next shot in the sequence can be accepted for execution. For example, if the next shot in the sequence should be shot 2, a request from CBB set for shot 3 is rejected.
- Any CBB that is set for the next shot or any of the following shots can be accepted for execution. For example, if the next shot in the sequence should be shot 2, also CBBs that are set for shots 3, 4 and 5 are accepted. In other words, shot 2 can be ignored.

In case there are multiple CBBs allowed for execution, the CBB with the smallest number is chosen. For example, if CBB2 and CBB4 request an execution, CBB2 is allowed to execute the shot.

The auto-reclose function can perform up to five auto-reclose shots or cycles.

9.9.6.3 Configuration examples

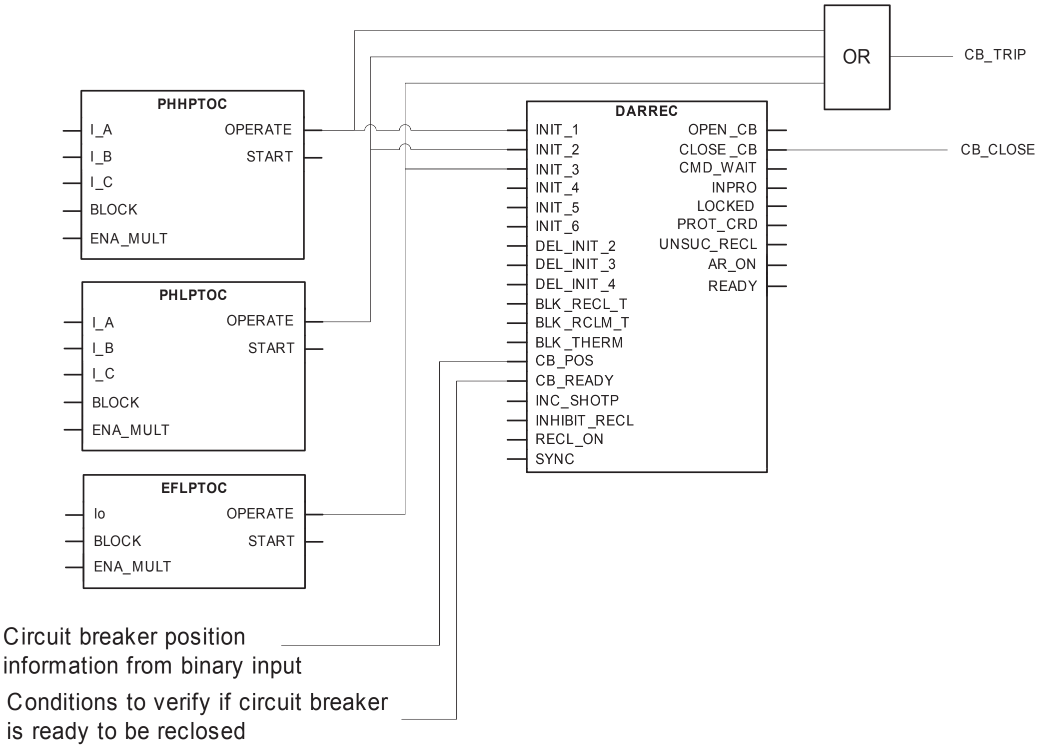


Figure 908: Example connection between protection and autoreclosing functions in protection relay configuration

It is possible to create several sequences for a configuration.

Autoreclose sequences for overcurrent and non-directional earth-fault protection applications where high speed and delayed autoreclosings are needed can be as follows:

Example 1

The sequence is implemented by two shots which have the same reclosing time for all protection functions, namely I>>, I> and Io>. The initiation of the shots is done by activating the operating signals of the protection functions.

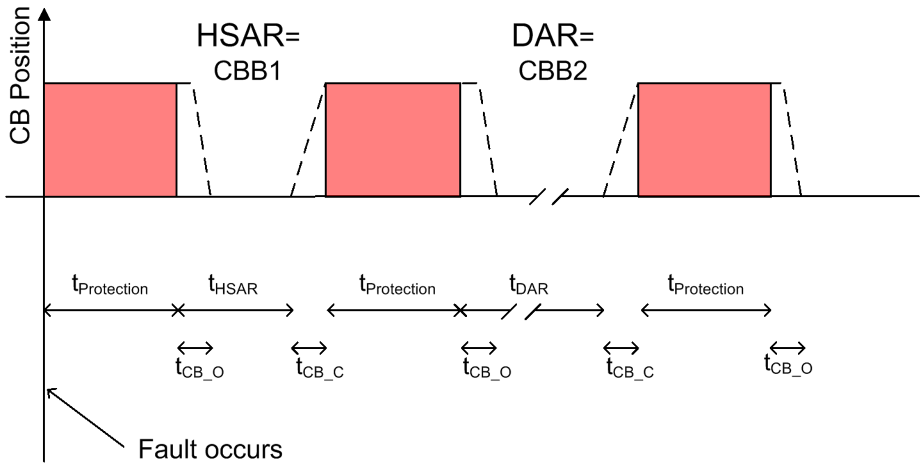


Figure 909: Autoreclosing sequence with two shots

t_{HSAR}	Time delay of high-speed autoreclosing, here: *First reclose time*
t_{DAR}	Time delay of delayed autoreclosing, here: *Second reclose time*
$t_{Protection}$	Operating time for the protection stage to clear the fault
t_{CB_O}	Operating time for opening the circuit breaker
t_{CB_C}	Operating time for closing the circuit breaker

In this case, the sequence needs two CBBs. The reclosing times for shot 1 and shot 2 are different, but each protection function initiates the same sequence. The CBB sequence is described in *Table 1560* as follows:

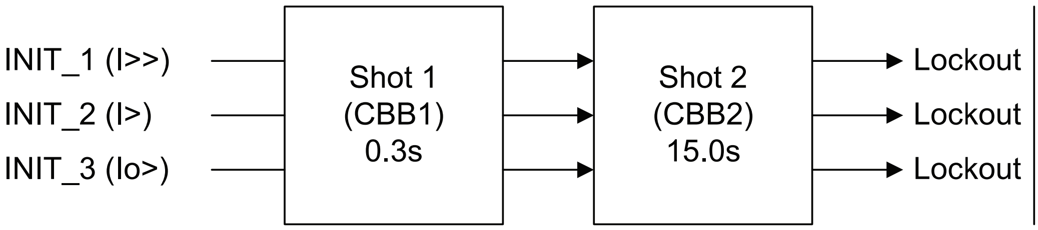


Figure 910: Two shots with three initiation lines

Table 1560: Settings for configuration example 1

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	7 (lines 1, 2 and 3 = 1+2+4 = 7)
First reclose time	0.3s (an example)
Shot number CBB2	2
Init signals CBB2	7 (lines 1, 2 and 3 = 1+2+4 = 7)
Second reclose time	15.0s (an example)

Example 2

There are two separate sequences implemented with three shots. Shot 1 is implemented by CBB1 and it is initiated with the high stage of the overcurrent protection (I>>). Shot 1 is set as a high-speed autoreclosing with a short time delay. Shot 2 is implemented with CBB2 and meant to be the first shot of the autoreclose sequence initiated by the low stage of the overcurrent protection (I>) and the low stage of the non-directional earth-fault protection (Io>). It has the same reclosing time in both situations. It is set as a high-speed autoreclosing for corresponding faults. The third shot, which is the second shot in the autoreclose sequence initiated by I> or Io>, is set as a delayed autoreclosing and executed after an unsuccessful high-speed autoreclosing of a corresponding sequence.

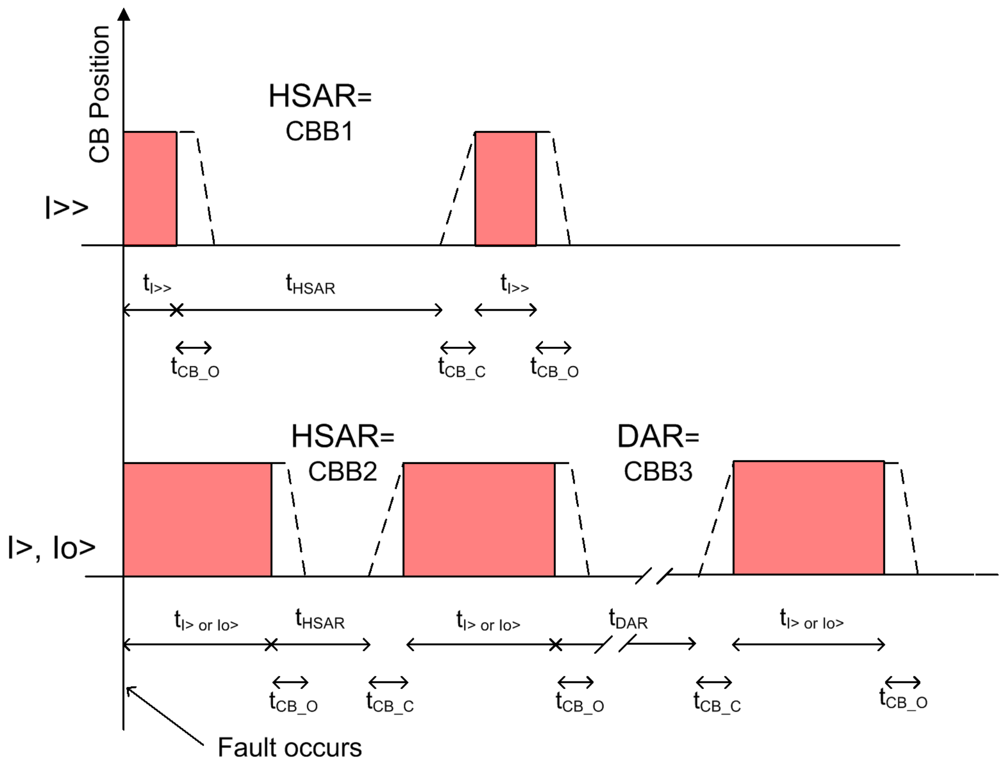


Figure 911: Autoreclosing sequence with two shots with different shot settings according to initiation signal

t_{HSAR}	Time delay of high-speed autoreclosing, here: *First reclose time*
t_{DAR}	Time delay of delayed autoreclosing, here: *Second reclose time*
$t_{I>>}$	Operating time for the I>> protection stage to clear the fault
$t_{I>}$ or $_{Io>}$	Operating time for the I> or Io> protection stage to clear the fault
t_{CB_O}	Operating time for opening the circuit breaker
t_{CB_C}	Operating time for closing the circuit breaker

In this case, the number of needed CBBs is three, that is, the first shot's reclosing time depends on the initiation signal.

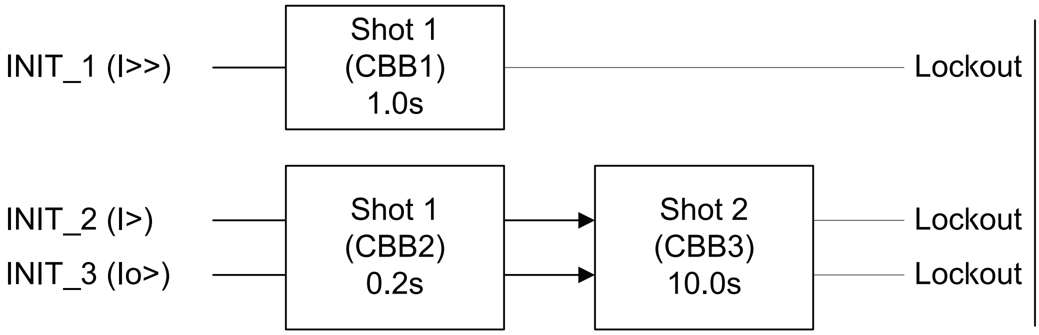


Figure 912: Three shots with three initiation lines

If the sequence is initiated from the INIT_1 line, that is, the overcurrent protection high stage, the sequence is one shot long. If the sequence is initiated from the INIT_2 or INIT_3 lines, the sequence is two shots long.

Table 1561: Settings for configuration example 2

Setting name	Setting value
Shot number CBB1	1
Init signals CBB1	1 (line 1)
First reclose time	0.0s (an example)
Shot number CBB2	1
Init signals CBB2	6 (lines 2 and 3 = 2+4 = 6)
Second reclose time	0.2s (an example)
Shot number CBB3	2
Init signals CBB3	6 (lines 2 and 3 = 2+4 = 6)
Third reclose time	10.0s

9.9.6.4 Delayed initiation lines

The auto-reclose function consists of six individual auto-reclose initiation lines INIT_1...INIT 6 and three delayed initiation lines:

- DEL_INIT_2
- DEL_INIT_3
- DEL_INIT_4

DEL_INIT_2 and INIT_2 are connected together with an OR-gate, as are inputs 3 and 4. Inputs 1, 5 and 6 do not have any delayed input. From the auto-reclosing point of view, it does not matter whether INIT_x or DEL_INIT_x line is used for shot initiation or blocking.

The auto-reclose function can also open the circuit breaker from any of the initiation lines. It is selected with the *Tripping line* setting. As a default, all initiation lines activate the OPEN_CB output.

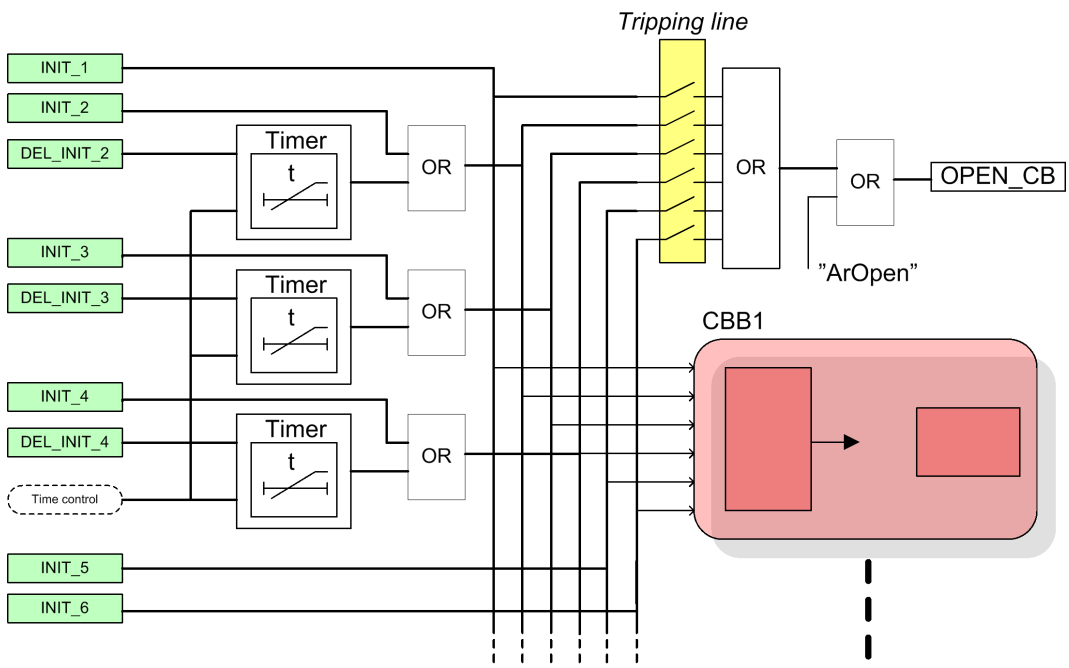


Figure 913: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 1562: Settings for delayed initiation lines

Setting name	Description and purpose
Str x delay shot 1	Time delay for the `DEL_INIT_x` line, where x is the number of the line 2, 3 or 4. Used for shot 1.
Str x delay shot 2	Time delay for the `DEL_INIT_x` line, used for shot 2.
Str x delay shot 3	Time delay for the `DEL_INIT_x` line, used for shot 3.
Str x delay shot 4	Time delay for the `DEL_INIT_x` line, used for shots 4 and 5. Optionally, can also be used with SOTF.

9.9.6.5 Shot initiation from protection start signal

In it simplest, all auto-reclose shots are initiated by protection trips. As a result, all trip times in the sequence are the same. This is why using protection trips may not be the optimal solution. Using protection start signals instead of protection trips for initiating shots shortens the trip times.

Example 1

When a two-shot-sequence is used, the start information from the protection function is routed to the `DEL_INIT 2` input and the operate information to the `INIT_2` input. The following conditions have to apply:

- protection operate time = 0.5s
- *Str 2 delay shot 1* = 0.05s

- *Str 2 delay shot 2* = 60s
- *Str 2 delay shot 3* = 60s

Operation in a permanent fault:

1. Protection starts and activates the `DEL_INIT 2` input.
2. After 0.05 seconds, the first autoreclose shot is initiated. The function opens the circuit breaker: the `OPEN_CB` output activates. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.
3. After the first shot, the circuit breaker is reclosed and the protection starts again.
4. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time, activating the `INIT 2` input. The second shot is initiated.
5. After the second shot, the circuit breaker is reclosed and the protection starts again.
6. Because the delay of the second shot is 60 seconds, the protection is faster and trips after the set operation time. No further shots are programmed after the final trip. The function is in lockout and the sequence is considered unsuccessful.

Example 2

The delays can be used also for fast final trip. The conditions are the same as in Example 1, with the exception of *Str 2 delay shot 3* = 0.10 seconds.

The operation in a permanent fault is the same as in Example 1, except that after the second shot when the protection starts again, *Str 2 delay shot 3* elapses before the protection operate time and the final trip follows. The total trip time is the protection start delay + 0.10 seconds + the time it takes to open the circuit breaker.

9.9.6.6 Fast trip in Switch on to fault

The *Str _ delay shot 4* parameter delays can also be used to achieve a fast and accelerated trip with SOTF. This is done by setting the *Fourth delay in SOTF* parameter to "1" and connecting the protection start information to the corresponding `DEL_INIT_` input.

When the function detects a closing of the circuit breaker, that is, any other closing except the reclosing done by the function itself, it always prohibits shot initiation for the time set with the *Reclaim time* parameter. Furthermore, if the *Fourth delay in SOTF* parameter is "1", the *Str _ delay shot 4* parameter delays are also activated.

Example 1

The protection operation time is 0.5 seconds, the *Fourth delay in SOTF* parameter is set to "1" and the *Str 2 delay shot 4* parameter is 0.05 seconds. The protection start signal is connected to the `DEL_INIT_2` input.

If the protection starts after the circuit breaker closes, the fast trip follows after the set 0.05 seconds. The total trip time is the protection start delay + 0.05 seconds + the time it takes to open the circuit breaker.

9.9.7 Signals

9.9.7.1 DARREC Input signals

Table 1563: DARREC Input signals

Name	Type	Default	Description
INIT_1	BOOLEAN	0=False	AR initialization / blocking signal 1
INIT_2	BOOLEAN	0=False	AR initialization / blocking signal 2
INIT_3	BOOLEAN	0=False	AR initialization / blocking signal 3
INIT_4	BOOLEAN	0=False	AR initialization / blocking signal 4
INIT_5	BOOLEAN	0=False	AR initialization / blocking signal 5
INIT_6	BOOLEAN	0=False	AR initialization / blocking signal 6
DEL_INIT_2	BOOLEAN	0=False	Delayed AR initialization / blocking signal 2
DEL_INIT_3	BOOLEAN	0=False	Delayed AR initialization / blocking signal 3
DEL_INIT_4	BOOLEAN	0=False	Delayed AR initialization / blocking signal 4
BLK_RECL_T	BOOLEAN	0=False	Blocks and resets reclose time
BLK_RCLM_T	BOOLEAN	0=False	Blocks and resets reclaim time
BLK_THERM	BOOLEAN	0=False	Blocks and holds the reclose shot from the thermal overload
CB_POS	BOOLEAN	0=False	Circuit breaker position input
CB_READY	BOOLEAN	1=True	Circuit breaker status signal
INC_SHOTP	BOOLEAN	0=False	A zone sequence coordination signal
INHIBIT_RECL	BOOLEAN	0=False	Interrupts and inhibits reclosing sequence

Table continues on the next page

Name	Type	Default	Description
RECL_ON	BOOLEAN	0=False	Level sensitive signal for allowing (high) / not allowing (low) re-closing
SYNC	BOOLEAN	0=False	Synchronizing check fulfilled

9.9.7.2 DARREC Output signals

Table 1564: DARREC Output signals

Name	Type	Description
OPEN_CB	BOOLEAN	Open command for circuit breaker
CLOSE_CB	BOOLEAN	Close (reclose) command for circuit breaker
CMD_WAIT	BOOLEAN	Wait for master command
INPRO	BOOLEAN	Reclosing shot in progress, activated during dead time
LOCKED	BOOLEAN	Signal indicating that AR is locked out
PROT_CRD	BOOLEAN	A signal for coordination be-tween the AR and the protec-tion
UNSUC_RECL	BOOLEAN	Indicates an unsuccessful re-closing sequence
AR_ON	BOOLEAN	Autoreclosing allowed
READY	BOOLEAN	Indicates that the AR is ready for a new sequence, i.e. the CB_READY input equals TRUE
ACTIVE	BOOLEAN	Reclosing sequence is in pro-gress

9.9.8 DARREC Settings

Table 1565: DARREC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off/On
Reclosing opera-tion	1=Off 2=External Ctl 3=On			1=Off	Reclosing opera-tion (Off, External Ctl / On)
Close pulse time	10...10000	ms	10	200	CB close pulse time

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Reclaim time	100...1800000	ms	100	10000	Reclaim time
Terminal priority	1=None 2=Low (follower) 3=High (master)			1=None	Terminal priority
Synchronisation set	0...127		1	0	Selection for synchronizing requirement for reclosing
Auto initiation cnd	1=Not allowed 2=When sync fails 3=CB doesn't close 4=Both			2=When sync fails	Auto initiation condition
Tripping line	0...63		1	0	Tripping line, defines INIT inputs which cause OPEN_CB activation
Fourth delay in SOTF	0=False 1=True			0=False	Sets 4th delay into use for all DEL_INIT signals during SOTF
First reclose time	0...300000	ms	10	5000	Dead time for CBB1
Second reclose time	0...300000	ms	10	5000	Dead time for CBB2
Third reclose time	0...300000	ms	10	5000	Dead time for CBB3
Fourth reclose time	0...300000	ms	10	5000	Dead time for CBB4
Fifth reclose time	0...300000	ms	10	5000	Dead time for CBB5
Sixth reclose time	0...300000	ms	10	5000	Dead time for CBB6
Seventh reclose time	0...300000	ms	10	5000	Dead time for CBB7
Init signals CBB1	0...63		1	0	Initiation lines for CBB1
Init signals CBB2	0...63		1	0	Initiation lines for CBB2
Init signals CBB3	0...63		1	0	Initiation lines for CBB3
Init signals CBB4	0...63		1	0	Initiation lines for CBB4
Init signals CBB5	0...63		1	0	Initiation lines for CBB5
Init signals CBB6	0...63		1	0	Initiation lines for CBB6
Init signals CBB7	0...63		1	0	Initiation lines for CBB7
Shot number CBB1	0...5		1	0	Shot number for CBB1
Shot number CBB2	0...5		1	0	Shot number for CBB2
Shot number CBB3	0...5		1	0	Shot number for CBB3
Shot number CBB4	0...5		1	0	Shot number for CBB4
Shot number CBB5	0...5		1	0	Shot number for CBB5
Shot number CBB6	0...5		1	0	Shot number for CBB6
Shot number CBB7	0...5		1	0	Shot number for CBB7
Frq Op counter limit	0...250		1	0	Frequent operation counter lockout limit

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Frq Op counter time	1...250	min	1	1	Frequent operation counter time
Frq Op recovery time	1...250	min	1	1	Frequent operation counter recovery time
Auto init	0...63		1	0	Defines INIT lines that are activated at auto initiation

Table 1566: DARREC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Manual close mode	0=False 1=True			0=False	Manual close mode
Wait close time	50...10000	ms	50	250	Allowed CB closing time after reclose command
Max wait time	100...1800000	ms	100	10000	Maximum wait time for BLK_RECL_T release
Max trip time	100...10000	ms	100	10000	Maximum wait time for deactivation of protection signals
Max Thm block time	100...1800000	ms	100	10000	Maximum wait time for thermal blocking signal deactivation
Cut-out time	0...1800000	ms	100	10000	Cutout time for protection coordination
Dsr time shot 1	0...10000	ms	100	0	Discrimination time for first reclosing
Dsr time shot 2	0...10000	ms	100	0	Discrimination time for second reclosing
Dsr time shot 3	0...10000	ms	100	0	Discrimination time for third reclosing
Dsr time shot 4	0...10000	ms	100	0	Discrimination time for fourth reclosing
Auto wait time	0...60000	ms	10	2000	Wait time for reclosing condition fullfilling
Auto lockout reset	0=False 1=True			1=True	Automatic lockout reset
Protection crd limit	1...5		1	1	Protection coordination shot limit
Protection crd mode	1=No condition 2=AR inoperative 3=CB close manual 4=AR inop, CB man 5=Always			4=AR inop, CB man	Protection coordination mode
Control line	0...63		1	63	Control line, defines INIT inputs which are protection signals
Enable shot jump	0=False 1=True			1=True	Enable shot jumping
CB closed Pos status	0=False 1=True			0=False	Circuit breaker closed position status

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Blk signals CBB1	0...63		1	0	Blocking lines for CBB1
Blk signals CBB2	0...63		1	0	Blocking lines for CBB2
Blk signals CBB3	0...63		1	0	Blocking lines for CBB3
Blk signals CBB4	0...63		1	0	Blocking lines for CBB4
Blk signals CBB5	0...63		1	0	Blocking lines for CBB5
Blk signals CBB6	0...63		1	0	Blocking lines for CBB6
Blk signals CBB7	0...63		1	0	Blocking lines for CBB7
Str 2 delay shot 1	0...300000	ms	10	0	Delay time for start2, 1st reclose
Str 2 delay shot 2	0...300000	ms	10	0	Delay time for start2 2nd reclose
Str 2 delay shot 3	0...300000	ms	10	0	Delay time for start2 3rd reclose
Str 2 delay shot 4	0...300000	ms	10	0	Delay time for start2, 4th reclose
Str 3 delay shot 1	0...300000	ms	10	0	Delay time for start3, 1st reclose
Str 3 delay shot 2	0...300000	ms	10	0	Delay time for start3 2nd reclose
Str 3 delay shot 3	0...300000	ms	10	0	Delay time for start3 3rd reclose
Str 3 delay shot 4	0...300000	ms	10	0	Delay time for start3, 4th reclose
Str 4 delay shot 1	0...300000	ms	10	0	Delay time for start4, 1st reclose
Str 4 delay shot 2	0...300000	ms	10	0	Delay time for start4 2nd reclose
Str 4 delay shot 3	0...300000	ms	10	0	Delay time for start4 3rd reclose
Str 4 delay shot 4	0...300000	ms	10	0	Delay time for start4, 4th reclose

9.9.9 DARREC Monitored data

Table 1567: DARREC Monitored data

Name	Type	Values (Range)	Unit	Description
DISA_COUNT	BOOLEAN	0=False 1=True		Signal for counter disa-bling
FRQ_OPR_CNT	INT32	0...2147483647		Frequent operation counter
FRQ_OPR_AL	BOOLEAN	0=False 1=True		Frequent operation counter alarm
STATUS	Enum	-1=Not defined 1=Ready 2=InProgress 3=Successful 4=WaitingForTrip 5=TripFromProtection		AR status signal for IEC61850

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		6=FaultDisappeared 7=WaitToComplete 8=CBclosed 9=CycleUnsuccessful 10=Unsuccessful 11=Aborted		
INPRO_1	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 1
INPRO_2	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 2
INPRO_3	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 3
INPRO_4	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 4
INPRO_5	BOOLEAN	0=False 1=True		Reclosing shot in progress, shot 5
DISCR_INPRO	BOOLEAN	0=False 1=True		Signal indicating that discrimination time is in progress
CUTOUT_INPRO	BOOLEAN	0=False 1=True		Signal indicating that cut-out time is in progress
SUC_RECL	BOOLEAN	0=False 1=True		Indicates a successful reclosing sequence
UNSUC_CB	BOOLEAN	0=False 1=True		Indicates an unsuccessful CB closing
CNT_SHOT1	INT32	0...2147483647		Resetable operation counter, shot 1
CNT_SHOT2	INT32	0...2147483647		Resetable operation counter, shot 2
CNT_SHOT3	INT32	0...2147483647		Resetable operation counter, shot 3
CNT_SHOT4	INT32	0...2147483647		Resetable operation counter, shot 4
CNT_SHOT5	INT32	0...2147483647		Resetable operation counter, shot 5
COUNTER	INT32	0...2147483647		Resetable operation counter, all shots
SHOT_PTR	INT32	1...7		Shot pointer value
MAN_CB_CL	BOOLEAN	0=False 1=True		Indicates CB manual closing during reclosing sequence
SOTF	BOOLEAN	0=False 1=True		Switch-onto-fault
DARREC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.9.10 Technical data

Table 1568: DARREC Technical data

Characteristic	Value
Operate time accuracy	±1.0 % of the set value or ±20 ms

9.10 Tap changer control with voltage regulator OL5ATCC (ANSI 90V)

9.10.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Tap changer control with voltage regulator	OL5ATCC	COLTC	90V

9.10.2 Function block

Figure 914: Function block symbol

9.10.3 Functionality

The tap changer control with voltage regulator function OL5ATCC (on-load tap changer controller) regulates the voltage of power transformers with on-load tap changers in distribution substations. OL5ATCC provides manual or automatic voltage control of the power transformer by using the raising or lowering signals to the on-load tap changer.

The automatic voltage regulation can be used in single or parallel transformer applications. The parallel operation can be based on the Master/Follower principle (M/F), Negative Reactance Principle (NRP) or Minimizing Circulating Current (MCC).

OL5ATCC includes the line drop compensation (LDC) functionality, and the load decrease is possible with a dynamic voltage reduction. Further, OL5ATCC can manage voltage regulation in case of reverse power flow.

Either definite time characteristic (DT) or inverse time characteristic (IDMT) is selectable for delays between the raising and lowering operations.

The function contains a blocking functionality. It is possible to block the voltage control operations with an external signal or with the supervision functionality of the function.

9.10.4 Analog channel configuration

Function block OL5ATCC has four analog group inputs which all must be properly configured. The table below presents inputs and their purpose.

Table 1569: Analog inputs

Input	Purpose
I3P1	Three-phase currents from transformer secondary side.
U3P1	Three-phase voltages from transformer secondary side.
I3P2[1]	Three-phase currents from transformer primary side.
U3P2[1]	Three-phase voltages from transformer primary side.

Please refer to Preprocessing function block section in this manual for possible signal sources.

There are few special conditions which must be noted with configuration. See *Table 1570*.

Table 1570: Special conditions

Condition	Note
U3P1 or U3P2 connected to real measurements	Function can work with one voltage connected to channel 1 or with two voltages connected to channels 2 and 3 or with all three voltage channels connected.

Improper analog channel configuration causes validation error in Application configuration tool. In such a case analog channels and certain settings are not matching. For troubleshooting, check the given material in this chapter. Configuration can be written to relay once the mismatch is corrected.

9.10.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of OL5ATCC can be described with a module diagram. All the modules in the diagram are explained in the next sections.

[1] Should be connected to GRPOFF if HV side measurements are not available when “Regulation mode” is “Forward” or “Bi-dir(calc)”

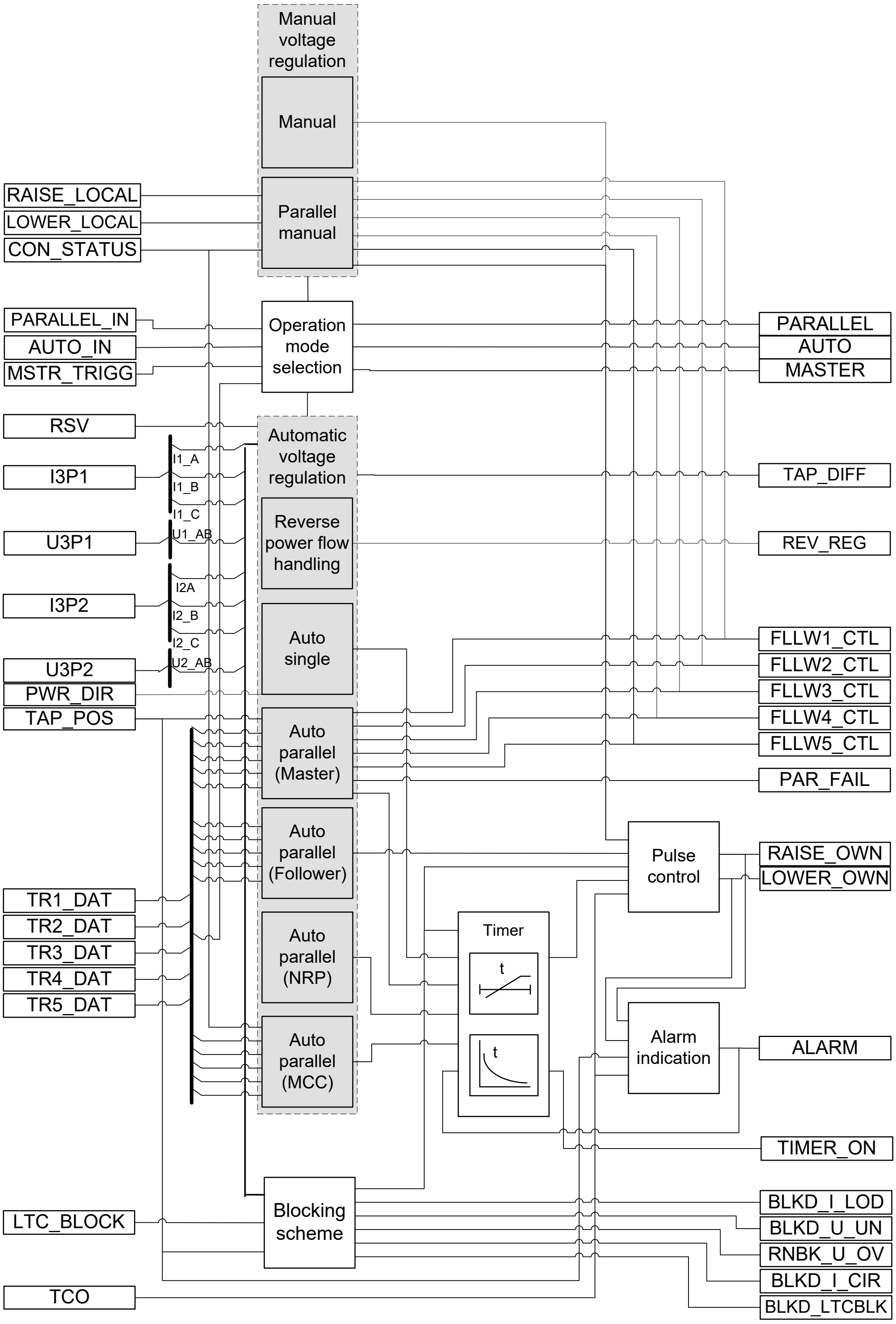


Figure 915: Functional module diagram

9.10.5.1 Voltage and current measurements

The measured voltage must be a phase-to-phase voltage from the regulated side. Typically, it is the phase-to-phase voltage U_AB from the secondary side of the power transformer. If the phase voltages are measured, the voltage U_AB is calculated internally in the protection relay. In case bi-directional regulation is expected, then voltage measurement from primary side is also required. If not available, calculated values can be used under certain conditions.

The currents from the secondary side of the power transformer (I_x, where x is A, B or C) have several uses.

- The highest phase current value is used for overcurrent blocking.
- The currents from the secondary side of the power transformer are used for LDC (average of the connected inputs).
- The currents from the secondary side of the power transformer are used for calculating the circulating current in the NRP and MCC operation modes.

When reverse regulation takes place, primary side current measurements are expected and is used in a similar way.

Both voltage U_AB and the phase currents are always measured using the value of the filtered fundamental frequency component (DFT). Hence, the harmonics are always suppressed. Moreover, the measured voltage value is continuously average-filtered with the eight-value-long sliding window. The phase-compensated voltage U_A is always used in calculations, although it is not connected. This averaged value, the parameter U_m in *Equation 384*, is used for control, and its magnitude can be read from the monitored data U_MEAS.

Similarly, the magnitude of the phase current of the own transformer, I_x, and the phase angle difference between the internally phase-compensated voltage U_A and phase current I_x (the angle difference used in *Equation 376* and *Equation 378*) are also average-filtered by the same fixed-length window. The phase angle value can be read from the monitored data ANGL_UA_IA. These currents and phase angle differences are used solely in circulating current calculations.

There are minimum limits for the voltage and current magnitudes, so the magnitude and phase angle difference values diverge from zero. The voltage magnitude must exceed three percent of U_n and the current I_A must exceed two percent of I_n.

9.10.5.2 Tap changer position inputs

The position value of the tap changer can be brought to OL5ATCC as a resistance value, a mA signal or as a binary-coded signal. More information on how the resistance value, the mA signal or a binary-coded interface are implemented can be found in TPOSYLTC in this manual.

The indicated tap changer position of the own transformer is internally connected to the `TAP_POS` input, and the tap changer positions of the parallel transformers are fed to inputs `TRx_DAT` via data combiner function blocks OLGAPC. This also defines the connection identity so that follower 1 is connected to `TR1_DAT`, follower 2 is connected to `TR2_DAT` and follower 3 is connected to `TR3_DAT`. The own transformer position can be read from the input `TAP_POS`. The follower tap changer positions can be read from the input data `TR_TAP_POS` of OLGAPCx.

The tap changer position value is given in parentheses. For example, (0) indicates that there is no tap changer position connected or the quality of the tap changer position value is bad. Typically, if no tap changer position is connected, all the TPOSYLTC binary inputs are FALSE by default and the value shown is (0). A value other than zero indicates bad quality. OL5ATCC treats a bad-quality tap changer position as unconnected tap position information.

9.10.5.3 Operation mode selection

OL5ATCC has the *Operation mode* and *Parallel mode* settings for selecting the desired operation mode. The *Operation mode* setting can have any of the following values: "Manual", "Auto single", "Parallel manual", "Auto parallel", "Input control" and “Command”. If the *Operation mode* setting is set to "Input control", the active operation mode is determined by the inputs PARALLEL and AUTO.

The PARALLEL input defines if the transformer (voltage regulator) is in parallel or single mode. The AUTO input defines if the operation is in auto or manual mode. The PARALLEL and AUTO outputs represent acting “Parallel or single operation” and “Auto/Manual indication”, respectively.

When the *Operation mode* setting is set to "Command", the active operation mode is determined by the IEC 61850 command data points Auto and ParOp.

Furthermore, if the operation mode has been set to any parallel mode, that is "Parallel manual" or "Auto parallel" via the *Operation mode* setting, binary inputs or commands, the parallel mode is selected by the setting *Parallel mode*.

The *Parallel mode* setting can have any of following values: "Master", "Follower", "NRP", "MCC", "Input control" or "Command".

If the *Parallel mode* setting is set to "Input control", the active operation mode is determined by the input MSTR_TRIGG.

When the *Parallel mode* setting is set to "Command", the active operation mode is determined by the IEC 61850 command data point MstrOp.

MSTR_TRIGG is a rising edge input, that is, the master role is kept even though the MSTR_TRIGG input changes from “true” to “false”. This functionality is used because another parallel transformer must be able to assume the master role even though the MSTR_TRIGG input has remained in “true” state. Switching between operation mode states resets the internal master set. However, switching between Auto master mode and Parallel manual mode keeps the master role.

Table 1571: Active operation mode when Operation mode setting is "Manual", "Auto single", "Parallel manual" or "Auto parallel"

Operation mode	Parallel mode	MSTR_TRIGG	OPR_MODE_STS
Manual	–	–	Manual
Auto single	–	–	Auto single
Parallel manual	Master	–	Parallel manual
Parallel manual	Input control Command	0 [1]	Manual
Parallel manual	Input control Command	1 [1]	Parallel manual
Auto parallel	Master	–	Auto master
Auto parallel	Follower	–	Auto follower
Auto parallel	MCC	–	MCC
Auto parallel	NRP	–	NRP

Table continues on the next page

[1] The master role is set on rising edge and internally kept until another parallel transformer assumes the master role, or the operation mode is changed.

Operation mode	Parallel mode	MSTR_TRIGG	OPR_MODE_STS
Auto parallel	Input control Command	0 [1]	Auto follower
Auto parallel	Input control Command	1 [1]	Auto master

Table 1572: Active operation mode when Operation mode setting is "Input control" or "Command"

PARALLEL	AUTO	Parallel mode	MSTR_TRIGG	OPR_MODE_STS
0	0	–	–	Manual
0	1	–	–	Auto single
1	0	Master	–	Parallel manual
1	0	Follower	–	Manual
1	0	MCC	–	Manual
1	0	NRP	–	Manual
1	0	Input control Command	0 [1]	Manual
1	0	Input control Command	1 [1]	Parallel manual
1	1	Master	–	Auto master
1	1	Follower	–	Auto follower
1	1	MCC	–	MCC
1	1	NRP	–	NRP
1	1	Input control Command	0 [1]	Auto follower
1	1	Input control Command	1 [1]	Auto master

The active operation mode can be read from the monitored data OPR_MODE_STS.

Command exclusion

An active operation mode change using three inputs (PARALLEL, AUTO, MSTR_TRIGG and setting group change either by input or via menu) is needed when the active operation mode must be changed automatically, that is, there is a logic which drives these three inputs based on the status information from the circuit breakers.

The common Local/Remote (L/R) exclusion concerns the manual raise and lower commands of OL5ATCC, that is, it internally provides the exclusion mechanism to prevent remote commands (from SCADA) when the protection relay is in local mode and vice versa.

9.10.5.4 Manual voltage regulation

The manual raising and lowering commands can be given via the configuration inputs LOWER_LOCAL and RAISE_LOCAL, via the HMI of the protection relay or via

[1] The master role is set on rising edge and internally kept until another parallel transformer assumes the master role, or the operation mode is changed.

remote commands. The active operation mode of OL5ATCC must be set to "Manual" or "Parallel manual" and the Local/Remote control LR state monitored data of the protection relay has to be "Local" to execute the control commands manually from HMI or via configuration inputs. If OL5ATCC is set to "Manual" or "Parallel manual" but the LR state is set to "OFF" or "Remote", no manual control commands can be given.

For remote commands, the active operation mode of OL5ATCC must also be set to "Manual" or "Parallel manual" and the LR state monitored data has to be "Remote".

The manual raising or lowering commands can be given locally either via the *Manual control* parameter ("Cancel"/"Lower"/"Raise") located in the HMI menu **Control** > **OL5ATCC1** or via the configuration inputs LOWER_LOCAL or RAISE_LOCAL.

A raising command is given by selecting the enumeration value "Raise" and the lowering command is given by selecting the enumeration value "Lower". An accepted manual raising or lowering command activates the corresponding output RAISE_OWN or LOWER_OWN to control the voltage of the own transformer.

Parallel manual voltage regulation

While in single manual mode the voltage regulator acts independently, in parallel manual mode the voltage regulator set to "Parallel manual" acts as master and the others follow.

The parallel manual mode is intended for maintenance work and has no permanent settings. When the mode is set again to automatic, the voltage is stepped back to the set value.

Followers not responding to parallel manual command are indicated at output PAR_FAIL and the number of failed followers at monitored data FAIL_FLLW.

In parallel manual mode, the TR_STATUS monitored data indicates "Master" status to the other parallel transformers.

Voltage control vs. tap changer moving direction

OL5ATCC has the control settings *Lower block tap* and *Raise block tap* which give the tap changer position that results in the lowest and highest controlled voltage value (usually at the LV side of the transformer). *Raise block tap* can be set higher than *Lower block tap* and *Lower block tap* can be set higher than *Raise block tap*.

When the value of *Raise block tap* exceeds the *Lower block tap* value, the raise control activates the RAISE_OWN output. This results in raising the tap changer position, and the measured voltage rises. Furthermore, the RAISE_OWN output value is TRUE. If the own tap changer position is connected (that is, the own tap changer's quality is good), the tap changer alarm is activated if the tap changer does not move upwards within *Cmd error delay time* after the pulse activation. As a result, ALARM_REAS in the monitored data contains a command error value. The default value of the *Cmd error delay time* setting is 20 seconds.

The lowering control works in a similar way, as shown in *Figure 916*. In the output data, the LOWER_OWN output value is TRUE. An alarm is generated if the tap changer does not move downwards in *Cmd error delay time* after the pulse activation, assuming that the own tap changer position is connected.

In the second case, the parameters are set so that the value of Lower block tap exceeds the value of Raise block tap. The raising control activates the RAISE_OWN output. The result should be that the tap changer lowers its position and the measured voltage rises. Furthermore, the RAISE_OWN output value is TRUE in the output data. If the own tap changer position is connected, the tap changer alarm is activated if the tap changer does not move downwards in *Cmd error delay time* after the pulse activation. As a result, ALARM_REAS in the monitored data contains a command error value.

The lowering control works in a similar way, as shown in *Figure 916*. In the output data, the `LOWER_OWN` output value is TRUE. An alarm is generated if the tap changer does not move upwards in *Cmd error delay time* after the pulse activation, assuming that the own tap changer position is connected. When doing HV side regulation, the *Lower block tap* and *Raise block tap* are internally reversed to achieve regulation of the primary side voltage of the transformer.

9.10.5.5 Automatic voltage regulation of single transformers (Auto single)

OL5ATCC is intended to control the power transformers with a motor-driven on-load tap changer. The function regulates the voltage at the secondary side (or primary side during HV side regulation) of the power transformer. The control method is based on a step-by-step principle, which means that one control pulse at a time is issued to the tap changer mechanism to move it exactly one position upwards or downwards. However, when intermediate steps are not indicated for the tap changer, it does not cause alarm if more than one step change is met.

The purpose of the regulator is to maintain a stable voltage on the regulated side of the power transformer. The basis for this operation is the *Band center voltage* setting. By increasing or decreasing various compensation factors, the regulator calculates a control voltage from the band center voltage as shown in *Equation 373*. Hence, the control voltage is the desired transformer regulated side voltage to be maintained by the regulator. The control voltage is compared to the measured voltage and the difference between the two forms the regulating process error.

Since the tap changer changes the voltage in steps, a certain error has to be allowed. The error, called *Band width voltage*, is also set by the user. A recommended setting for *Band width voltage* should be close to twice the step voltage of the transformer ΔU_{step} and never below it as a minimum. For example, *Band width voltage* is twice the value of ΔU_{step} in *Figure 916*.

If the measured voltage fluctuates within the control voltage ± half the *Band width voltage* setting, the regulator is inactive. If the measured voltage is outside the half-bandwidth voltage limits, an adjustable delay T1 (*Control delay time 1*) starts, as shown in *Figure 916*, where the lowering function is an example. The delay T1 remains active as long as the measured voltage is outside the hysteresis limits of half the value of *Band width voltage*. The factory setting for the hysteresis is 10 percent of the set *Band width voltage*.

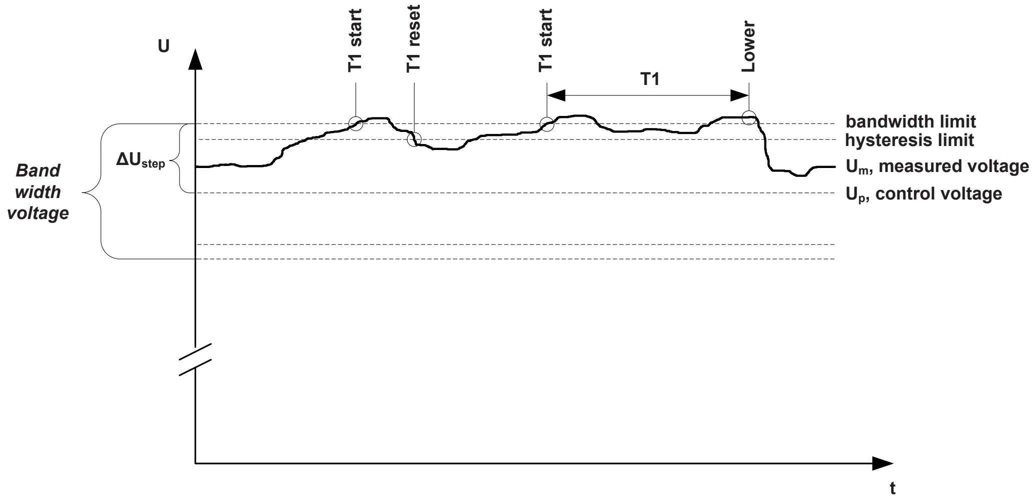


Figure 916: Voltage-regulating function. A control pulse to lower the voltage is issued after the elapsed T1.

If the measured voltage is outside the hysteresis when the delay counter T1 reaches its setting value, the raising or lowering output relay is activated. This activates either output pulse `RAISE_OWN` or `LOWER_OWN`, and the motor drive of the tap changer operates. The status of these outputs can be read from the output data `RAISE_OWN` or `LOWER_OWN`.

If the measured voltage falls or rises within the hysteresis limits during the operating time, the delay counter is reset.

The pulse length can be defined with the *LTC pulse time* setting. The default value is 1.5 seconds.

A short delay, same as the typical tap changer operating time, is active before the start of the next operating timer. For OL5ATCC, the delay is set to 6 seconds. If one tap changer operation is not enough to regulate the transformer voltage within the hysteresis limits, a second adjustable delay T2 (*Control delay time 2*), usually with a shorter time setting than T1, starts. This delay is used for the control commands within the same sequence until the recovery of voltage occurs. The delays T1 and T2 can be selected either with definite or inverse time characteristics. In the inverse time mode, the operate time depends on the difference between the control voltage and the measured voltage as shown in *Equation 384*. The bigger the difference in the voltage, the shorter the operating time. More information on the inverse time operation can be found in the *Chapter 9.10.5.8 Timer characteristics*.

Regulation equation

The simple regulating principle is often complemented by additional features to take the voltage drop of lines into account (line drop compensation), coordinate the regulation of parallel transformers and change the voltage level according to the loading state of the network. The control voltage U_p is calculated according to the equation

$$U_p = U_s + U_z + U_{ci} - U_{rsv}$$

(Equation 373)

U_p	Control voltage
U_s	Set voltage level *Band center voltage*
U_z	Line drop compensation term
U_{ci}	Circulating current compensation term
U_{rsv}	Voltage reduction parameter

U_p can be directly read in the monitored data U_CTL.

The circulating current compensation term is calculated only in the parallel acting operation modes "NRP" and "MCC".

Line Drop Compensation (LDC)

The LDC feature is used to compensate the voltage drop along a line or network fed by the transformer. The compensation setting parameters can be either calculated if the resistance and reactance of the line are known or measured from the line drop.

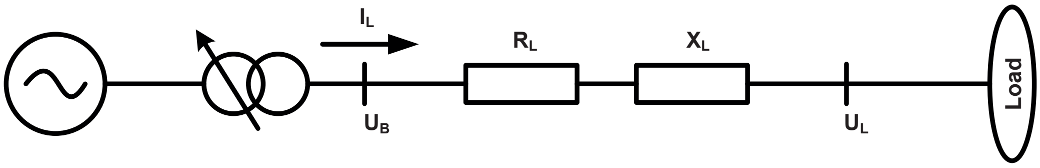


Figure 917: Equivalent electrical circuit for calculating the LDC term

The compensation parameters *Line drop V Ris* (U_r) and *Line drop V React* (U_x), are percentage values of U_n according to the equations.

$$Line\ drop\ V\ Ris = U_r[\%] = \frac{\sqrt{3}\cdot I_{CT\_n1}\cdot R}{U_{VT\_n1}}\cdot 100 \quad [\%\mathrm{U_n}]$$

$$Line\ drop\ V\ React = U_x[\%] = \frac{\sqrt{3}\cdot I_{CT\_n1}\cdot X}{U_{VT\_n1}}\cdot 100 \quad [\%U_n]$$

(Equation 374)

I_{CT_n1}	Nominal primary current of the CT
U_{VT_n1}	Nominal primary voltage of the VT (phase-to-phase voltage)
R	Resistance of the line, Ω/phase
X	Reactance of the line, Ω/phase

The general LDC equation can be calculated.

$$U_z = \frac{I_L}{I_{CT\_n1}}\cdot\frac{\left(U_r[\%]\cos\varphi + U_x[\%]\sin\varphi\right)}{100} \quad [xU_n]$$

(Equation 375)

I_L	Average of the currents I_A, I_B and I_C
I_{CT_n1}	Nominal primary current of the CT
U_r	Setting *Line drop V Ris*

Table continues on the next page

U_x	Setting *Line drop V React*
ϕ	Phase angle between U_A and I_A (ANGL_UA_IA)

By default, LDC is not active, but it can be activated by setting *LDC enable* to "True". To keep the LDC term within acceptable limits in all situations, OL5ATCC has a setting parameter *LDC limit*, which has a default value of 0.10 xU_n. This gives the maximum value for U_z in *Equation 373*.

If more than one line is connected to the LV busbar, the equivalent impedance is calculated and given as a parameter setting as shown in *Figure 917* for the equivalent electrical circuit for calculating LDC. For example, if there are N number of identical lines with identical loads in the substation, the R- and X-values needed for the settings *Line drop V React* and *Line drop V Ris* are obtained by dividing the resistance and the reactance of one line by N. Because the voltage drop is different in lines with different impedances and load currents, it is necessary to make a compromise when setting the *Line drop V React* and *Line drop V Ris* settings. Raising the voltage in the point of lowest voltage must not lead to overvoltage elsewhere.

By default, LDC is effective only on the normal active power flow direction. If the active power flow in the transformer turns opposite, that is, from the regulated side towards the system in the upper level, the LDC term is ignored, that is, set to zero. In such a case, it is assumed that the feeding units at the regulated side of the transformers maintain proper voltage levels. This can cause a conflict if the transformer tries to reduce the voltage at the substation. Additionally, it is difficult to predict the actual voltage levels in the feeder lines in such a case, and lowering the voltage at the substation can have harmful effects in the far end of the network. However, the *Rv Pwr flow allowed* setting allows also negative LDC terms to be taken into equation.

The topology changes in the network can cause changes to the equivalent impedance value of the network. If the change is substantial, the setting groups can be used to switch between different setting values for *Line drop V React* and *Line drop V Ris*. This means that the boolean-type information from the topology change is connected to the active setting group change.

The use of the LDC equation in the case of parallel transformers is described in *Chapter 9.10.5.6 Automatic voltage regulation of parallel transformers (Auto parallel)*.

Reduce Set Voltage (RSV) input

The system frequency decreases when the active power production in the network is smaller than its consumption. Either the power supply has to be increased or some loads have to be shed to restore the power balance.

The simplest way to decrease the load is to reduce the voltage level by giving a lower band center voltage value to the regulators. For this purpose, OL5ATCC has the setting group parameter *Band reduction*. The `RSV` input activation results in reduction. If this input is set to TRUE, a set target voltage value is decreased by *Band reduction*. If more than one `RSV` reduction steps are desired, the setting group change has to be used where different *Band reduction* values are supported. The decreased value is kept as a target value as long as the `RSV` input is TRUE.

Because the decrease of frequency indicates a need to reduce the load, it is practical to connect the start signal of an underfrequency function block to the `RSV` digital input.

It depends on the load characteristics how much the load is reduced as the voltage drops. For instance, purely resistive loads are proportional to the square of the voltage, whereas motor drives based on frequency controllers may draw constant power despite small voltage changes.

The status of the RSV input can be read from the RSV input data.

9.10.5.6 Automatic voltage regulation of parallel transformers (Auto parallel)

A circulating current may occur between transformers if two or more transformers with slightly different ratios are energized in parallel. This is due to the unbalanced short circuit impedances of the parallel transformers. To avoid such currents, the tap changers of the transformers should be adjusted to achieve equilibrium. If the transformers are assumed identical, the tap (voltage) steps and tap positions should also match. In this case, the Master/Follower principle can be used. However, unequally rated transformers with different tap steps can be connected in parallel and these configurations can also be managed by the tap changer control function. For these configurations, the Minimizing Circulating Current (MCC) or Negative Reactance Principle (NRP) should be used. MCC and NRP are also suitable for identical transformers.

The circulating current, which is almost purely inductive, is defined as negative if it flows towards the transformer. U_{ci} in *Equation 373* is positive and the control voltage U_p rises as a result to the RAISE_OWN output signal activation if the circulating current level is sufficient (*Equation 377* and *Equation 379*) and the other parameters remain the same. As a result, the voltage rise should diminish the circulating current.

LDC equation and parallel connection

The additional challenge in the parallel connection regarding LDC is to know the total current which flows through the parallel transformers.

In the Master/Follower mode, it is easier to know the total current than in other parallel modes since the transformers are assumed to have identical ratings, that is, the total current (I_L in *Equation 375*) is obtained by multiplying the measured load current (the average of the currents I_A, I_B and I_C of the connected own transformer) by the number of parallel transformers. OL5ATCC can internally conclude the number of parallel transformers from the connected tap changer position inputs. However, if there is no connected position information from the other parallel transformers, the correct number of the parallel transformers, excluding the own transformer, needs to be set with the *Parallel trafos* setting.

In the MCC mode, the horizontal communication transfers the information from the measured load currents between the regulators so that the total current needed in the line drop compensation can be summed accurately. Here, I_L is defined to be the phasor sum of all the parallel power transformer currents. The currents from other transformers must be fed via the TR_I_AMPL and TR_I_ANGL inputs of the OLGAPC function.

In the NRP mode, the parallel transformers have different ratings and there is no communication between the regulators. Therefore, when setting *Line drop V React* and *Line drop V Ris*, the I_{CT_n1} used in the equation should be the sum of the rated currents of all the transformers operating in parallel. Here, I_L is also defined as the average of the currents (I_A, I_B and I_C). The calculated line drop compensation value can be read from the monitored data LDC.

Master/Follower principle M/F

The M/F operation principle is suitable for power transformers with identical ratings and step voltages. One voltage regulator (master) measures and controls and the other regulators (followers) follow the master, that is, all the tap changers connected in parallel are synchronized. This parallel operation is obtained by connecting the FLLWx_CTL output of the master to the corresponding OLGAPC function input TR_TAP_FLLW of the followers via horizontal GOOSE communication.

The values for the FLLWx_CTL command are 1=Lower follower x and 2=Raise follower x. Consequently, the values for OLGAPC function TR_TAP_FLLW command are 1=Lower and 2=Raise.

If several regulators act as masters (one at a time), their outputs also have to be routed to the inputs of the other regulators. To start the parallel operation, the master regulator is set to the "Auto master" mode and the followers to the "Auto follower" mode. A regulator acting as a follower can be set to master in three ways.

- Activating input MSTR_TRIGG if *Parallel mode* is set to "Input control"
- Activating MstrOp via communication if *Parallel mode* is set to "Command"
- Activating the Master Trig button in the LHMI control dialog for OL5ATCC if *Parallel mode* is set to "Command"

The regulator indicates its master status (“Independent”, “Master” or “Follower”) by the TR_STATUS monitored data. A parallel regulator, previously acting as master, receives this signal via the TR_STATUS input of OLGAPC and changes its status to follower.

Connect the TR_STATUS input to the OLGAPC of the parallel transformer and route the TR_DAT output from OLGAPC to OL5ATCC TRx_DAT for proper M/F functionality. If TR_STATUS is left unconnected, that particular parallel transformer is assumed to not be participating even though receiving valid tap position information.

To keep all the tap changers in the same position, the master needs to know the tap positions of the followers. This way, the circulating current is kept at its minimum. The position values of the followers can be brought to the master either via horizontal GOOSE communication or TPOSYLTC.

If it is not possible to use horizontal communication between the protection relays and the position information cannot be wired from the parallel transformers, the M/F principle can still be used to regulate two or an unlimited number of transformers in parallel. Since the master cannot detect the tap positions of parallel transformers, it just activates the lowering and raising outputs for all the followers when it controls its own tap changer. This is called blind control. In this case, a number of parallel transformers are regulated as one unit.

The combined data inputs TRx_DAT must be left unconnected for the master to know that the tap positions of the followers are unknown. The time delay between successive commands can be set by the *Follower delay time* setting. The default value is 6 seconds.

When a disconnected transformer is taken into use and the tap position is unknown, it is recommended that the follower should be manually controlled to the same position as the master. In the M/F mode, the master gives its own transformer a control command which is echoed to the followers (the follower's tap positions must be connected). Thereafter, successive control commands to the followers take place until the master and followers have the same tap positions.

To indicate if a follower is on a different tap position compared to the active master, TAP_DIFF output is set to TRUE at that specific follower. Even though the follower transformer is not yet included in parallel connection, that is, its TR_STATUS is “Independent”, tap difference to master can be indicated. To enable TAP_DIFF output usage, valid tap position TR_TAP_POS and M/F status TR_STATUS from master must be routed through OLGAPC to the follower. The TAP_DIFF output can be used as an alarm or to block the closing of the circuit breaker of the follower transformer.

Out-of-step function

The out-of-step means that the master detects a difference of at least one step between the tap changer positions in the follower and in the master. The out-of-step function is usually used in the M/F mode only. The out-of-step function means that the master is able to detect the position values of the followers and control them to the same position as the master's. In this case, the master assumes that the followers also have either *Raise block tap* higher than *Lower block tap* or *Lower block tap* higher than *Raise block tap* because this defines what is the given command pulse for a follower. If the master has *Raise block tap* higher than *Lower block tap* and the follower has *Lower block tap* higher than *Raise block tap*, the corresponding tap changer follow included control signals should be connected crosswise. This requires extra logic where dual point command bits have to be converted, that is, 0=>0, [01]=1=>[10]=2 and [10]=2=>[01]=1.

M/F is the only parallel mode which has an out-of-step functionality. In the MCC and NRP operation modes, the circulating current is minimized, which often means different tap positions in the parallel transformers. Moreover, these modes allow different ratings and step voltages for the parallel transformers. Therefore, it is reasonable to apply the out-of-step function only to the M/F operation mode.

In an out-of-step situation at startup, follower commands take place only after the master has given its own control command, which is echoed to the followers. This is followed by special raise or lower commands to the diverging follower.

By setting the parameter *Inst out of step Cor* to "TRUE", an out-of-step situation at startup sends special raise or lower commands to the diverging follower after *Follower delay time*. *Inst out of step Cor* is by default set to "FALSE".

If two consecutive commands fail to change the position of the follower to the right direction, the master activates the PAR_FAIL output, that is, PAR_FAIL is set to TRUE, and stops the special recovery efforts. However, every time the master controls its own tap changer later, it sends a controlling pulse to the diverging follower too. Furthermore, if the master notices a correct position change after a sent pulse, it restarts the attempts to drive the follower to the same position and deactivates the PAR_FAIL output, that is, PAR_FAIL is set to FALSE. However, if there still are diverging followers, the reset is not indicated. It is indicated only when no diverging followers exist. Monitoring, and hence the indication of a paralleling failure, is not possible in blind control.

The followers with a parallel failure can be read from the monitored data FAIL_FLLW. For example, if only follower 3 is in the parallel failure state, FAIL_FLLW has the value "T3". If both followers 1 and 2 are in the parallel failure state, FAIL_FLLW has the value "T1+T2". By default, when no failed followers exist, the value is "No failed followers".

Negative Reactance Principle NRP

This parallel control scheme is suitable for power transformers with different ratings and step voltages. Since no communication between the regulators is needed, this principle can be applied even when the parallel transformers are located at different substations. To start the parallel operation, the active operation mode has to be set to "NRP" for all the regulators of the connection. The active operation mode can be changed via function block inputs or by setting it either locally or remotely.

When applying this principle, each regulator has a phase angle setting ϕ_{Load} (setting parameter *Load phase angle*) towards which it tries to regulate the current. The setting value is chosen according to the expected power factor of the load (positive setting value equals inductive load). When the actual phase angle of the load current is the same as the setting and the transformers and their tap changer positions are identical, the currents of the transformers are in the same phase as the total load current. If the tap changer positions are different, the circulating current flows and the currents of different transformers either lag or lead the load current. *Figure 918* shows that the circulating current is the reactive component which separates the measured current vector from the expected angle value.

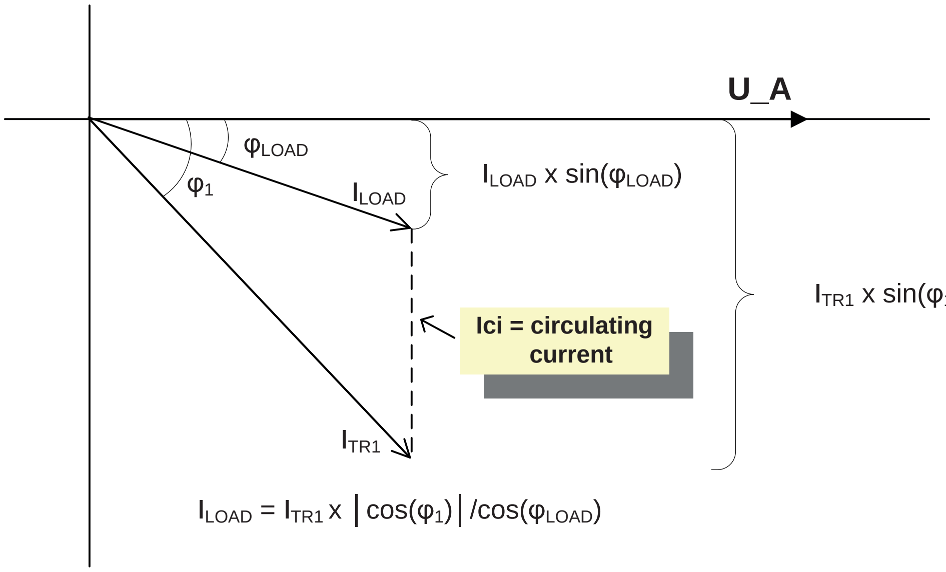


Figure 918: The expected phase angle of the load supplied by the transformers operating in parallel is entered as a setting value ϕLoad

The regulators calculate the circulating current with the equation

$$I_{ci} = (\sin\varphi_1 - \tan\varphi_{Load} \cdot |\cos\varphi_1|) \cdot I_{TR1}$$

(Equation 376)

I_{TR1}	Average of the currents I_A, I_B and I_C
ϕ_1	Phase angle between U_A and I_A
ϕ_{Load}	Set *Load phase angle* of the load current

In the negative reactance method, the circulating current is minimized by changing the control voltage according to the measured circulating current. The regulator calculates the circulating current compensation term U_{ci} (*Equation 373*) as in the MCC.

$$U_{ci} = \frac{-I_{ci}}{I_n} \cdot \frac{Stability\ factor}{100} \cdot U_n$$

(Equation 377)

I_{ci}	Circulating current
Stability factor	Stability setting (the recommended value depends on the loop impedance)

If the transformers operating in parallel have different rated currents, the value of the *Stability factor* setting of the regulator should be proportional to the rated currents, that is, the higher the rated current, the higher the *Stability factor* setting value.

It is possible to find out if the circulating current has been minimized by comparing the reactive components of the currents measured by the different regulators. The circulating current is minimized when the reactive components are equal.

The negative reactance method gives satisfactory results only if the phase angle of the load current is known relatively accurately. If the actual phase angle deviates from the phase angle setting, a regulating error occurs. However, if there is an occasional stepwise change in the phase angle of the load, the regulating error can be suppressed with the logic. This kind of stepwise change can occur, for example, when a capacitor bank is switched on to compensate a reactive power flow. Another possibility is to use an automatic setting group change between setting groups in different loading situations. The setting groups then have different set values for the load phase angle.

Minimizing Circulating Current MCC

The MCC principle is an optimal solution for controlling parallel transformers of different ratings or step voltages in substations with varying reactive loads. Since this control scheme allows the exchange of data between regulators, the circulating current can be calculated more accurately than with other schemes. However, a maximum of six regulators can be connected in parallel. To start the parallel operation, the active operation mode parameter has to be set to "MCC" for all the regulators of the connection. Furthermore, the signal `CON_STATUS` must indicate that the transformers are connected to the network. A unit that minimizes the circulating current must have the active operation mode set to "MCC". Units that have the active operation mode set to "Manual" do not perform any circulating current minimization operations themselves.

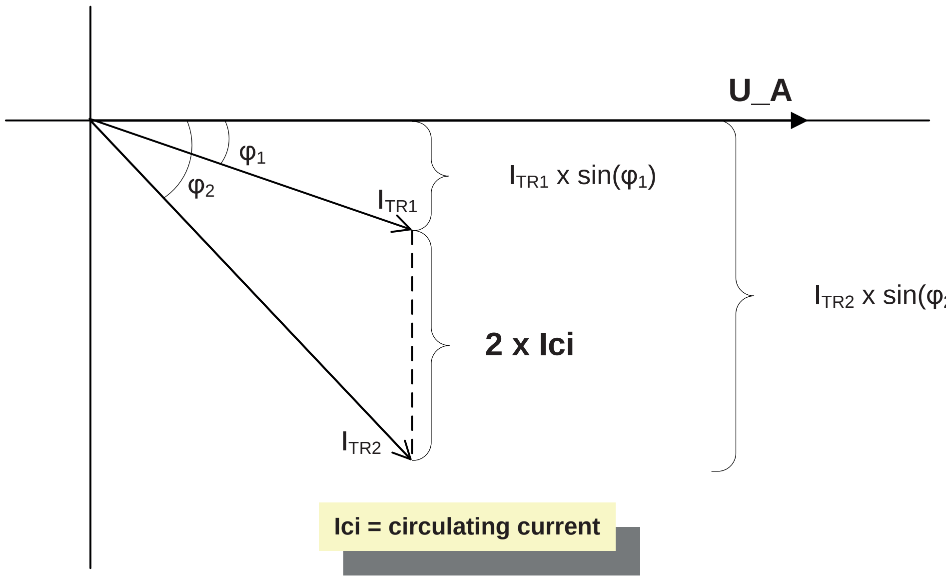


Figure 919: The circulating current between two parallel transformers

In this case, the circulating current can be calculated with the equation

$$I_{ci} = \frac{(\sin\phi_1 \cdot I_{TR1} - \sin\phi_2 \cdot I_{TR2})}{2}$$

(Equation 378)

I_{TR1}	Current magnitude of regulator 1
I_{TR2}	Current magnitude of regulator 2
ϕ_1	Phase angle between U_A and I_A in regulator 1
ϕ_2	Phase angle between U_A and I_A in regulator 2

The circulating current can be read from the monitored data I_CIR.

Using the circulating current, the compensation term U_{ci} can be calculated with the equation

$$U_{ci} = \frac{-I_{ci}}{I_{CT\_n1}} \cdot \frac{Stability\ factor}{100} \cdot U_n$$

(Equation 379)

I_{ci}	Circulating current
I_{CT_n1}	Nominal primary current of the CT
Stability factor	Stability setting (the recommended value depends on the loop impedance)

The value of U_{ci}, which can be positive or negative, is added to the *Band center voltage Us* (*Equation 373*). According to *Figure 919* and *Equation 378*, the phasor information from the other protection relays is needed.

Parallel unit detection and the MCC mode

The network connection status information is essential for the MCC operation mode. The status FALSE needs to be connected to the CON_STATUS input to ensure a proper operation of the MCC calculation if the transformer is disconnected but OL5ATCC remains in the MCC mode. This way the disconnected transformer is excluded from the circulating current calculations.

The CON_STATUS input is used to identify if a transformer controller can send the current information to other transformer controllers for circulating current minimization purposes. As a result, this input has effect only in the MCC or Manual active operation modes. In these modes, if CON_STATUS is TRUE, the information transmission is started. The circulating current information receiving is allowed only in the MCC active operation mode when CON_STATUS is TRUE. PAR_UNIT_MCC can be seen in the Monitored data view.

Communication and the MCC mode

The phasor information from the other parallel protection relays is needed for the circulating current calculation. Therefore, horizontal GOOSE communication is needed between protection relays when the MCC principle is used.

The transferred current phasor information contains a primary value of the measured current. The magnitude and angle of the current phasor can be read from the OLGAPC function input data TR_I_AMPL and TR_I_ANGL, respectively.

The sent phasor information always represents the difference between the voltage phasor *U_A* and current phasor *I_A*. The information about the current phasor can be read from the monitored data TR0_I_AMPL and TR0_I_ANGL. The allowed active operation modes for sending data are MCC or Manual, both with the input CON_STATUS activated. The communication is active when the sent and received phasor magnitude is not clamped to zero. The communication phasor magnitude is zero due to a rejected active operation mode or too low signal magnitudes (see *Chapter 9.10.5.1 Voltage and current measurements*). Active CON_STATUS indicates that the corresponding transformer is connected to the network and its current affects the circulating current of other transformers even when it is in the manual operating mode.

9.10.5.7 Reverse power flow handling

Power flowing through the transformer can be bi-directional under certain circumstances. Traditionally, power flows from high voltage (HV) side to medium voltage (MV) side. In this case the target is to keep the MV side voltage constant despite of load current and HV side voltage variations. This is achieved by monitoring the MV side voltage and controlling tap changer position accordingly. Increasing the HV winding turns will lower the MV side voltage and vice versa.

But when power flow direction changes from the MV side to the HV side, the relay has to adapt to this situation based on the *Regulation Mode* setting.

The direction of power flow in all the parallel connected transformers should be same at any given point of time.

If the *Regulation Mode* is set as “Forward”, normal regulation of MV side voltage takes place irrespective of the power flow direction, If the setting is kept as “Bi-dir(meas)” or “Bi-dir(calc)”, when power flow direction reverses, the target is to keep the HV side voltage constant despite of variations in the load current and the MV side voltage. This is achieved by monitoring the HV side voltage.

"Bi-dir(meas)" or "Bi-dir(calc)" set values should be used only when it is clear that the source of reverse power flow is a strong source.

If HV side measurements are directly available, "Bi-dir(meas)" mode can be used. If it is not available, "Bi-dir(calc)" can be set and HV side values are calculated (after power reversal) from MV side measurements with the help of settings *Step of tap*, *Tap nominal* and *Impedance voltage* as given below.

If *Raise block tap* > *Lower block tap*, then HV side voltage and current are calculated as

$$U_{HV} = \{1 + (TAP\_POS - TAP\_NOM) * \Delta U_{step}\} * \{U_{MV} - I_{MV} * ZV\}$$

(Equation 380)

$$I_{HV} = \frac{I_{MV}}{\{1 + (TAP\_POS - TAP\_NOM) * \Delta U_{step}\}}$$

(Equation 381)

If *Raise block tap* < *Lower block tap*, then HV side voltage and current are calculated as

$$U_{HV} = \{1 + (TAP\_NOM - TAP\_POS) * \Delta U_{step}\} * \{U_{MV} - I_{MV} * ZV\}$$

(Equation 382)

$$I_{HV} = \frac{I_{MV}}{\{1 + (TAP\_NOM - TAP\_POS) * \Delta U_{step}\}}$$

(Equation 383)

U_{HV}	HV side voltage which will be compared with control voltage U_p for HV side regulation
I_{HV}	HV side current
U_{MV}	MV side measured voltage
I_{MV}	MV side measured current
TAP_NOM	*Tap nominal*
TAP_POS	Own tap position
ΔU_{step}	*Step of Tap*
ZV	Impedance voltage referred to MV side

When "Bi-dir(calc)" set value is used, it is mandatory that own tap position information should be connected.

Since it is not always possible to know the source strengths on either side of the transformer, an additional setting option "Auto select" is also provided. If the *Regulation mode* is set as "Auto select", the direction of regulation will be automatically selected by OL5ATCC function as below. A power ratio factor (PRF) is calculated by the OL5ATCC function utilizing HV and MV side voltage and current measurements. If this factor is less than 1, it implies that the source on MV side is comparatively weak and hence forward regulation will be carried out. Here, if *LDC enable* is set as TRUE, then *Rv pwr flow allowed* must be internally set as TRUE if not already so.

If PRF > 1, it implies that the source on MV side is stronger and then HV side regulation will take place. It should be noted that in HV side regulation, increasing the HV winding turns will increase the HV side voltage and vice versa. The commands issued will be opposite of that issued for forward regulation. The output REV_REG is activated during HV side regulation, which can be used to select the setting group which gives the line parameters on HV side for LDC.

If *Regulation mode* is set as “Auto select”, measurements from both HV and MV side should be available for the accuracy of PRF calculation.

9.10.5.8 Timer characteristics

Operation timer functionality

The delay times can be set to follow either the definite time characteristic or the inverse time characteristic with the *Delay characteristic* setting. By default, the "Definite time" mode is selected. The timer mode cannot be changed between cycles T1 and T2, only either before T1 has started or after T2 has elapsed.

Table 1573: Different timer mode delays

Timer mode	Setting	Description
T1	*Control delay time 1*	First delay when the measured voltage exceeds or falls below the limit value.
T2	*Control delay time 2*	Second delay when the first control did not bring the measured voltage to a desired level.

The delay after the command pulse activation and the restart of the timer is six seconds. The delay is assumed to be the tap changer operating delay. The timer status can also be read from the monitoring data TIMER_STS, where T1 active gives a value "Lower timer1 on" or "Raise timer1 on" while T2 active gives a value "Lower timer2 on" or "Raise timer2 on". Furthermore, the "Fast lower T on" value indicates that the fast lowering control functionality is active (*Chapter 9.10.5.10 Blocking scheme*).

Activation of operation timer also activates the `TIMER_ON` output.

IDMT type operation

The IDMT timer can be selected by setting *Delay characteristic* to "Inverse time". The minimum time at the inverse time characteristic is limited to 1.0 second. However, the minimum recommended setting of the control delay times T1 and T2 is 10 seconds when the definite time delay is used and 25 seconds when the inverse time delay is used.

The inverse time function is defined by the equations:

$$B = \frac{U_d}{(U_{BW} / 2)}$$

(Equation 384)

U_d	$\lvert U_m - U_p \rvert$, differential voltage
U_{BW}	Setting parameter *Band width voltage*

$$t = \frac{T}{2^{(B-1)}}$$

(Equation 385)

T	T1 or T2

The monitored data UD_CTL shows the differential voltage value $U_m - U_p$. If the value exceeds half of the *Band width voltage* setting and has a negative sign, a raising pulse is issued. The UD_CTL monitored data can also be seen in the DT timer mode.

The hysteresis approach is presented in *Figure 916*.

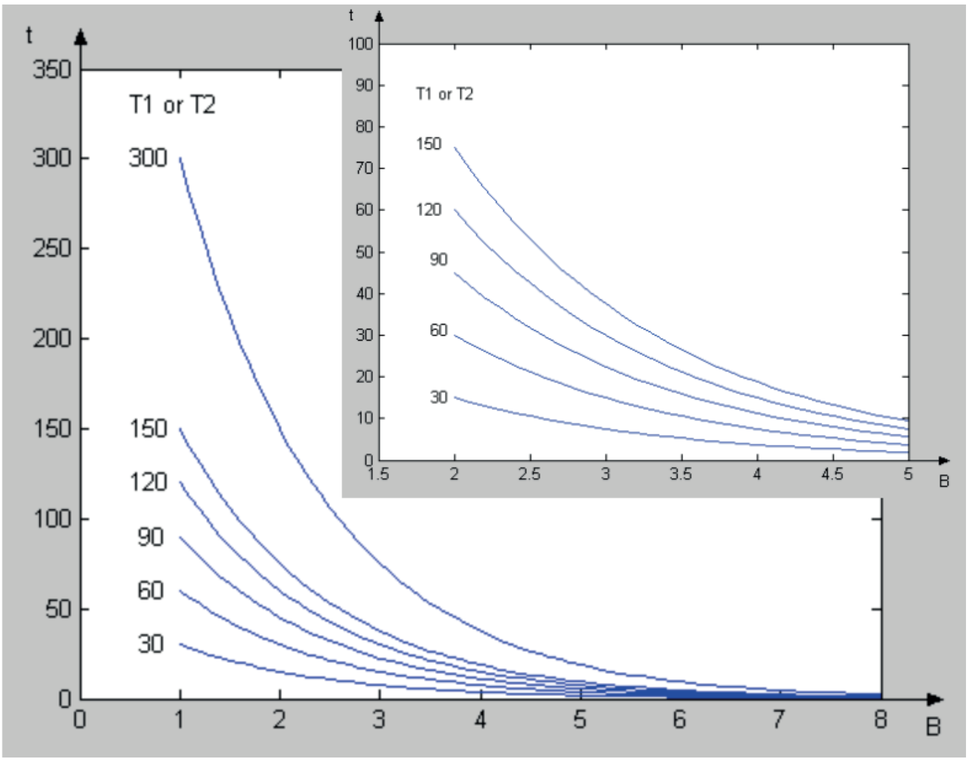


Figure 920: Inverse time characteristic for different values on T1 or T2 (The smaller figure is a zoom-in of the larger one)

9.10.5.9 Pulse control

The tap changer generates an active operating signal when the tap-changing process is active. This signal is used for alarming purposes and must be connected to the TCO input. If the signal is active (=TRUE) for more than 15 seconds after the control pulse has been deactivated, an alarm is generated (*Chapter 9.10.5.11 Alarm indication*). If the TCO input is not connected, no alarm is generated.

The control operation is disabled when the TCO input signal is active, unless no tap changer stuck is detected (*Chapter 9.10.5.11 Alarm indication*). Thus, the controller cannot send new pulses to the tap changer when this is already operating because tap changers are typically immune to new pulses when they operate. Furthermore, because the pulses are omitted, the tap changer pulse counter of the controller is not incremented.

The commands are not tolerated during an active pulse. Therefore the command pulse length (setting *LTC pulse time*) has to be carefully selected, although an active TCO input is used internally to prevent new commands from reaching the tap changer.

To be more certain that no new pulses are sent when the tap changer is in operation, the tap changer operating signal can be connected to the LTC_BLOCK input. In this case, external blocking is achieved when an automatic pulse is sent to the operating tap changer. By default, the external LTC_BLOCK has no effect when the active operation mode is set to "Manual" or "Parallel manual".

The status of the TCO input can be read from the TCO input data.

9.10.5.10 Blocking scheme

The operation of the voltage regulator can be blocked for several reasons. The purpose of blocking is to prevent the tap changer from operating under conditions that can damage the tap changer or exceed other power system limits. The BLK_STATUS monitored data does not imply actual blocking but reveals if the coming command pulse is issued or not. The blocking itself happens when the corresponding bit in the signal BLK_STATUS is active and the command pulse is started due to a timer elapse or a local command. This is to avoid unnecessary event sending.

The BLK_STATUS monitored data is also packed. It contains information about the blocking status as bit-coded output. The block status output does not indicate the actual blocking but indicates if the coming command is successful. The actual blocking is indicated by the corresponding output (BLKD_I_LOD, BLKD_U_UN, RNBK_U_OV, BLKD_LTCBLK, BLKD_I_CIR, BLK_RAISE and BLK_LOWER) values. *Table 1574* illustrates the meaning of different monitored data values. For example, block status value 9 indicates that there are conditional circulating current and load current blockings (8 + 1 = 9) indicated. By default, the status is “0”.

Table 1574: Bit-coded block status and the meaning of different bits

Bit	Active value	Blocking reason
6 (msb)	64	Lowest position reached
5	32	Highest position reached
4	16	External LTC_BLOCK
3	8	High circuit current
2	4	Overvoltage - Runback raise voltage
1	2	Undervoltage - Block lower voltage
0 (lsb)	1	Overcurrent - Load current

The cross (X) in the table defines when the operation is blocked (if the corresponding bit is active in BLK_STATUS). For example, an overvoltage (runback raising voltage) results in blocking only when the active operation mode is "Manual" and the manual raising command is given.

Table 1575: Default blocking schema in OL5ATCC

Active operation mode	Command	Load current	Block lower voltage	Runback raise voltage	High circulating current	External block	Extreme positions
Manual, Parallel manual	Raise	X		X			X
	Lower	X					X
Auto follower	Raise	X	X			X	X
	Lower	X	X			X	X
Auto single, Auto master, NRP, MCC	Raise	X	X		X [1]	X	X [2]
	Lower	X	X		X [1]	X	X [2]

In addition to the default blocking, the *Custom Man blocking* setting has been added due to different operation practices of the manual command blocking. The setting can be used to adapt blockings considering the manual overcurrent, undervoltage or external blocking. (The blockings are in *Table 1575* in columns Load current, Block lower voltage and External block for the manual operating mode.) The default value for the parameter is "OC". This means that the default blocking schema explained in *Table 1575* operates as such. However, there are other alternatives that cause different operations.

Table 1576: Customized manual blocking schema

Manual blocking type	Enumeration	Description
1	Custom disabled	No load current, block lower (under) voltage, external blocking has no effect in the manual operation modes
2	OC	Load current blocking has an effect in the manual operation mode
3	UV	Block lowering (under) voltage blocking has an effect in the manual operation mode
4	OC, UV	Conditions 2 and 3 together: Load current and block lowering (under) voltage blocking have effect in the manual operation mode

Table continues on the next page

1 Because the circulating current is calculated only in the NRP and MCC modes, it can have a blocking effect only in these modes.

2 In these cases the automatic operation notices that the extreme position has already been reached and there is no need to activate the signal for data set event sending. The automatic follower case can here be compared to a manual case and an event can be sent, that is, the corresponding output is activated.

Manual blocking type	Enumeration	Description
5	EXT	External blocking has an effect in the manual operation mode
6	OC, EXT	Conditions 2 and 5 together: Load current and external blocking have effect in the manual operation mode
7	UV, EXT	Conditions 3 and 5 together: Block lowering (under) voltage and external blocking have effect in the manual operation mode
8	OC, UV, EXT	All conditions 2, 3 and 5 together: Load current and block lowering (under) voltage and external blocking have effect in the manual operation mode

If the *Custom Man blocking* setting is "Custom disabled", the blocking schema regarding the acting operation mode "Manual" or “Parallel manual” is as given in *Table 1577*. Other operation modes follow the default schema.

Table 1577: Blocking schema for selection "Custom disabled"

Active operation mode	Command	Load current	Block lower voltage	Runback raise voltage	High circulating current	External block	Extreme positions
Manual, Parallel manual	Raise			x			x
	Lower						x

Table 1578: Blocking schema for selection "OC, UV, EXT"

Active operation mode	Command	Load current	Block lower voltage	Runback raise voltage	High circulating current	External block	Extreme positions
Manual, Parallel manual	Raise	x	x	x		x	x
	Lower	x	x			x	x

Table 1579: Blocking schema for selection “UV, EXT”

Active operation mode	Command	Load current	Block lower voltage	Runback raise voltage	High circulating current	External block	Extreme positions
Manual, Parallel manual	Raise		x	x		x	x
	Lower		x			x	x

Load current

The load current blocking is mainly used for preventing the tap changer from operating in an overcurrent situation. For example, if the current is not high enough to activate the protection relay of the substation, it can still be fatal for the diverter switch of the tap changer. This operation can be adjusted with the setting parameter *Load current limit*. The maximum of measurements from the current phases is used for blocking. By default, both the automatic operation and the manual operation are blocked (*Table 1575*) when the set limit is exceeded.

The blocking status can be read from the output BLKD_I_LOD.

Block lowering voltage

The block lowering voltage feature blocks both raise and lower voltage commands if the measured voltage is too low to be corrected by operating the tap changer. Such a situation can occur due to a faulty measuring circuit, an earth fault or an overcurrent situation. By default, only the automatic (also automatic follower) operation is blocked when the undervoltage condition is met (*Table 1575*). This operation can be adjusted with the setting parameter *Block lower voltage*.

The blocking status can be read from the output BLKD_U_UN.

However, there is no minimum limit for the undervoltage blocking. The blocking is allowed even if the measured voltage is not connected or it temporarily has a very low value. There is a minimum limit for the phase angle calculation based on the voltage phasor magnitude.

Runback raising voltage

The manual raising command is blocked if the overvoltage limit is exceeded (*Table 1575*). However, in the automatic operation mode, the overvoltage situation triggers the fast lowering feature. More information can be found in *Chapter 9.10.5.4 Manual voltage regulation* . This operation can be adjusted with the setting parameter *Runback raise V*.

The blocking status can be read from the output RNBK_U_OV.

High Circulating Current

The circulating current value is calculated in the operation modes Negative Reactance Principle (NRP) and Minimizing Circulating Current (MCC). Only the automatic operation in these modes is blocked when the high circulating current is measured (*Table 1575*). This operation can be adjusted with the setting parameter *Cir current limit*.

The blocking status can be read from the output BLKD_I_CIR.

LTC_BLOCK – external block input

With the PCM600 tool configuration possibilities, a desired blocking condition can be built by connecting an outcome to this input. The blocking status can be read from the output BLKD_LTCBLK. When activated, this input blocks only the automatic operation of the regulator by default (*Table 1575*). For the fully automatic modes, the signal activation resets the timer, and the monitored data BLKD_LTCBLK is not activated.

Extreme positions

This blocking function supervises the extreme positions of the tap changer. These extreme positions can be adjusted with the setting parameters *Raise block tap* and *Lower block tap*. When the tap changer reaches one of these two positions, the commands in the corresponding direction are blocked (*Table 1575*). It depends on the comparison between the *Raise block tap* and *Lower block tap* settings, which direction is blocked (*AAVoltage control vs. tap changer moving direction*). This blocking affects both the automatic and manual operation modes.

However, as shown in *Table 1575*, no blocking indication is generated in the fully automatic modes. Here "Auto follower" is not a fully automatic mode. The unconnected position information does not cause the total block of OL5ATCC, only the extreme position blocking does not work.

The blocking status can be seen in the generated events.

Fast lowering control

OL5ATCC provides the fast lowering control in the automatic operation modes. When the set *Runback raise V* is exceeded, the regulator gives fast lowering control pulses until the voltage drops below the specified limit. This fast lowering control can be seen with the monitoring data TIMER_STS, where the value "Fast lower T on" indicates this functionality to be active.

To allow the fast lowering operation, *Runback raise V* has to be set always to a value higher than the control voltage (U_CTL) plus half of *Band width voltage*.

Typically, the blockings are reset when the corresponding limit with the hysteresis is undershoot or exceeded. Although blocking is reset after undershooting the above-mentioned limit, the fast lowering control operation continues until the measured voltage signal difference undershoots half the *Band width voltage* hysteresis limit (*Figure 916*). As a result, normal automatic operation mode is not possible before this happens.

Fast lowering control causes successive LOWER_OWN pulses to be activated. The time between consecutive pulses is the pulse length plus 1.5 seconds.

- There is no tap changer operating delay (otherwise 6 seconds) taken into account in this cycle meaning that some command pulses are ineffective due to tap changer operation, as described in the *Chapter 9.10.5.9 Pulse control*.
- Timer mode set by *Delay characteristic* has no effect here (always the DT timer-type operation). Because the minimum pulse length (the *LTC pulse time* setting) is 0.5 seconds, the shortest interval between successive pulses can be two seconds.

In the automatic follower mode, the fast lowering is not triggered. In this way, the awkward dispersion of position values in different units can be avoided. The master always decides on the fast lowering on behalf of the follower units. Moreover, master and follower should measure an equal voltage level and have similar setting values for the overvoltage blocking limit.

9.10.5.11 Alarm indication

Tap changer monitoring

OL5ATCC supervises the operation of the tap changer and generates alarms if the alarm condition is detected. An alarm activation means that the ALARM output is activated and the alarm reason can be read from the monitored data ALARM_REAS. Alarms are in use by default but they can be disabled by setting *Alarms enabled* to "False". Three different alarm conditions and their combinations can be detected by OL5ATCC.

Command error

OL5ATCC supervises the tap changer position information of the own transformer when a control pulse is given. If the correct position change (direction depends on the comparison of the settings *Raise block tap* and *Lower block tap*) is not seen by OL5ATCC in *Cmd error delay time* after the pulse start, the alarm is issued.

If the position information is not connected, no alarm is generated. The alarm is reset when the correct change in position value is detected after a given pulse or if a new command pulse is given.

The monitored data ALARM_REAS is set during an alarm. This means that if the alarm reason is active, ALARM_REAS has the value "Cmd error".

TCO signal fails

If the tap changer operating signal `TCO` stays active for more than 15 seconds after the output pulse deactivation, OL5ATCC sees this as an abnormal condition and assumes that the tap changer is stuck. The alarm is reset when the `TCO` input signal deactivates. The monitored data ALARM_REAS is set during the alarm. This means that only if the alarm reason is active, ALARM_REAS has the value "TCO error".

If the `TCO` input signal is not connected (indicated by bad quality), this type of alarm is not possible.

Regulator pumping

Faulty settings may cause the regulator to give control pulses too frequently. For example, too low a setting for the *Band width voltage* (*Figure 916*) can result in a pumping condition where the regulator has problems to bring the regulated voltage to a desired level. To detect this, OL5ATCC has a setting *Max operations in 1h*, which defines the allowed number of lowering and raising commands during a one-hour sliding time window. The detection is active both in the manual and automatic operation modes. The alarm is reset after the counted number of the operations during the one-hour time window is less than the set value. The number of executed operations per last one hour can be read from the monitored data OP_TM_NUM_H. However, this parameter is updated only in three-minute intervals. Again, the monitored data ALARM_REAS is set during an alarm. This means that only if alarm reason is active, ALARM_REAS has the value "Pump error".

The operation of OL5ATCC is not blocked during an alarm situation, but all the alarms mentioned above cause the automatic operation to be delayed, which means that the set delay times T1 and T2 are doubled.

In addition to the alarm detections, OL5ATCC provides a nonvolatile operation counter parameter (monitored data OPR_CNT) for determining the service intervals of the tap changer. The counter gives the total number of raising and lowering commands given in the manual and automatic modes. All commands, even those that are omitted by the tap changer due to its operation sequence, are calculated in a cumulative counter. This data parameter can be reset via the parameter *OL5ATCC counter* on the Clear menu.

9.10.6 Application

See the application manual for more information.

9.10.7 Signals

9.10.7.1 OL5ATCC Input signals

Table 1580: OL5ATCC Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
U3P1	SIGNAL	-	Three-phase voltages 1
U3P2	SIGNAL	-	Three-phase voltages 2
TAP_POS	INT8	0	Integer value representing tap changer position of own transformer
RAISE_LOCAL	BOOLEAN	0=False	Raise command input from configuration
LOWER_LOCAL	BOOLEAN	0=False	Lower command input from configuration
CON_STATUS	BOOLEAN	0=False	Network connection status of the (own) transformer
LTC_BLOCK	BOOLEAN	0=False	External signal for blocking
TCO	BOOLEAN	0=False	Tap changer operating input
RSV	BOOLEAN	0=False	Reduce set voltage active
PWR_DIR	Enum	1=forward	Power flow direction

9.10.7.2 OL5ATCC Output signals

Table 1581: OL5ATCC Output signals

Name	Type	Description
RAISE_OWN	BOOLEAN	Raise command for own transformer
LOWER_OWN	BOOLEAN	Lower command for own transformer

Table continues on the next page

Name	Type	Description
FLLW1_CTL	INT32	Lower/Raise command for follower transformer 1 in the Master/Follower operation mode
FLLW2_CTL	INT32	Lower/Raise command for follower transformer 2 in the Master/Follower operation mode
FLLW3_CTL	INT32	Lower/Raise command for follower transformer 3 in the Master/Follower operation mode
FLLW4_CTL	INT32	Lower/Raise command for follower transformer 4 in the Master/Follower operation mode
FLLW5_CTL	INT32	Lower/Raise command for follower transformer 5 in the Master/Follower operation mode
BLKD_I_LOD	BOOLEAN	Indication of over current blocking
BLKD_U_UN	BOOLEAN	Indication of under voltage blocking
RNBK_U_OV	BOOLEAN	Indication of raise voltage runback
BLKD_I_CIR	BOOLEAN	Indication of high circulating current blocking
BLKD_LTCBLK	BOOLEAN	Indication of external blocking
ALARM	BOOLEAN	Alarm status
PAR_FAIL	BOOLEAN	Parallel failure detected
PARALLEL	BOOLEAN	Parallel or single operation
AUTO	BOOLEAN	Auto/Manual indication
MASTER	BOOLEAN	Master indication
TAP_DIFF	BOOLEAN	Tap difference between follower and master
REV_REG	BOOLEAN	Reverse regulation

9.10.8 OL5ATCC Settings

Table 1582: OL5ATCC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
LDC limit	0.00...2.00	xUn	0.01	0.10	Maximum limit for line drop compensation term
Lower block tap	-36...36		1	0	Tap changer limit position which gives lowest voltage on the regulated side
Raise block tap	-36...36		1	17	Tap changer limit position which gives highest voltage on the regulated side
LDC enable	0=False 1=True			1=True	Selection for line drop compensation
Parallel mode	2=Master 3=Follower 5=NRP 7=MCC -1=Input control -2=Command			2=Master	Parallel mode selection
Band center voltage	0.000...2.000	xUn	0.001	1.000	Band center voltage Us
Line drop V Ris	0.0...25.0	%	0.1	0.0	Resistive line-drop compensation factor
Line drop V React	0.0...25.0	%	0.1	0.0	Reactive line-drop compensation factor
Band reduction	0.00...9.00	%Un	0.01	0.00	Step size for reduce set voltage (RSV)
Stability factor	0.0...70.0	%	0.1	0.0	Stability factor in parallel operation
Load phase angle	-89...89	deg	1	0	Load phase-shift, used only with the negative reactance principle
Control delay time 1	1000...300000	ms	100	60000	Control delay time for the first control pulse
Control delay time 2	1000...300000	ms	100	30000	Control delay time for the following control pulses

Table 1583: OL5ATCC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Rv Pwr flow allowed	0=False 1=True			0=False	Reverse power flow allowed

Table 1584: OL5ATCC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operation mode	1=Manual 2=Auto single			6=Command	The operation mode

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Parallel manual 4=Auto parallel 5=Input control 6=Command				
Custom Man blocking	1=Custom disabled 2=OC 3=UV 4=OC, UV 5=EXT 6=OC, EXT 7=UV, EXT 8=OC, UV, EXT			2=OC	Customized manual blocking
Parallel trafos	0...10		1	0	Number of parallel transformers in addition to own transformer
Delay characteristic	0=Inverse time 1=Definite time			1=Definite time	Selection of delay characteristic
Band width voltage	1.00...18.00	%Un	0.01	3.00	Allowed deviation of the control voltage
Load current limit	0.10...5.00	xIn	0.01	2.00	Load current blocking limit
Block lower voltage	0.10...1.20	xUn	0.01	0.70	Voltage limit, where further voltage lowering commands are blocked
Runback raise V	0.80...2.40	xUn	0.01	1.25	Voltage limit, where fast lower commands takes place
Cir current limit	0.10...5.00	xIn	0.01	0.15	Blocking limit for high circulating current
LTC pulse time	500...10000	ms	100	1500	Output pulse duration, common for raise and lower pulses
Regulation mode	1=Forward 2=Bi-dir(meas) 3=Bi-dir(calc) 4=Auto select			1=Forward	Regulation mode

Table 1585: OL5ATCC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Max operations in 1h	0...10000		1	100	Allowed number of controls per one hour sliding window
Cmd error delay time	10...50	s	1	20	Time delay before command error will be activated
Follower delay time	6...20	s	1	6	Time delay between successive follower commands by a master
Alarms enabled	0=False 1=True			1=True	Alarm selection

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Inst out of step Cor	0=False 1=True			0=False	Enable instant out of step correction in M/F mode
Step of tap	0.60...9.00	%	0.01	1.50	The percentage change in voltage corresponding one step of the tap changer
Tap nominal	-36...36		1	8	The nominal position of the tap changer resulting the default transformation ratio of the transformer (as if there was no tap changer)
Impedance voltage	0.00...100.00	%	0.01	5.00	The percentage impedance voltage at rated current referred to MV side

9.10.9 OL5ATCC Monitored data

Table 1586: OL5ATCC Monitored data

Name	Type	Values (Range)	Unit	Description
U_MEAS	FLOAT32	0.00...5.00	xUn	Phase-to-phase voltage, average filtered
ANGL_UA_IA	FLOAT32	-180...180	deg	Measured angle value between phase A voltage and current
TIMER_STS	Enum	0=Timer off 1=Lower timer1 on 2=Raise timer1 on 3=Lower timer2 on 4=Raise timer2 on 5=Fast lower T on		Timer T1, T2 or fast lower timer active
OPR_MODE_STS	Enum	0=Not in use 1=Manual 2=Auto single 3=Parallel manual 4=Auto master 5=Auto follower 6=MCC 7=NRP		The acting operation mode of the function block
U_CTL	FLOAT32	0.000...3.000	xUn	Control voltage, Up, target voltage level
UD_CTL	FLOAT32	-2.000...2.000	xUn	Voltage difference between Measured voltage - Control Voltage: Um - Up
I_CIR	FLOAT32	-10.00...10.00	xIn	Calculated circulating current - calculated in operation modes NRP and MCC
LDC	FLOAT32	-2.00...2.00	xUn	Calculated line drop compensation

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
BLK_STATUS	INT32	0...127		Bit-coded output showing the blocking status for the next operation
ALARM_REAS	Enum	0=No alarm 1=Cmd error 2=TCO error 3=Cmd + TCO err 4=Pump error 5=Pump + cmd err 6=Pump + TCO err 7=Pmp+TCO+cmd err		Status and reason for alarm
OP_TM_NUM_H	INT32	0...2147483647		Number of controls for own tap changer during last hour
FAIL_FLLW	Enum	0=No failed followers 1=T1 2=T2 3=T1+T2 4=T3 5=T1+T3 6=T2+T3 7=T1+T2+T3 8=T4 9=T1+T4 10=T2+T4 11=T1+T2+T4 12=T3+T4 13=T1+T3+T4 14=T2+T3+T4 15=T1+T2+T3+T4 16=T5 17=T1+T5 18=T2+T5 19=T1+T2+T5 20=T3+T5 21=T1+T3+T5 22=T2+T3+T5 23=T1+T2+T3+T5 24=T4+T5 25=T1+T4+T5 26=T2+T4+T5 27=T1+T2+T4+T5 28=T3+T4+T5 29=T1+T3+T4+T5 30=T2+T3+T4+T5 31=T1+T2+T3+T4+T5		Failed followers
PAR_UNIT_MCC	Enum	0=No parallel units 1=T1 2=T2 3=T1+T2		Parallel units included in MCC calculation

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		4=T3 5=T1+T3 6=T2+T3 7=T1+T2+T3 8=T4 9=T1+T4 10=T2+T4 11=T1+T2+T4 12=T3+T4 13=T1+T3+T4 14=T2+T3+T4 15=T1+T2+T3+T4 16=T5 17=T1+T5 18=T2+T5 19=T1+T2+T5 20=T3+T5 21=T1+T3+T5 22=T2+T3+T5 23=T1+T2+T3+T5 24=T4+T5 25=T1+T4+T5 26=T2+T4+T5 27=T1+T2+T4+T5 28=T3+T4+T5 29=T1+T3+T4+T5 30=T2+T3+T4+T5 31=T1+T2+T3+T4+T5		
OPR_CNT	INT32	0...2147483647		Total number of raise and lower commands given in the manual and automatic modes
TR0_I_AMPL	FLOAT32	0.00...15000.00	A	Transmitted current magnitude
TR0_I_ANGL	FLOAT32	-180.00...180.00	deg	Transmitted current angle
TR_STATUS	Enum	0=Independent 1=Master 2=Follower		Transformer status information
OL5ATCC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.10.10 Technical data

Table 1587: OL5ATCC Technical data

Characteristic	Value
Operation accuracy [1]	Depending on the frequency of the measured current: f_n ±2 Hz
	Differential voltage U_d = ±0.5% of the measured value or ±0.005 × U_n (in measured voltages <2.0 × U_n) Operation value = ±1.5 % of the U_d for Us = 1.0 × U_n
Operate time accuracy in definite time mode [2]	+4.0 %/-0 % of the set value
Operate time accuracy in inverse time mode [2]	+8.5 %/-0 % of the set value (at theoretical B in range of 1.1…5.0) Also note fixed minimum operate time (IDMT) 1 s.
Reset ratio for control operation	Typically 0.80 (1.20)
Reset ratio for analog based blockings (except run back raise voltage blocking)	Typically 0.96 (1.04)

9.10.11 Technical revision history

Table 1588: OL5ATCC Technical revision history

Product connectivity level	Technical revision	Change
PCL2	B	Added new output `TAP_DIFF` for indicating the difference in tap position between master and follower Changed the *Band width voltage* minimum value to "1.00" Added setting *Inst out of step Cor* for enabling triggering of instant out-of-step sequence in M/F mode
PCL4	C	Added new inputs I3P2, U3P2, PWR_DIR. Added new output REV_REG. Added new settings *Regulation mode*, *Step of Tap*, *Tap nominal* and *Impedance voltage*. Updated the implementation to handle HV side regulation during reverse power flow from stronger sources.

[1] Default setting values used.
[2] Voltage before deviation = set *Band center voltage*.

9.11 Petersen coil controller PASANCR (ANSI 90)

9.11.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Petersen coil controller	PASANCR	ANCR	90

9.11.2 Function block

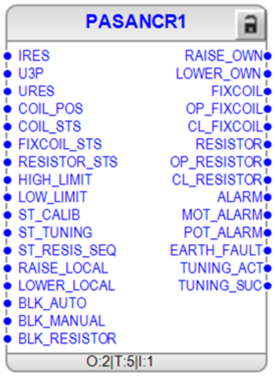


Figure 921: Function block

9.11.3 Functionality

The Petersen coil controller function PASANCR is a numerical automatic controller for the stepless adjustment of the arc suppression coil (ASC or Petersen coil) and the control of the parallel resistor of the coil. It can be applied to compensated networks for arc suppression coils with or without parallel resistor to increase the resistive earth-fault current. The controller can also manage an additional parallel fixed coil control.

PASANCR is intended for controlling arc suppression coils in networks with natural ground capacitance asymmetry, for example, mixed overhead line and cable networks. The main features of the function are:

- Operation based on forced change in zero-sequence voltage
- Arc suppression coil tuning to the desired position
- Network parameter calculation and displaying of the resonance curve and the fault current estimate curve of the network
- Control of the parallel resistor
- Clear numerical value of the resonance point steady-state zero-sequence voltage, for example, for earth-fault protection purposes

9.11.4 Analog channel configuration

PASANCR has three analog group inputs which must be properly configured.

Table 1589: Analog inputs

Input	Description
U3P	Three-phase voltages
IRES [1]	Residual current (measured or calculated)
URES	Residual voltage (measured)

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

9.11.5 Controller connections

Voltages

PASANCR supports zero-sequence voltage measurement from busbar or from coil. Busbar measurement is, for example, an open-delta connection of phase-to-earth voltage transformers. Coil measurement uses the coil's own secondary measurement winding. *Voltage measurement setting* is used to select the active measurement. Available options are "Busbar" and "Coil".

Phase-to-phase voltage AB must be connected to the controller. If only the phase voltages are measured, the voltage U_AB is calculated internally in the protection relay.

Coil position

The controller supports two possibilities for the coil position measurement. *Position Meas mode* setting is used to select the active coil position measurement. Available options are:

- "Pos. indication": Using only the RTD input module to measure the resistance value from the arc suppression coil potentiometer with `COIL_POS` input and to convert it into corresponding coil position according to the linearization table.
- "Pos. ind. and meas.": Using both `COIL_POS` and `IRES` signals. `IRES` is arc suppression coil current measurement using conventional CTs or sensors. Special attention should be paid to the accuracy of the current signals at low amplitudes. Additionally, high accuracy can be ensured by applying measurement class CTs and sensors. Accurate current measurement improves controller speed and

[1] The possible connection options are measured IRES from the coil/main transformer neutral point, calculated IRES from the phase CTs of earthing transformer, or GRPOFF. If GRPOFF is connected to IRES, the *Position Meas mode* is restricted to "Pos. indication" only.

accuracy. The recommendation for the CT is a primary current equivalent to the coil's maximum current and accuracy class 0.5S or better. The IRES signal is not sufficient for the controller as it does not allow manual control of the coil if it is disconnected from the network.

All voltage and current signals are measured using the value of the filtered fundamental frequency component (DFT). Hence, the harmonics are always suppressed.

Status information

The connection status (COIL_STS) information from the adjustable arc suppression coil disconnector or circuit breaker should be wired to the controller. Also, fixed parallel coil status (FIXCOIL_STS) and the parallel resistor status (RESISTOR_STS) should be wired to the controller if they are present in the system. Inactive status information signal means that the device is not connected and active status information signal means that the device is connected.

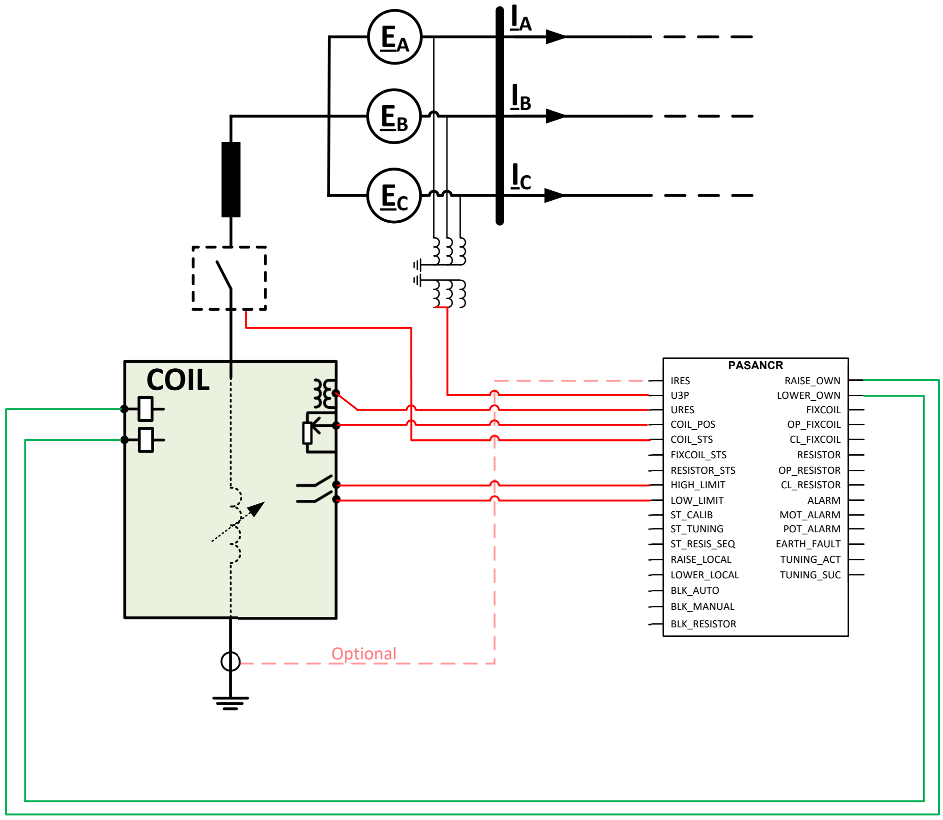
Outputs

The following outputs should be considered in order to ensure correct operation of the controller if a fixed parallel coil or parallel resistor is installed in the network:

- FIXCOIL, OP_FIXCOIL and CL_FIXCOIL: Status signal and corresponding open and close command signals, with 100 ms fixed pulse length for controlling the circuit breaker or disconnector of the fixed parallel coil. These signals are applied if a fixed parallel coil is installed in the system.
- RESISTOR, OP_RESISTOR and CL_RESISTOR: Status signal and corresponding open and close command signals, with 100 ms fixed pulse length for controlling the contactor, circuit breaker or disconnector of the parallel resistor. These signals are applied if a parallel resistor is installed in the system.

An example configuration of the connections is shown in *Figure 922*. Controller inputs are indicated with red lines and outputs with green lines. This example shows a simple, one-controller setup without the parallel resistor of the coil.

Figure 922: Example configuration of the controller connections



9.11.6 Operation principle

The *Operation* setting is used to enable or disable the function. The corresponding parameter values are "on" and "off".

The operation of PASANCR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

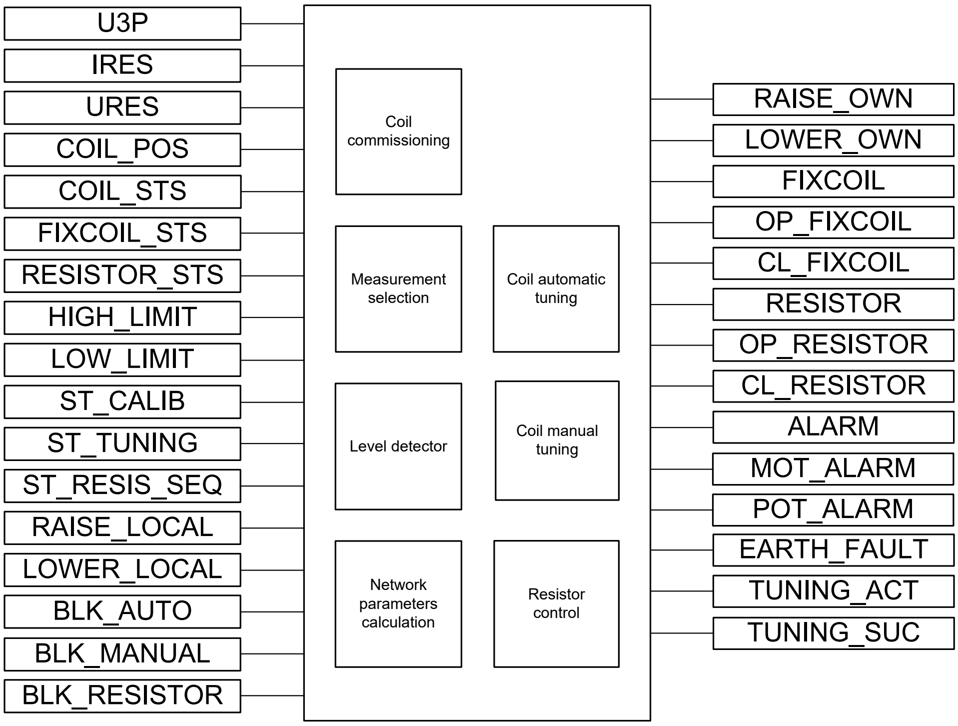


Figure 923: Functional module diagram

9.11.6.1 Measurement selection

PASANCR supports two possibilities for zero-sequence voltage and coil position measurement.

Voltage measurement setting is used to define the location of voltage measurement: from busbar or from coil. Busbar measurement is usually an open-delta connection of phase-to-earth voltage transformers. Coil measurement is available from the arc suppression coil's measurement winding.

Position Meas mode setting is used to select the measurement between coil position indication and coil position indication with a CT or sensor. "Pos. indication" option uses the potentiometer-based `COIL_POS` information only. If "Pos. ind. and meas." option is selected, the measured `IRES` is used for the control algorithm. In this case, the `COIL_POS` signal works as a backup and is switched automatically into use if the coil is disconnected from the network.

9.11.6.2 Level detector

Level detector op setting is used to enable or disable the Level detector module. "Enable" means that the Level detector module is enabled and can be used to start the tuning procedure.

When "Disable" is selected, the automatic coil tuning procedure can be started with input `ST_TUNING`.

Level detector's main task is to release the coil automatic tuning procedure in case of network switching operation. After every successful tuning procedure, the measured zero-sequence voltage is stored as a new reference voltage U_{ref}. Also, the calculated network admittances are stored as new reference admittances Y_{symm_ref} and Y_{asymm_ref} (for more information, see *Chapter 9.11.6.3 Network parameter calculation*).

If the change in the measured zero-sequence voltage exceeds the setting *V Res change level* with respect to U_{ref}, then a new coil tuning procedure is released. The measured zero-sequence voltage must exceed the threshold at least by the time defined with *Tuning delay* setting, otherwise the start of the tuning procedure is canceled.

Zero-sequence voltage change can be determined considering the voltage amplitude only or a phasor value. Setting *V Res Meas mode* is used to select between these two modes. The available options are "Amplitude" and "Phasor". The phasor triggering mode is explained in *Figure 924*. Monitored data output TUNING_TRIGG indicates the relation between present zero-sequence voltage and the reference voltage. When TUNING_TRIGG value is below 100%, the controller is at stand-by. When TUNING_TRIGG value is above 100%, that is, Uo vector in *Figure 924* enters the red area, the tuning delay is started.

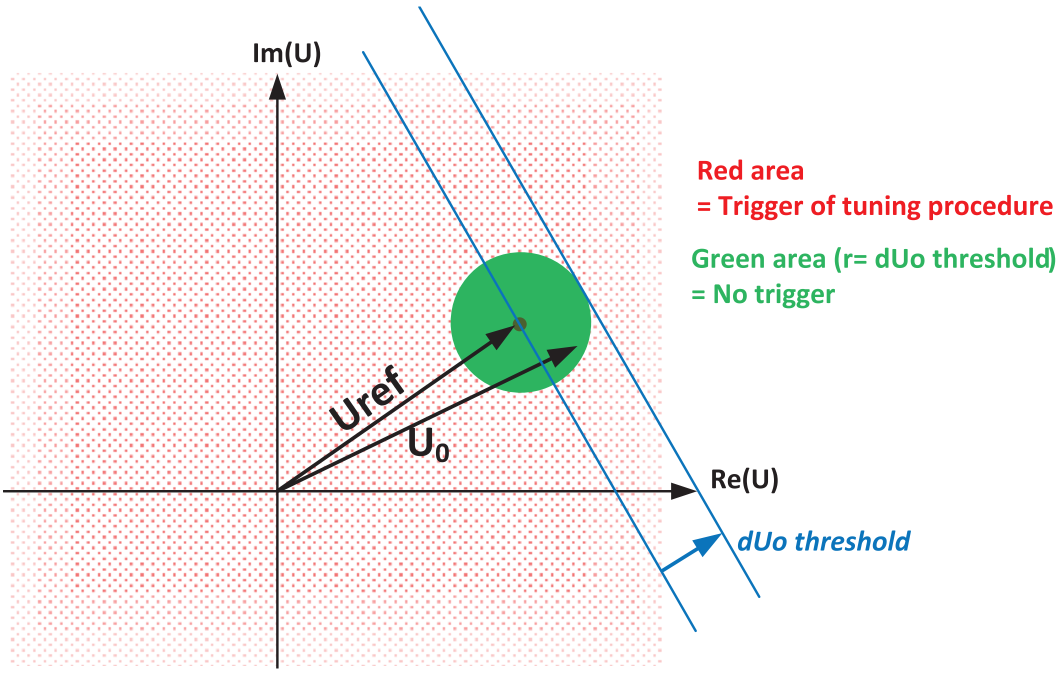


Figure 924: Phasor triggering mode

Level detector also includes a threshold-based earth-fault detection functionality. The detection is based on *V Res EF level* voltage threshold setting. If the measured zero-sequence voltage exceeds the threshold at least by the time defined in *Transient time EF* setting, the earth fault is indicated by activating the `EARTH_FAULT` output and the controller proceeds as described in *Chapter 9.11.6.4.1 Operation during earth faults*.

The delay defined in *Tuning delay* can be bypassed by activating `ST_TUNING` input, for example, via HMI application. When the rising edge of the signal is detected, the controller skips the tuning delay and proceeds immediately with the coil automatic tuning procedure. The automatic tuning procedure can be started with `ST_TUNING` input even without the zero-sequence voltage trigger. The automatic tuning procedure is also released when the *Controller mode* is switched from "Manual" to "Automatic".

PASANCR has an adaptive U_{ref} feature. The *V Ref adaptive mode* setting is used to enable or disable the functionality. The functionality allows slow changes in measured zero-sequence voltage and therefore reduces unnecessary tuning operations. If the measured zero-sequence voltage does not exceed the *V Res change level* setting during the time defined in *V Ref adaptive delay* setting, the existing measured zero-sequence voltage is stored as a new reference voltage U_{ref} at the end of the adaptive period. The operation principle of the adaptive U_{ref} feature is explained in *Figure 925*.

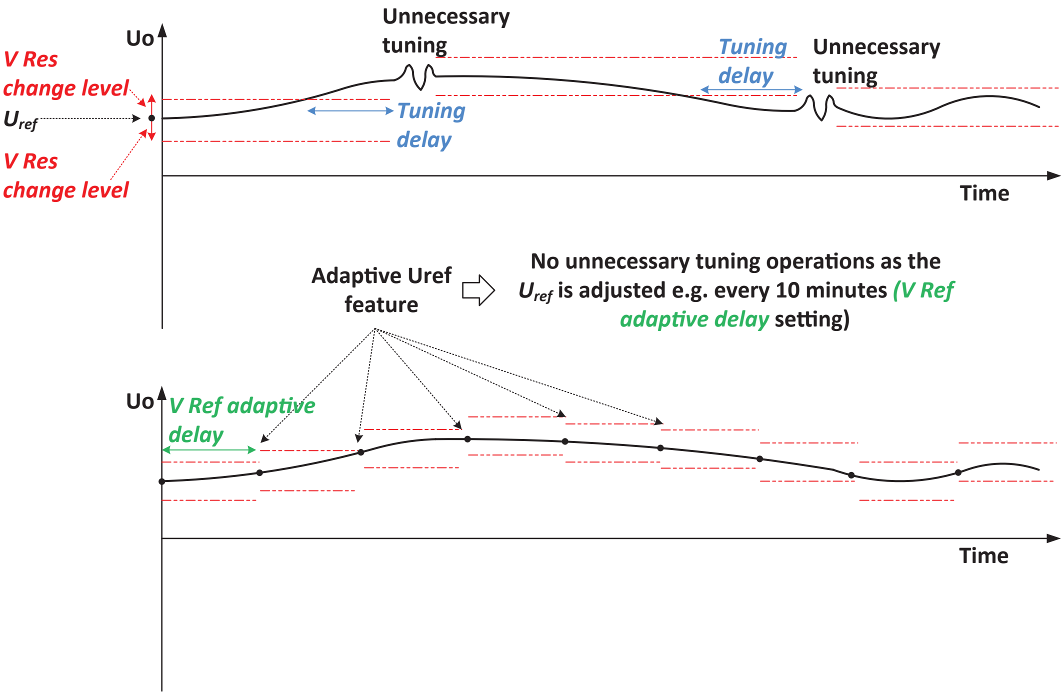


Figure 925: Example of Uo fluctuation with and without adaptive Uref feature (amplitude triggering mode)

9.11.6.3 Network parameter calculation

To explain the controller, the simplified equivalent circuit of a three-phase distribution network illustrated in *Figure 926* is used. The controller assumes that:

- The real network is presented with its shunt admittances neglecting line series impedances as their values are very small compared with the shunt admittances.
- The individual phase admittances of the network are presented with symmetrical phase admittances whose sum equals

$$\underline{Y}_{symm} = G_{symm} + j \cdot B_{symm}$$

(Equation 386)

  (one third connected in each phase)
- The natural asymmetry in a real network is due to differences in individual phase admittances and it is presented with an asymmetry admittance concentrated into phase A and presented with admittance

$$\underline{Y}_{asymm} = G_{asymm} + j \cdot B_{asymm}$$

(Equation 387)

(only connected in phase A)

- The single-phase earth fault in the network is presented with admittance $\underline{Y}_f = G_f + j \cdot B_f$. Fault impedance can be assumed to be purely resistive (fault resistance R_f) which is connected between phase A, B or C and earth depending on the faulted phase.
- The zero-sequence impedance of the earthing (or main) transformer with the neutral point connected to the coil is represented with impedance $\underline{Z}_{oTr}$ (in the three-phase equivalent scheme one third must be applied).

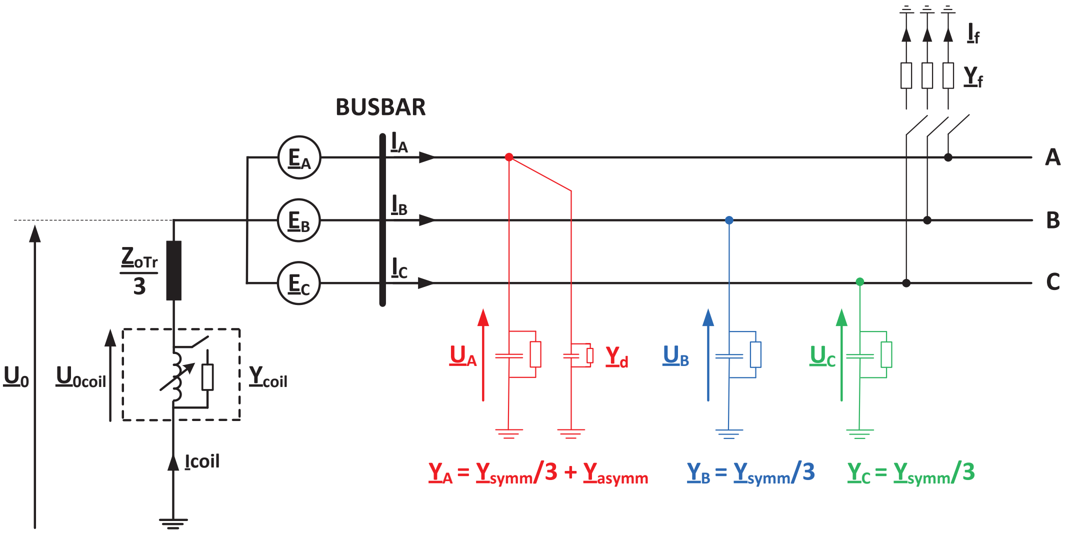


Figure 926: Simplified three-phase equivalent circuit of a compensated distribution network

$\underline{E}_A$	Phase A to earth voltage of the source
$\underline{E}_B$	Phase B to earth voltage of the source
$\underline{E}_C$	Phase C to earth voltage of the source
$\underline{U}_A$	Phase A to earth voltage at busbar (= $\underline{E}_A + \underline{U}_o$)
$\underline{U}_B$	Phase B to earth voltage at busbar (= $\underline{E}_B + \underline{U}_o$)
$\underline{U}_C$	Phase C to earth voltage at busbar (= $\underline{E}_C + \underline{U}_o$)
$\underline{U}_0$	Zero-sequence voltage = $(\underline{U}_A + \underline{U}_B + \underline{U}_C)/3$
$\underline{U}_{0coil}$	Zero-sequence voltage measured at coil
$\underline{I}_A$	Phase A current at the source
$\underline{I}_B$	Phase B current at the source
$\underline{I}_C$	Phase C current at the source
$\underline{I}_{coil}$	Current through the central compensation coil
$\underline{Y}_A$	Phase A to earth admittance of the network
$\underline{Y}_B$	Phase B to earth admittance of the network
$\underline{Y}_C$	Phase C to earth admittance of the network
$\underline{Y}_{coil}$	Admittance of central compensation coil including the parallel resistor
$\underline{Z}_{oTr}$	Zero-sequence impedance of the earthing transformer or the main transformer through which the coil is connected to the network. Settings *R0Transformer*

and *X0Transformer* are used to input the zero-sequence impedance of the earthing / main transformer. If the settings are applied, the controller can consider the transformer when calculating network parameters.

Using this network model, the controller determines network parameters G_{symm}, B_{symm}, G_{asymm}, B_{asymm}, G_{coil} and B_{coil}.

G_{symm}	Real part of symmetrical part of the total network admittance. The sign is positive and it represents the shunt losses of the network (excluding the losses of the central coil and the parallel resistor). If there are distributed compensation coils in the network, their shunt losses are included in this value.
B_{symm}	Imaginary part of symmetrical part of the total network admittance. The sign is positive (capacitive) and it represents the capacitive uncompensated earth-fault current of the network. If there are distributed compensation coils in the network, their effect is included in this value.
G_{asymm}	Real part of asymmetry admittance. The sign may be positive or negative depending on the actual level of asymmetry.
B_{asymm}	Imaginary part of asymmetry admittance. The sign may be positive or negative depending on the actual level of asymmetry.
G_{coil}	Real part of the coil admittance. The sign is positive and it represents the resistive losses of the central coil including the parallel resistor.
B_{coil}	Imaginary part of the coil admittance. The sign is negative and it represents the inductive current of the central coil, which defines the compensation degree of the network.

All previous admittance terms can be easily converted into equivalent current values by multiplying them by the system nominal phase-to-earth voltage U_n.

$I_{ef\_network} = (B_{symm} + B_{asymm}) \cdot U_n$	Uncompensated earth-fault current
$I_{loss\_network} = (G_{symm} + G_{asymm}) \cdot U_n$	Network shunt losses
$I_{coil} = B_{coil} \cdot U_n$	Coil inductive current
$I_{loss\_coil} = G_{coil} \cdot U_n$	Coil loss current

Network parameter calculation is based on the forced change in network zero-sequence voltage. This is achieved by changing the coil position or by changing the connection state of the parallel resistor of the coil. All the Monitored data values expressed in Amperes are scaled with reference to U_0 primary voltage.

9.11.6.4 Coil automatic tuning

Coil automatic tuning mode is enabled with setting *Controller mode* = "Automatic". In this mode, the `TUNING_ACT` binary output is activated. The coil automatic tuning procedure consists of two parts. First, sufficient zero-sequence voltage variation is obtained using coil movement or resistor switching. Secondly, network parameters are calculated.

The automatic tuning procedure requires a sufficient change to be detected in the measured zero-sequence voltage. This can be achieved by coil movement or switching the parallel resistor of the coil. The mode is selected with *Tuning mode* setting. The available options are "Coil movement" and "Resistor switching".

In the coil movement mode, the controller first moves the coil a little towards the coil's default position and determines the direction of raising Uo voltage. Then the controller moves the coil preferably to the direction of raising zero-sequence voltage until the measured zero-sequence voltage is changed by the amount defined with *V Res variation* setting. *V Res maximum* setting defines the maximum zero-sequence voltage that the controller does not exceed when obtaining the required Uo variation. If the zero-sequence voltage reaches the value defined in *V Res maximum* setting, the controller seeks the required Uo variation from the direction of decreasing zero-sequence voltage.

The measured zero-sequence voltage level must exceed setting *V Res minimum* during the whole tuning process. If the measured zero-sequence voltage is initially below the *V Res minimum* setting, the controller extends the search range in order to achieve this minimum level. If the minimum required level of zero-sequence voltage cannot be reached, the controller cancels the tuning. If the required zero-sequence voltage variation cannot be reached, the controller moves the coil to *Error position*.

The most accurate tuning is possible when *Pass resonance* setting is enabled: the controller moves the coil over the network resonance point and collects additional measurement points resulting in the most accurate estimate of the network parameters. Particularly passing the resonance point improves the estimate of network losses. Setting *V Res maximum* can deny the resonance point passing functionality.

V Res EF level setting should be set to a higher value than *V Res maximum*.

If the coil is equipped with a parallel resistor, the resistor switching mode offers a fast alternative to obtain the change in measured zero-sequence voltage. In the resistor switching mode, the controller changes the connection status of the parallel resistor for three seconds and then switches the resistor back to its original position. If the change in the measured zero-sequence voltage exceeds the *V Res variation* setting, the controller can proceed immediately to network parameters calculation. If the change defined in *V Res variation* setting cannot be obtained using resistor switching, the controller automatically uses the coil movement method.

In the case of resistor switching, the setting *V Res maximum* is ineffective.

After sufficient change in the measured zero-sequence voltage is obtained using coil movement or resistor switching, the controller calculates new network parameters and compares them to the reference values. If the network’s capacitive earth-fault current has changed, the controller moves the coil to maintain the set compensation level. The active compensation mode is selected with *Compensation mode* setting. The available options are "Absolute" (tuning level selected with *Detuning level* setting) and "Relative" (tuning level selected with *Detuning level Rl* setting). The controller monitors the actual coil current while moving it to the desired tuning position. Taking into account the after-running of the coil motor, it is stopped just before reaching the desired tuning point. If the zero-sequence voltage reaches the voltage level set with *V Res maximum* setting, the controller stops the coil movement.

If the parallel resistor is installed in the system (setting *Parallel resistor* = "True"), PASANCR includes a feature to temporarily connect the parallel resistor into the system while moving the coil to the desired tuning position if the resistor is initially disconnected. The temporary connection of the parallel resistor should lower the zero-sequence voltage and therefore the movement of the coil to the desired tuning position could be possible. The feature can be enabled with *Temporary damping* setting. The available options are "True" and "False".

An example of the feature is shown in *Figure 927* where the initial coil position is at 60 A, the parallel resistor is disconnected and the target position is at 110 A. Before the controller starts moving the coil, it estimates if the zero-sequence voltage at target position is below the *V Res maximum* setting and if the movement is allowed. If the conditions allow, the controller starts moving the coil towards the higher current. While the movement stops at *V Res maximum* (set to 3.5 percent of the system's nominal phase-to-earth voltage in this example), the controller automatically connects the parallel resistor and moves the coil to the desired inductive current position (that is, 110 A). After the coil has reached the target position, the controller automatically disconnects the resistor, that is, returns it to its original connection state while simultaneously obtaining the target position of 110 A with the parallel resistor disconnected.

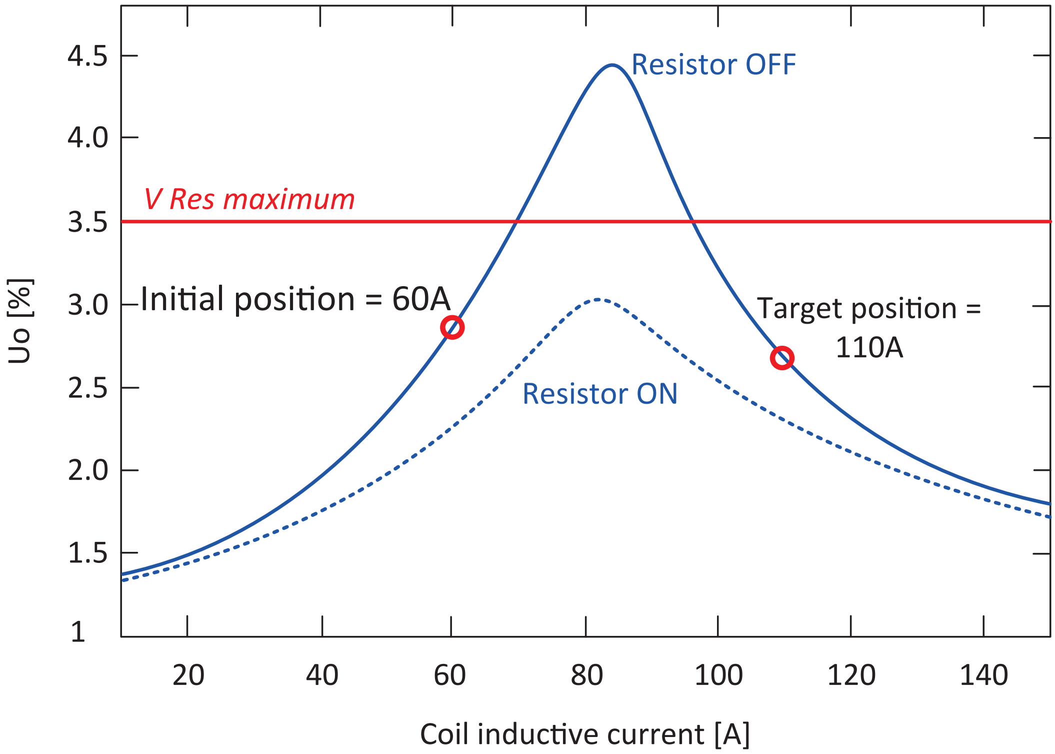


Figure 927: Damping of the resonance curve by using the parallel resistor

The number of maximum tuning cycles can be limited with *Tuning cycles* setting. The delay between consecutive tuning cycles is controllable by setting *Tuning cycles delay*. After the maximum number of tuning cycles is reached, the tuning procedure can be started by activating the `ST_TUNING` input, for example, via HMI application. The counter for maximum tuning cycles is reset after a successful tuning operation.

The `ALARM` output is a general problem indication during the tuning process. Usually, it is an indication of not obtaining a required minimum level or change of zero-sequence voltage during the coil movement. The reason for this might be, for example, a very symmetrical network. Other reasons for the `ALARM` indication are coil movement into wrong direction, maximum number of tuning sequences exceeded or simultaneous indication from both end switches of the coil. There is a dedicated `MOT_ALARM` output indicating no detected coil movement after activating `RAISE_OWN` or `LOWER_OWN` outputs.

After `ALARM` indication with ALARM_STS “Umin not reached” or “Cannot obtain minimum Uo variation” the coil is moved to a position which is defined with *Error* *position* setting. The same procedure is executed after CLC_SEQ_WRN indication. The options are to move the coil to the position from where the tuning procedure was started, leave it to its present position or to move the coil to the default position which is settable by the user.

The active tuning range of the arc suppression coil can be limited with *Minimum current* and *Maximum current* settings. Once the operating limits are activated, the controller does not leave the selected range during the tuning procedure. If the operating limits are applied, the limited range of the coil is indicated on the HMI resonance curve view.

Operation during earth faults

The controller supports three modes for operation during earth fault. The active mode can be selected with *EF mode* setting. The available modes are "Blocked during EF", "Resonance" and "Tuning during EF".

- Blocked during EF: No coil movement when the earth fault is detected.
- Resonance: Coil is moved to the resonance point which is determined during the healthy-state operation of the network.
- Tuning during EF: The controller determines the network parameters during a sustained earth fault and maintains the set compensation level. The controller can also detect network switching operations and tune the ASC correspondingly (for example, disconnecting feeders to isolate the earth fault). Tuning during EF can be performed when the measured zero-sequence voltage is below 80 percent of the system's nominal phase-to-earth voltage. If the measured zero-sequence voltage is over 80 percent of the system's nominal phase-to-earth voltage, the “Blocked during EF” mode is automatically switched into use.

Fixed parallel coil control

PASANCR supports the control of the fixed parallel coil. The ampere value and the nominal voltage of the coil can be set with *Fix coil value* and *Fix coil V Nom* settings. The treatment of the fixed parallel coil is selected with *Fix coil type* setting. By applying “OFF” or “ON”, the controller cannot automatically switch the connection status of the fixed parallel coil. If “Automatic” is selected, the controller can change the connection status of the fixed parallel coil to reach the desired compensation level. During the automatic operation, the controller tunes the adjustable ASC first. If the desired compensation level cannot be reached, the fixed parallel coil can be switched on or off. The presence of the fixed parallel coil in the system has effect on correct tuning when the compensation mode is relative.

Absolute detuning current can be calculated:

$$I_v = I_{coil} + I_{fix} - I_{reson}$$

(Equation 388)

The corresponding relative detuning is calculated as:

$$v = \frac{I_{coil} + I_{fix} - I_{reson}}{I_{reson}} \cdot 100\%$$

(Equation 389)

I_{coil}	Current of the adjustable ASC
I_{fix}	Value of the fixed parallel coil
I_{reson}	Current at resonance point

If a fixed parallel coil is introduced in the network (“ON” or “Automatic”), the x axis title of the resonance curve displayed on the HMI can be selected with the *Resonance curve Cur* setting. Available options are:

- Icoil: Only the current of adjustable ASC
- Icoil + Ifix: Total current of adjustable ASC and fixed parallel coil

Statistics

The controller supports displaying resettable statistics. The statistics can be reset via settings menu using *Clear counters* command.

Table 1590: Displayed statistics

Type	Statistics	Description
General	Operation time	Controller time in operation
	Tuning procedures	Number of started tuning procedures
	Tuned	Number of successful tuning operations
	Canceled tunings	Number of the canceled tuning procedures, that is, *Tuning delay* has not elapsed
	Tuned at Uo max	Number of tuning cases when coil movement has stopped to *V Res maximum* position
	Tuned at low limit	Number of cases when coil final position is limited either by low end position indication of the coil or the limited operating range *Minimum current*
	Tuned at high limit	Number of cases when coil final position is limited either by high end position indication of the coil or the limited operating range *Maximum current*
Earth faults	Transient earth-faults	Number of transient earth faults (that is, fault time shorter than time defined in *Transient time EF* setting)
	Permanent earth-faults	Number of permanent earth faults (that is, fault time longer than time defined in *Transient time EF* setting)
Resistor control	Switch parallel resistor (auto)	Number of parallel resistor switch operations. For example, if the resistor is initially off, then it is switched on and after a defined delay, it is again switched off, this increases the counter by two.
	Switch parallel resistor (manual)	Number of manual switch operations for parallel resistor
Other	Motor running time	Sum time of `RAISE_OWN` and `LOWER_OWN` outputs activated

9.11.6.5 Coil manual tuning

PASANCR supports manual coil tuning when *Controller mode* setting is "Manual". Manual control is achieved by activating RAISE_LOCAL and LOWER_LOCAL inputs which activate the corresponding RAISE_OWN and LOWER_OWN outputs. The manual mode and the corresponding inputs can be activated, for example, via HMI application. Moreover, the manual control of the coil can be achieved via communication by using the *Coil Target Pos* setting. Once the setting is committed, the controller moves to the desired position. Also the activated operating limits can restrict the coil movement. The MOT_ALARM output is activated during manual control if the coil position is not changed due to activated RAISE_OWN and LOWER_OWN commands. The ALARM output is activated when the movement of the coil is in wrong direction or both end switches indicate simultaneously enabled signaling.

Coil manual movement is possible only after calibration.

During the manual control mode the network resonance curve is not updated automatically. The previous automatically detected resonance curve is displayed on the HMI view.

It is possible to manually control the connection status of the fixed parallel coil with *Fix coil type* setting by selecting "ON" or "OFF". The setting can be changed via the settings menu or HMI application.

9.11.6.6 Resistor control

Zero-sequence currents in compensated networks are usually very low, making it difficult to select the faulty line. To avoid sensitivity problems, the parallel resistor of the ASC is often used to increase the zero-sequence current allowing a simple earth-fault protection to locate the faulty line. PASANCR contains a functionality to switch the resistor on and off automatically or on user input.

First, the resistor installation status is set with *Parallel resistor* setting. The available options are "True" and "False". If the parallel resistor is installed in the system, the value is selected with *Resistor Nom value* setting. Second, the nominal voltage level of the power auxiliary winding is selected with *Auxiliary Wnd V Nom* setting.

The *Resistor control* setting is used to enable the automatic control sequence or to connect or disconnect the resistor. The automatic control sequence is released if the functionality is enabled (*Resistor control* = "Automatic") and the EARTH_FAULT output is active. The resistor control sequence after the earth-fault indication depends on the resistor connection status during the healthy state. The healthy-state status is selected with the *Resistor healthy St* setting. The available options are "On" and "Off". The settings affecting the control sequence are explained in Figure 928.

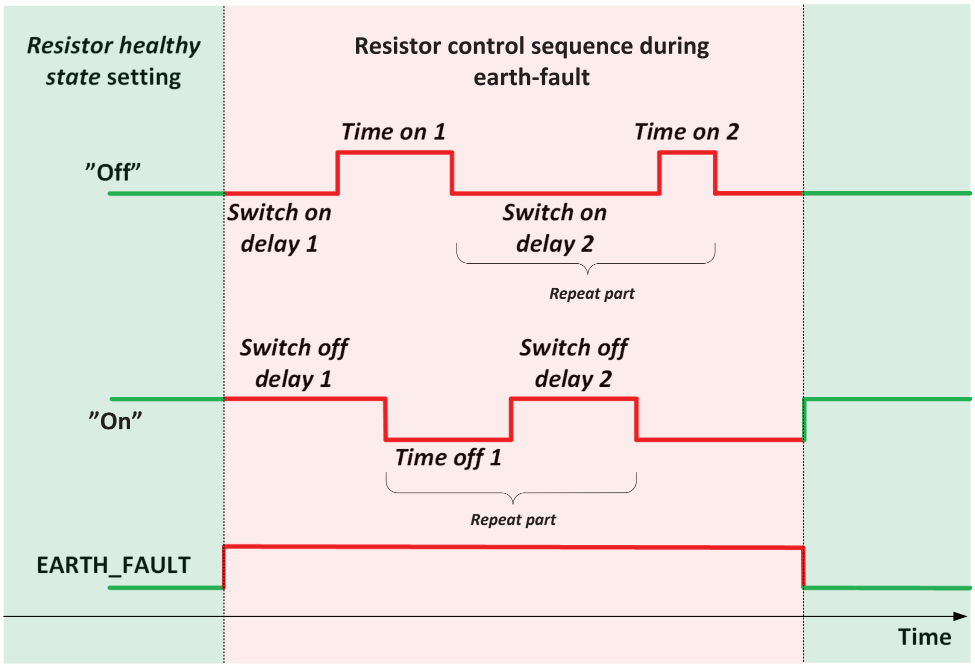


Figure 928: Resistor control sequence

When the earth-fault indication becomes inactive, any active single sequence or repeat sequence is cancelled, and the resistor is switched back to its initial state.

The resistor control sequence contains a repeat part which can be repeated after the whole sequence is executed once. The number of repetitions can be selected with *Resistor repeats* setting. Additionally, the pause between the consecutive repeats can be selected with *Resistor pause* setting. If the resistor status is the opposite to the *Resistor healthy state* when the earth-fault recovers, the resistor is restored to healthy state at latest after one second from the last resistor change. If the resistor already is in its healthy state when the earth-fault recovers, the status remains.

It is also possible to manually trigger the resistor control sequence with `ST_RESIS_SEQ` binary input.

9.11.6.7 Blocking

The `BLK_AUTO` input blocks the automatic operation of the function. PASANCR's automatic operation is blocked internally if the ASC is disconnected at the substation, that is, `COIL_STS` signal is low. The `BLK_MANUAL` input blocks the manual control of the coil. The `BLK_RESISTOR` input disconnects the parallel resistor and blocks its switching on, for example, due to resistor overheating.

9.11.7 Application

PASANCR is a numerical automatic controller for arc suppression coil (Petersen coil) and the parallel resistor. It can be applied to compensated networks where a switched parallel resistor is optionally connected in parallel with the arc-suppression coil. An efficient protecting method against earth faults occurring in a medium-voltage compensated network is the earth-fault compensation. It is carried out by inserting an inductive coil (arc suppression coil or Petersen coil) between the transformer's star point and the earth in order to compensate the zero-sequence capacitive current of the network. It increases the probability of the arc extinction in case of a temporary earth fault. The arc extinction coil is effective only if its value is tuned to the zero-sequence capacity of the network so they are in resonance state and as a consequence the earth-fault current is very low.

9.11.8 Commissioning

During the coil setup process, it is not yet needed to connect the ASC to the network. The coil setup consists of two parts:

- Calibration of coil
- Evaluation of coil linearity

The coil calibration procedure is started by activating `ST_CALIB` input which can be done via local HMI application. Before starting the procedure, it must be checked that coil end switches (`HIGH_LIMIT` and `LOW_LIMIT`) are connected to the controller. If end switches are not available, end positions are detected during the calibration process if there was no coil movement for more than 20 s.

First, in the coil calibration procedure the coil is moved automatically from the lower-end switch to the upper-end switch. In both locations, the corresponding potentiometer values are recorded for further use. Also, the coil movement speed is determined during the calibration procedure. Secondly, the coil is moved to its middle position and the after-running and mechanical play of the coil are determined. Finally, the potentiometer gaps are determined. All results from coil calibration (running speed, after running, mechanical play and potentiometer gap locations) are visible in the Monitored data view.

After the calibration, the coil linearity is evaluated. The automatic coil calibration determined the potentiometer ohmic end-switch values. These values are displayed on the HMI and can be entered into the linearization table. The corresponding coil position values (that is, inductive current of the coil) might be entered, for example, from the coil routine test report delivered by the coil manufacturer. The values are entered at coil nominal voltage level which is defined with *Coil V Nom* setting. Moreover, if the potentiometer/coil position relationship is nonlinear, additional eight interpolation points, or part of them, might be applied. This is done by entering the potentiometer and corresponding coil position values into the linearization table. Values which are left to default value of 0.0 are discarded from the actual linearization curve. Both end values of the linearization table are displayed on the HMI view of the resonance curve. An example of the linearization table is given in *Table 1591* and the corresponding linearization curve is plotted in *Figure 929*.

The values put in ascending order are automatically adjusted so they are in the neighboring positions of the array, irrespective of the position in the linearization table.

Table 1591: Example of a linearization table

Potentiometer value (setting Pot value x, x = 1...10)	Coil position (setting Coil current x, x = 1... 10)
100	10
150	20
200	30
250	37
300	43
350	48
400	53
450	57
600	68
1000	90

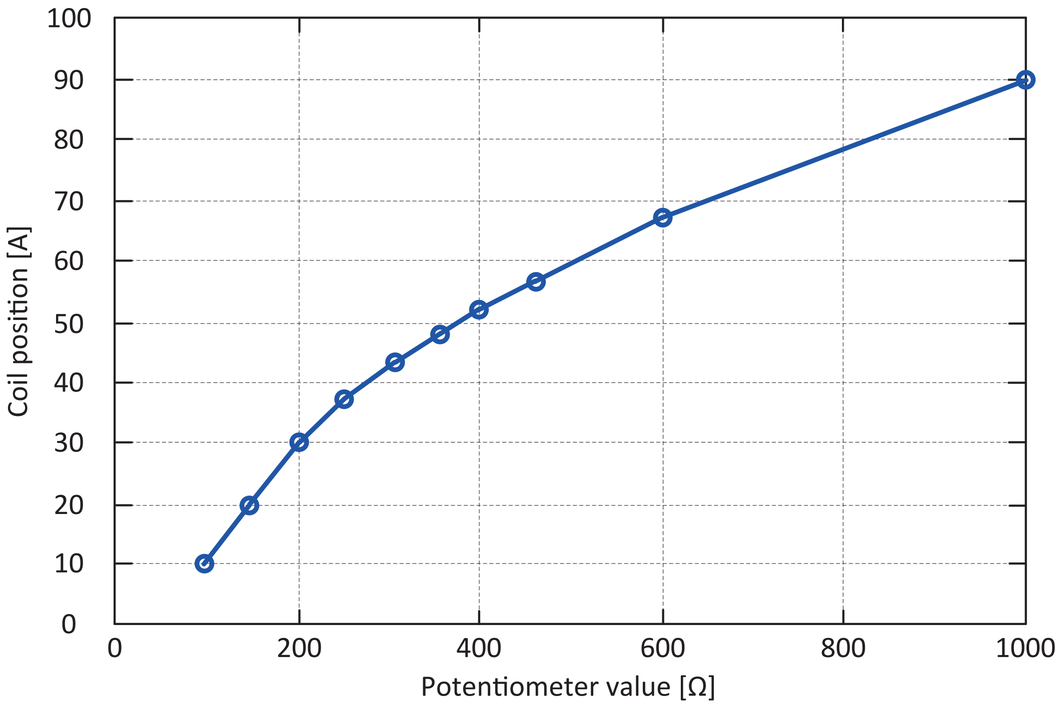


Figure 929: Example of a linearization curve

Aged ASCs can suffer from wearing of the position-indicating potentiometer. The potentiometer gaps are identified during the calibration and the number of the gaps is displayed on the HMI after the calibration. Actual gap locations GAP_LO_VAL_x and GAP_HI_VAL_x (x = 1...5, which corresponds to the gap identification number) are visible in the Monitored data view. If the maximum number of five gap locations is exceeded, the first pair is overwritten.

The coil position should be known and the controller operation should be guaranteed even if no new calibration is done. When potentiometer gaps are present in either both ends or in the middle of the potentiometer range, the potentiometer should be replaced. These are the three critical points of the calibration where ohmic measurements must be precise.

The maximum percentage length of the potentiometer gap can be set with setting *Pot Max gap*. The controller determines a gap length by measuring the distance between both ends of a gap in ohms. A gap is indicated when the ohmic position exceeds 2000 Ω.

If the coil potentiometer enters a gap during the normal operation, the controller estimates the coil position based on its previous known position and coil movement speed. If the actual gap length exceeds the setting *Pot Max gap* or a new gap appears during daily operation, POT_ALARM output is activated. Moreover, TUNING_STS monitored data indicates the reason of alarm. High values of the *Pot Max gap* setting introduce inaccuracy to the coil movement as the coil position is based on a calculated estimate. The purpose of the gap detection functionality is to enable the controller operation even if the potentiometer is worn out during the normal operation. The potentiometer should be replaced during the next service break in order to guarantee accurate operation of the controller. The gap detection functionality can be disabled by setting the *Pot Max gap* value to 0. Potentiometer gaps are illustrated in *Figure 930*.

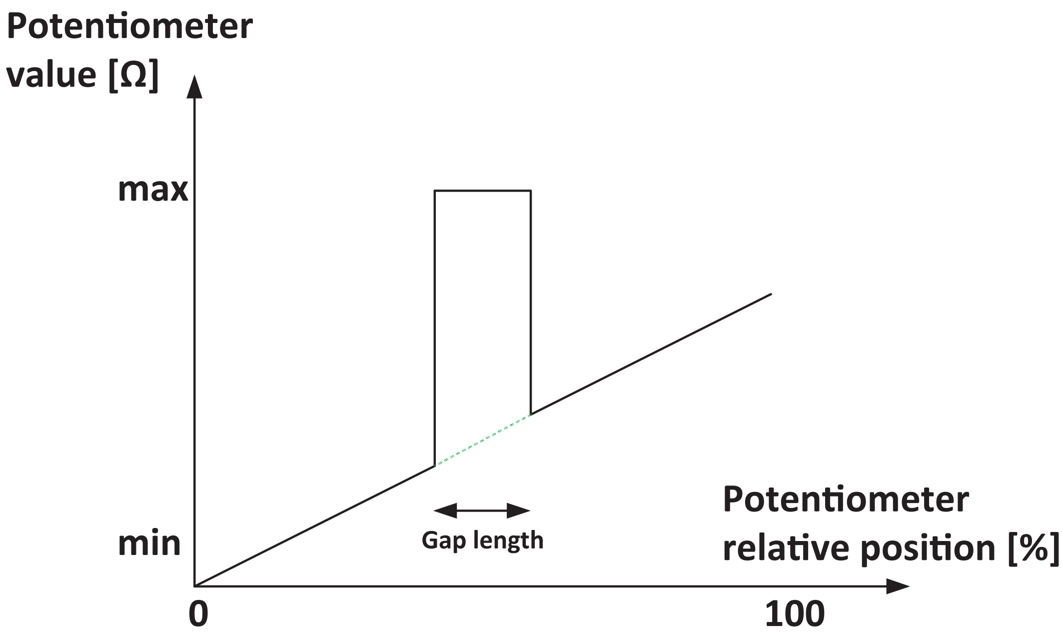


Figure 930: Potentiometer gaps

9.11.9 Signals

9.11.9.1 PASANCR Input signals

Table 1592: PASANCR Input signals

Name	Type	Default	Description
IRES	SIGNAL	-	Residual current
U3P	SIGNAL	-	Three-phase voltages
URES	SIGNAL	-	Residual voltage

Table continues on the next page

Name	Type	Default	Description
COIL_STS	BOOLEAN	0=False	Connection status of the variable arc suppression coil
FIXCOIL_STS	BOOLEAN	0=False	Connection status of the fixed coil
RESISTOR_STS	BOOLEAN	0=False	Connection status of the parallel current raising resistor
HIGH_LIMIT	BOOLEAN	0=False	High end position reached
LOW_LIMIT	BOOLEAN	0=False	Low end position reached
ST_CALIB	BOOLEAN	0=False	Rising edge of this signal triggers the calibration procedure of the coil
ST_TUNING	BOOLEAN	0=False	Rising edge of this signal triggers the automatic tuning procedure
ST_RESIS_SEQ	BOOLEAN	0=False	Rising edge of this signal triggers the resistor control sequence
RAISE_LOCAL	BOOLEAN	0=False	Increase arc suppression coil current
LOWER_LOCAL	BOOLEAN	0=False	Decrease arc suppression coil current
PARALLEL	BOOLEAN	0=False	Parallel controller has coil movement in progress
BLK_AUTO	BOOLEAN	0=False	Blocking the coil automatic tuning
BLK_MANUAL	BOOLEAN	0=False	Blocking the coil manual operation
BLK_RESISTOR	BOOLEAN	0=False	Disconnect and block switching on the parallel resistor
HIGH_LIMIT	BOOLEAN	0=False	High coil position
LOW_LIMIT	BOOLEAN	0=False	Low coil position

9.11.9.2 PASANCR Output signals

Table 1593: PASANCR Output signals

Name	Type	Description
RAISE_OWN	BOOLEAN	Increase coil current
LOWER_OWN	BOOLEAN	Decrease coil current
FIXCOIL	BOOLEAN	Status information to control fixed coil on/off
OP_FIXCOIL	BOOLEAN	Command to disconnect fix coil
CL_FIXCOIL	BOOLEAN	Command to connect fix coil
RESISTOR	BOOLEAN	Status information to control parallel current rising resistor on/off
OP_RESISTOR	BOOLEAN	Command to disconnect parallel current rising resistor
CL_RESISTOR	BOOLEAN	Command to connect parallel current rising resistor
ALARM	BOOLEAN	General alarm indication
MOT_ALARM	BOOLEAN	Motor alarm: no detected coil movement
POT_ALARM	BOOLEAN	Potentiometer alarm
EARTH_FAULT	BOOLEAN	Earth-fault indication
HIF	BOOLEAN	High impedance fault indication
TUNING_ACT	BOOLEAN	Automatic tuning procedure ongoing
TUNING_SUC	BOOLEAN	Tuning successful

9.11.10 PASANCR Settings

Table 1594: PASANCR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Compensation mode	1=Absolute 2=Relative			1=Absolute	Compensation degree in absolute amperes or relative to the resonance point
Detuning level	-100...100	A	1	0	Detuning level in amperes
Detuning level Rl	-100.0...100.0	%	0.1	0.0	Detuning level in percent
V Res change level	0.0...1000.0	%Uref	0.1	10.0	Zero-sequence voltage change threshold as percent of reference voltage
V Res Meas mode	1=Amplitude			2=Phasor	Uo trigger based on amplitude or

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Phasor				phasor measurement
Tuning delay	0...3600	s	1	60	Zero-sequence voltage trigger delay to start control procedure
V Res variation	0.10...100.00	%Un	0.01	2.00	Req. change in Uo that calc. of net. param. can be executed
Tuning mode	1=Coil movement 2=Resistor switching			1=Coil movement	Method for obtaining Uo variation
V Ref adaptive mode	0=Disable 1=Enable			1=Enable	Uref adaptive mode
V Ref adaptive delay	0...1000	min	1	20	Uref adaptive delay
V Res EF level	0.00...100.00	%Un	0.01	15.00	Uo level for detection of earth fault in the network
Default position	0...1000	A	1	50	Coil default position
V Res minimum	0.00...20.00	%Un	0.01	0.10	Minimum level for zero-sequence voltage to allow coil automatic tuning
V Res maximum	0.00...150.00	%Un	0.01	10.00	Maximum level for zero-sequence voltage allowed during automatic tuning process
Temporary damping	0=False 1=True			0=False	Resistor switching on/off allowed during the automatic tuning procedure
Minimum current	0...100	A	1	0	Minimum current of arc-suppression coil (low operating limit)
Maximum current	0...10000	A	1	10000	Maximum current of arc-suppression coil (high operating limit)
Error position	1=Current 2=Previous 3=Default			2=Previous	Coil position in the case error occurred during the automatic tuning process
Pass resonance	0=False 1=True			0=False	Pass resonance enabled / disabled
Transient time EF	0...1000000	ms	1	5	Transient earth-fault duration threshold
EF mode	1=Blocked during EF 2=Resonance 3=Tuning during EF			1=Blocked during EF	Operation mode during earth-fault (alarming earth-fault)
Resistor healthy St	0=Off 1=On			0=Off	Resistor connection status during healthy state operation
Resistor repeats	0...100		1	0	Number of resistor control sequence repeats

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Resistor pause	0...100000000	ms	1	5	Time between consecutive resistor control sequence repeats
Resonance curve Cur	1=Icoil 2=Icoil + Ifix			2=Icoil + Ifix	Resonance curve x-axis title on HMI
Switch on delay 1	0...300000	ms	1	1000	Resistor switch-on delay time
Time on 1	0...300000	ms	1	1000	Resistor switch on time
Switch on delay 2	0...300000	ms	1	1000	Resistor repetition switch-on delay time
Time on 2	0...300000	ms	1	1000	Resistor repetition switch-on time
Switch off delay 1	0...300000	ms	1	1000	Resistor switch-off delay time
Time off 1	0...300000	ms	1	1000	Resistor switch-off time
Switch off delay 2	0...300000	ms	1	1000	Resistor repetition switch-off delay time

Table 1595: PASANCR Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Tuning cycles	1...100		1	5	Maximum number of tuning cycles
Tuning cycle delay	0...86400	s	1	300	Delay between consecutive tuning cycles

Table 1596: PASANCR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Coil V Nom	0...400000	V	1	10000	Adjustable arc suppression coil nominal voltage
Fix coil V Nom	0...400000	V	1	10000	Fixed arc suppression coil nominal voltage
Auxiliary Wnd V Nom	0...10000	V	1	500	Power auxiliary winding nominal voltage
Controller mode	0=Manual 1=Automatic			0=Manual	Coil controller operating in automatic or manual mode
Parallel resistor	0=False 1=True			0=False	Parallel resistor installation status
R0Transformer	0...100	ohm	1	0	Zero-sequence resistance of the earthing/main transformer
X0Transformer	0...100	ohm	1	0	Zero-sequence reactance of the earthing/main transformer
Voltage measurement	1=Busbar 2=Coil			2=Coil	Residual voltage measurement from busbar or from coil

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Position Meas mode	1=Pos. indication 2=Pos. ind. and meas.			1=Pos. indication	Coil position measurement mode
Resistor control	1=OFF 2=ON 3=Automatic			1=OFF	Resistor control mode
Resistor Nom value	0.00...100.00	ohm	0.01	5.00	Nominal resistance of the parallel resistor at power auxiliary winding secondary voltage level
Coil losses	0.00...20.00	%	0.01	2.00	Coil losses
Fix coil value	0...10000	A	1	0	Inductive current produced by fixed coil at fixed coil nominal voltage level
Fix coil losses	0.00...20.00	%	0.01	2.00	Fix coil losses
Pot Max gap	0...100	%	1	5	Potentiometer maximum gap length
Fix coil type	1=OFF 2=ON 3=Automatic			1=OFF	Fix coil type
Level detector op	0=Disable 1=Enable			1=Enable	Enable / disable level detector module
Pot value 1	0...3000	ohm	1	0	Potentiometer value 1
Coil current 1	0...10000	A	1	0	Coil current 1
Pot value 2	0...3000	ohm	1	0	Potentiometer value 2
Coil current 2	0...10000	A	1	0	Coil current 2
Pot value 3	0...3000	ohm	1	0	Potentiometer value 3
Coil current 3	0...10000	A	1	0	Coil current 3
Pot value 4	0...3000	ohm	1	0	Potentiometer value 4
Coil current 4	0...10000	A	1	0	Coil current 4
Pot value 5	0...3000	ohm	1	0	Potentiometer value 5
Coil current 5	0...10000	A	1	0	Coil current 5
Pot value 6	0...3000	ohm	1	0	Potentiometer value 6
Coil current 6	0...10000	A	1	0	Coil current 6
Pot value 7	0...3000	ohm	1	0	Potentiometer value 7
Coil current 7	0...10000	A	1	0	Coil current 7
Pot value 8	0...3000	ohm	1	0	Potentiometer value 8
Coil current 8	0...10000	A	1	0	Coil current 8
Pot value 9	0...3000	ohm	1	0	Potentiometer value 9
Coil current 9	0...10000	A	1	0	Coil current 9
Pot value 10	0...3000	ohm	1	0	Potentiometer value 10
Coil current 10	0...10000	A	1	0	Coil current 10
Reset delay time EF	0...1000000	ms	1	500	Reset delay time for earth-fault

9.11.11 PASANCR Monitored data

Table 1597: PASANCR Monitored data

Name	Type	Values (Range)	Unit	Description
COIL_MV_SPD	FLOAT32	0.00...100.00	A/s	Coil movement speed detected during calibration
I_AFTER_RUN	FLOAT32	0.00...100.00	A	Coil after-running current
I_MCH_PLAY	FLOAT32	0.00...100.00	A	Mechanical play of the coil
I_COIL_TOT	FLOAT32	0.00...10000.00	A	Total inductive current of adjustable and fixed arc suppression coil
OHM_COIL	FLOAT32	0...3000	ohm	Coil position indicating potentiometer value
I_DAMPING	FLOAT32	0.00...10000.00	A	Wattmetric part of the residual current at the fault location
I_C_NETWORK	FLOAT32	0.00...10000.00	A	Uncompensated earth-fault current of the network
I_EF	FLOAT32	0.00...10000.00	A	Earth-fault current at present operate point
I_RESONANCE	FLOAT32	0.00...10000.00	A	Current at the resonance point
DAMPING	FLOAT32	0.00...100.00		Damping of the network
I_DETUNING	FLOAT32	-100.00...100.00	A	Petersen coil detuning in amperes
DETUNING_REL	FLOAT32	-100.00...100.00	%	Petersen coil detuning in percent
UREF_AMPL	FLOAT32	0.00...100.00	xUn	Reference voltage amplitude
UREF_ANG	FLOAT32	-180.00...180.00	deg	Reference voltage angle
URESO_AMPL	FLOAT32	0...100000	V	Resonance point voltage amplitude without the parallel resistor
URESO_REL	FLOAT32	0.0...100.0	%	Resonance point voltage in percent without the parallel resistor
URESO_AMPL_R	FLOAT32	0...100000	V	Resonance point voltage amplitude with the parallel resistor connected
URESO_REL_R	FLOAT32	0.0...100.0	%	Resonance point voltage in percent with the parallel resistor connected
TUNING_TRIGG	FLOAT32	0...100	%	Percentage value indicating present deviation in zero-sequence voltage with respect to reference voltage
GAP_LO_VAL_1	FLOAT32	0...3000	ohm	Potentiometer 1st gap low value
GAP_HI_VAL_1	FLOAT32	0...3000	ohm	Potentiometer 1st gap high value
GAP_LO_VAL_2	FLOAT32	0...3000	ohm	Potentiometer 2nd gap low value
GAP_HI_VAL_2	FLOAT32	0...3000	ohm	Potentiometer 2nd gap high value

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
GAP_LO_VAL_3	FLOAT32	0...3000	ohm	Potentiometer 3rd gap low value
GAP_HI_VAL_3	FLOAT32	0...3000	ohm	Potentiometer 3rd gap high value
GAP_LO_VAL_4	FLOAT32	0...3000	ohm	Potentiometer 4th gap low value
GAP_HI_VAL_4	FLOAT32	0...3000	ohm	Potentiometer 4th gap high value
GAP_LO_VAL_5	FLOAT32	0...3000	ohm	Potentiometer 5th gap low value
GAP_HI_VAL_5	FLOAT32	0...3000	ohm	Potentiometer 5th gap high value
CLC_SEQ_WRN	BOOLEAN	0=False 1=True		Maximum number of tuning cycles is reached
DEFAULT_POS	BOOLEAN	0=False 1=True		Coil has been moved to its default position
ERROR_POS	BOOLEAN	0=False 1=True		Coil has been moved to its error position
UMAX_RES_STS	BOOLEAN	0=False 1=True		Zero-sequence voltage has reached U0 max level
UMIN_RES_STS	BOOLEAN	0=False 1=True		Zero-sequence voltage has reached Uo min level
TUNING_DL_ON	BOOLEAN	0=False 1=True		Tuning delay ongoing
TUNING_ST_DELAY	INT32	0...3600	s	Remaining delay time in seconds to start automatic tuning procedure
OPR_TIME	INT32	0...999999	h	Controller time in operation (hours)
CNT_TUNINGS	INT32	0...999999		Counter of started tuning procedures
CNT_TUNED	INT32	0...999999		Counter of successful tuning procedures
CNT_CNL_TUN	INT32	0...999999		Counter of cancelled tuning procedures
CNT_TUN_UMAX	INT32	0...999999		Counter of coil final tuning position at Uo max
CNT_TUN_HIGH	INT32	0...999999		Counter of cases when coil final tuning position is at high limit (high end switch or high operating limit)
CNT_TUN_LOW	INT32	0...999999		Counter of cases when coil final tuning position is at low limit (low end switch or low operating limit)
CNT_TRNS_EF	INT32	0...999999		Counter of transient earth-faults
CNT_EF	INT32	0...999999		Counter of earth-faults
CNT_RES_SW_A	INT32	0...999999		Counter of parallel resistor automatic switching operations
CNT_RES_SW_M	INT32	0...999999		Counter of parallel resistor manual switching operations

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
MOT_RUN_TIME	INT32	0...999999	h	Total arc suppression coil motor run time (hours)
CALIB_RSL	Enum	1=Calibration successful 2=Calibration ongoing 3=Calibration failed 4=Not calibrated		Calibration result
CALIB_STS	Enum	1=Detect end switches 2=Move to middle position 3=Detect mechanical play 4=Detect after running 5=Detect potentiometer gaps 6=Calibration not ongoing		Calibration status
ALARM_STS	Enum	1=No alarm 2=No movement detected 3=Movement into wrong direction 4=Simultaneously indication from both end-switches 5=Potentiometer maximum gap length exceeded 6=Potentiometer new gap appeared 7=Maximum number of potentiometer gaps exceeded 8=Check measurements 9=Umin not reached 10=Cannot obtain minimum Uo variation		Alarm status
TUNING_STS	Enum	1=Tuned successfully 2=Not tuned 3=Tuned at Umax 4=Tuned at low limit (low end switch or low operating limit) 5=Tuned at high limit (high end switch or high operating limit) 6=Tuning delay ongoing 7=Move to Ures min 8=Direction determination 9=Pick up 1st point 10=Pick up 2nd point 11=Pick up 3rd point 12=Calculate parameters		Tuning status

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		13=Move to detuning point		
BSYMM	FLOAT32	-1000.000...1000.000	mS	Symmetrical susceptance of network
GSYMM	FLOAT32	-1000.000...1000.000	mS	Symmetrical conductance of network
BASYMM	FLOAT32	-1000.000...1000.000	mS	Asymmetrical susceptance of network
GASYMM	FLOAT32	-1000.000...1000.000	mS	Asymmetrical conductance of network
BSYMM_REF	FLOAT32	-1000.000...1000.000	mS	Reference value of symmetrical susceptance of network
GSYMM_REF	FLOAT32	-1000.000...1000.000	mS	Reference value of symmetrical conductance of network
BASYMM_REF	FLOAT32	-1000.000...1000.000	mS	Reference value of asymmetrical susceptance of network
GASYMM_REF	FLOAT32	-1000.000...1000.000	mS	Reference value of asymmetrical conductance of network
BCOIL	FLOAT32	-1000.000...1000.000	mS	Coil susceptance
GCOIL	FLOAT32	-1000.000...1000.000	mS	Coil conductance
BFIXCOIL	FLOAT32	-1000.000...1000.000	mS	Fixed parallel coil susceptance
GFIXCOIL	FLOAT32	-1000.000...1000.000	mS	Fixed parallel coil conductance
GPARALLEL	FLOAT32	-1000.000...1000.000	mS	Parallel resistor conductance
I_COIL_HMI	FLOAT32	0.00...10000.00	A	Coil current value dedicated for HMI purposes (depends on Resonance curve Cur setting)
I_COIL	FLOAT32	0.00...10000.00	A	Adjustable arc suppression coil value
CALIB_O_MIN	FLOAT32	0...3000	ohm	Low end switch position of the coil (ohms)
CALIB_O_MAX	FLOAT32	0...3000	ohm	High end switch position of the coil (ohms)
B_RATIO	FLOAT32	0.000...100.000		Susceptance ratio
PASANCR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.11.12 Technical data

Table 1598: PASANCR Technical data

Characteristic	Value
Measuring accuracy	Resistance: ±2% or ±1 Ω
Operation accuracy [1]	I_C_NETWORK:

Characteristic	Value
	Typically ±5%

9.11.13 Technical revision history

Table 1599: PASANCR Technical revision history

Product connectivity level	Technical revision	Change
PCL4	B	More accurate operation of controller with low residual voltage magnitudes. Parallel resistor automatic control sequence is reset if earth-fault indication becomes inactive. New output TUNING_SUC ("Tuned successfully"). New monitored data B_RATIO. Network capacitive current I_C_NETWORK is scaled with respect to residual voltage channel setting *Primary voltage*. IRES input allows connection from GRPOFF function block. Outputs OP_RESISTOR, CL_RESISTOR, OP_FIXCOIL and CL_FIXCOIL are fixed to 100 ms pulses. TUNING_STS enumerator has new elements.

[1] Network resonance point voltage must be at least 0.005 × U_n, where U_n = nominal phase-to-earth voltage

9.12 High speed bus transfer HSABTC (ANSI I<->O BT)

9.12.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
High speed bus transfer	HSABTC	I<->O BT	I<->O BT

9.12.2 Function block

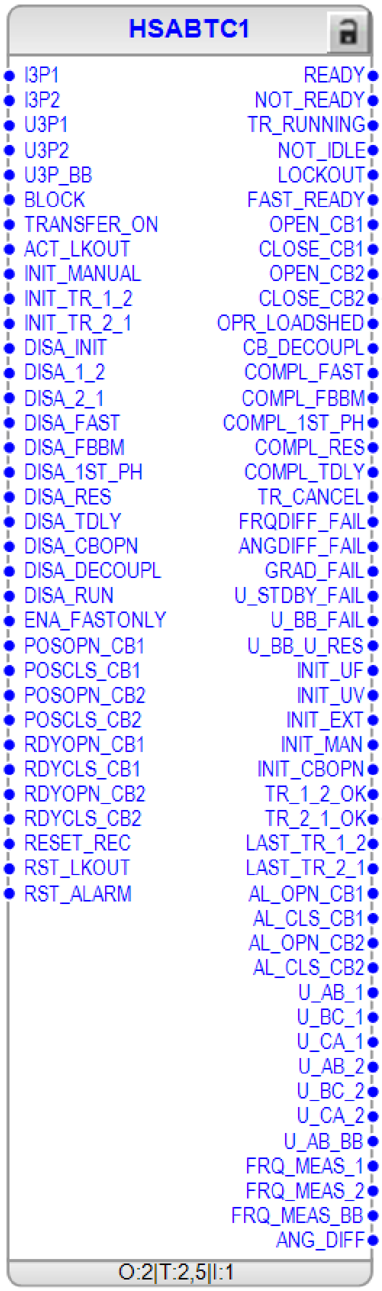


Figure 931: Function block

9.12.3 Functionality

The high speed bus transfer function HSABTC is used for securing alternative (standby) supply for loads connected to a busbar, thus minimizing disturbances for the primary process.

Electrical power supply stability and availability is most essential for many industrial processes. Interruptions in the power supply can cause considerable production losses or even dangerous operation conditions for the process itself. Solution is to connect a standby power supply for the installation.

The HSABTC function monitors the voltage and frequency of the available supply feeders and the busbar. Function continuously keeps track on the allowed transfer direction and the standby incomer(s) readiness for transfer. Bus transfer can be initiated internally by the function, based on drop on voltage or frequency. Alternatively external initiation can be used. Once transfer is initiated, sequence for busbar transfer is executed according to the allowed and enabled transfer modes. HSABTC also provides support for load shedding as a part of the transfer sequence.

9.12.4 Analog channel configuration

HSABTC has five analog group inputs which must be properly configured.

Table 1600: Analog inputs

Input	Description
U3P1	Voltage from feeder 1
U3P2	Voltage from feeder 2
U3P_BB	Voltage from busbar
I3P1	Current from feeder 1
I3P2	Current from feeder 2

Recommended number of measured voltages is following:

- U3P1: all three phases, can be phase-to-phase or phase-to-ground voltages
- U3P2: all three phases, can be phase-to-phase or phase-to-ground voltages
- U3P_BB: one phase-to-phase voltage

Minimum requirement is to have one voltage connected to each voltage group. In this case all measurements must be made with the same connection type, meaning all measurements must be either phase-to-ground or phase-to-phase voltages. Mixing between different connections types in this case is not allowed. Measurements must also be made from same phase (phase A or phase AB), mixing between phases is not allowed.

Table 1601 shows supported voltage connections.

Table 1601: Supported voltage connections

U3P1	U3P2	U3P_BB	Note
3 phase-to-phase	3 phase-to-phase	1 phase-to-phase	Recommended
3 phase-to-ground	3 phase-to-ground	1 phase-to-phase	Recommended
3 phase-to-phase	3 phase-to-phase	1 phase-to-ground	Not recommended

Table continues on the next page

U3P1	U3P2	U3P_BB	Note
			Allowed only if Uo is also measured from U3P1 and U3P2
3 phase-to-ground	3 phase-to-ground	1 phase-to-ground	Supported
1 phase-to-phase	1 phase-to-phase	1 phase-to-phase	Limited functionality
1 phase-to-ground	1 phase-to-ground	1 phase-to-ground	Limited functionality

Limited functionality due to limited voltage connections is related to under-voltage triggering. In case only one voltage is connected, function is blind to unconnected phases. In this case external triggering is recommended.

Phase currents can be left unconnected but then circuit breaker monitoring has limited functionality available. Recommendation is to connect full three phase current triplet to both I3P inputs.

Table 1602: Supported current connections

I3P1	I3P2	Note
All three phases connected	All three phases connected	Recommended
Not connected	Not connected	Limited functionality

9.12.5 Operation principle

The *Operation* setting is used to enable or disable the function. When selected "On" the function is enabled and respectively "Off" means function is disabled. Function state can be controlled also with level sensitive TRANSFER_ON input. If input is TRUE, function is “On” and if input is FALSE, function is “Off”. If TRANSFER_ON input is not connected in relay configuration tool, then status is “On”. The operation of HSABTC is described by a module diagram presented in *Figure 932*. All the modules in the diagram are explained in the next sections.

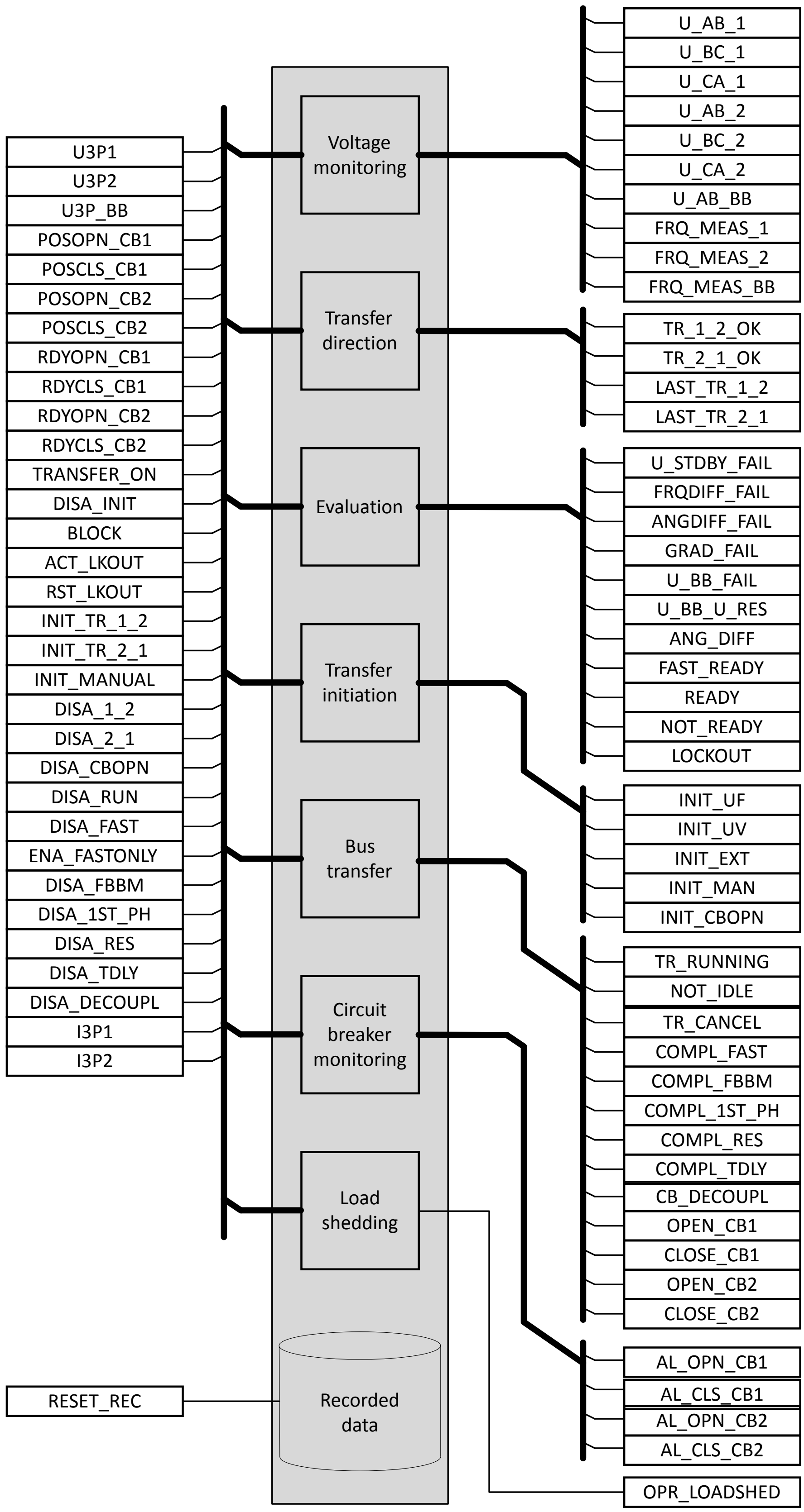


Figure 932: Functional module diagram. Grey area in figure presents internal signalling between modules. All signals are presented later in module specific description.

9.12.5.1 Voltage monitoring

Voltage monitoring module calculates measurement values necessary in HSABTC internal operation. Functionally module can be split to submodules presented in *Figure 933*. Each module is explained later below.

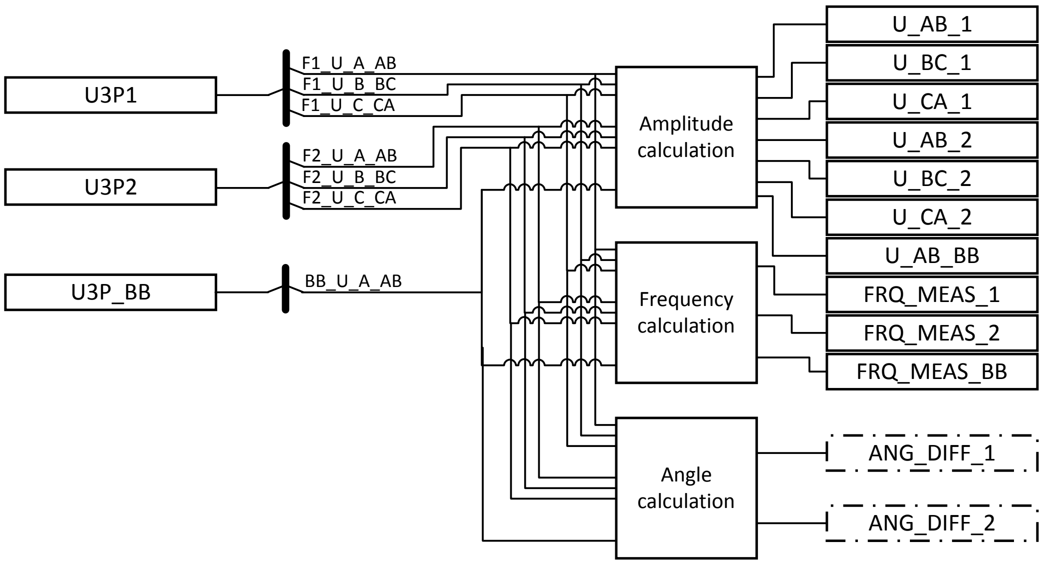


Figure 933: Voltage monitoring module diagram.

Amplitude calculation

Amplitude calculation reports phase-to-phase voltages from busbar (U_AB_BB), feeder 1 (U_AB_1, U_BC_1, U_CA_1) and feeder 2 (U_AB_2, U_BC_2, U_CA_2).

Frequency calculation

This module calculates the frequencies of feeder 1, feeder 2 and busbar. The calculated frequencies for feeder 1, feeder 2 and busbar, FRQ_MEAS_1, FRQ_MEAS_2 and FRQ_MEAS_BB respectively, are available as function outputs.

Angle calculation

This module calculates phase angle difference between feeder 1 and busbar (ANG_DIFF_1), and between feeder 2 and busbar (ANG_DIFF_2). Values are available in monitored data view.

9.12.5.2 Transfer direction

The module checks the present transfer direction and stores the valid saved transfer direction from the breaker's auxiliary contact states. Functionally module can be split to submodules presented in *Figure 934*. Each module is explained later below.

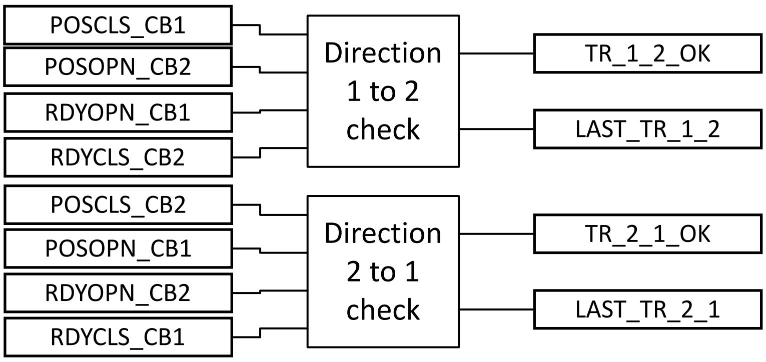


Figure 934: Module diagram for Transfer direction

Direction 1 to 2 check

Breaker position information for feeder 1 is obtained from `POSOPN_CB1` and `POSCLS_CB1` inputs. Circuit breaker readiness to open and close are defined with inputs `RDYOPN_CB1` and `RDYCLS_CB2`.

If the CB1 is closed and CB2 is open, CB1 is ready to open and CB2 is ready close, then TR_1_2_OK is TRUE, meaning transfer from feeder 1 to feeder 2 is allowed (*Figure 935*, left side).

All other combinations of CB status will set TR_1_2_OK FALSE.

TR_1_2_OK – TRUE when present direction of transfer is from feeder 1 to feeder 2 and stand-by feeder is feeder 2.

LAST_TR_1_2 output shows if the last valid transfer has been from feeder 1 to feeder 2.

Direction 2 to 1 check

Breaker position information for feeder 2 is obtained from `POSOPN_CB2` and `POSCLS_CB2` inputs. Circuit breaker readiness to open and close are defined with inputs `RDYCLS_CB1` and `RDYOPN_CB2`.

If the CB2 is closed and CB1 is open, CB2 is ready to open and CB1 is ready to close, then TR_2_1_OK is TRUE, meaning transfer from feeder 2 to feeder 1 is allowed (*Figure 935*, right side).

All other combinations of CB status will set TR_2_1_OK to FALSE.

TR_2_1_OK – TRUE when present direction of transfer is from feeder 2 to feeder 1 and stand-by feeder is feeder 1.

LAST_TR_2_1 output shows if the last valid transfer has been from feeder 2 to feeder 1.

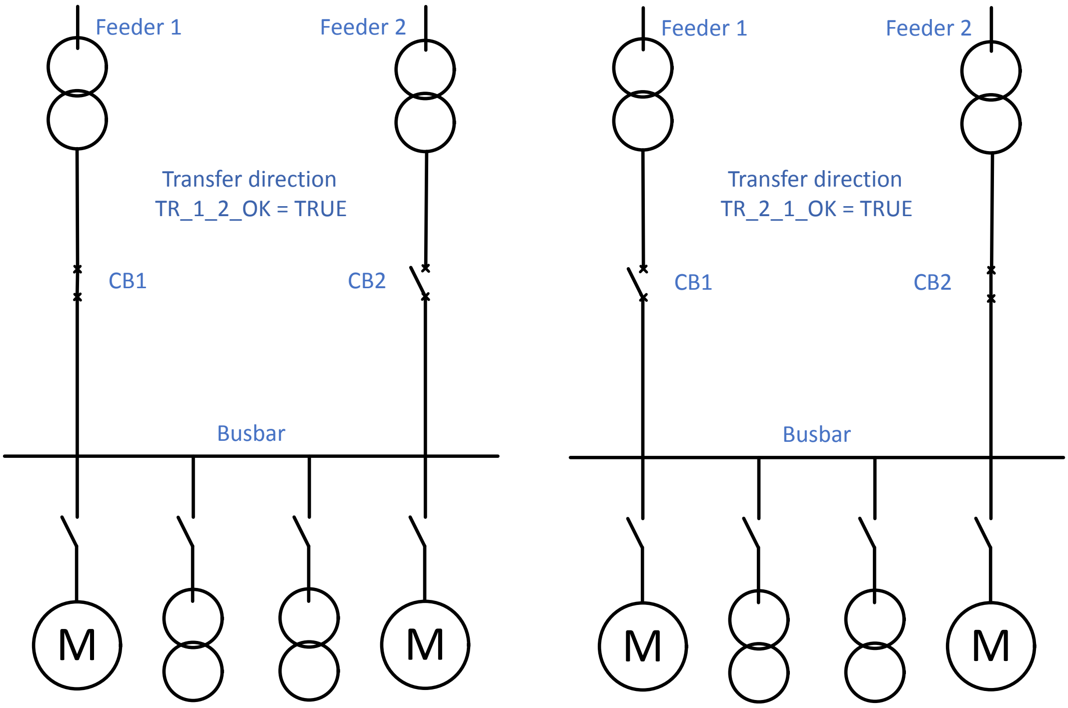


Figure 935: Example figure of breaker configuration

9.12.5.3 Evaluation

Functionally module can be split to submodules presented in *Figure 936*. Each module is explained later below.

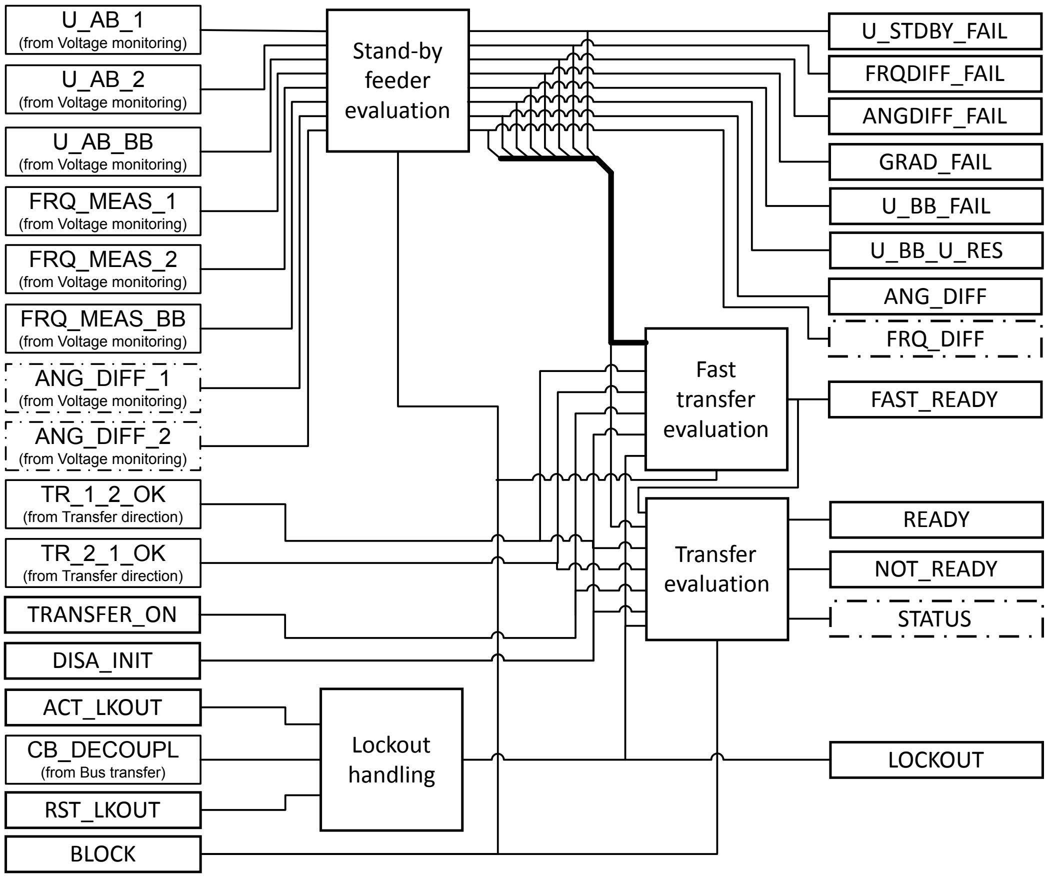


Figure 936: Transfer readiness evaluation module diagram.

Stand-by feeder evaluation

The phase angle difference is determined between the voltage of busbar and the voltage of the standby feeder. If phase angle difference is outside sector defined by *Maximum phase lead* and *Maximum phase lag*, output `ANG_DIFF_FAIL` is activated. The measured angle difference between stand-by feeder and busbar (ANG_DIFF) is available as function output.

Same way frequency difference is determined between the voltage of busbar and the voltage of the stand-by feeder. If frequency difference is greater than setting *Max frequency Diff*, output `FRQ_DIFF_FAIL` is activated. The measured frequency difference (FRQ_DIFF) is shown in monitored data.

Busbar frequency gradient is also monitored and if frequency gradient is larger than setting *Maximum DfDt*, output `GRAD_FAIL` is activated.

Stand-by feeder voltage must be higher than setting *Min standby voltage*. If stand-by feeder voltage falls below the setting value, U_STDBY_FAIL is activated. If U_STDBY_FAIL is active, then all transfers are prohibited.

Busbar voltage must be higher that setting *Min busbar voltage*. If busbar voltage falls below the setting value, U_BB_FAIL is activated. If U_BB_FAIL is active, then fast transfer is not allowed.

If busbar voltage falls below *Res voltage limit* setting, U_BB_U_RES output is activated. This allows transfer based on residual voltage transfer.

BLOCK input activation resets all outputs.

Lockout handling

Function can be set to lockout state by activation of ACT_LKOUT input. When function is in lockout, this is shown with LOCKOUT output. Lockout state can be reset with RST_LKOUT input or via clear menu parameter *HSABTC reset lockout*. Lockout state can be activated also when circuit breaker decoupling, CB_DECOUPL, activates.

Fast transfer evaluation

This module evaluates fast transfer readiness. Fast transfer is allowed if following conditions are met:

- U_STDBY_FAIL is FALSE

  Stand-by feeder voltage is greater than setting *Min standby voltage*
- U_BB_FAIL is FALSE

  Busbar voltage is greater than setting *Min busbar voltage*
- FRQ_DIFF_FAIL is FALSE

  Frequency difference between standby feeder and busbar is less than setting *Max frequency Diff*
- ANG_DIFF_FAIL is FALSE

  Phase angle difference is inside sector defined by *Maximum phase lead* and *Maximum phase lag*
- GRAD_FAIL is FALSE

  Frequency rate of change in busbar is less than setting *Max DfDt*
- BLOCK input is FALSE
- TRANSFER_ON input is TRUE
- DISA_INIT input is FALSE
- LOCKOUT is FALSE (Function is not in lockout)
- Transfer is allowed to one direction, i.e. TR_1_2_OK or TR_2_1_OK is true

If all conditions are met, then the information is signaled to Bus transfer with FAST_READY signal.

Transfer evaluation

This module evaluates the transfer enable signal. The READY output is active if following conditions are fulfilled:

- U_STDBY_FAIL is FALSE

  Stand-by feeder voltage is greater than setting *Min standby voltage*
- BLOCK input is FALSE
- TRANSFER_ON input is TRUE
- DISA_INIT input is FALSE
- LOCKOUT is FALSE
- Transfer is allowed to one direction, i.e. TR_1_2_OK or TR_2_1_OK is true

When function is ready for transfer, this is shown with output READY. If transfer initiation is not possible, then NOT_READY output is activated.

Monitored data STATUS is updated based on the function state. STATUS output can have following values:

- Ready – sync
  - Function is ready for transfer, i.e. READY output is TRUE
  - FAST_READY is TRUE (Fast transfer conditions are met)
- Ready – not sync: function is ready
  - Function is ready for transfer, i.e. READY output is TRUE
  - FAST_READY is FALSE (Fast transfer conditions are not met)
- Not ready – sync
  - Function is not ready for transfer, i.e. READY output is FALSE
  - FAST_READY is TRUE (Fast transfer conditions are met)
- Not ready – not sync
  - Function is not ready for transfer, i.e. READY output is FALSE
  - Function is set “off” or TRANSFER_ON is FALSE.
- Off
  - Function is set “off” or TRANSFER_ON is FALSE.

9.12.5.4 Transfer initiation

Functionally module can be split to submodules presented in *Figure 937*. Each module is explained later below.

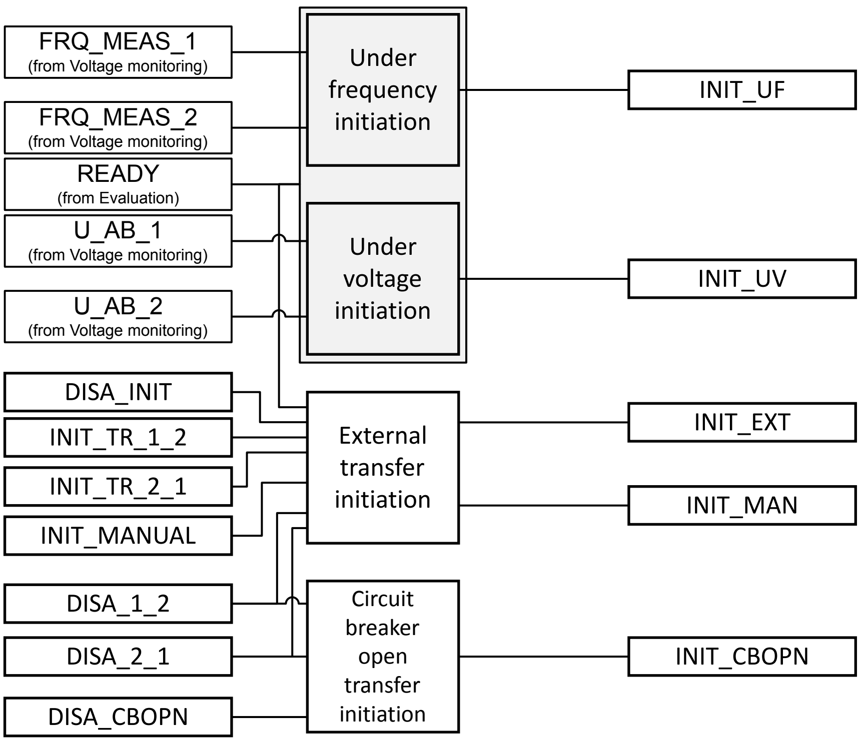


Figure 937: Transfer initiation module diagram

Under frequency initiation

Function monitors the active supply feeder frequency. If under frequency initiation is enabled, then transfer is initiated if the supply feeder frequency falls below the set value. The threshold can be set with a setting *Start Val frequency*. Under frequency initiation is enabled if *Operation mode* setting is “Freq<” or “Freq< or U<”.

Under frequency transfer initiation can be delayed with a setting *Under frequency time*.

Output `INIT_UF` is activated if transfer is initiated by internal under frequency initiation. Output `INIT_UF` can be activated only if function is ready for transfer, i.e. `READY` output is active.

Under voltage initiation

Function monitors the active supply feeder voltage. If under voltage initiation is enabled, then transfer is initiated if any the connected supply feeder voltages fall below the set value. The threshold can be set with a setting *Start Val voltage*. Under voltage initiation is enabled if *Operation mode* setting is “U<“ or “Freq< or U<”.

Under voltage-based transfer initiation can be delayed with a setting *Under voltage time*.

Output `INIT_UV` is activated if transfer is initiated by internal under voltage initiation. Output `INIT_UV` can be activated only if function is ready for transfer, i.e. `READY` output is active.

External transfer initiation

The bus transfer action can be initiated externally by different inputs:

- INIT_TR_1_2 – Initiates any enabled transfer from feeder 1 to feeder 2
- INIT_TR_2_1 – Initiates any enabled transfer from feeder 2 to feeder 1
- INIT_MANUAL – Initiates manual transfer, transfer direction depends on which direction is enabled in transfer direction block

Bus transfer initiation can be disabled with different inputs:

- DISA_INIT – Disables all transfers
- DISA_1_2 – Disables all transfers from feeder 1 to feeder 2
- DISA_2_1 – Disables all transfers from feeder 2 to feeder 1

If transfer initiation is signaled to direction that is allowed, transfer initiation is signaled to Bus transfer module (transfer initiation).

Output `INIT_EXT` is activated if transfer is initiated by external initiation. Output `INIT_EXT` can be activated only if function is ready for transfer, i.e. READY signal (from Evaluation module) is active.

When function is ready for transfer, this is shown with output `READY`. If transfer initiation is not possible, then `NOT_READY` output is activated.

Output `INIT_MAN` is activated if transfer is initiated manually. Output `INIT_MAN` is activated only if function is ready for transfer, i.e. READY signal (from Evaluation module) is active. Manual initiation is controlled by *Manual transfer* setting as explained in *Table 1603*.

Table 1603: Manual transfer setting description

Manual transfer setting values	Description
“Off”	Manual transfer is disabled
“On”	Manual transfer is enabled
“Fast MBB”	Manual transfer is enabled. With this selection fast transfer is always made as fast sequential make before break transfer.

Circuit-breaker open transfer initiation

In case the circuit breaker of the active feeder is opened without reason (no transfer initiation, breaker opened manually or directly by external triggering), function initiates transfer in case transfer conditions are fulfilled. Circuit breaker open transfer can be enabled with setting *Ena CB open transfer*. Transfer can be enabled to one direction only or to both directions:

- Setting value “1>2” enables transfer from feeder 1 to feeder 2.
- Setting value “2>1” enables transfer from feeder 2 to feeder 1.
- Setting value “both” enables transfer to both directions.
- Setting value “Off” disables the transfer initiation based on circuit breaker opening.

Activation based on CB open transfer can be also disabled via input DISA_CBOPN.

Output INIT_CBOPN is activated if transfer is initiated by CB open transfer.

Transfer initiation signal combines all initiation signals.

9.12.5.5 Bus transfer

Functionally module can be split to submodules presented in *Figure 938*. Each module is explained later below.

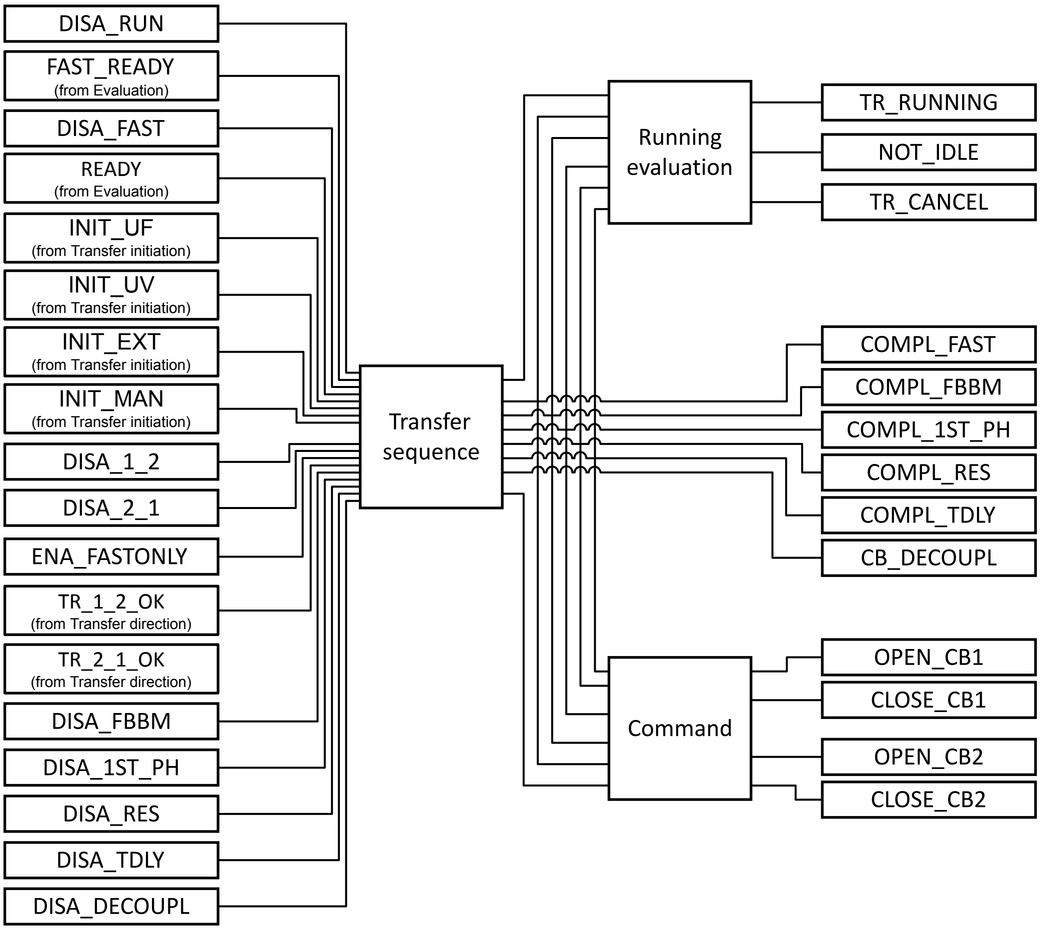


Figure 938: Bus transfer module diagram

Function supports following transfer modes:

- Fast transfer
  - simultaneous control of both involved circuit breakers (fastest mode)
  - sequential control of both involved circuit breakers
- Transfer at the 1^{st} phase coincidence
- Residual voltage transfer
- Time-delayed transfer

Both fast transfer modes, simultaneous and sequential, are optimum transfer modes for ensuring only a minimum interruption of the voltage supply in case of faults in external network. If the network status does not permit fast transfer, slower transfer modes are selected.

Figure 939 shows the typical decay characteristic (voltage and frequency) of a disconnected busbar and the possible closing moments.

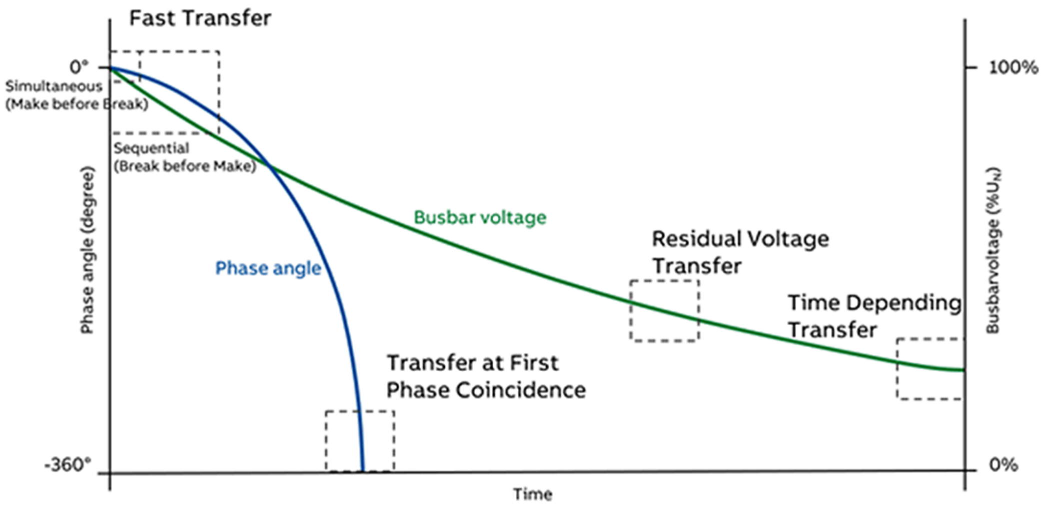


Figure 939: Transfer mode overview

Running evaluation

The transfer in progress is indicated by TR_RUNNING output. If any of the transfer mode(s) is/are in progress, the TR_RUNNING output is TRUE. This output remains TRUE until reset by any of the following conditions:

- The COMPL_FAST, COMPL_1ST_PH, COMPL_FBBM, COMPL_RES or COMPL_TDLY output is TRUE
- The TR_RUNNING signal is active for more than *Max Trn run time* setting

NOT_IDLE output is TRUE when transfer is running or when transfer wait timer is running. Transfer wait time is set with *Transfer wait time* setting. Transfer wait time indicates minimum time between successive transfers.

All transfer mode(s) are reset if TR_RUNNING output changes from TRUE to FALSE.

If transfer is not successful and transfer is interrupted, this is indicated with TR_CANCEL output.

The transfer modes are explained in next chapters.

Transfer sequence

Bus transfer follows always certain sequence presented in *Figure 940*. Simultaneous fast transfer (if enabled) is attempted first. If disabled or not successful, next step is sequential fast transfer (if enabled). If disabled or not successful, function attempts to perform 1st phase transfer. If not successful, residual voltage transfer is attempted. If not successful, function attempts to execute time delayed transfer (if enabled). If all previous transfer attempts are unsuccessful, finally function allows busbar to be decoupled.

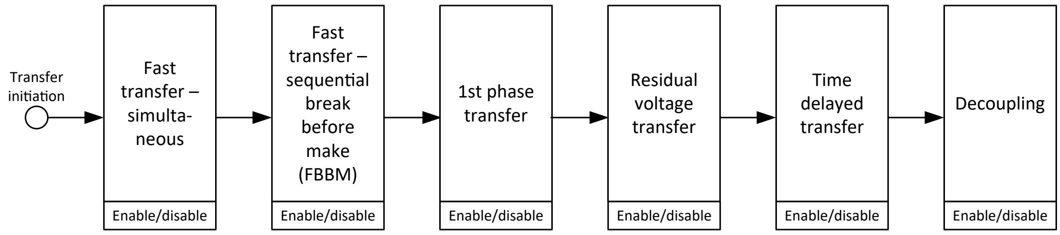


Figure 940: Transfer sequence steps

Fast transfer – simultaneous

A fast transfer takes place when both the main and the stand-by feeders are within specified limit values at the moment of initiation, e.g. frequency slip and phase angle difference are limited between the networks and the stand-by voltage lies above a minimum value.

Fast transfer can be enabled with the setting *Enable fast transfer*. If *Enable fast transfer* setting is set to “1>2”, then fast transfer is allowed to the direction from feeder 1 to feeder 2. If *Enable fast transfer* setting is set to “2>1”, then fast transfer is allowed to the direction from feeder 2 to feeder 1. Setting value “Both” allows fast transfer to both directions. Fast transfer can be disabled by setting *Enable fast transfer* to “Off”.

If *Enable FBBM* setting is set to “false”, then function executes simultaneous fast transfer. In case *Enable FBBM* is set to “true”, then function executes sequential transfer.

In simultaneous fast transfer circuit breaker open and close commands are issued at the same time (see *Figure 941*)

For uninterrupted transfer, the HSABTC function carries out a fast transfer, under the condition that busbar and stand-by feeder are synchronous and other criteria as described below are satisfied. For this the circuit breaker open and close signals are issued simultaneously to the respective circuit breakers of main feeder and standby feeder.

The fast transfer occurs in the direction of feeder 1 to feeder 2, if following conditions are fulfilled simultaneously:

- The FAST_READY (from Evaluation module) is TRUE
- The READY (from Evaluation module) is TRUE
- `DISA_FAST` input is FALSE
- `DISA_1_2` input is FALSE
- Setting *Enable fast transfer* is “1 > 2” or “Both”
- Transfer is activated as described in transfer initiation

The simultaneous fast transfer minimizes the dead time without current flow. *Figure 941* shows fast transfer with current free transfer time (dead time) of about 20ms. The dead time depends on the used circuit breakers and settings and this can be optimized.

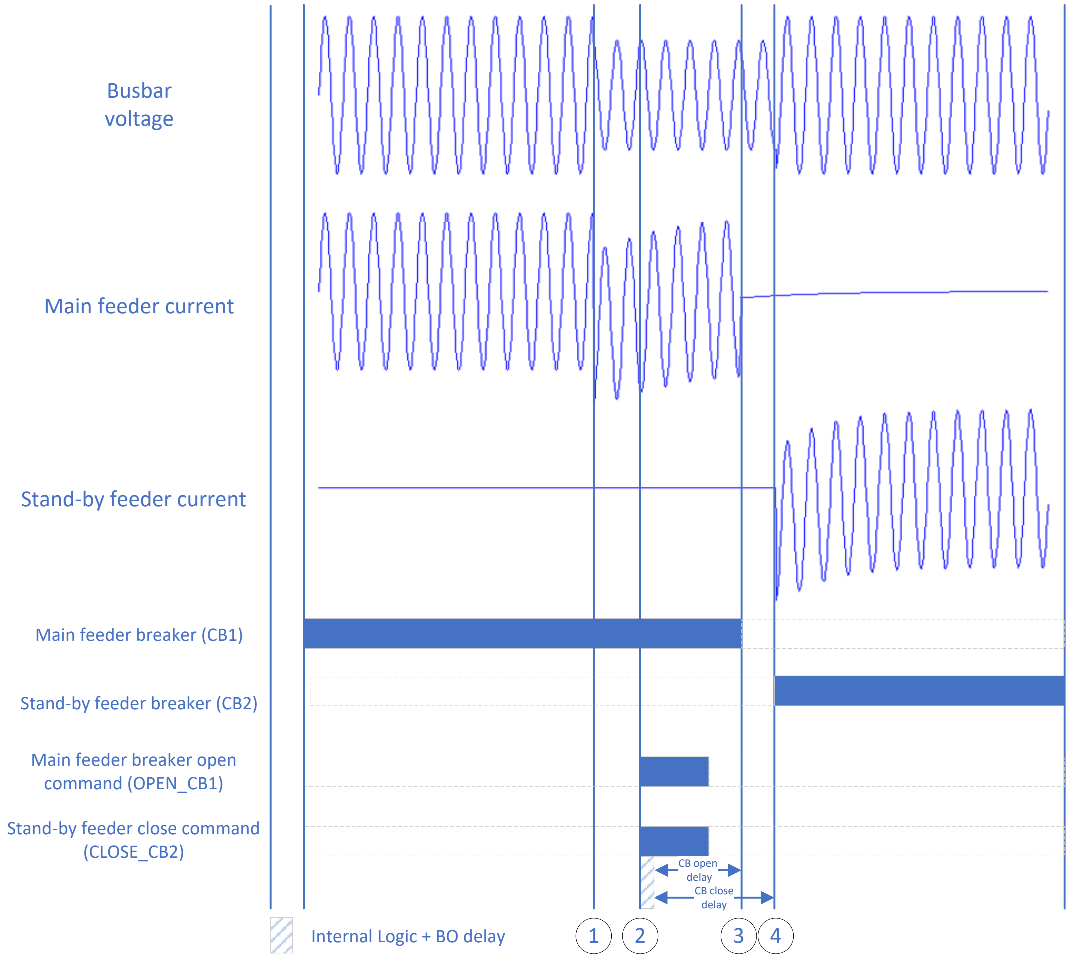


Figure 941: Signal diagram of a fast simultaneous transfer (Fast) (For simplicity reasons only one voltage is presented in the figure)

1 External fault begins

2 Main feeder breaker open command (`OPEN_CB1`) and stand-by feeder close command (`CLOSE_CB2`), both are HSABTC function outputs

3 Main feeder breaker opens

4 Stand-by feeder breaker closes

If `DISA_RUN` input is active, transfer is not allowed to complete until input is deactivated.

When fast transfer is completed, this is indicated with `COMPL_FAST` output.

Fast transfer – sequential break before make (FBBM)

Fast Sequential break before make transfer is activated if fast transfer has been enabled with *Enable fast transfer* (defined in the previous chapter) and *Enable FBBM* is “True”. If fast sequential transfer is enabled, then simultaneous transfer is not enabled, i.e. only one can be active at the same time.

In the sequential fast transfer mode (FBBM) the transfer function waits for the OPEN position indication of the feeding circuit breaker before issuing the close command to the circuit breaker of the stand-by feeder. The dead time without current flow in the sequential transfer mode is therefore longer in sequential transfer mode than in simultaneous. Once open information from feeding circuit breaker is received, transfer conditions are evaluated once more before close command is given to the standby feeder. If conditions are not met, fast transfer is canceled. Function will switch to next available transfer mode. Conditions to be fulfilled before close command can be given are:

- READY (from Evaluation module) is TRUE
- Busbar voltage phase angle compared to standby feeder is still within angle defined by *Max angle Diff FBBM* setting. Phase angle evaluation includes circuit breaker closing time and frequency and frequency gradient of busbar voltage.

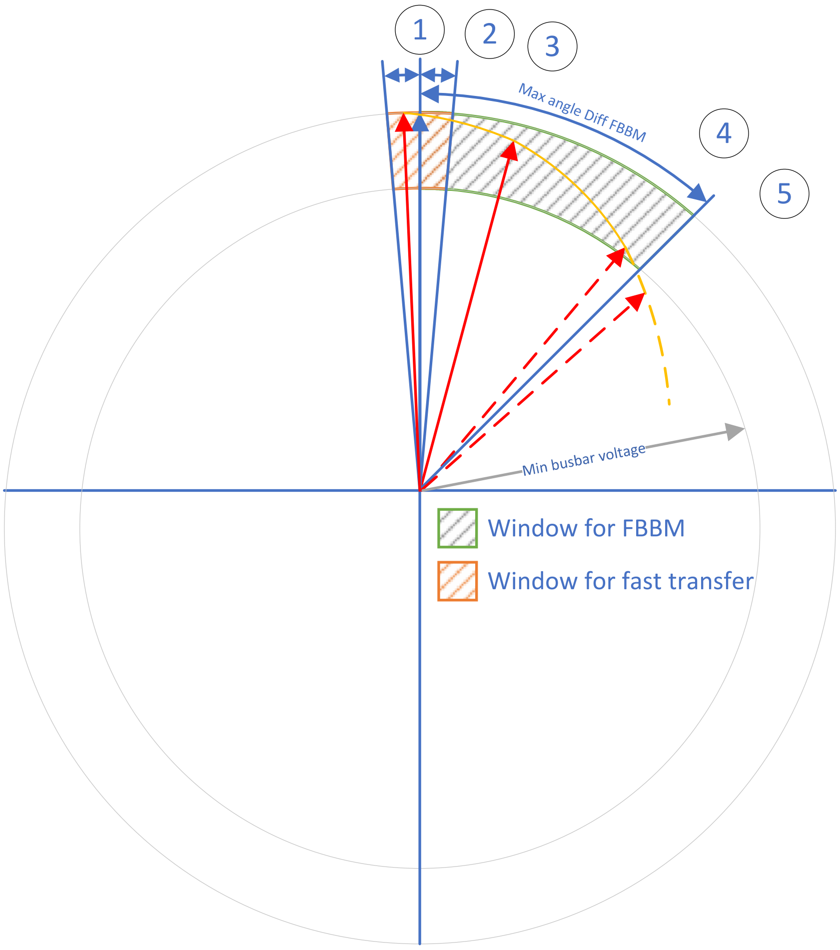


Figure 942: Phase angle trajectory during fast sequential transfer (FBBM)

1	Synchronous conditions, transfer initiation
2	Circuit breaker opening
3	Circuit breaker opening detected, transfer conditions are evaluated before close command is activated
4	Evaluated phase angle and amplitude of busbar voltage that would allow close command
5	Evaluated phase angle and amplitude of busbar voltage that would not allow close command, amplitude too low (Min busbar voltage) or phase angle outside (Max angle Diff FBBM)

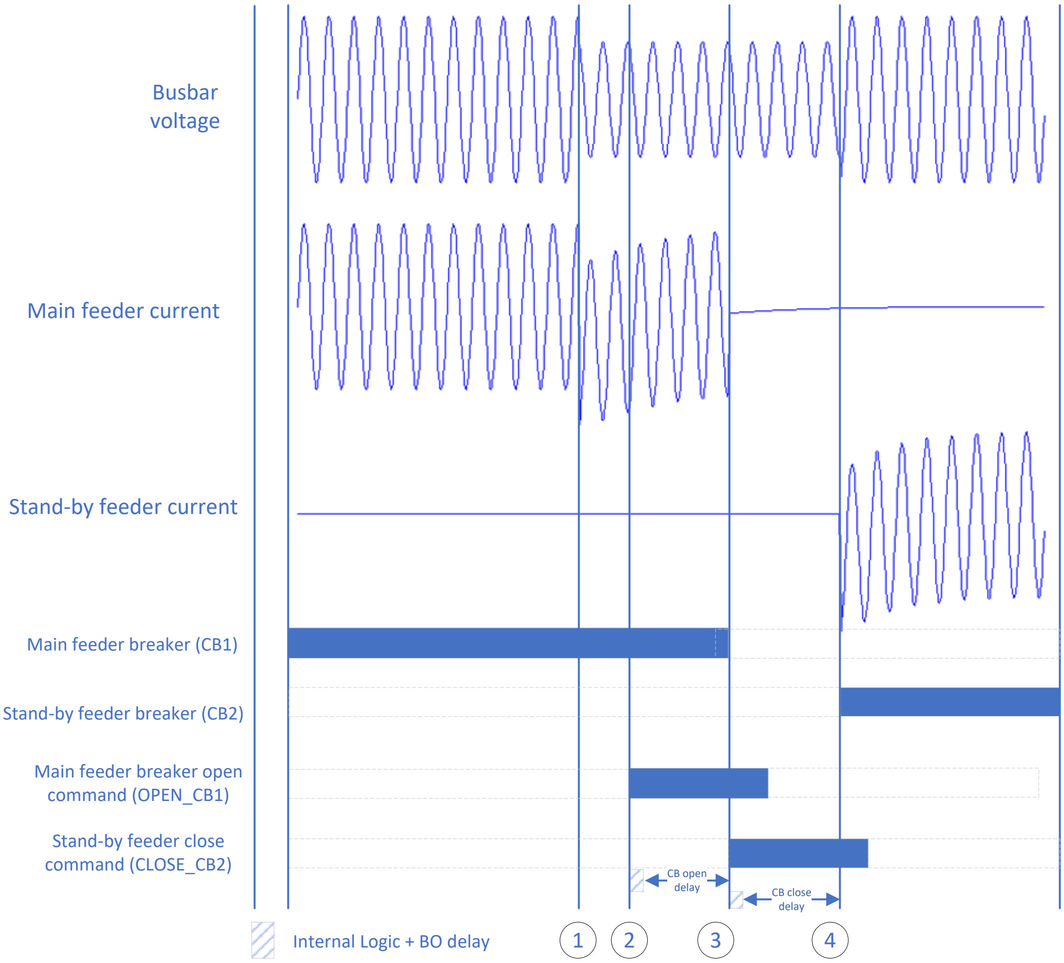


Figure 943: Signal diagram of a fast sequential transfer (FBBM) (For simplicity reasons only one voltage is presented in the figure)

1 External fault begins

2 Main feeder breaker open command (OPEN_CB1)

3 Main feeder breaker opens, stand-by feeder close command (CLOSE_CB2)

4 Stand-by feeder breaker closes

If `DISA_RUN` input is active, transfer is not allowed to complete until input is deactivated.

When fast sequential transfer is completed, this is indicated with `COMPL_FBBM` output.

1st phase transfer

The transfer at the 1^{st}st phase coincidence is executed when there are no synchronized conditions present at the moment of the transfer initiation, so that no fast transfer can be carried our due to physical reasons.

Initial conditions required for 1^{st} phase transfer initiation are (transfer from feeder 1 to feeder 2):

- DISA_1ST_PH is FALSE

- DISA_1_2 is FALSE
- GRAD_FAIL is FALSE
- Setting Ena 1st Ph transfer is “1>2” or “both”
- READY (from Evaluation module) is TRUE
- If transfer is initiated manually, then ENA_FASTONLY must be FALSE

First the main supply feeder will be opened without delay. Once the supply feeder breaker opens, the connected busbar is without power supply and will run down in accordance with its specific characteristic curve.

For the connection of the stand-by feeder, variety of points in time are possible at which circuit breaker closing is possible with minimal stress to the system. Closing of the circuit breaker is timed is such way that at the closing time of the breaker, phase angle difference between stand-by feeder and busbar is close to zero.

The HSABTC determines the course of the difference voltage and the point in time of the 1st phase coincidence through anticipatory computation. In order to compensate for the installation-specific processing time (system response time, circuit breaker operating time), the close command is issued accordingly before the actual first minimum of the difference voltage occurs within a previously defined connection window.

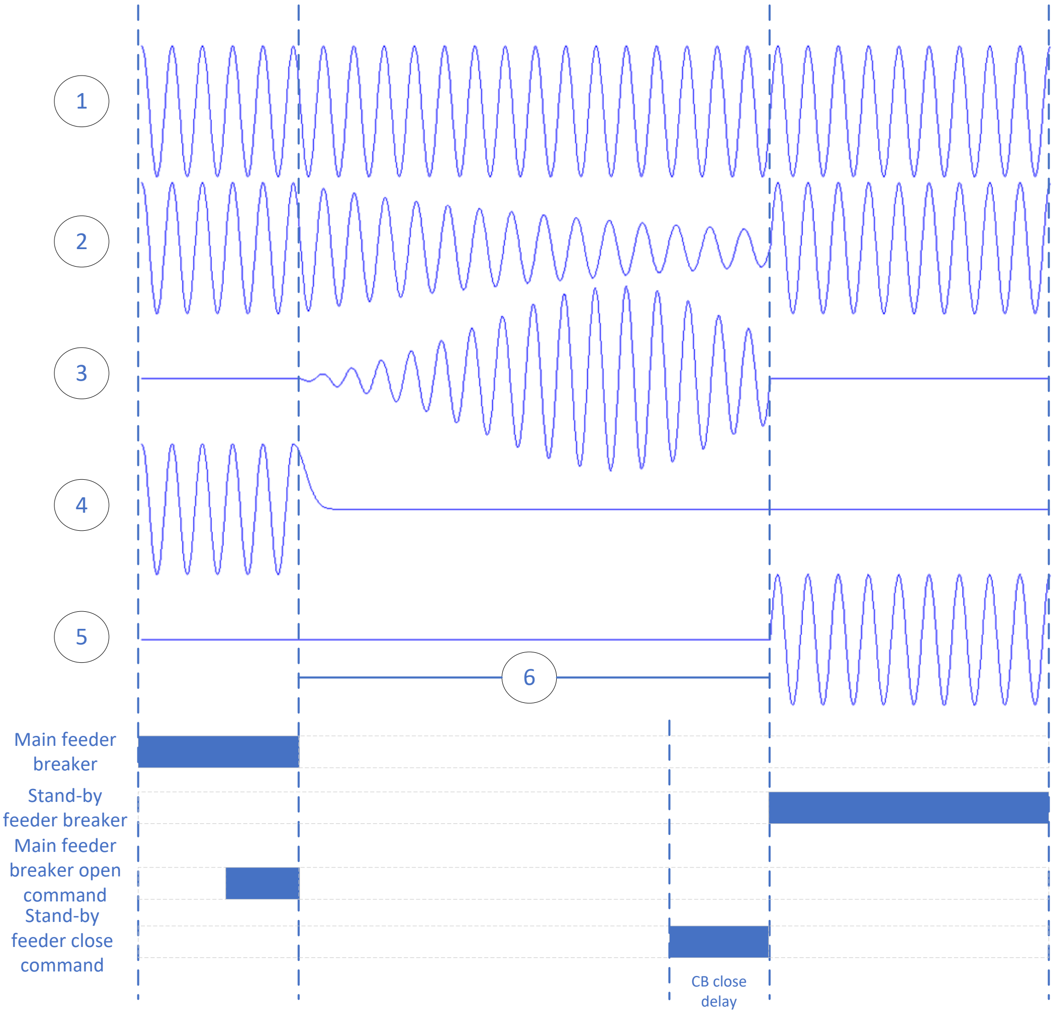


Figure 944: Signal diagram of 1st phase transfer

1 Stand-by feeder voltage

2 Busbar voltage

3 Voltage difference between stand-by and busbar voltage

4 Main feeder current

5 Stand-by feeder current

6 Transfer duration

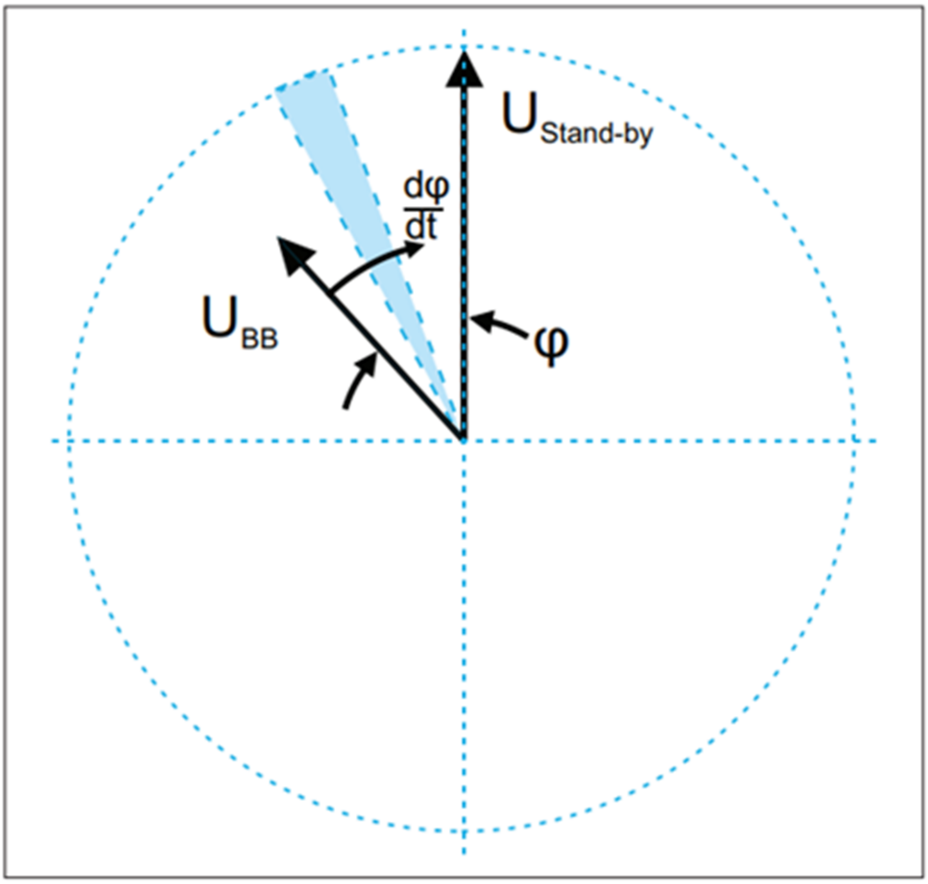


Figure 945: Vector diagram of a transfer at the 1st phase coincidence

$U_{Stand\text{-}by}$	Stand-by feeder voltage
U_{Busbar}	Busbar voltage
ϕ	Angle between stand-by voltage and busbar voltage
dϕ/dt	Angle speed between stand-by voltage and busbar voltage
Blue area	Connection window (dependent upon breaker closing time and dϕ/dt

If DISA_RUN input is active, transfer is not allowed to complete until input is deactivated.

When 1st phase transfer is completed, this is indicated with COMPL_1ST_PH output.

Residual voltage transfer

The residual voltage transfer is utilized when a connection in the 1st phase coincidence is not possible. Following conditions must be met for residual voltage transfer:

- transfer is running
- both breakers are open
- DISA_RES is FALSE
- setting *Ena Res V transfer* allows transfer
- if transfer is initiated manually, then ENA_FASTONLY must be FALSE

The connection of the stand-by feeder takes place when the voltage of the busbar has subsided to a preset, permissible value. The threshold value for the busbar voltage for residual voltage transfer is set with setting *Residual voltage limit*. Residual voltage transfer is enabled with setting *Ena Res V transfer*.

The connection takes place without assessment of the angle or of the difference frequency, thus in unsynchronized fashion. Because the voltage of the busbars has however reached a sufficiently low residual voltage value, the transient effects of the connection are manageable (momentary jolt, current needed for users to run up again, voltage reduction).

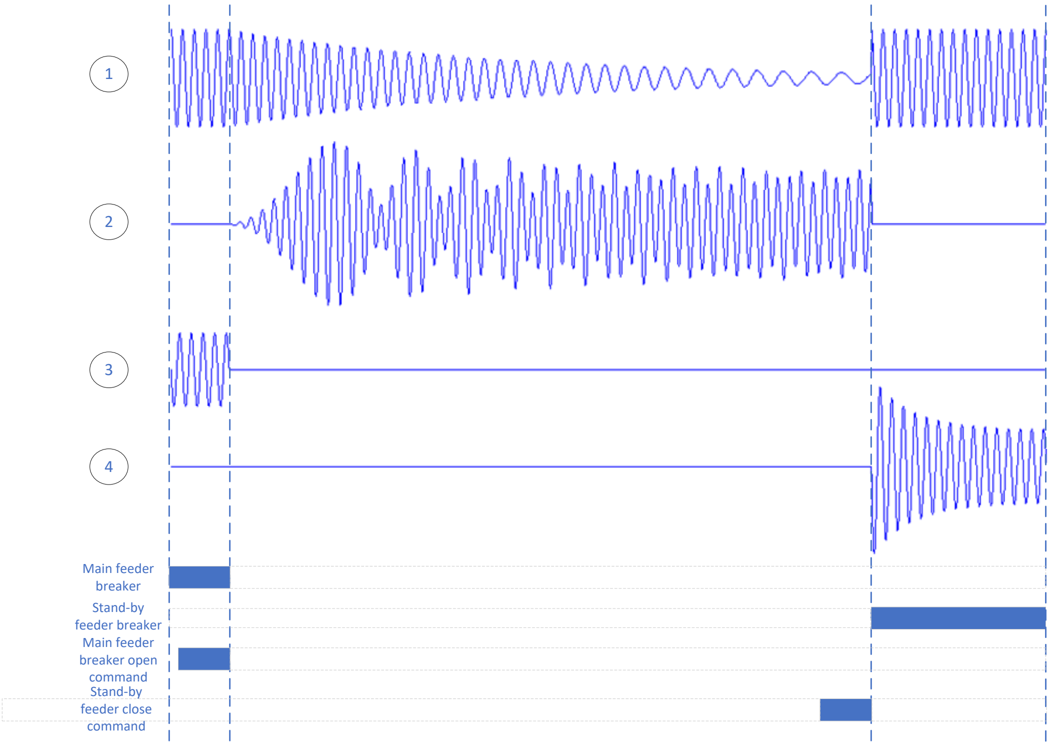


Figure 946: Signal diagram of residual voltage transfer

1 Busbar voltage

2 Voltage difference between stand-by and busbar voltage

3 Main feeder current

4 Stand-by feeder current

If `DISA_RUN` input is active, transfer is not allowed to complete until input is deactivated.

When residual voltage transfer is completed, this is indicated with COMPL_RES output.

Residual voltage transfer can be disabled with DISA_RES input.

Time delayed transfer

The time delayed transfer takes place when *Transfer delay time* elapses. Following conditions must be met for time delayed transfer:

- transfer is running
- both breakers are open
- DISA_TDLY is FALSE
- setting *Ena Time delay transfer* allows transfer
- if transfer is initiated manually, then ENA_FASTONLY must be FALSE

If DISA_RUN input is active, transfer is not allowed to complete until input is deactivated.

Time delayed transfer can be enabled with a setting *Ena Time delay transfer*. When time delayed transfer is completed, this is indicated with COMPL_TDLY output.

Time delayed transfer can be disabled with DISA_TDLY input.

Decoupling

Decoupling is a configurable safety feature. In case during transfer both controllable breakers end up closed or breaker position is unknown after transfer, last closed breaker can be set to be reopened. Opening time can be configured with *Decoupling delay* setting. If decoupling is activated, this is indicated with CB_DECOUPL output. Decoupling functionality can be enabled with setting *Enable decoupling*.

Enable decoupling has following modes:

- “Off”, decoupling functionality disabled
- “CB man close”, decoupling is done when both connected breakers closed. Note that this mode does not require active transfer for the decoupling.
- “Transfer based”, decoupling is done during transfer incase both controllable breakers end up closed after transfer
- “Both”, both operation modes are in use

Decoupling functionality can be disabled with DISA_DECOUPL input.

If decoupling is activated, function is set to lockout state and this is indicated with LOCKOUT output. Lockout state can be reset via RST_LKOUT input.

Command

Circuit breaker opening and closing is handled by this module based on the inputs from transfer modes.

If feeder 2 is the standby feeder, then OPEN_CB1 is activated if:

- transfer is allowed from feeder 1 to feeder 2
- transfer is not started by CB open transfer
- transfer is running, i.e. one of more transfers are active

CLOSE_CB2 is activated if:

- transfer is allowed from feeder 1 to feeder 2
- transfer is completed, this is indicated with following signals:

- COMPL_FAST
- COMPL_FBBM
- COMPL_1ST_PH
- COMPL_RES
- COMPL_TDLY

If feeder 1 is the standby feeder, then OPEN_CB2 is activated if:

- transfer is allowed from feeder 2 to feeder 1
- transfer is not started by CB open transfer
- transfer is running, i.e. one or more transfers are active

CLOSE_CB1 is activated if:

- transfer is allowed from feeder 2 to feeder 1
- transfer is completed, this is indicated with following signals:
  - COMPL_FAST
  - COMPL_FBBM
  - COMPL_1ST_PH
  - COMPL_RES
  - COMPL_TDLY

9.12.5.6 Load shedding

The load-shedding action can be performed based on various load shedding modes during transfer action.

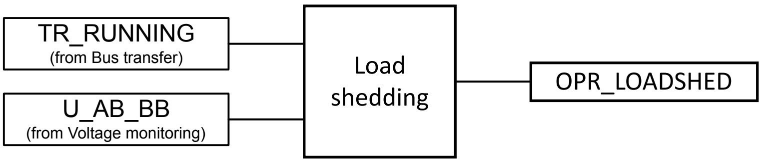


Figure 947: Load shedding module diagram

The OPR_LOADSHED output is TRUE if any of the following conditions are satisfied:

- Instantaneous: If the transfer is active (TR_RUNNING is TRUE), and *Load shedding mode* setting is "Instantaneous", the OPR_LOADSHED will be TRUE.

  Load shedding is not activated during fast transfer.

- Voltage based: If the TR_RUNNING signal is TRUE, and *Load shedding mode* setting is "Voltage based" and busbar voltage is less than *Loadshed V limit*.
- Time based: If the TR_RUNNING signal is TRUE, and *Load shedding mode* setting is "Time based" and the fast transfer is not active (FAST_READY is FALSE), the OPR_LOADSHED is TRUE after *Loadshed time delay* setting parameter value.

If *Load shedding mode* setting is "None", the OPR_LOADSHED output remains FALSE.

9.12.5.7 Circuit breaker monitoring

Breaker closing time is essential information for the function, especially the 1st phase transfer needs accurate information of the circuit breaker closing time in order to schedule the close command properly. Function monitors both circuit breaker opening and closing times and issues alarm in case opening or closing time is too long. Added to this the closing time difference is also monitored and an alarm is given incase circuit breaker closing time differs too much between closings.

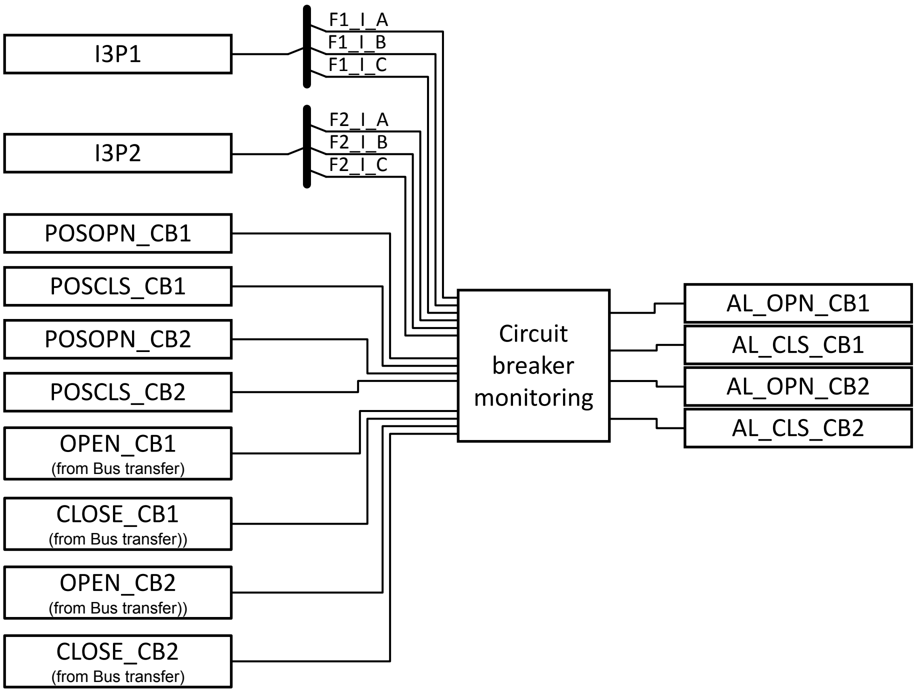


Figure 948: Circuit breaker monitoring module diagram

Circuit breaker monitoring can operate in several modes. Operation mode is set with setting *Travel time Clc mode*. Supported calculation modes are shown in *Table 1604*.

Table 1604: Supported traveling time measurement modes

Setting values	Description
From Cmd to Pos	Traveling time is measured from command to position change
From Pos to Pos	Traveling time is measured from position change to position change
From Cmd to Curr	Traveling time is measured from command till current is measured to flow through circuit breaker
From Pos to Curr	Traveling time is measured from position change till current is measured to flow through circuit breaker

Circuit breaker opening and closing times are defined with following settings: *Closing time CB1, Closing time CB2, Opening time CB1* and *Opening time CB2*. Measured closing and opening times can be taken into use via control menu by activating parameter Set travel times.

Reset travel times set the travelling times back to set values.

Measured circuit breaker opening and closing times are shown in the monitored data with outputs CB_OPN_T_CB1, CB_OPN_T_CB2, CB_CLS_T_CB1 and CB_CLS_T_CB2.

An alarm is issued in case circuit breaker opening or closing time exceeds the set limits. Opening time alarm limit is set with setting *CB open alarm time* and closing time alarm limit is set with setting *CB close alarm time*.

An alarm is also issued in case closing time between consecutive closings varies more than set by setting *CB closing time Dif*.

Alarm outputs are AL_OPN_CB1 and AL_CLS_CB1 for circuit breaker 1 and AL_OPN_CB2 and AL_CLS_CB2 for circuit breaker 2.

Circuit breaker closing time measurement, “From Cmd to Pos”

“From Cmd to Pos” mode measures the closing time from binary output activation till position change has been indicated by auxiliary contacts.

Figure 949 shows an example of CB closing time measurement in “From Cmd to Pos” mode.

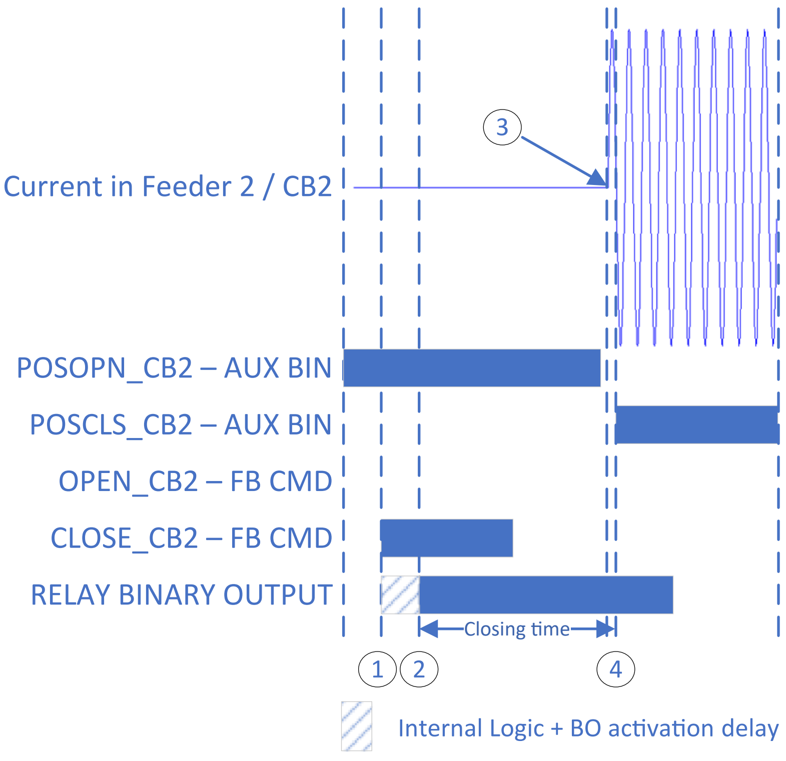


Figure 949: Circuit breaker closing time measurement (“From Cmd to Pos”)

1 HSABTC function activates CLOSE_CB2 output

2 Relay binary output activates – closing time measurement starts from this point

3 Circuit breaker main contacts close

4 Close position indicated to relay with auxiliary contacts

Closing time is time from 2 to 4

Circuit breaker closing time measurement, “From Pos to Pos”

“From Pos to Pos” measures the closing time from auxiliary contacts. This will not represent the actual closing time but it can be used to check that circuit breaker reaches end state and that it will not hang to intermediate state (POSOPN and POS CLS are both False).

This mode is recommended only for supervision purposes to alarm incase breaker doesn’t close properly, not to measure actual travelling time .

Circuit breaker closing time measurement, “From Cmd to Curr”

“From Cmd to Curr” measures the closing time from binary output activation till current is flowing in the primary circuit. This operation mode requires that current signal is connected to I3P1 and I3P2 inputs.

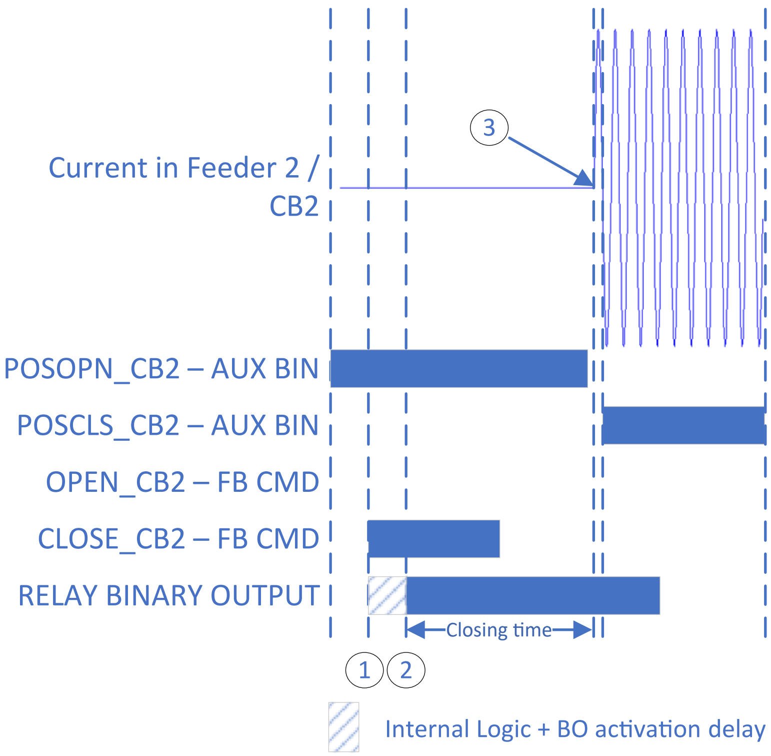


Figure 950: Circuit breaker closing time measurement (“From Cmd to Curr”)

1 HSABTC function activates `CLOSE_CB2` output

2 Relay binary output activates – closing time measurement starts from this point

3 Circuit breaker main contacts close and current flows

Recommended operation mode

Circuit breaker closing time measurement, "From Pos to Curr"

"From Pos to Curr" measures the closing time from position change indicated by auxiliary contacts till current is flowing in the primary circuit.

This operation mode requires that current signal is connected to I3P1 and I3P2 inputs. This mode is recommended only for supervision purposes to alarm incase breaker doesn't close properly, not to measure actual travelling time.

Circuit breaker opening time measurement

From the function operation point of view the opening time measurement is not as important as closing time. Hence the opening time is always measured in "From Cmd to Pos" mode which would provide accurate enough information.

9.12.5.8 Recorded data

The transfer related information is stored when the Recorded data module is triggered. This happens when *Decoupling delay* time is elapsed after TR_RUNNING signal goes from TRUE to FALSE. Three sets of recorded data are available in total for each of the measurement. The sets are saved in data banks 1-3.

The data bank 1 of the respective measurement holds the most recent recorded data. Older data are moved to the subsequent banks (1→2 and 2→3). When all three banks have data of a respective measurement and there is a new transfer complete operation, the latest data set is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2.

The recorded data can be reset with the RESET_REC binary input, from Clear menu or via communication.

Table 1605: Recorded data

Parameter	Type	Description
Transfer mode	ENUM	Transfer mode
Transfer direction	ENUM	Transfer direction
Transfer cause	ENUM	Cause of transfer
Transfer failure	ENUM	Transfer failure cause
Transfer time	TimeStamp	The time at which the close command is issued for transfer
Transfer Dur	INT	Time between transfer initiation and CB close command
Busbar Max dv/dt	REAL	Maximum rate of change of busbar voltage
Busbar Max df/dt	REAL	Maximum rate of change of frequency of busbar voltage

Table continues on the next page

Parameter	Type	Description
Busbar voltage	REAL	Busbar voltage at the time of CB close command
Busbar frequency	REAL	Busbar frequency at the time of CB close command
Phase Diff	REAL	Busbar and standby feeder phase diff at CB close command
CB decoupled	ENUM	CB decoupling happened during the transfer
Loadshed operated	ENUM	Load shedding operated during transfer

Table 1606: Enumeration values for the recorded values parameters

Parameter name	Enum name	Value
Transfer mode	None	0
Transfer mode	Fast	1
Transfer mode	FBBM	2
Transfer mode	Phase coincidence	3
Transfer mode	Res Voltage	4
Transfer mode	Time delay	5
Transfer direction	Unknown	0
Transfer direction	Feeder 1 to Feeder 2	1
Transfer direction	Feeder 2 to Feeder 1	2
Transfer cause	None	0
Transfer cause	External	1
Transfer cause	External under voltage	2
Transfer cause	Internal under frequency	3
Transfer cause	Internal under voltage	4
Transfer cause	Circuit breaker open	5
Transfer cause	Manual	6
CB decoupled	TRUE	0
CB decoupled	FALSE	1

Table continues on the next page

Parameter name	Enum name	Value
Load shed mode	None	0
Load shed mode	Instantaneous	1
Load shed mode	Voltage base	2
Load shed mode	Time base	3

The active transfer mode that carries out the transfer action is provided by Transfer mode output. *Table 1607* shows the calculation for Transfer mode recorded data parameter and priority order in case multiple modes are active for bus transfer.

Table 1607: Transfer mode output calculation

Priority order	Cause of Transfer	Transfer mode output
1	Fast transfer completed & Transfer cause > 0	1=Fast transfer
2	FBBM transfer completed & Transfer cause > 0	2=FBBM
3	1st phase coincidence transfer completed & Transfer cause > 0	3=Phase coincidence
4	Residual voltage transfer completed & Transfer cause > 0	4=Res Voltage transfer
5	Time delay transfer completed & Transfer cause > 0	5=Time delay transfer
6	None	0=None

The transfer direction from feeder 1 to feeder 2 or vice – versa is recorded by Transfer direction recorded data parameter.

The maximum rate of change of busbar voltage, the maximum rate of change of frequency and frequency difference between stand-by feeder and busbar, busbar frequency, busbar voltage, phase angle difference between stand-by feeder and busbar are provided by Max dv/dt, Max df/dt, Bus frequency, Bus voltage, Phase Diff recorded data parameters respectively at the instance transfer complete is activated.

9.12.6 Application

The High speed transfer device is utilized where the availability of a safe voltage supply is important and where a breakdown of the electrical energy supply would mean an interruption in production and thus lead to costs and/or damages as a result.

The usual areas of installation include, for example:

1. Auxiliary distributions in power stations, for example

- Steam power stations
- Combined cycle power plants
- Nuclear power stations

2. Environmental technology installations
   - Flue gas purification
   - Refuse incineration installations
3. Voltage supply to continuous industrial processes
   - Chemical plants
   - Industrial facilities with high degrees of automation
   - Fiber manufacturing
   - Petrochemical processes

A typical switchgear configuration with two circuit breakers is shown in *Figure 951*. One of the two feeders is connected to the busbar. One of the two feeder’s circuit breaker is closed, the other is open. A parallel operation of both feeders is not intended. If an error leads to an interruption of the feeder currently in operation say feeder 1, the transfer device switches the load over to the second feeder 2 in the shortest possible time. Following successful transfer, the busbar is then supplied by the second feeder 2. Once the main feeder 1 is again in operation, a manually-initiated transfer back can take place and the normal status can be restored once again. A protection-initiated transfer can be executed from either of feeder 1 or feeder 2.

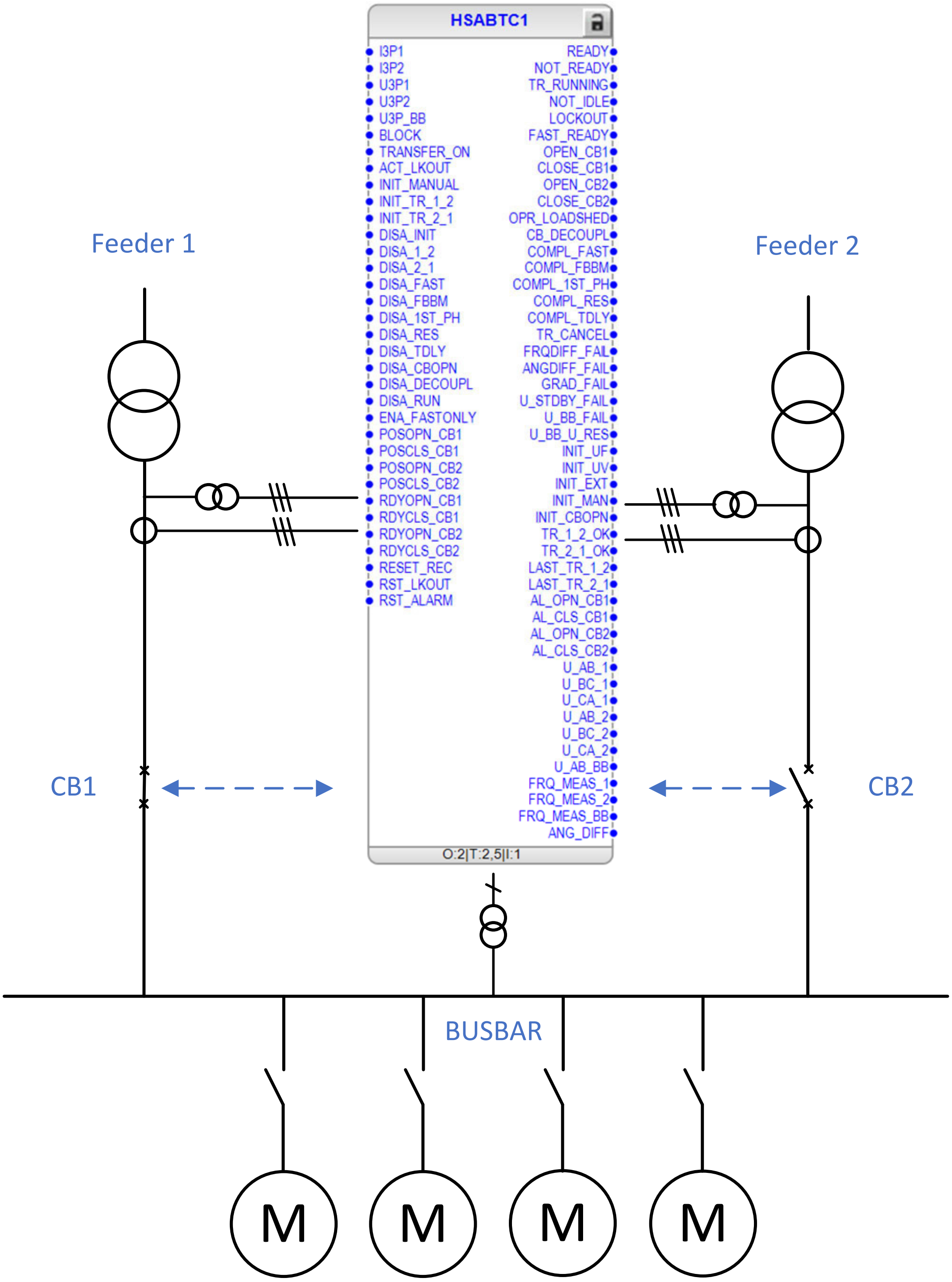


Figure 951: Busbar with two feeders

This function is intended to perform the core responsibility of the High speed transfer device, i.e., to transfer the busbar load from one feeder to another upon initiation in the shortest possible time, safely. The primary functional mode of this function is the execution of fast transfer. In this, the commands are issued simultaneously to the respective circuit breakers which is to be opened or closed, on condition that the feeders be synchronous with one another. In the event of non-synchronous feeders or break before make arrangements, it offers a number of other mechanisms such as FBBM transfer, first phase transfer, residual voltage transfer and time delayed transfer.

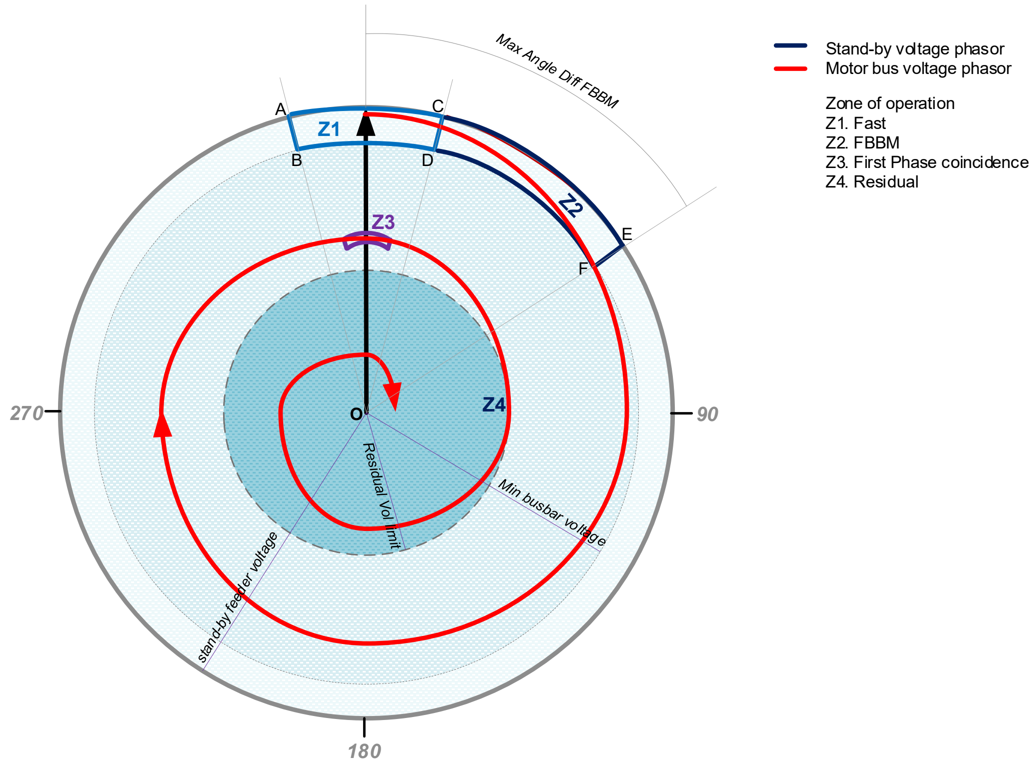


Figure 952: Busbar phasor and zones of operation for different transfer modes

The *Figure 952* provides an insight into the movement of busbar voltage phasor w.r.t stand-by feeder voltage phasor after the circuit breaker of the main supply feeder is opened. The busbar voltage phasor starts to move away from the stand-by feeder phasor. The rate of this movement is guided by the frequency difference and rate of change of frequency difference between the stand-by feeder and busbar voltage phasors. The rate of this movement depends upon the moment of inertia of the motors and the loads connected to the busbar.

The radius of the outermost circle in the *Figure 952* represent the voltage magnitude of the stand-by feeder. The radius of inner circle represents the setting, *Min busbar voltage* magnitude used for Fast and FBBM transfer. The radius of innermost circle represents the setting, *Res voltage limit*.

Fast transfer can occur if the busbar phasor lies in the zone Z1, defined by the area under curve ACDB, after transfer initiation is active. This area reflects the criterion for the fast transfer to occur i.e., the phase angle difference, frequency difference between stand-by feeder and busbar voltage phasor must within specified limits and busbar voltage phasor magnitude must be above the specified limit defined by minimum busbar voltage setting.

FBBM mode attempts to transfer such that the phase angle difference between stand-by voltage and busbar voltage phasor lies within a defined limit, represented by Max Angle Diff FBBM, after the stand-by feeder is completely closed. It estimates this advance phase angle difference ahead of CB closing time based on the prevailing frequency difference and rate of change of frequency difference between the stand-by and busbar voltage. Fast break before make, FBBM, transfer can occur if the estimated busbar phasor, after advance angle adjustment, lies in the zone Z2, defined by the area under the curve AEFB.

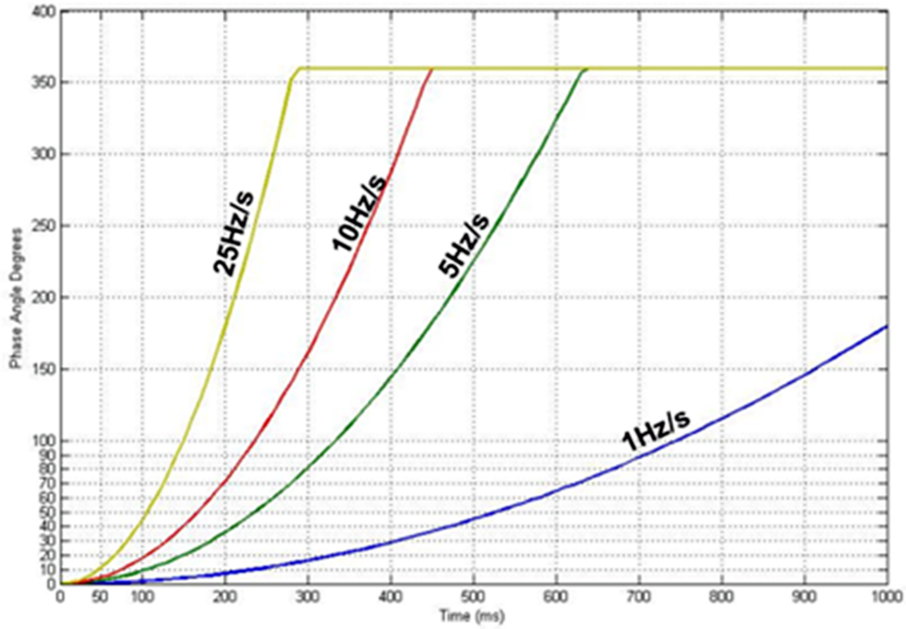


Figure 953: Trajectory of phase-angle in relation to time

Figure 953 shows the trajectory of phase angle between stand-by feeder and busbar and voltages and time after main supply feeder opening. It is shown for various linear rates of frequency difference between the stand-by feeder and busbar, assuming main supply feeder and stand-by feeders were in synch and the frequency difference is zero prior to circuit breaker opening for main supply feeder. FBBM transfer mode is suitable for setups having low frequency difference and rate of change of frequency difference between the stand-by and busbar voltage.

First phase coincidence mode attempts to transfer at the 1st phase coincidence, differential voltage minimum, between the stand-by feeder and busbar voltages through anticipatory computation. It estimates the phase angle difference between the stand-by feeder and busbar voltage ahead of CB closing time keeping into account the prevailing frequency difference and rate of change of frequency difference between the stand-by and busbar voltage. It attempts to transfer such that phase angle difference is zero (ideally zero, practically near zero) after stand-by feeder is completely closed. First phase coincidence transfer can occur if the estimated busbar phasor, after anticipatory calculation, lies in the zone Z3.

Residual mode attempts to transfer if busbar voltage magnitude drops below predefined setting, *Res voltage limit*. Residual transfer can occur if the busbar phasor lies in the zone Z4, represented by the area under the inner most circle with radius *Res voltage limit*.

Application variants

The following different variants, depending on various circuit breaker configurations, can be realized with the instances of this function.

Application package APP51

The following different variants, depending on various circuit breaker configurations, can be realized with the instances of this function.

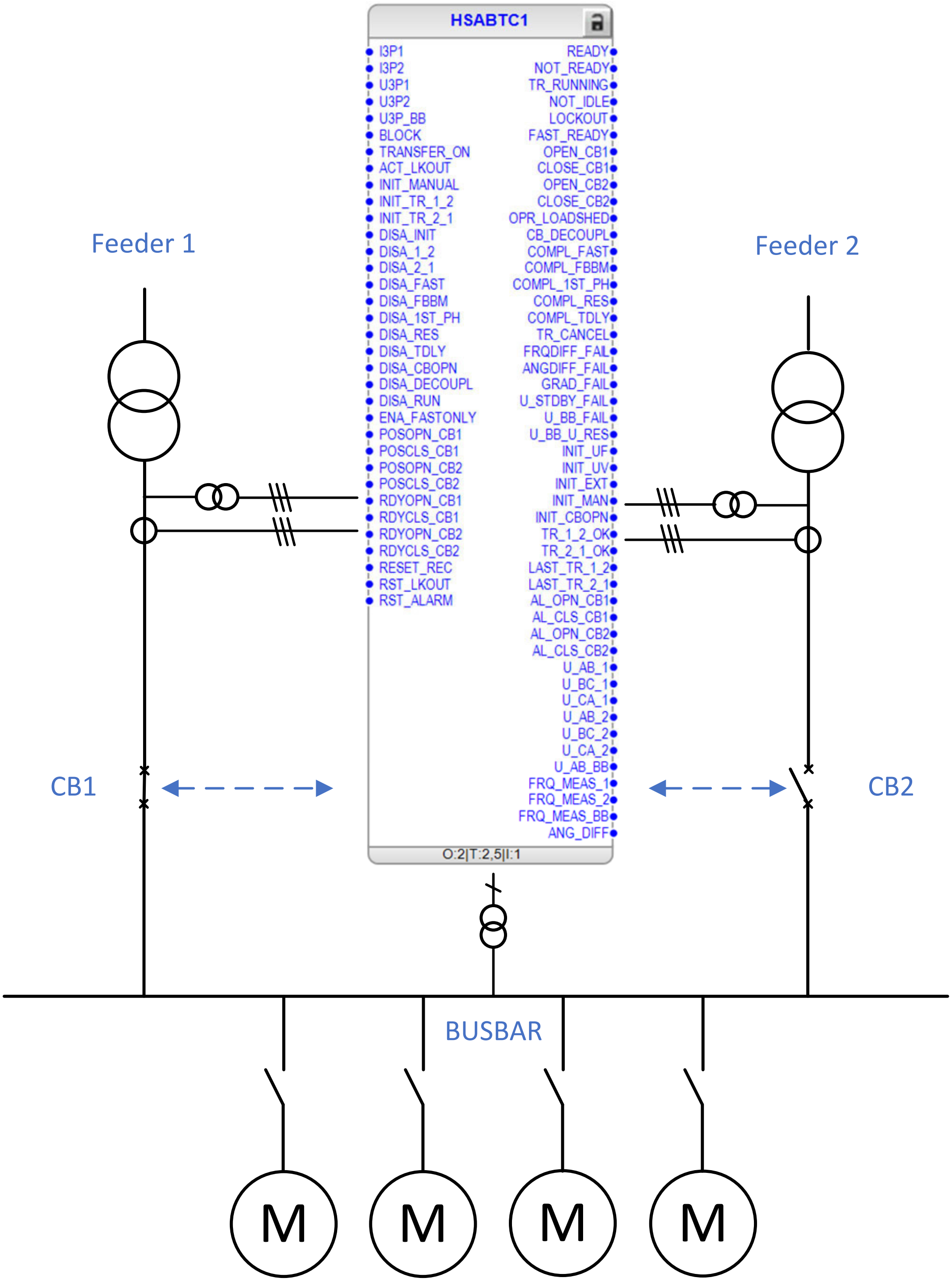


Figure 954: Application package APP51

2-Circuit-breaker configuration

- One busbar
- Transfer takes place between the two feeders

- One instance of HSABTC function can perform the transfer operation between feeder 1 and feeder 2.

Application package APP52

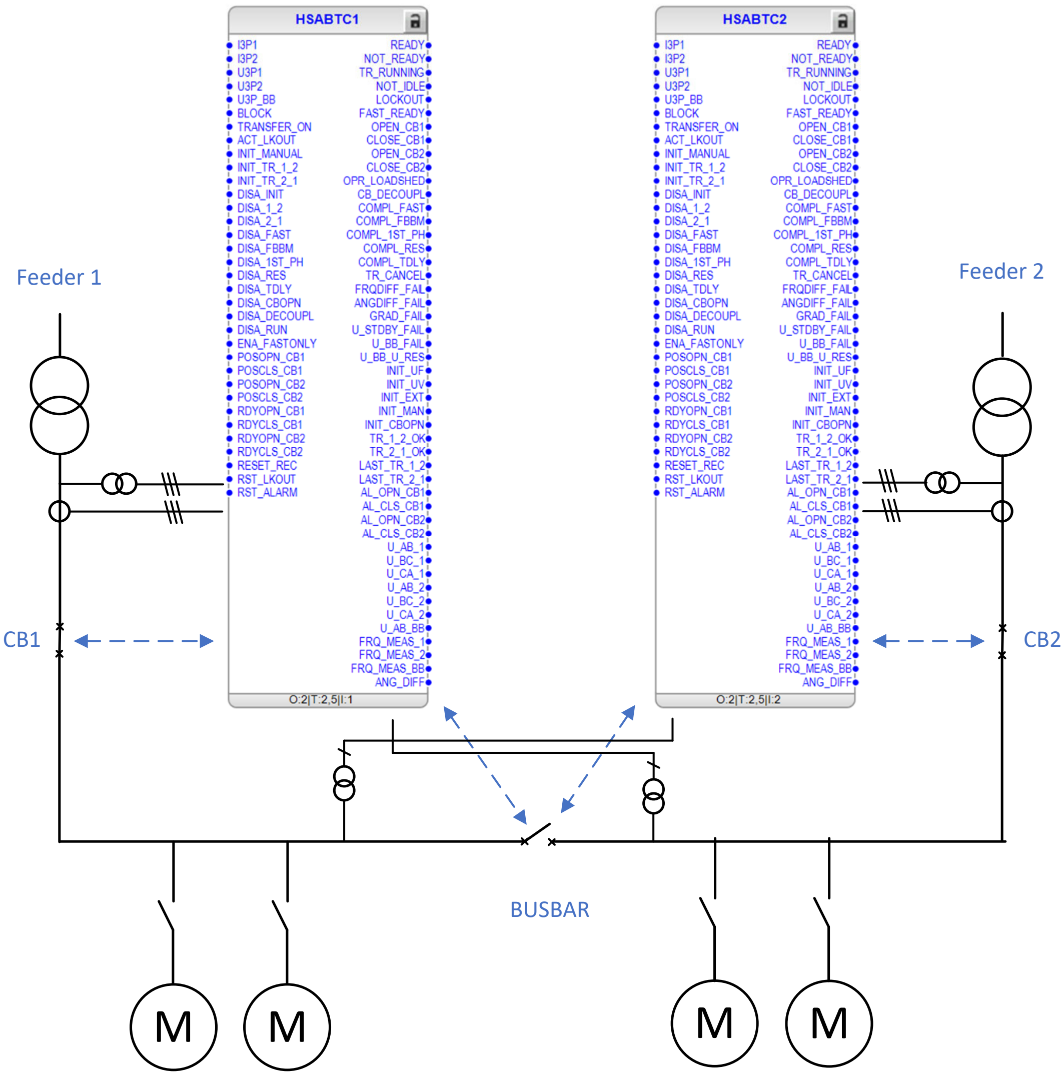


Figure 955: Application package APP52

3-Circuit-breaker configuration

- Two busbar sections, Busbar coupling breaker
- Transfer between each feeder and bus coupling breaker
- Two instances of HSABTC function are required for this variant. The first instance performs the transfer operation between feeder 1 and bus coupling breaker. The second instance performs the transfer operation between feeder 2 and bus coupling breaker.

Application package APP52

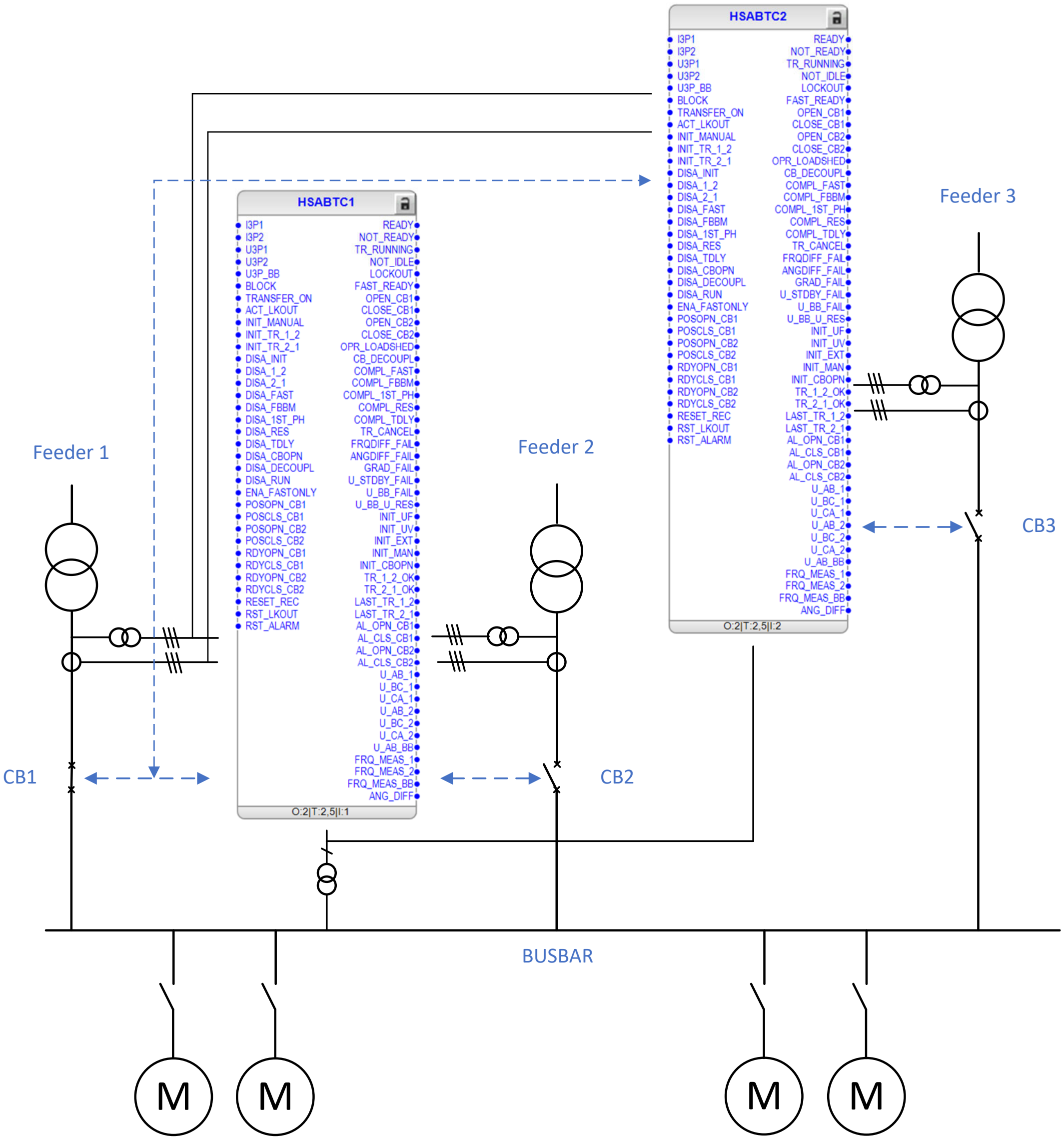


Figure 956: Application package APP52

3-Circuit-breaker configuration with pre-selection

- One busbar
- 2 out of 3 selection
- Two instances of HSABTC function are required for this variant. The first instance performs the transfer operation between feeder 1 and feeder 2. The second instance performs the transfer operation between feeder 1 and feeder 3.

Application package APP53

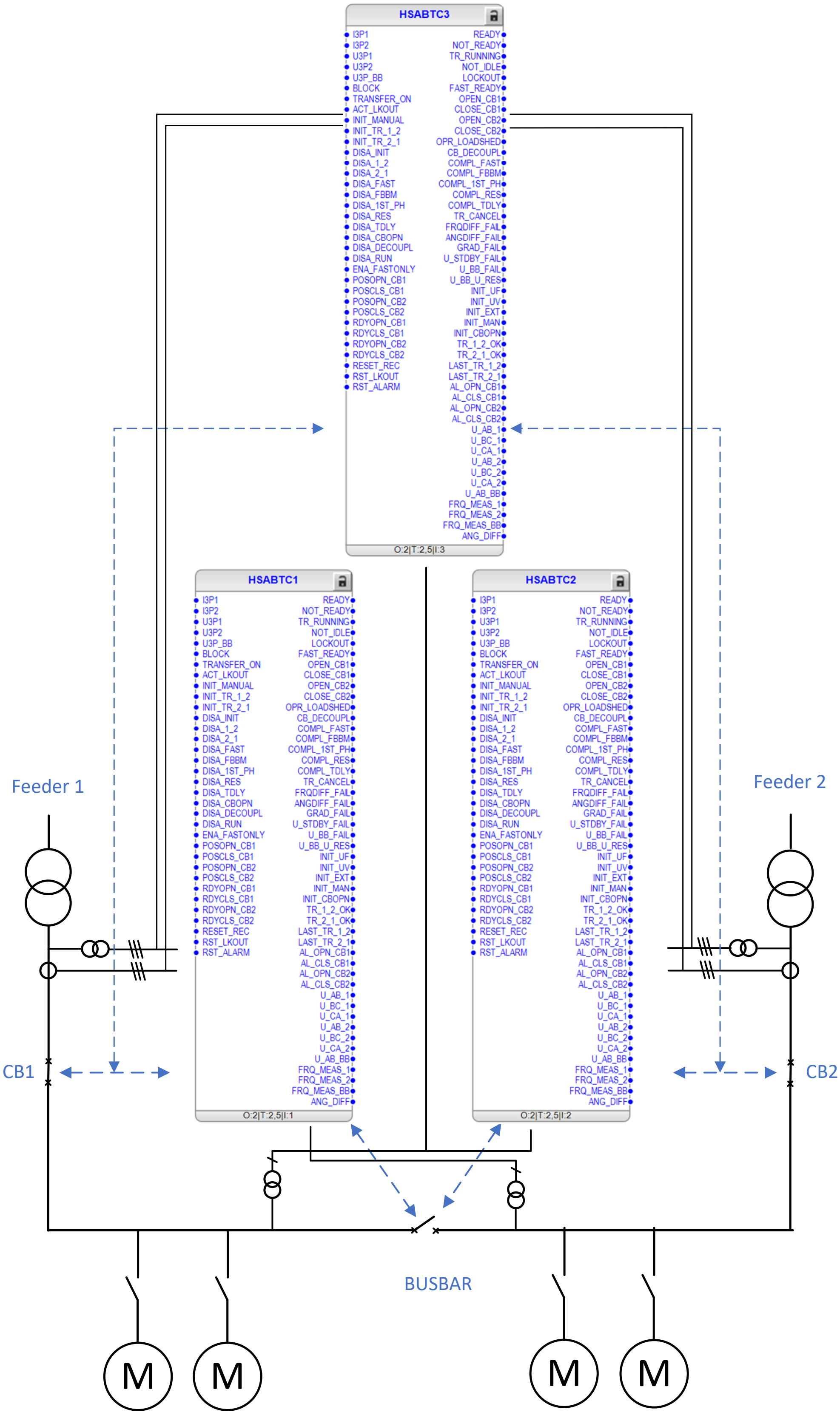


Figure 957: Application package APP53

3-Circuit-breaker configuration

- 2 busbar sections, Busbar coupling breaker
- Transfer takes place between the two feeders and bus coupling breaker and feeder 1 and feeder 2 when bus coupler breaker is closed.
- Three instances of HSABTC function are required for this variant. The first instance performs the transfer operation between feeder 1 and bus coupling breaker. The second instance performs the transfer operation between feeder 2 and bus coupling breaker. The third instance performs the transfer operation between feeder 1 and feeder 2.

Application package APP53

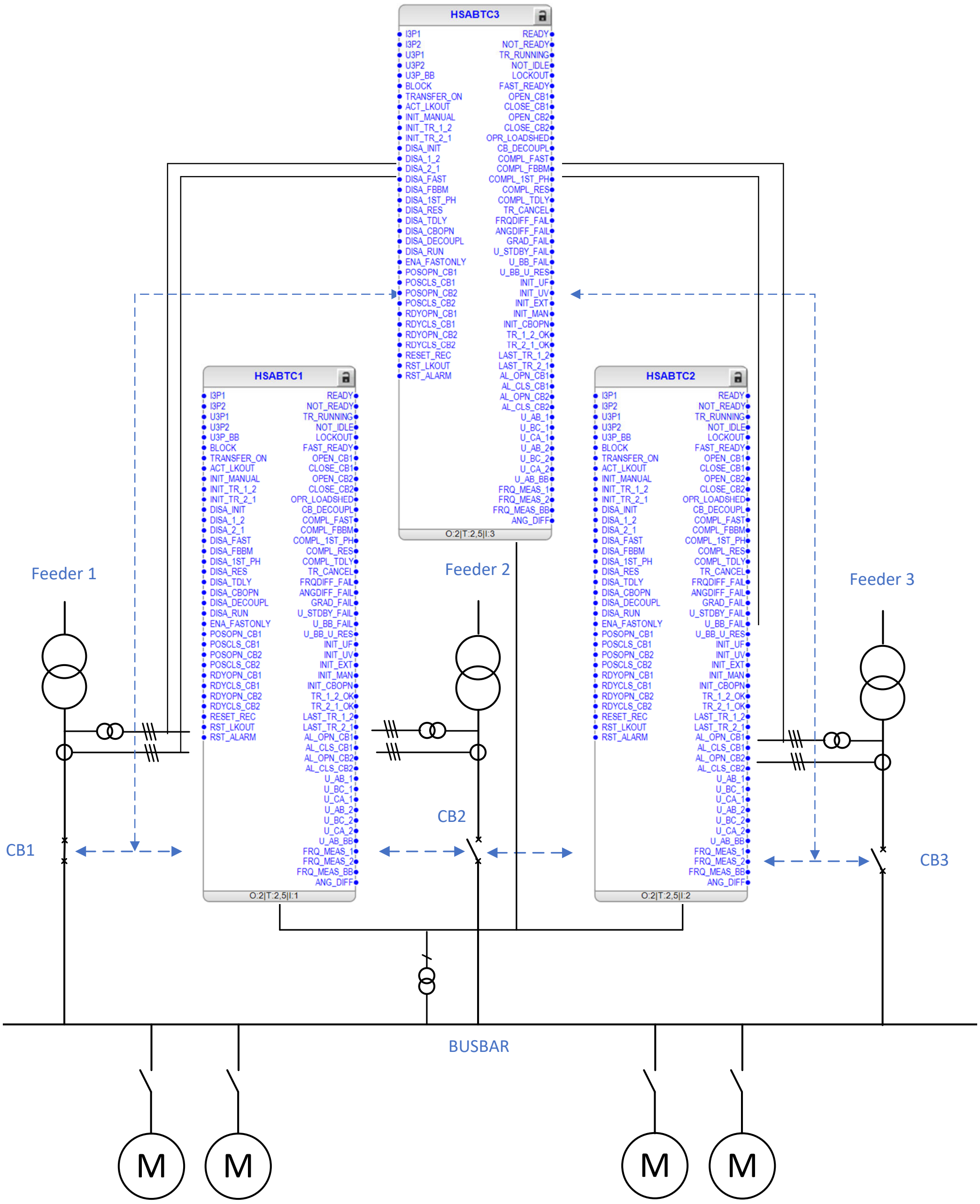


Figure 958: Application package APP53

3-Circuit-breaker configuration with pre-selection

- One busbar
- Transfer takes place between each feeder
- Three instances of HSABTC function are required for this variant. The first instance performs the transfer operation between feeder 1 and feeder 2. The second instance performs the transfer operation between feeder 1 and feeder 3. The third instance performs the transfer operation between feeder 2 and feeder 3.

9.12.7 Signals

9.12.7.1 HSABTC Input signals

Table 1608: HSABTC Input signals

Name	Type	Default	Description
I3P1	SIGNAL	-	Three-phase currents 1
I3P2	SIGNAL	-	Three-phase currents 2
U3P1	SIGNAL	-	Three-phase voltages (Bus B side)
U3P2	SIGNAL	-	Three-phase voltages (Bus A side)
U3P_BB	SIGNAL	-	Analog input
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
TRANSFER_ON	BOOLEAN	0=False	Level sensitive signal for enabling transfer
ACT_LKOUT	BOOLEAN	0=False	Activate transfer lock-out until function is reset
INIT_MANUAL	BOOLEAN	0=False	Manual transfer initiation
INIT_TR_1_2	BOOLEAN	0=False	Transfer initiation from feeder 1 to feeder 2
INIT_TR_2_1	BOOLEAN	0=False	Transfer initiation from feeder 2 to feeder 1
DISA_INIT	BOOLEAN	0=False	Disable transfer initiation
DISA_1_2	BOOLEAN	0=False	Disable transfer from feeder 1 to feeder 2

Table continues on the next page

Name	Type	Default	Description
DISA_2_1	BOOLEAN	0=False	Disable transfer from feeder 2 to feeder 1
DISA_FAST	BOOLEAN	0=False	Disable transfer based on fast trans-fer
DISA_FBBM	BOOLEAN	0=False	Disable transfer based on fast break before make
DISA_1ST_PH	BOOLEAN	0=False	Disable transfer based on first phase coincidence
DISA_RES	BOOLEAN	0=False	Disable transfer based on residual voltage
DISA_TDLY	BOOLEAN	0=False	Disable transfer based on time delay
DISA_CBOPN	BOOLEAN	0=False	Disable transfer ini-tiation based on CB open transfer
DISA_DECOUPL	BOOLEAN	0=False	Disable decoupling
DISA_RUN	BOOLEAN	0=False	Disable transfer com-pletion when active
ENA_FASTONLY	BOOLEAN	0=False	Enable fast transfer only
POSOPN_CB1	BOOLEAN	0=False	Signal for open po-sition of apparatus from I/O
POSCLS_CB1	BOOLEAN	0=False	Signal for close po-sition of apparatus from I/O
POSOPN_CB2	BOOLEAN	0=False	Signal for open po-sition of apparatus from I/O
POSCLS_CB2	BOOLEAN	0=False	Signal for close po-sition of apparatus from I/O
RDYOPN_CB1	BOOLEAN	0=False	Circuit breaker ready to open feeder 1
RDYCLS_CB1	BOOLEAN	0=False	Circuit breaker ready to close feeder 1
RDYOPN_CB2	BOOLEAN	0=False	Circuit breaker ready to open feeder 2
RDYCLS_CB2	BOOLEAN	0=False	Circuit breaker ready to close feeder 2
RESET_REC	BOOLEAN	0=False	Reset recorded data

Table continues on the next page

Name	Type	Default	Description
RST_LKOUT	BOOLEAN	0=False	Reset lockout
RST_ALARM	BOOLEAN	0=False	Reset traveling time alarms

9.12.7.2 HSABTC Output signals

Table 1609: HSABTC Output signals

Name	Type	Description
READY	BOOLEAN	Ready for transfer
NOT_READY	BOOLEAN	Not ready for transfer
TR_RUNNING	BOOLEAN	Transfer is in running state
NOT_IDLE	BOOLEAN	Transfer is not in idle state
LOCKOUT	BOOLEAN	Transfer lockout status
FAST_READY	BOOLEAN	Ready for fast transfer
OPEN_CB1	BOOLEAN	Open command for feeder 1 breaker
CLOSE_CB1	BOOLEAN	Close command for feeder 1 breaker
OPEN_CB2	BOOLEAN	Open command for feeder 2 breaker
CLOSE_CB2	BOOLEAN	Close command for feeder 2 breaker
OPR_LOADSHED	BOOLEAN	Activate load shedding
CB_DECOUPL	BOOLEAN	CB decoupling activated
COMPL_FAST	BOOLEAN	Fast transfer complete
COMPL_FBBM	BOOLEAN	Fast break before make transfer complete
COMPL_1ST_PH	BOOLEAN	First phase coincidence transfer complete
COMPL_RES	BOOLEAN	Residual voltage based transfer complete
COMPL_TDLY	BOOLEAN	Time delayed based transfer complete
TR_CANCEL	BOOLEAN	Transfer cancelled
FRQDIFF_FAIL	BOOLEAN	Frequency difference is not in range for fast transfer
ANGDIFF_FAIL	BOOLEAN	Phase angle difference is not in range for fast transfer
GRAD_FAIL	BOOLEAN	Frequency gradient over permissible for 1st phase transfer

Table continues on the next page

Name	Type	Description
U_STDBY_FAIL	BOOLEAN	Standby voltage below permissible limit for transfer
U_BB_FAIL	BOOLEAN	Busbar voltage below permissible limit for fast transfer
U_BB_U_RES	BOOLEAN	Busbar voltage below residual voltage limit
INIT_UF	BOOLEAN	Transfer is initiated by under frequency initiation
INIT_UV	BOOLEAN	Transfer is initiated by under voltage initiation
INIT_EXT	BOOLEAN	Transfer is initiated by external initiation
INIT_MAN	BOOLEAN	Transfer is initiated by manual initiation
INIT_CBOPN	BOOLEAN	Transfer initiated by CB open initiation
TR_1_2_OK	BOOLEAN	Transfer is allowed from feeder 1 to feeder 2
TR_2_1_OK	BOOLEAN	Transfer is allowed from feeder 2 to feeder 1
LAST_TR_1_2	BOOLEAN	Last valid transfer has been from feeder 1 to feeder 2
LAST_TR_2_1	BOOLEAN	Last valid transfer has been from feeder 2 to feeder 1
AL_OPN_CB1	BOOLEAN	Circuit breaker 1 opening time alarm
AL_CLS_CB1	BOOLEAN	Circuit breaker 1 closing time alarm
AL_OPN_CB2	BOOLEAN	Circuit breaker 2 opening time alarm
AL_CLS_CB2	BOOLEAN	Circuit breaker 2 closing time alarm
U_AB_1	FLOAT32	Analog output
U_BC_1	FLOAT32	Analog output
U_CA_1	FLOAT32	Analog output
U_AB_2	FLOAT32	Analog output
U_BC_2	FLOAT32	Analog output
U_CA_2	FLOAT32	Analog output
U_AB_BB	FLOAT32	Analog output
FRQ_MEAS_1	FLOAT32	Analog output
FRQ_MEAS_2	FLOAT32	Analog output
FRQ_MEAS_BB	FLOAT32	Analog output
ANG_DIFF	FLOAT32	Analog output

9.12.8 HSABTC Settings

Table 1610: HSABTC Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Start Val frequency	0.900...1.100	xFn	0.001	0.980	Under frequency limit for internal transfer initiation
Start Val voltage	0.50...1.20	xUn	0.01	0.70	Under voltage limit for internal transfer initiation
Under frequency time	10...1000	ms	1	100	Under frequency initiation delay
Under voltage time	10...1000	ms	1	100	Under voltage initiation delay
Min standby voltage	0.05...1.20	xUn	0.01	0.70	Minimum standby feeder voltage
Min busbar voltage	0.05...1.20	xUn	0.01	0.70	Minimum busbar voltage
Residual voltage limit	0.01...1.00	xUn	0.01	0.10	Residual voltage limit for residual transfer

Table 1611: HSABTC Group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Loadshed V limit	0.05...1.00		0.01	0.50	Busbar voltage limit in load shedding
Loadshed V time delay	0...200000	ms	10	0	Voltage based load shedding time delay
Loadshed time delay	100...200000	ms	10	100	Load shedding time delay

Table 1612: HSABTC Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Operation mode	1=Only ext 2=Freq< 3=U< 4=Both			1=Only ext	Operation mode for transfer initiation
Enable fast transfer	1=1>2 2=2>1 3=Both 4=Off			3=Both	Enable fast transfer
Enable FBBM	0=False 1=True			0=False	Enable Fast break before make transfer
Ena 1st Ph transfer	1=1>2 2=2>1 3=Both 4=Off			4=Off	Ena 1st phase transfer
Ena Res V transfer	1=1>2 2=2>1			3=Both	Enable residual voltage transfer

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
	3=Both 4=Off				
Ena Time delay transfer	1=1>2 2=2>1 3=Both 4=Off			3=Both	Enable Time delay transfer
Ena CB open transfer	1=1>2 2=2>1 3=Both 4=Off			4=Off	Enable transfer based on CB opening
Manual transfer	1=Off 2=On 3=Fast MBB			1=Off	Enable manual transfer
Max frequency Diff	0.05...2.50	Hz	0.01	1.00	Maximum frequency difference limit for fast transfer
Maximum phase lead	5...50	deg	1	20	Maximum phase lead limit for fast transfer
Maximum phase lag	5...50	deg	1	20	Maximum phase lag limit for fast transfer
Max angle Diff FBBM	5...90	deg	1	45	Max phase angle allowed for fast break before make transfer
Maximum DfDt	5...40		1	40	Maximum DfDt limit for transfer
Transfer delay time	100...200000	ms	1	2000	Time delayed transfer activation time
Max Trn run time	100...200000	ms	1	5000	Maximum transfer running time
Travel time Clc mode	1=From Cmd to Pos 2=From Pos to Pos 3=From Cmd to Curr 4=From Pos to Curr			1=From Cmd to Pos	Travel time calculation mode selection
CB open alarm time	0...1000	ms	1	60	Alarm level setting for open travel time in ms
CB close alarm time	0...1000	ms	1	80	Alarm level setting for close travel time in ms
CB closing time Dif	0...1000	ms	1	10	Allowed closing time difference for alarm activation in ms

Table 1613: HSABTC Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Transfer wait time	100...200000	ms	10	5000	Transfer wait time until new transfer is allowed
Closing time of CB1	0...200	ms	1	60	Closing time of the breaker feeder1
Closing time of CB2	0...200	ms	1	60	Closing time of the breaker feeder2

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Opening time of CB1	0...200	ms	1	40	Opening time of the breaker feeder1
Opening time of CB2	0...200	ms	1	40	Opening time of the breaker feeder2
Close cmd delay time	0...200	ms	1	0	Breaker close command delay time
Load shedding mode	1=None 2=Instantaneous 3=Voltage based 4=Time based			1=None	Load shedding operation mode
Enable decoupling	1=Off 2=Transfer based 3=CB man close 4=Both			1=Off	Enable circuit breaker decoupling
Decoupling delay	50...200000	ms	1	1000	Circuit breaker decoupling delay

9.12.9 HSABTC Monitored data

Table 1614: HSABTC Monitored data

Name	Type	Values (Range)	Unit	Description
STATUS	Enum	0=Off 1=Ready - sync 2=Ready - no sync 3=Not ready - sync 4=Not ready - no sync 5=Transfer running 6=Not defined		Transfer status
FRQ_DIFF	FLOAT32	-30.00...30.00	Hz	Frequency difference between standby feeder and busbar
ANG_DIFF_1	FLOAT32	-180.0...180.0	deg	Angle difference between feeder 1 and busbar
ANG_DIFF_2	FLOAT32	-180.0...180.0	deg	Angle difference between feeder 2 and busbar
CLS_T_CB1	FLOAT32	0.0...10000.0	ms	Measured close time for circuit breaker of feeder 1
CLS_T_CB2	FLOAT32	0.0...10000.0	ms	Measured close time for circuit breaker of feeder 2
OPN_T_CB1	FLOAT32	0.0...10000.0	ms	Measured open time for circuit breaker of feeder 1
OPN_T_CB2	FLOAT32	0.0...10000.0	ms	Measured open time for circuit breaker of feeder 2
ACT_CLS_T_CB1	FLOAT32	0.0...10000.0	ms	Active close time for circuit breaker of feeder 1
ACT_CLS_T_CB2	FLOAT32	0.0...10000.0	ms	Active close time for circuit breaker of feeder 2

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
ACT_OPN_T_CB1	FLOAT32	0.0...10000.0	ms	Active open time for circuit breaker of feeder 1
ACT_OPN_T_CB2	FLOAT32	0.0...10000.0	ms	Active open time for circuit breaker of feeder 2
HSABTC1	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Triggering time	Timestamp			Triggering time
Transfer mode	Enum	0=None 1=Fast 2=FBBM 3=Ph coincidence 4=Res Voltage 5=Time delay		Transfer mode
Transfer reason	Enum	0=None 1=External 2=External UV 3=Internal UF 4=Internal UV 5=CB open 6=Manual		Transfer reason
Transfer direction	Enum	0=Unknown 1=1>2 2=2>1		Transfer direction
Transfer duration	FLOAT32	0.0...200000.0	ms	Time between transfer initiation and CB close command
Busbar Max dv/dt	FLOAT32	-100.00...100.00		Maximum rate of change of busbar voltage
Busbar Max df/dt	FLOAT32	-100.00...100.00		Maximum rate of change of frequency of busbar voltage
Busbar voltage	FLOAT32	0.0...10.0		Busbar voltage at the time of CB close command
Busbar frequency	FLOAT32	35.00...75.00	Hz	Busbar frequency at the time of CB close command
Phase difference	FLOAT32	-180.0...180.0	deg	Busbar and standby feeder phase diff at CB close command
CB decoupled	BOOLEAN	0=False 1=True		CB decoupling happened during the transfer
Loadshed operated	BOOLEAN	0=False 1=True		Load shedding operated during transfer
Triggering time	Timestamp			Triggering time
Transfer mode	Enum	0=None 1=Fast 2=FBBM 3=Ph coincidence		Transfer mode

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
		4=Res Voltage 5=Time delay		
Transfer reason	Enum	0=None 1=External 2=External UV 3=Internal UF 4=Internal UV 5=CB open 6=Manual		Transfer reason
Transfer direction	Enum	0=Unknown 1=1>2 2=2>1		Transfer direction
Transfer duration	FLOAT32	0.0...200000.0	ms	Time between transfer initiation and CB close command
Busbar Max dv/dt	FLOAT32	-100.00...100.00		Maximum rate of change of busbar voltage
Busbar Max df/dt	FLOAT32	-100.00...100.00		Maximum rate of change of frequency of busbar voltage
Busbar voltage	FLOAT32	0.0...10.0		Busbar voltage at the time of CB close command
Busbar frequency	FLOAT32	35.00...75.00	Hz	Busbar frequency at the time of CB close command
Phase difference	FLOAT32	-180.0...180.0	deg	Busbar and standby feeder phase diff at CB close command
CB decoupled	BOOLEAN	0=False 1=True		CB decoupling happened during the transfer
Loadshed operated	BOOLEAN	0=False 1=True		Load shedding operated during transfer
Triggering time	Timestamp			Triggering time
Transfer mode	Enum	0=None 1=Fast 2=FBBM 3=Ph coincidence 4=Res Voltage 5=Time delay		Transfer mode
Transfer reason	Enum	0=None 1=External 2=External UV 3=Internal UF 4=Internal UV 5=CB open 6=Manual		Transfer reason
Transfer direction	Enum	0=Unknown 1=1>2 2=2>1		Transfer direction

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Transfer duration	FLOAT32	0.0...200000.0	ms	Time between transfer initiation and CB close command
Busbar Max dv/dt	FLOAT32	-100.00...100.00		Maximum rate of change of busbar voltage
Busbar Max df/dt	FLOAT32	-100.00...100.00		Maximum rate of change of frequency of busbar voltage
Busbar voltage	FLOAT32	0.0...10.0		Busbar voltage at the time of CB close command
Busbar frequency	FLOAT32	35.00...75.00	Hz	Busbar frequency at the time of CB close command
Phase difference	FLOAT32	-180.0...180.0	deg	Busbar and standby feeder phase diff at CB close command
CB decoupled	BOOLEAN	0=False 1=True		CB decoupling happened during the transfer
Loadshed operated	BOOLEAN	0=False 1=True		Load shedding operated during transfer

9.12.10 Technical data

Table 1615: HSABTC Technical data

Characteristic		Value		
Operation accuracy	Voltage	±1.5% of the set value or ±0.002 × Un, frequency range ±10Hz		
	Frequency	±25mHz of the set value		
Initiation time		Minimum	Typical	Maximum
	Under voltage[1, 2, 3]	14 ms	18 ms	21 ms
	Under frequency[2, 3, 4]	47 ms	49 ms	50 ms
	External (binary input)[2, 3, 5]	9 ms	10 ms	12 ms
Initiation time accuracy		±20 ms of the set value		
Operate time accuracy		±1.0% of the set value or ±20 ms		

1 *Start val Voltage* = 0.95 × Un, voltage before fault = 1.0 × Un, fault voltage = 0.9 × set *Start val Voltage*, undervoltage in one phase-to-phase voltage with nominal frequency injected from random phase angle
2 Measured with static power output (SPO)
3 Results based on statistical distribution of 1000 measurements
4 Applies to continuous frequency change. If frequency change ≥ 0.5Hz (disturbance in network or due to test setup), then initiation time is increased with 100ms to prevent false reaction.
5 Excluding the delay of the external triggering device

10 Power quality measurement functions

10.1 Current total demand, harmonic distortion, DC component (TDD, THD, DC) and individual harmonics CHMHAI (ANSI PQM ITHD,IDC)

10.1.1 Identification

Function description	**IEC 61850 identification**	**IEC 60617 identification**	**ANSI/IEEE C37.2 device number**
Current total demand, harmonic distortion, DC component (TDD, THD, DC) and individual harmonics	CHMHAI	PQM3IH	PQM ITHD,IDC

10.1.2 Function block

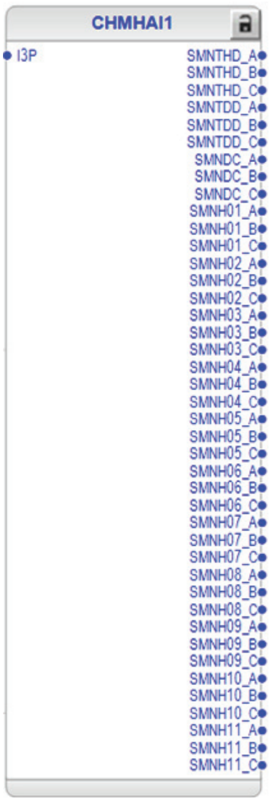


Figure 959: Function block

10.1.3 Functionality

Harmonic current values are available as measurements for each harmonic, THD and TDD. There are also direct current component and fundamental frequency values. The values of three phases are calculated separately.

There are short-time sliding measurement mean values (3 seconds, 1 minute or 5 minutes). In the configuration tool these values can be connected to other logics. Blocks can be used as limiters, timers and multipurpose analog protection, and alarms can be created when needed.

Non-sliding 10-minute measured mean values are available via communication to substation monitoring products such as COM600S. Only the main function part with an analog signal input must be connected in relay configuration. Data can be collected and stored with the substation monitoring system to the historian database.

These mean values can also be found in the LHMI menus of the protection relay and WHMI.

The applicable power quality standards include EN 50160:2010, IEEE 519-2014, IEC 61000-4-7:2002+A1:2008 and IEC 61000-4-30:2015.

10.1.4 Analog channel configuration

CHMHAI has one analog group input which must be properly configured.

Table 1616: Analog inputs

Input	Description
I3P	Three-phase currents

See the preprocessing function blocks in this document for the possible signal sources.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

10.1.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off". Changes will result to reset the function internal data.

The operation of CHMHAI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

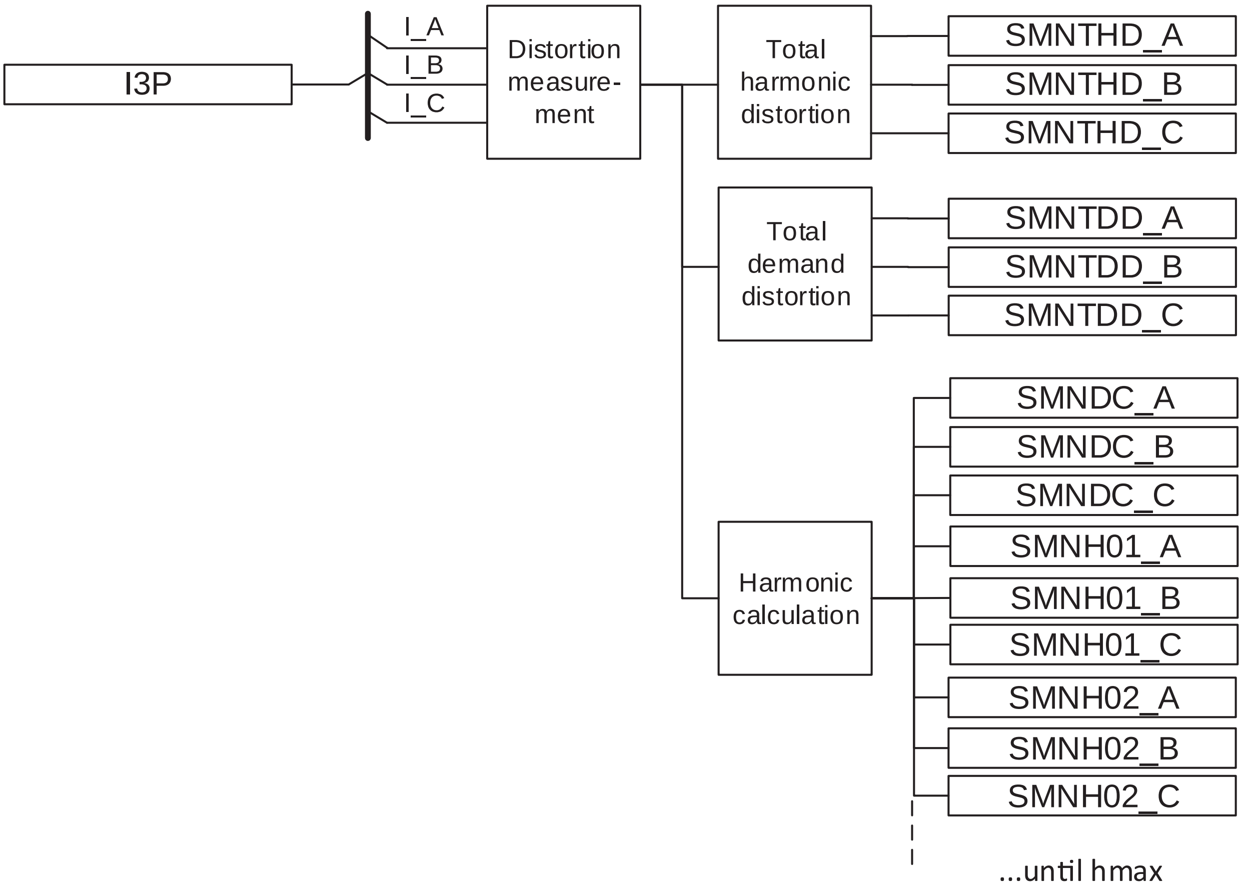


Figure 960: Functional module diagram

10.1.5.1 Distortion measurement

The Distortion measurement module measures harmonics up to the 11^{th} harmonic.

The filter used for harmonics includes a spectrum of frequencies near each harmonic frequency. FFT for one period is used. The resulting frequency spectrum is wider than in a harmonic subgroup. An anti-aliasing filter is used.

10.1.5.2 Total harmonic distortion

The total harmonic distortion THD is calculated from the measured harmonic components with the formula

$$THD = \sqrt{\sum_{h=2}^{n}\left(\frac{I_h}{I_1}\right)^2}$$

(Equation 390)

I_h	h^{th} harmonic component
I_1	Fundamental frequency current (1^{st} harmonic)
n	Number of harmonics

THD sliding mean value outputs are `SMNTHD_A`, `SMNTHD_B` and `SMNTHD_C`. Non-sliding 10-minute mean values LMNTHD_A, LMNTHD_B and LMNTHD_C are seen in the monitored data. These values are always shown as percentage of the fundamental frequency current mean value. The 10-minute mean values follow 10 min ticks. See also *Figure 961* and the description for sliding values.

10.1.5.3 Total demand distortion

The total demand distortion TDD is calculated from the measured harmonic components with the formula

$$TDD = \sqrt{\sum_{h=2}^{n} \left(\frac{I_h}{I_L} \right)^2}$$

(Equation 391)

I_h	h^{th} harmonic component
I_L	Maximum demand load current set with *Demand current setting*
n	Number of harmonics

The used reference current is the absolute value of the *Demand current* setting. It is typically set according to the maximum load current of the feeder. The TDD value is calculated separately for each phase.

TDD sliding mean value outputs are `SMNTDD_A`, `SMNTDD_B` and `SMNTDD_C`. Non-sliding 10-minute mean values LMNTDD_A, LMNTDD_B and LMNTDD_C are seen in the monitored data. These values are always shown as percentage of the setting *Demand current*. The 10-minute mean values follow 10 min ticks. See also *Figure 961* and the description for sliding values.

10.1.5.4 Harmonic calculation

Harmonic mean values are calculated for each phase. Also, the mean values of the nominal frequency (fundamental) and direct current component are calculated. The fundamental frequency mean values are shown as percentage of the nominal phase current.

The actual harmonic mean values are shown as percentage of the reference current. By default, the fundamental frequency current is used as reference. This can be selected by setting *Reference Cur Sel* to "fundamental". When amplitude of fundamental frequency current is very low, below 0.02 xIn, calculation is blocked internally. As a result, value zero is used in the mean value calculation. Extremely high harmonic values are limited to 2.0 xIn. This is also used for fundamental mean value, but not for reference.

The value of Demand current setting can be used as reference by setting *Reference Cur Sel* to "absolute". Typically, it is set according to the maximum demand load current. That is more typically used when TDD is preferred, but might also be found useful when THD is monitored.

Settings *Reference Cur Sel* and *Demand current* have no effect in THD calculation, but setting *Demand current* is used in TDD calculation.

The calculation window length is set with the *Sliding interval* setting. It has three window lengths ("3 seconds", "1 minute" or "5 minutes") for sliding mean value outputs. Output values can also be seen in monitoring.

The window type used for configuration tool output values is always sliding. Output values are updated once every 0.1 seconds.

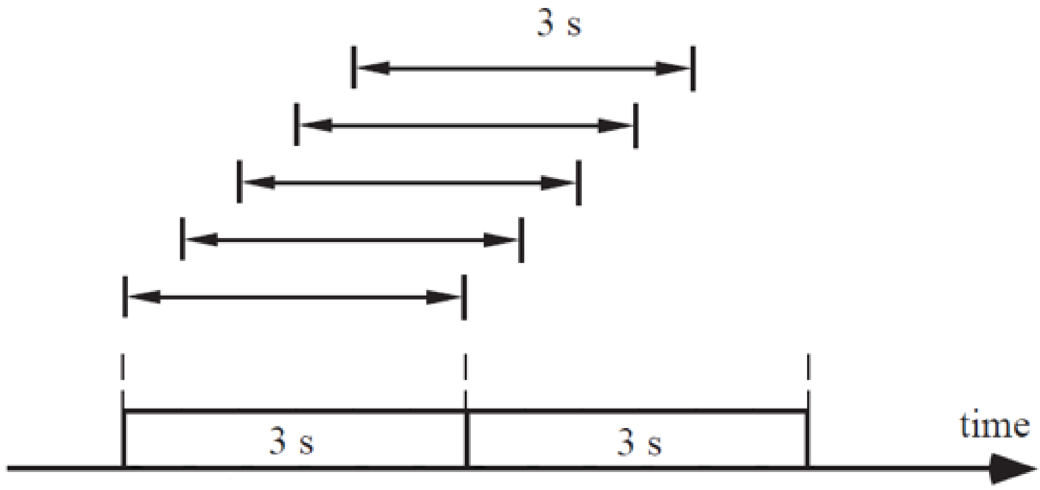


Figure 961: Sliding 3 seconds value calculation in principle

The sliding mean values of the fundamental of each phase are `SMNH01_A`, `SMNH01_B` and `SMNH01_C`. Actual harmonics are seen with their number, for example, phase A for second harmonic is `SMNH02_A` and phase C for 9th harmonic is `SMNH09_C`. Direct current component outputs are `SMNDC_A`, `SMNDC_B` and `SMNDC_C`.

Intervals that are longer than 3 seconds are calculated using free running 3-second mean values.

The longer 10-minute mean values of the fundamental of each phase are seen in monitored data as LMNH01_A, LMNH01_B and LMNH01_C. Actual harmonics are seen with their number. Direct current components are LMNDC_A, LMNDC_B and LMNDC_C.

Time stamps for ready 10-minute mean value calculation can be seen in the monitored data L time stamp.

The window type used for the 10-minute mean value calculation is always non-sliding. The 10-minute value calculation begins based on the protection relay's internal clock 10 minutes time (for example,11:00, 11:10, 11:20, 11:30, 11:40, 11:50, 12:00…). This is called 10 min tick.

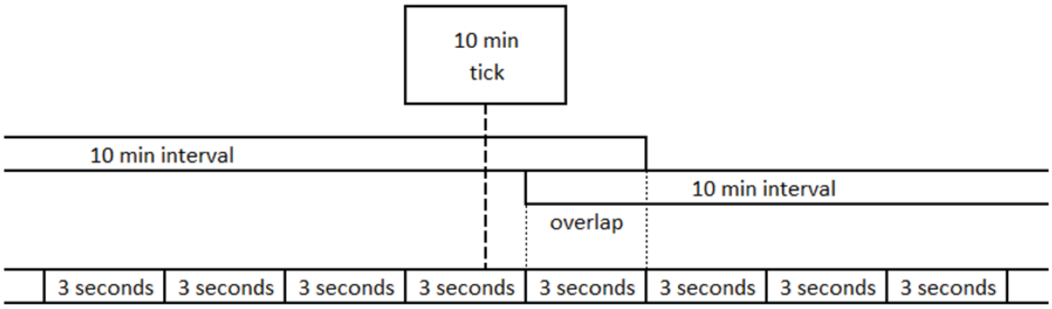


Figure 962: The 10-minute interval with time synchronization and free running 3 seconds

The 10-minute mean value is shown in the monitored data until the next 10-minute mean value has been cumulated. Another 10-minute calculation might be started when time synchronization is used to change the protection relay's internal clock. The first calculation continues for 10 minutes and is then seen in the monitored data with a time stamp. An event is sent every time a 10-minute value calculation is ready in the monitored data.

See the Time synchronization chapter in this document.

When the protection relay is powered on, the shown value is zero until the first 10- minute mean value has been cumulated. During this time, the 10-minute output quality is marked questionable in the IEC 61850 data.

When the settings *Reference Cur Sel* or *Demand current* are changed, older data is not cleared. Although older data is calculated based on different setting values, those can still be used as they are used to calculate mean values. The influence might be seen in mean values. These are considered as minor adjustments to the reference current, similar to varying fundamental current.

Changing setting *Sliding interval* has influence on the seen mean values. Sliding values change slowly towards the input value during the time interval. When mean values have not been calculated for a full interval, quality is marked questionable in the IEC 61850 data. Questionable quality is also indicated for a full interval if the protection relay is reset.

10.1.6 Application

Typically, the measured short-time 3-second mean values are used with a suitable logic to give alarms. If a more stabilized value is needed, a 1-minute or 5-minute mean value should be selected.

One example of using short-time mean values is to compare the level of THD and some harmonics, for example, 5^{th} and 7^{th}. The values to be compared to the same limit can be combined with MAX3R, and MAPGAPC can be used to test if the settable limit value is exceeded. Outputs of MAPGAPC can be connected to the needed logic and, for example, an event can be sent with MVGAPC.

The 10-minute mean values can be collected to an external substation monitoring system. Collected data can be used in weekly reporting. If longer mean values are needed, the collected 10-minute mean values can be used to calculate, for example, two-hour mean values.

Typically, 10-minute THD or TDD mean values are collected from all three phases. Individual harmonics and the fundamental frequency component can also be collected.

10.1.7 Signals

Table 1617: CHMHAI Input signals

Name	Type	Default	Description
I3P	SIGNAL	–	Three-phase currents

Table 1618: CHMHAI Output signals

Name	Type	Description
SMNTHD_A	FLOAT32	Mean THD for phase A in 3 s, 1 min or 5 min mean (%)
SMNTHD_B	FLOAT32	Mean THD for phase B in 3 s, 1 min or 5 min mean (%)
SMNTHD_C	FLOAT32	Mean THD for phase C in 3 s, 1 min or 5 min mean (%)
SMNTDD_A	FLOAT32	Mean TDD for phase A in 3 s, 1 min or 5 min mean (%)
SMNTDD_B	FLOAT32	Mean TDD for phase B in 3 s, 1 min or 5 min mean (%)
SMNTDD_C	FLOAT32	Mean TDD for phase C in 3 s, 1 min or 5 min mean (%)
SMNDC_A	FLOAT32	Shorter mean value of DC component for Phase A (%)
SMNDC_B	FLOAT32	Shorter mean value of DC component for Phase B (%)
SMNDC_C	FLOAT32	Shorter mean value of DC component for Phase C (%)
SMNH01_A	FLOAT32	Shorter mean value of basic freq. for Phase A (%)
SMNH01_B	FLOAT32	Shorter mean value of basic freq. for Phase B (%)
SMNH01_C	FLOAT32	Shorter mean value of basic freq. for Phase C (%)
SMNH02_A	FLOAT32	Shorter mean value of 2nd harmonic for Phase A (%)
SMNH02_B	FLOAT32	Shorter mean value of 2nd harmonic for Phase B (%)
SMNH02_C	FLOAT32	Shorter mean value of 2nd harmonic for Phase C (%)
SMNH03_A	FLOAT32	Shorter mean value of 3rd harmonic for Phase A (%)
SMNH03_B	FLOAT32	Shorter mean value of 3rd harmonic for Phase B (%)
SMNH03_C	FLOAT32	Shorter mean value of 3rd harmonic for Phase C (%)
SMNH04_A	FLOAT32	Shorter mean value of 4th harmonic for Phase A (%)

Table continues on the next page

Name	Type	Description
SMNH04_B	FLOAT32	Shorter mean value of 4th harmonic for Phase B (%)
SMNH04_C	FLOAT32	Shorter mean value of 4th harmonic for Phase C (%)
SMNH05_A	FLOAT32	Shorter mean value of 5th harmonic for Phase A (%)
SMNH05_B	FLOAT32	Shorter mean value of 5th harmonic for Phase B (%)
SMNH05_C	FLOAT32	Shorter mean value of 5th harmonic for Phase C (%)
SMNH06_A	FLOAT32	Shorter mean value of 6th harmonic for Phase A (%)
SMNH06_B	FLOAT32	Shorter mean value of 6th harmonic for Phase B (%)
SMNH06_C	FLOAT32	Shorter mean value of 6th harmonic for Phase C (%)
SMNH07_A	FLOAT32	Shorter mean value of 7th harmonic for Phase A (%)
SMNH07_B	FLOAT32	Shorter mean value of 7th harmonic for Phase B (%)
SMNH07_C	FLOAT32	Shorter mean value of 7th harmonic for Phase C (%)
SMNH08_A	FLOAT32	Shorter mean value of 8th harmonic for Phase A (%)
SMNH08_B	FLOAT32	Shorter mean value of 8th harmonic for Phase B (%)
SMNH08_C	FLOAT32	Shorter mean value of 8th harmonic for Phase C (%)
SMNH09_A	FLOAT32	Shorter mean value of 9th harmonic for Phase A (%)
SMNH09_B	FLOAT32	Shorter mean value of 9th harmonic for Phase B (%)
SMNH09_C	FLOAT32	Shorter mean value of 9th harmonic for Phase C (%)
SMNH10_A	FLOAT32	Shorter mean value of 10th harmonic for Phase A (%)
SMNH10_B	FLOAT32	Shorter mean value of 10th harmonic for Phase B (%)
SMNH10_C	FLOAT32	Shorter mean value of 10th harmonic for Phase C (%)
SMNH11_A	FLOAT32	Shorter mean value of 11th harmonic for Phase A (%)
SMNH11_B	FLOAT32	Shorter mean value of 11th harmonic for Phase B (%)
SMNH11_C	FLOAT32	Shorter mean value of 11th harmonic for Phase C (%)

10.1.8 Settings

Table 1619: CHMHAI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Sliding interval	1=3 seconds 2=1 minute 3=5 minutes			1=3 seconds	Time interval for demand calculation

Table 1620: CHMHAI Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Reference Cur Sel	0=fundamental 2=absolute			0=fundamental	Selection of reference current used with individual harmonics
Demand current	0.10...1.00	xIn	0.01	1.00	Reference current for harmonic demand calculation

10.1.9 Monitored data

Table 1621: CHMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
LMNTHD_A	FLOAT32	0.00...500.00	%	Mean THD for phase A in 10 min non-sliding mean in %
LMNTHD_B	FLOAT32	0.00...500.00	%	Mean THD for phase B in 10 min non-sliding mean in %
LMNTHD_C	FLOAT32	0.00...500.00	%	Mean THD for phase C in 10 min non-sliding mean in %
LMNTDD_A	FLOAT32	0.00...500.00	%	Mean TDD for phase A in 10 min non-sliding mean in %
LMNTDD_B	FLOAT32	0.00...500.00	%	Mean TDD for phase B in 10 min non-sliding mean in %
LMNTDD_C	FLOAT32	0.00...500.00	%	Mean TDD for phase C in 10 min non-sliding mean in %

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
LMNDC_A	FLOAT32	0.00...500.00	%	Longer mean value of DC component for Phase A in %
LMNDC_B	FLOAT32	0.00...500.00	%	Longer mean value of DC component for Phase B in %
LMNDC_C	FLOAT32	0.00...500.00	%	Longer mean value of DC component for Phase C in %
LMNH01_A	FLOAT32	0.00...500.00	%	Longer mean value of basic freq. for Phase A in %
LMNH01_B	FLOAT32	0.00...500.00	%	Longer mean value of basic freq. for Phase B in %
LMNH01_C	FLOAT32	0.00...500.00	%	Longer mean value of basic freq. for Phase C in %
LMNH02_A	FLOAT32	0.00...500.00	%	Longer mean value of 2nd harmonic for Phase A in %
LMNH02_B	FLOAT32	0.00...500.00	%	Longer mean value of 2nd harmonic for Phase B in %
LMNH02_C	FLOAT32	0.00...500.00	%	Longer mean value of 2nd harmonic for Phase C in %
LMNH03_A	FLOAT32	0.00...500.00	%	Longer mean value of 3rd harmonic for Phase A in %
LMNH03_B	FLOAT32	0.00...500.00	%	Longer mean value of 3rd harmonic for Phase B in %
LMNH03_C	FLOAT32	0.00...500.00	%	Longer mean value of 3rd harmonic for Phase C in %
LMNH04_A	FLOAT32	0.00...500.00	%	Longer mean value of 4th harmonic for Phase A in %
LMNH04_B	FLOAT32	0.00...500.00	%	Longer mean value of 4th harmonic for Phase B in %

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
LMNH04_C	FLOAT32	0.00...500.00	%	Longer mean value of 4th harmonic for Phase C in %
LMNH05_A	FLOAT32	0.00...500.00	%	Longer mean value of 5th harmonic for Phase A in %
LMNH05_B	FLOAT32	0.00...500.00	%	Longer mean value of 5th harmonic for Phase B in %
LMNH05_C	FLOAT32	0.00...500.00	%	Longer mean value of 5th harmonic for Phase C in %
LMNH06_A	FLOAT32	0.00...500.00	%	Longer mean value of 6th harmonic for Phase A in %
LMNH06_B	FLOAT32	0.00...500.00	%	Longer mean value of 6th harmonic for Phase B in %
LMNH06_C	FLOAT32	0.00...500.00	%	Longer mean value of 6th harmonic for Phase C in %
LMNH07_A	FLOAT32	0.00...500.00	%	Longer mean value of 7th harmonic for Phase A in %
LMNH07_B	FLOAT32	0.00...500.00	%	Longer mean value of 7th harmonic for Phase B in %
LMNH07_C	FLOAT32	0.00...500.00	%	Longer mean value of 7th harmonic for Phase C in %
LMNH08_A	FLOAT32	0.00...500.00	%	Longer mean value of 8th harmonic for Phase A in %
LMNH08_B	FLOAT32	0.00...500.00	%	Longer mean value of 8th harmonic for Phase B in %
LMNH08_C	FLOAT32	0.00...500.00	%	Longer mean value of 8th harmonic for Phase C in %

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
LMNH09_A	FLOAT32	0.00...500.00	%	Longer mean value of 9th harmonic for Phase A in %
LMNH09_B	FLOAT32	0.00...500.00	%	Longer mean value of 9th harmonic for Phase B in %
LMNH09_C	FLOAT32	0.00...500.00	%	Longer mean value of 9th harmonic for Phase C in %
LMNH10_A	FLOAT32	0.00...500.00	%	Longer mean value of 10th harmonic for Phase A in %
LMNH10_B	FLOAT32	0.00...500.00	%	Longer mean value of 10th harmonic for Phase B in %
LMNH10_C	FLOAT32	0.00...500.00	%	Longer mean value of 10th harmonic for Phase C in %
LMNH11_A	FLOAT32	0.00...500.00	%	Longer mean value of 11th harmonic for Phase A in %
LMNH11_B	FLOAT32	0.00...500.00	%	Longer mean value of 11th harmonic for Phase B in %
LMNH11_C	FLOAT32	0.00...500.00	%	Longer mean value of 11th harmonic for Phase C in %
L time stamp	Timestamp			Time stamp of end of 10 min mean values

10.1.10 Technical data

Table 1622: CHMHAI Technical data

Characteristic	Value
Operation accuracy Nominal frequency 50 Hz. Harmonics in the range 0…0.21 × fundamental amplitude	±3.0 % or ±0.2

10.2 Voltage total harmonic distortion, DC component (THD, DC) and individual harmonics VHMHAI (ANSI PQM VTHD,VDC)

10.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage total harmonic distortion, DC component (THD, DC) and individual harmonics	VHMHAI	PQM3VH	PQM VTHD,VDC

10.2.2 Function block

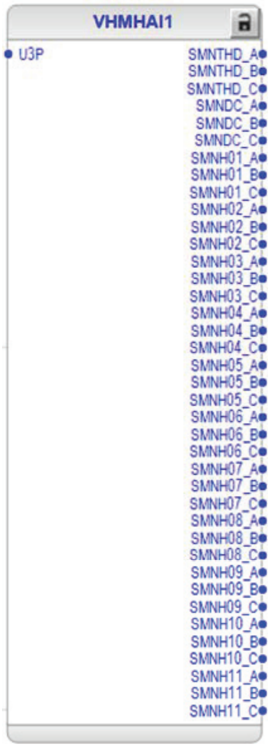


Figure 963: Function block

10.2.3 Functionality

Harmonic voltage values are available as measurements for each harmonic and THD. There are also direct current component and fundamental frequency values. The values of three phases are calculated separately.

There are short-time sliding measurement mean values (3 seconds, 1 minute or 5 minutes) which can be connected to other logics in the configuration tool. Blocks, such as limiters, timers and multipurpose analog protection, can be used and alarms can be created when needed.

Non-sliding 10-minute measured mean values are available via communication to substation monitoring products such as COM600S. Only the main function part with an analog signal input must be connected in relay configuration. Data can be collected and stored with the substation monitoring system to the historian database.

These mean values can also be found in the LHMI menus of the protection relay and WHMI.

The applicable power quality standards include EN 50160:2010, IEEE 519-2014, IEC 61000-4-7:2002+A1:2008 and IEC 61000-4-30:2015.

10.2.4 Analog channel configuration

VHMHAI has one analog group input which must be properly configured.

Table 1623: Analog inputs

Input	Description
U3P	Three-phase voltages for voltage harmonic measurement function VHMHAI

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1624: Special conditions

Condition	Description
U3P connected to real measurements	The function requires that all three voltage channels are connected.

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

10.2.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "on" and "off". Changes will result to reset the function internal data.

The operation of VHMHAI can be described with a module diagram. All the modules in the diagram are explained in the next sections.

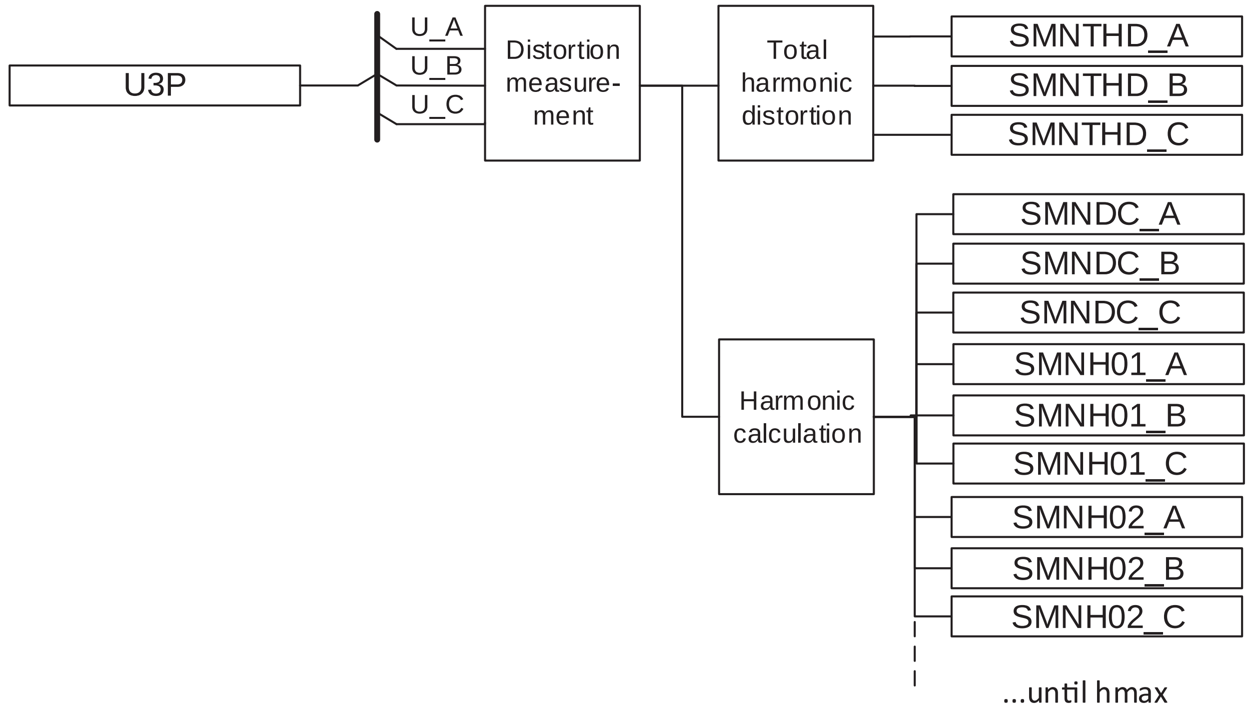


Figure 964: Functional module diagram

10.2.5.1 Distortion measurement

The Distortion measurement module measures harmonics up to the 11th harmonic.

The filter used for harmonics includes a spectrum of frequencies near each harmonic frequency. FFT for one period is used. The resulting frequency spectrum is wider than in a harmonic subgroup. An anti-aliasing filter is used.

10.2.5.2 Total harmonic distortion

The total harmonic distortion THD is calculated from the measured harmonic components with the formula

$$THD = \sqrt{\sum_{h=2}^{n} \left(\frac{I_h}{I_1} \right)^2}$$

(Equation 392)

I_h	hth harmonic component
I_1	Fundamental voltage (1st harmonic)
n	Number of harmonics

THD shorter mean value outputs are `SMNTHD_A`, `SMNTHD_B` and `SMNTHD_C`. These and also the 10-minute mean values LMNTHD_A, LMNTHD_B and LMNTHD_C are seen in the monitored data. These values are always shown as percentage of the fundamental frequency's phase-to-earth voltage 3-second mean value. The 10-minute mean values also follow 10 min ticks. See also *Figure 965* and the description for sliding values.

10.2.5.3 Harmonic calculation

Harmonic mean values are calculated for each phase. Also, the mean values of the nominal frequency (fundamental) and direct current component are calculated. The fundamental frequency mean values are shown as percentage of the nominal phase-to-earth voltage.

The actual harmonic mean values are shown as percentage of the fundamental voltage. When the reference voltage (the fundamental voltage) is extremely low (below 0.02 xUn), the calculation is blocked internally. As a result, value zero is used in the mean value calculation of individual harmonics. Extremely high harmonic values are limited to 2.0 xUn.

The calculation window length is set with the *Sliding interval* setting. It has three window lengths ("3 seconds", "1 minute" or "5 minutes") for shorter mean value outputs. Output values can also be seen in the monitored data.

The window type used for configuration tool output values is always sliding. Output values are updated once every 0.1 seconds.

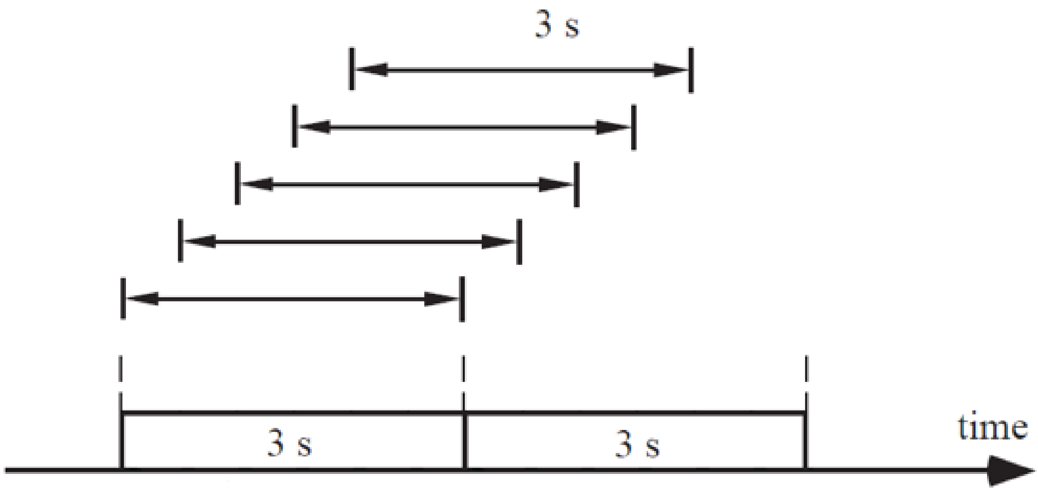


Figure 965: Sliding 3 seconds value calculation in principle

The shorter mean values of the fundamental of each phase are SMNH01_A, SMNH01_B and SMNH01_C. Actual harmonics are seen with their number, for example, phase A for second harmonic is SMNH02_A and phase C for 9th harmonic is SMNH09_C. Direct current component outputs are SMNDC_A, SMNDC_B and SMNDC_C.

Intervals that are longer than 3 seconds are calculated using free running 3-second mean values.

The longer 10-minute mean values of the fundamental of each phase are seen in monitored data as LMNH01_A, LMNH01_B and LMNH01_C. Actual harmonics are seen with their number. Direct current components are LMNDC_A, LMNDC_B and LMNDC_C.

The time stamp for the ready 10-minute mean value calculation can be seen in monitored data L time stamp.

The window type used for the 10-minute mean value calculation is always non-sliding. The 10-minute value calculation begins based on the protection relay's internal clock 10 minutes time (for example,11:00, 11:10, 11:20, 11:30, 11:40, 11:50, 12:00…). This is called 10 min tick.

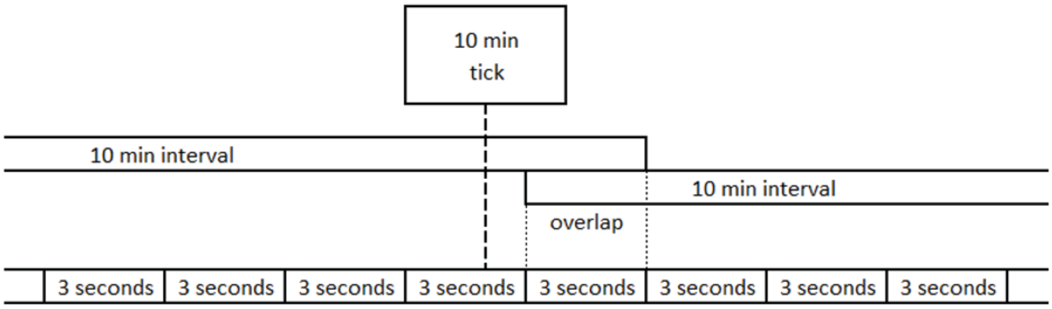


Figure 966: The 10-minute interval with time synchronization and free running 3 seconds

The 10-minute mean value is shown in monitored data until the next 10-minute mean value has been cumulated. Another 10-minute calculation can be started when time synchronization is used to change the protection relay's internal clock. The first calculation continues for 10 minutes and is then seen in the monitored data with a time stamp. An event is sent every time a 10-minute value calculation is ready in the monitored data.

See also the Time synchronization chapter in this document.

When the protection relay is powered on, the shown value is zero until the first 10-minute mean value has been cumulated. During this time, the 10-minute output quality is marked as bad in the IEC 61850 data.

Changing setting *Sliding interval* has influence on the seen mean values. Sliding values change slowly towards the input value during the time interval. When mean values have not been calculated for a full interval, quality is marked as bad in the IEC 61850 data. Bad quality is also indicated after the protection relay has been reset.

10.2.6 Application

Typically, the measured short-time 3-second mean values are used with a suitable logic to give alarms. If a more stabilized value is needed, a 1-minute or 5-minute mean value should be selected.

One example of using short-time mean values is to compare the level of THD and some harmonics, for example, 5^{th} and 7^{th}. The values to be compared to the same limit can be combined with MAX3R, and MAPGAPC can be used to test if the settable limit value is exceeded. Outputs of MAPGAPC can be connected to the needed logic and, for example, an event can be sent with MVGAPC.

The 10-minute mean values can be collected to an external substation monitoring system. Collected data can be used in weekly reporting. If longer mean values are needed, the collected 10-minute mean values can be used to calculate, for example, two-hour mean values.

Typically, 10-minute THD or TDD mean values are collected from all three phases. Individual harmonics and the fundamental frequency component can also be collected.

10.2.7 Signals

Table 1625: VHMHAI Input signals

Name	Type	Default	Description
U3P	SIGNAL	–	Three-phase voltages

Table 1626: VHMHAI Output signals

Name	Type	Description
SMNTHD_A	FLOAT32	Mean THD for phase A in 3 s, 1 min or 5 min mean (%)
SMNTHD_B	FLOAT32	Mean THD for phase B in 3 s, 1 min or 5 min mean (%)
SMNTHD_C	FLOAT32	Mean THD for phase C in 3 s, 1 min or 5 min mean (%)
SMNDC_A	FLOAT32	Shorter mean value of DC component for Phase A (%)
SMNDC_B	FLOAT32	Shorter mean value of DC component for Phase B (%)
SMNDC_C	FLOAT32	Shorter mean value of DC component for Phase C (%)
SMNH01_A	FLOAT32	Shorter mean value of basic freq. for Phase A (%)
SMNH01_B	FLOAT32	Shorter mean value of basic freq. for Phase B (%)
SMNH01_C	FLOAT32	Shorter mean value of basic freq. for Phase C (%)
SMNH02_A	FLOAT32	Shorter mean value of 2nd harmonic for Phase A (%)
SMNH02_B	FLOAT32	Shorter mean value of 2nd harmonic for Phase B (%)
SMNH02_C	FLOAT32	Shorter mean value of 2nd harmonic for Phase C (%)
SMNH03_A	FLOAT32	Shorter mean value of 3rd harmonic for Phase A (%)
SMNH03_B	FLOAT32	Shorter mean value of 3rd harmonic for Phase B (%)
SMNH03_C	FLOAT32	Shorter mean value of 3rd harmonic for Phase C (%)
SMNH04_A	FLOAT32	Shorter mean value of 4th harmonic for Phase A (%)
SMNH04_B	FLOAT32	Shorter mean value of 4th harmonic for Phase B (%)
SMNH04_C	FLOAT32	Shorter mean value of 4th harmonic for Phase C (%)
SMNH05_A	FLOAT32	Shorter mean value of 5th harmonic for Phase A (%)

Table continues on the next page

Name	Type	Description
SMNH05_B	FLOAT32	Shorter mean value of 5th harmonic for Phase B (%)
SMNH05_C	FLOAT32	Shorter mean value of 5th harmonic for Phase C (%)
SMNH06_A	FLOAT32	Shorter mean value of 6th harmonic for Phase A (%)
SMNH06_B	FLOAT32	Shorter mean value of 6th harmonic for Phase B (%)
SMNH06_C	FLOAT32	Shorter mean value of 6th harmonic for Phase C (%)
SMNH07_A	FLOAT32	Shorter mean value of 7th harmonic for Phase A (%)
SMNH07_B	FLOAT32	Shorter mean value of 7th harmonic for Phase B (%)
SMNH07_C	FLOAT32	Shorter mean value of 7th harmonic for Phase C (%)
SMNH08_A	FLOAT32	Shorter mean value of 8th harmonic for Phase A (%)
SMNH08_B	FLOAT32	Shorter mean value of 8th harmonic for Phase B (%)
SMNH08_C	FLOAT32	Shorter mean value of 8th harmonic for Phase C (%)
SMNH09_A	FLOAT32	Shorter mean value of 9th harmonic for Phase A (%)
SMNH09_B	FLOAT32	Shorter mean value of 9th harmonic for Phase B (%)
SMNH09_C	FLOAT32	Shorter mean value of 9th harmonic for Phase C (%)
SMNH10_A	FLOAT32	Shorter mean value of 10th harmonic for Phase A (%)
SMNH10_B	FLOAT32	Shorter mean value of 10th harmonic for Phase B (%)
SMNH10_C	FLOAT32	Shorter mean value of 10th harmonic for Phase C (%)
SMNH11_A	FLOAT32	Shorter mean value of 11th harmonic for Phase A (%)
SMNH11_B	FLOAT32	Shorter mean value of 11th harmonic for Phase B (%)
SMNH11_C	FLOAT32	Shorter mean value of 11th harmonic for Phase C (%)

10.2.8 Settings

Table 1627: VHMHAI Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Sliding interval	1=3 seconds 2=1 minute 3=5 minutes			1=3 seconds	Time interval for demand calculation

10.2.9 Monitored data

Table 1628: VHMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
LMNTHD_A	FLOAT32	0.00...500.00	%	Mean THD for phase A in 10 min non-sliding mean in %
LMNTHD_B	FLOAT32	0.00...500.00	%	Mean THD for phase B in 10 min non-sliding mean in %
LMNTHD_C	FLOAT32	0.00...500.00	%	Mean THD for phase C in 10 min non-sliding mean in %
LMNDC_A	FLOAT32	0.00...500.00	%	Longer mean value of DC component for Phase A in %
LMNDC_B	FLOAT32	0.00...500.00	%	Longer mean value of DC component for Phase B in %
LMNDC_C	FLOAT32	0.00...500.00	%	Longer mean value of DC component for Phase C in %
LMNH01_A	FLOAT32	0.00...500.00	%	Longer mean value of basic freq. for Phase A in %
LMNH01_B	FLOAT32	0.00...500.00	%	Longer mean value of basic freq. for Phase B in %
LMNH01_C	FLOAT32	0.00...500.00	%	Longer mean value of basic freq. for Phase C in %
LMNH02_A	FLOAT32	0.00...500.00	%	Longer mean value of 2nd harmonic for Phase A in %
LMNH02_B	FLOAT32	0.00...500.00	%	Longer mean value of 2nd harmonic for Phase B in %
LMNH02_C	FLOAT32	0.00...500.00	%	Longer mean value of 2nd harmonic for Phase C in %
LMNH03_A	FLOAT32	0.00...500.00	%	Longer mean value of 3rd harmonic for Phase A in %
LMNH03_B	FLOAT32	0.00...500.00	%	Longer mean value of 3rd harmonic for Phase B in %

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
LMNH03_C	FLOAT32	0.00...500.00	%	Longer mean value of 3rd harmonic for Phase C in %
LMNH04_A	FLOAT32	0.00...500.00	%	Longer mean value of 4th harmonic for Phase A in %
LMNH04_B	FLOAT32	0.00...500.00	%	Longer mean value of 4th harmonic for Phase B in %
LMNH04_C	FLOAT32	0.00...500.00	%	Longer mean value of 4th harmonic for Phase C in %
LMNH05_A	FLOAT32	0.00...500.00	%	Longer mean value of 5th harmonic for Phase A in %
LMNH05_B	FLOAT32	0.00...500.00	%	Longer mean value of 5th harmonic for Phase B in %
LMNH05_C	FLOAT32	0.00...500.00	%	Longer mean value of 5th harmonic for Phase C in %
LMNH06_A	FLOAT32	0.00...500.00	%	Longer mean value of 6th harmonic for Phase A in %
LMNH06_B	FLOAT32	0.00...500.00	%	Longer mean value of 6th harmonic for Phase B in %
LMNH06_C	FLOAT32	0.00...500.00	%	Longer mean value of 6th harmonic for Phase C in %
LMNH07_A	FLOAT32	0.00...500.00	%	Longer mean value of 7th harmonic for Phase A in %
LMNH07_B	FLOAT32	0.00...500.00	%	Longer mean value of 7th harmonic for Phase B in %
LMNH07_C	FLOAT32	0.00...500.00	%	Longer mean value of 7th harmonic for Phase C in %
LMNH08_A	FLOAT32	0.00...500.00	%	Longer mean value of 8th harmonic for Phase A in %
LMNH08_B	FLOAT32	0.00...500.00	%	Longer mean value of 8th harmonic for Phase B in %
LMNH08_C	FLOAT32	0.00...500.00	%	Longer mean value of 8th harmonic for Phase C in %
LMNH09_A	FLOAT32	0.00...500.00	%	Longer mean value of 9th harmonic for Phase A in %
LMNH09_B	FLOAT32	0.00...500.00	%	Longer mean value of 9th harmonic for Phase B in %
LMNH09_C	FLOAT32	0.00...500.00	%	Longer mean value of 9th harmonic for Phase C in %
LMNH10_A	FLOAT32	0.00...500.00	%	Longer mean value of 10th harmonic for Phase A in %
LMNH10_B	FLOAT32	0.00...500.00	%	Longer mean value of 10th harmonic for Phase B in %
LMNH10_C	FLOAT32	0.00...500.00	%	Longer mean value of 10th harmonic for Phase C in %

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
LMNH11_A	FLOAT32	0.00...500.00	%	Longer mean value of 11th harmonic for Phase A in %
LMNH11_B	FLOAT32	0.00...500.00	%	Longer mean value of 11th harmonic for Phase B in %
LMNH11_C	FLOAT32	0.00...500.00	%	Longer mean value of 11th harmonic for Phase C in %
L time stamp	Timestamp			Time stamp of end of 10 min mean values

10.2.10 Technical data

Table 1629: VHMHAI Technical data

Characteristic	Value
Operation accuracy Nominal frequency 50 Hz. Harmonics in the range 0…0.21 × fundamental amplitude	±3.0 % or ±0.2

10.3 Voltage variation PHQVVR (ANSI PQMV SWE,SAG,INT)

10.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage variation	PHQVVR	PQMU	PQMV SWE,SAG,INT

10.3.2 Function block

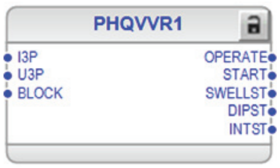


Figure 967: Function block

10.3.3 Functionality

The voltage variation function PHQVVR is used for measuring the short-duration voltage variations in distribution networks.

Power quality in the voltage waveform is evaluated by measuring voltage swells, dips and interruptions. PHQVVR includes single-phase and three-phase voltage variation modes.

Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute. The maximum magnitude (in the case of a voltage swell) or depth (in the case of a voltage dip or interruption) and the duration of the variation can be obtained by measuring the RMS value of the voltage for each phase. International standard 61000-4-30 defines the voltage variation to be implemented using the RMS value of the voltage. IEEE standard 1159-1995 provides recommendations for monitoring the electric power quality of the single-phase and polyphase ac power systems.

PHQVVR contains a blocking functionality. It is possible to block a set of function outputs or the function itself.

10.3.4 Analog channel configuration

PHQVVR has two analog group inputs which must be properly configured.

Table 1630: Analog inputs

Input	Description
I3P [1]	Three-phase currents
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources. The GRPOFF signal is available in the function block called Protection.

There are a few special conditions which must be noted with the configuration.

Table 1631: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with one voltage channel connected (A, B or C depending on the *Phase supervision* setting "Ph A", "Ph B" or "Ph C") if *Phase mode* is set to "Single Phase".
	The function can work with two voltage channel connected (A-B, B-C or C-A depending on the *Phase supervision* setting "Ph A+B", "Ph B+C" or "Ph A+C") if *Phase mode* is set to "Three Phase".
	The function requires that all three voltage channels are connected if *Phase supervision* is set to "Ph A+B+C" and *Phase mode* setting is set to "Three Phase".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

1 Can be connected to GRPOFF

10.3.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of PHQVVR can be described with a module diagram. All the modules in the diagram are explained in the next sections.

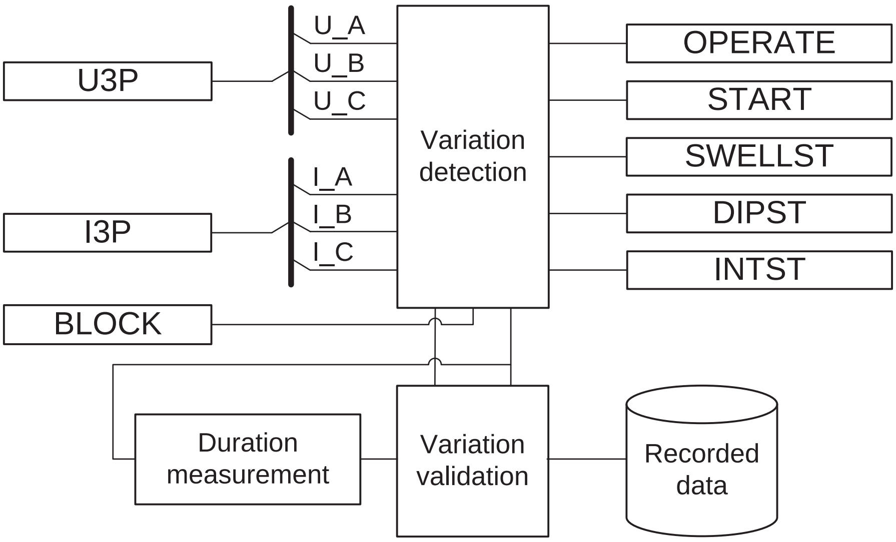


Figure 968: Functional module diagram

10.3.5.1 Phase mode setting

PHQVVR is designed for both single-phase and polyphase ac power systems, and selection can be made with the *Phase mode* setting, which can be set either to the "Single Phase" or "Three Phase" mode. The default setting is "Single Phase".

The basic difference between these alternatives depends on how many phases are needed to have the voltage variation activated. When the *Phase mode* setting is "Single Phase", the activation is straightforward. There is no dependence between the phases for variation start. The START output and the corresponding phase start are activated when the limit is exceeded or undershot. The corresponding phase start deactivation takes place when the limit (includes small hysteresis) is undershot or exceeded. The START output is deactivated when there are no more active phases.

However, when *Phase mode* is "Three Phase", all the monitored phase signal magnitudes, defined with *Phase supervision*, have to fall below or rise above the limit setting to activate the START output and the corresponding phase output, that is, all the monitored phases have to be activated. Accordingly, the deactivation occurs when the activation requirement is not fulfilled, that is, one or more monitored phase signal magnitudes return beyond their limits. Phases do not need to be activated by the same variation type to activate the START output. Another consequence is that if only one or two phases are monitored, it is sufficient that these monitored phases activate the START output.

10.3.5.2 Variation detection

The module compares the measured voltage against the limit settings. If there is a permanent undervoltage or overvoltage, the *Reference voltage* setting can be set to this voltage level to avoid the undesired voltage dip or swell indications. This is accomplished by converting the variation limits with the *Reference voltage* setting in the variation detection module, that is, when there is a voltage different from the nominal voltage, the *Reference voltage* setting is set to this voltage.

The *Variation enable* setting is used for enabling or disabling the variation types. By default, the setting value is "Swell+dip+Int" and all the alternative variation types are indicated. For example, for setting "Swell+dip", the interruption detection is not active and only swell or dip events are indicated.

In a case where *Phase mode* is "Single Phase" and the dip functionality is available, the output `DIPST` is activated when the measured TRMS value drops below the *Voltage dip set 3* setting in one phase and also remains above the *Voltage Int set* setting. If the voltage drops below the *Voltage Int set* setting, the output `INTST` is activated. `INTST` is deactivated when the voltage value rises above the setting *Voltage Int set*. When the same measured TRMS magnitude rises above the setting *Voltage swell set 3*, the `SWELLST` output is activated.

There are three setting value limits for dip (*Voltage dip set 1..3*) and swell activation (*Voltage swell set 1..3*) and one setting value limit for interruption.

If *Phase mode* is "Three Phase", the `DIPST` and `INTST` outputs are activated when the voltage levels of all monitored phases, defined with the parameter *Phase supervision*, drop below the *Voltage Int set* setting value. An example for the detection principle of voltage interruption for "Three Phase" when *Phase supervision* is "Ph A + B + C", and also the corresponding start signals when *Phase mode* is "Single Phase", are as shown in the example for the detection of a three-phase interruption.

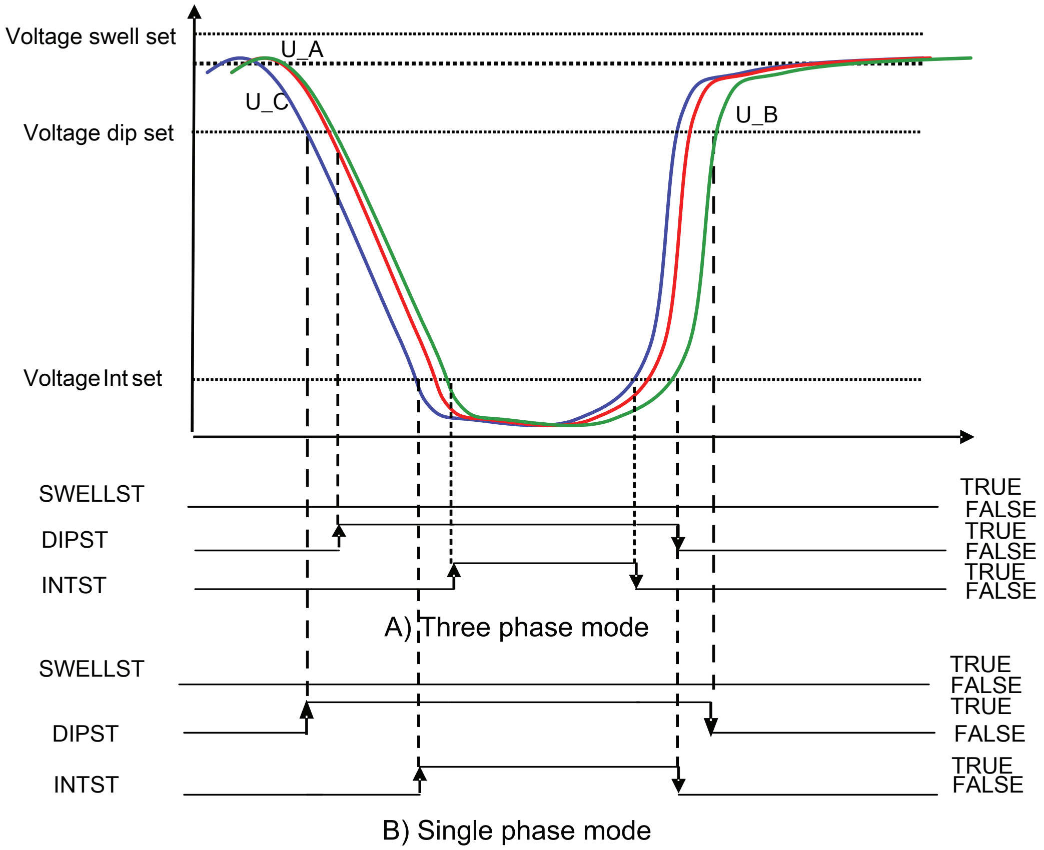


Figure 969: Detection of three-phase voltage interruption

The module measures voltage variation magnitude on each phase separately, that is, there are phase-segregated outputs ST_A, ST_B and ST_C for voltage variation indication. The configuration parameter *Phase supervision* defines which voltage phase or phases are monitored. If a voltage phase is selected to be monitored, the function assumes it to be connected to a voltage measurement channel. In other words, if an unconnected phase is monitored, the function falsely detects a voltage interruption in that phase.

The maximum magnitude and depth are defined as percentage values calculated from the difference between the reference and the measured voltage. For example, a dip to 70 percent means that the minimum voltage dip magnitude variation is 70 percent of the reference voltage amplitude.

The activation of the BLOCK input resets the function and outputs.

10.3.5.3 Variation validation

The validation criterion for voltage variation is that the measured total variation duration is between the set minimum and maximum durations (Either one of *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, depending on the variation type, and *VVa Dur Max*). The maximum variation duration setting is the same for all variation types.

Figure 970 shows voltage dip operational regions. In *Figure 969*, only one voltage dip/swell/Int set is drawn, whereas in this figure there are three sub-limits for the dip operation. When *Voltage dip set 3* is undershot, the corresponding ST_x and also the DIPST outputs are activated. When the TRMS voltage magnitude remains between *Voltage dip set 2* and *Voltage dip set 1* for a period longer than *VVa dip time 2* (shorter time than *VVa dip time 3*), a momentary dip event is detected. Furthermore, if the signal magnitude stays between the limits longer than *VVa dip time 3* (shorter time than *VVa Dur max*), a temporary dip event is detected. If the voltage remains below *Voltage dip set 1* for a period longer than *VVa dip time 1* but a shorter time than *VVa dip time 2*, an instantaneous dip event is detected.

For an event detection, the OPERATE output is always activated for one task cycle. The corresponding counter and only one of them (INSTDIPCNT, MOMDIPCNT or TEMPDIPCNT) is increased by one. If the dip limit undershooting duration is shorter than *VVa dip time 1*, *VVa swell time 1* or *VVa Int time 1*, the event is not detected at all, and if the duration is longer than *VVa Dur Max*, MAXDURDIPCNT is increased by one but no event detection resulting in the activation of the OPERATE output and recording data update takes place. These counters are available through the monitored data view on the LHMI or through tools via communications. There are no phase-segregated counters but all the variation detections are registered to a common time/magnitude-classified counter type. Consequently, a simultaneous multiphase event, that is, the variation-type event detection time moment is exactly the same for two or more phases, is counted only once also for single-phase power systems.

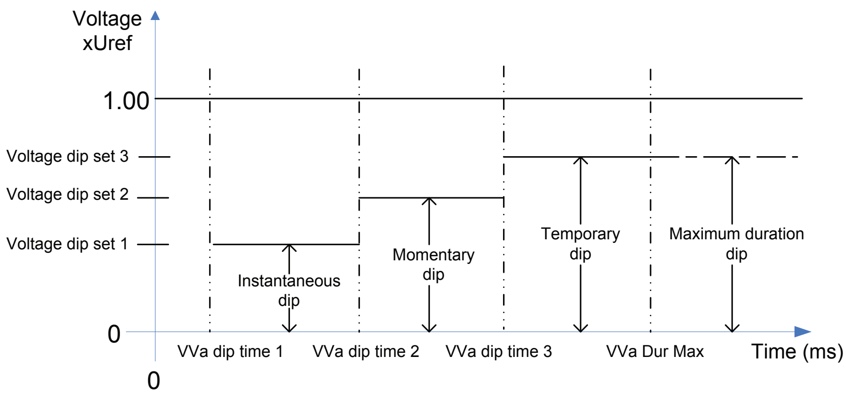


Figure 970: Voltage dip operational regions

In *Figure 971*, the corresponding limits regarding the swell operation are provided with the inherent magnitude limit order difference. The swell functionality principle is the same as for dips, but the different limits for the signal magnitude and times and the inherent operating zone change (here, *Voltage swell set x* > 1.0 xUn) are applied.

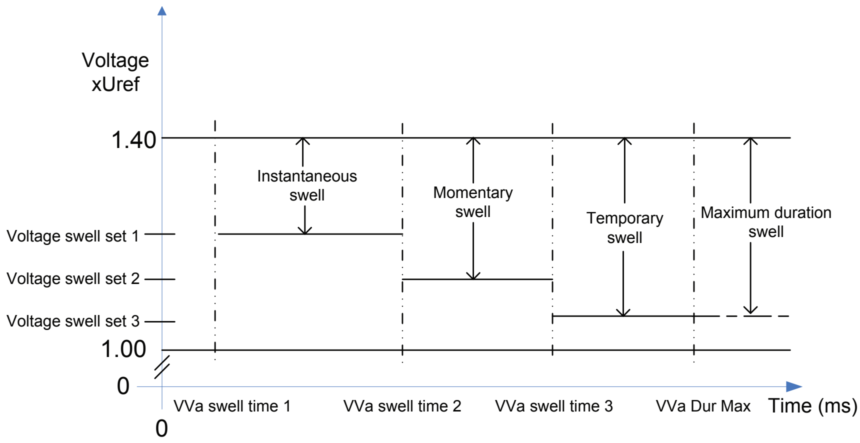


Figure 971: Voltage swell operational regions

For interruption, as shown in *Figure 972*, there is only one magnitude limit but four duration limits for interruption classification. Now the event and counter type depends only on variation duration time.

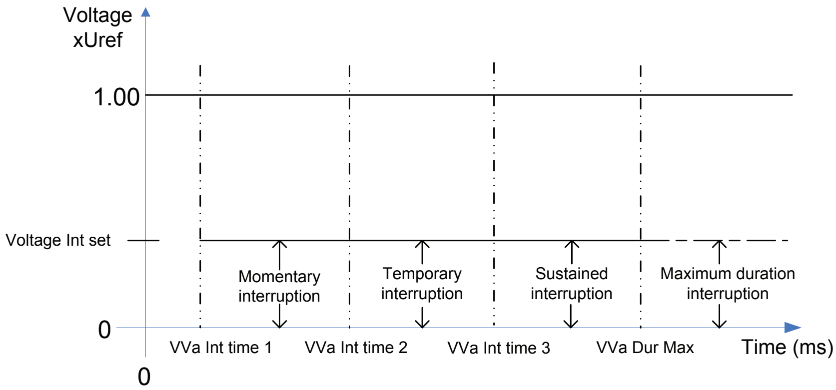


Figure 972: Interruption operating regions

Generally, no event detection is done if both the magnitude and duration requirements are not fulfilled. For example, the dip event does not indicate if the TRMS voltage magnitude remains between *Voltage dip set 3* and *Voltage dip set 2* for a period shorter than *VVa dip time 3* before rising back above *Voltage dip set 3*.

The event indication ends and possible detection is done when the TRMS voltage returns above (for dip and interruption) or below (for swell) the activation-starting limit. For example, after an instantaneous dip, the event indication when the voltage magnitude exceeds *Voltage dip set 1* is not detected (and recorded) immediately but only if no longer dip indication for the same dip variation takes place and maximum duration time for dip variation does not exceed before the signal magnitude rises above *Voltage dip set 3*. There is a small hysteresis for all these limits to avoid the oscillation of the output activation. No drop-off approach is applied here due to the hysteresis.

Consequently, only one event detection and recording of the same variation type can take place for one voltage variation, so the longest indicated variation of each variation type is detected. Furthermore, it is possible that another instantaneous dip event replaces the one already indicated if the magnitude again undershoots *Voltage dip set 1* for the set time after the first detection and the signal magnitude or time requirement is again fulfilled. Another possibility is that if the time condition is not fulfilled for an instantaneous dip detection but the signal rises above *Voltage dip set 1*, the already elapsed time is included in the momentary dip timer. Especially the interruption time is included in the dip time. If the signal does not exceed *Voltage dip set 2* before the timer *VVa dip time 2* has elapsed when the momentary dip timer is also started after the magnitude undershooting *Voltage dip set 2*, the momentary dip event instead is detected. Consequently, the same dip occurrence with a changing variation depth can result in several dip event indications but only one detection. For example, if the magnitude has undershot *Voltage dip set 1* but remained above *Voltage Intr set* for a shorter time than the value of *VVa dip time 1* but the signal rises between *Voltage dip set 1* and *Voltage dip set 2* so that the total duration of the dip activation is longer than *VVa dip time 2* and the maximum time is not overshot, this is detected as a momentary dip even though a short instantaneous dip period has been included. In text, the terms "deeper" and "higher" are used for referring to dip or interruption.

Although examples are given for dip events, the same rules can be applied to the swell and interruption functionality too. For swell indication, "deeper" means that the signal rises even more and "higher" means that the signal magnitude becomes lower respectively.

The adjustable voltage thresholds adhere to the relationships:

VVa dip time 1 ≤ *VVa dip time 2* ≤ *VVa dip time 3*.

VVa swell time 1 ≤ *VVa swell time 2* ≤ *VVa swell time 3*.

VVa Int time 1 ≤ *VVa Int time 2* ≤ *VVa Int time 3*.

There is a validation functionality built-in function that checks the relationship adherence so that if *VVa x time 1* is set higher than *VVa x time 2* or *VVa x time 3*, *VVa x time 2* and *VVa x time 3* are set equal to the new *VVa x time 1*. If *VVa x time 2* is set higher than *VVa x time 3*, *VVa x time 3* is set to the new *VVa x time 2*. If *VVa x time 2* is set lower than *VVa x time 1*, the entered *VVa x time 2* is rejected. If *VVa x time 3* is set lower than *VVa x time 2*, the entered *VVa x time 3* is rejected.

10.3.5.4 Duration measurement

The duration of each voltage phase corresponds to the period during which the measured TRMS values remain above (swell) or below (dip, interruption) the corresponding limit.

Besides the three limit settings for the variation types dip and swell, there is also a specific duration setting for each limit setting. For interruption, there is only one limit setting common for the three duration settings. The maximum duration setting is common for all variation types.

The duration measurement module measures the voltage variation duration of each phase voltage separately when the *Phase mode* setting is "Single Phase". The phase variation durations are independent. However, when the *Phase mode* setting is "Three Phase", voltage variation may start only when all the monitored phases are active. An example of variation duration when *Phase mode* is "Single Phase" can be seen in *Figure 973*. The voltage variation in the example is detected as an interruption for the phase B and a dip for the phase A, and also the variation durations are interpreted as independent `U_B` and `U_A` durations. In case of single-phase interruption, the `DIPST` output is active when either `ST_A` or `ST_B` is active. The measured variation durations are the times measured between the activation of the `ST_A` or `ST_B` outputs and deactivation of the `ST_A` or `ST_B` outputs. When the *Phase mode* setting is "Three Phase", the example case does not result in any activation.

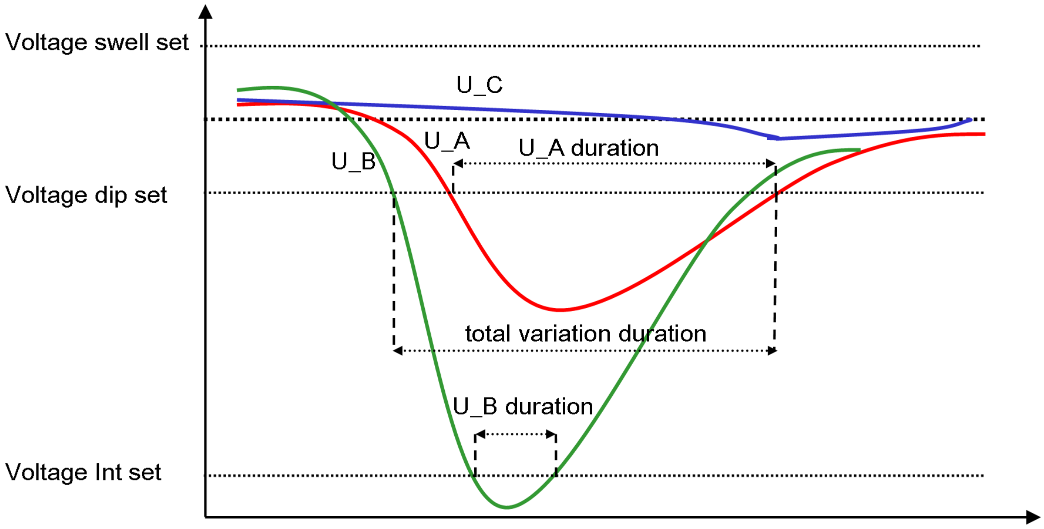


Figure 973: Single-phase interruption for the Phase mode value "Single Phase"

10.3.5.5 Three/single-phase selection variation examples

The provided rules always apply for single-phase (*Phase mode* is "Single Phase") power systems. However, for three-phase power systems (where *Phase mode* is "Three Phase"), it is required that all the phases have to be activated before the activation of the `START` output. Interruption event indication requires all three phases to undershoot *Voltage Int set* simultaneously, as shown in *Figure 969*. When the requirement for interruption for "Three Phase" is no longer fulfilled, variation is indicated as a dip as long as all phases are active.

In case of a single-phase interruption of *Chapter 10.3.5.4 Duration measurement*, when there is a dip indicated in another phase but the third phase is not active, there is no variation indication start when *Phase mode* is "Three Phase". In this case, only the *Phase Mode* value "Single Phase" results in the `ST_B` interruption and the `ST_A` dip.

It is also possible that there are simultaneously a dip in one phase and a swell in other phases. The functionality of the corresponding event indication with one inactive phase is shown in *Figure 974*. Here, the "Swell + dip" variation type of *Phase mode* is "Single Phase". For the selection "Three Phase" of *Phase mode*, no event indication or any activation takes place due to a non-active phase.

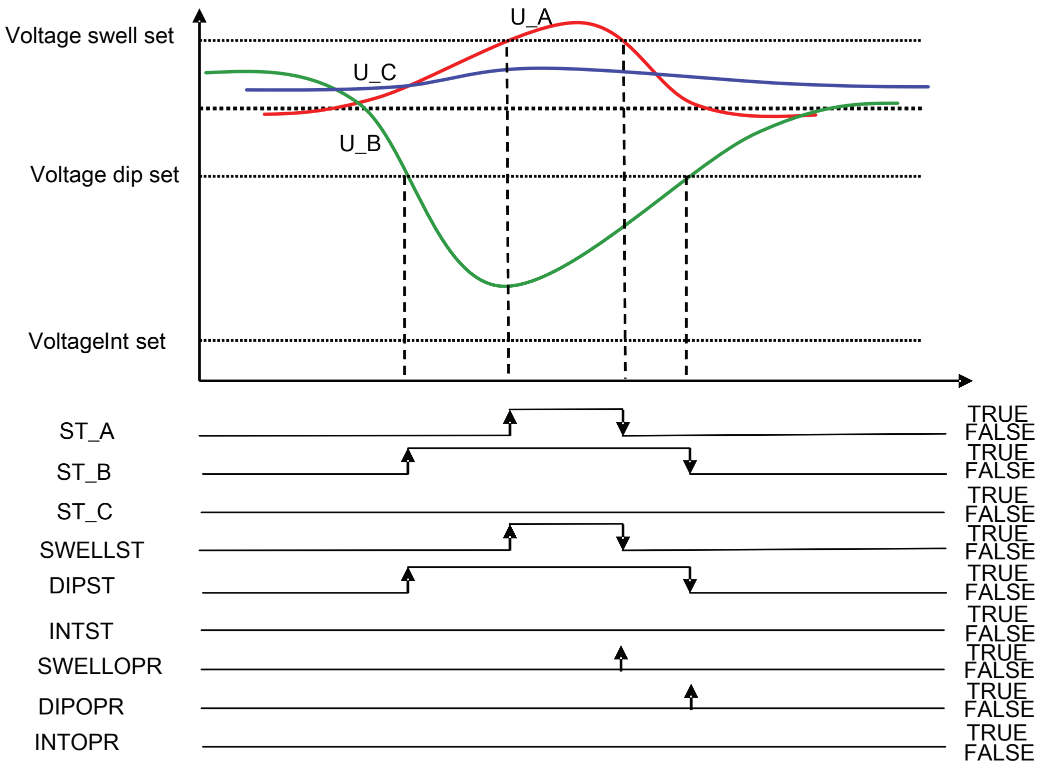


Figure 974: Concurrent dip and swell when Phase mode is "Single Phase"

In *Figure 975*, one phase is in dip and two phases have a swell indication. For the *Phase mode* value "Three Phase", the activation occurs only when all the phases are active. Furthermore, both swell and dip variation event detections take place simultaneously. In case of a concurrent voltage dip and voltage swell, both SWELLCNT and DIPCNT are incremented by one.

Also *Figure 975* shows that for the *Phase mode* value "Three Phase", two different time moment variation event swell detections take place and, consequently, DIPCNT is incremented by one but SWELLCNT is totally incremented by two. Both in *Figure 974* and *Figure 975* it is assumed that variation durations are sufficient for detections to take place.

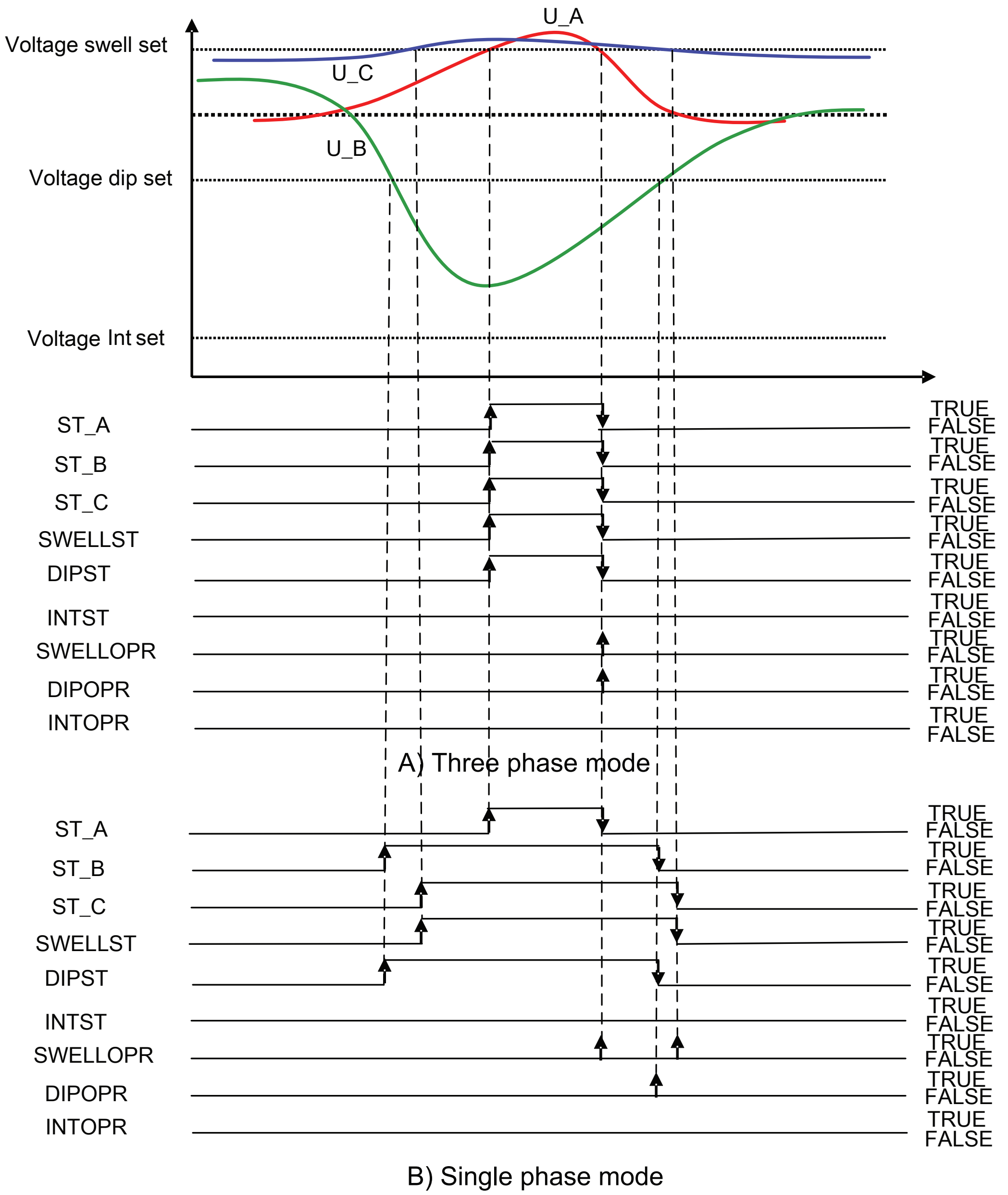


Figure 975: Concurrent dip and two-phase swell

10.3.6 Recorded data

Besides counter increments, the information required for a later fault analysis is stored after a valid voltage variation is detected.

Recorded data information

When voltage variation starts, the phase current magnitudes preceding the activation moment are stored. Also, the initial voltage magnitudes are temporarily stored at the variation starting moment. If the variation is, for example, a two-phase voltage dip, the voltage magnitude of the non-active phase is stored from this same moment, as shown in *Figure 976*. The function tracks each variation-active voltage phase, and the minimum or maximum magnitude corresponding to swell or dip/ interruption during variation is temporarily stored. If the minimum or maximum is found in tracking and a new magnitude is stored, also the inactive phase voltages are stored at the same moment, that is, the inactive phases are not magnitudetracked. The time instant (time stamp) at which the minimum or maximum magnitude is measured is also temporarily stored for each voltage phase where variation is active. Finally, variation detection triggers the recorded data update when the variation activation ends and the maximum duration time is not exceeded.

The data objects to be recorded for PHQVVR are given in *Table 1632*. There are totally three data banks, and the information given in the table refers to one data bank content.

The three sets of recorded data available are saved in data banks 1-3. The data bank 1 holds always the most recent recorded data, and the older data sets are moved to the next banks (1→2 and 2→3) when a valid voltage variation is detected. When all three banks have data and a new variation is detected, the newest data are placed into bank 1 and the data in bank 3 are overwritten by the data from bank 2.

Figure 976 shows a valid recorded voltage interruption and two dips for the *Phase mode* value "Single Phase". The first dip event duration is based on the `U_A` duration, while the second dip is based on the time difference between the dip stop and start times. The first detected event is an interruption based on the `U_B` duration given in *Figure 976*. It is shown also with dotted arrows how voltage time stamps are taken before the final time stamp for recording, which is shown as a solid arrow. Here, the `U_B` timestamp is not taken when the `U_A` activation starts.

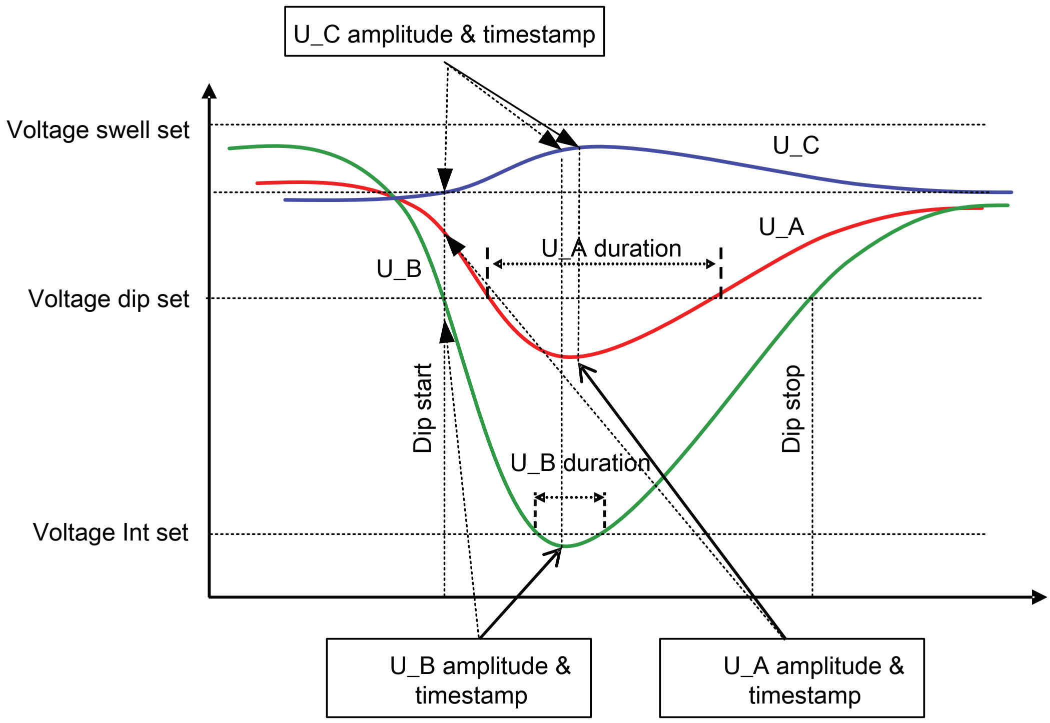


Figure 976: Valid recorded voltage interruption and two dips

Table 1632: PHQVVR recording data bank parameters

Parameter description	Parameter name
Event detection triggering time stamp	Time
Variation type	Variation type
Variation magnitude Ph A	Variation Ph A
Variation magnitude Ph A time stamp (maximum/minimum magnitude measuring time moment during variation)	Var Ph A rec time
Variation magnitude Ph B	Variation Ph B
Variation magnitude Ph B time stamp (maximum/minimum magnitude measuring time moment during variation)	Var Ph B rec time
Variation magnitude Ph C	Variation Ph C
Variation magnitude Ph C time stamp (maximum/minimum magnitude measuring time moment during variation)	Var Ph C rec time
Variation duration Ph A	Variation Dur Ph A
Variation Ph A start time stamp (phase A variation start time moment)	Var Dur Ph A time
Variation duration Ph B	Variation Dur Ph B
Variation Ph B start time stamp (phase B variation start time moment)	Var Dur Ph B time
Variation duration Ph C	Variation Dur Ph C
Variation Ph C start time stamp (phase C variation start time moment)	Var Dur Ph C time
Current magnitude Ph A preceding variation	Var current Ph A
Current magnitude Ph B preceding variation	Var current Ph B
Current magnitude Ph C preceding variation	Var current Ph C

Table 1633: Enumeration values for the recorded data parameters

Setting name	Enum name	Value
Variation type	Swell	1
Variation type	Dip	2
Variation type	Swell + dip	3
Variation type	Interruption	4
Variation type	Swell + Int	5
Variation type	Dip + Int	6
Variation type	Swell+dip+Int	7

10.3.7 Application

Voltage variations are the most typical power quality variations on the public electric network. Typically, short-duration voltage variations are defined to last more than half of the nominal frequency period and less than one minute (European Standard EN 50160 and IEEE Std 1159-1995).

These short-duration voltage variations are almost always caused by a fault condition. Depending on where the fault is located, it can cause either a temporary voltage rise (swell) or voltage drop (dip). A special case of voltage drop is the complete loss of voltage (interruption).

PHQVVR is used for measuring short-duration voltage variations in distribution networks. The power quality is evaluated in the voltage waveform by measuring the voltage swells, dips and interruptions.

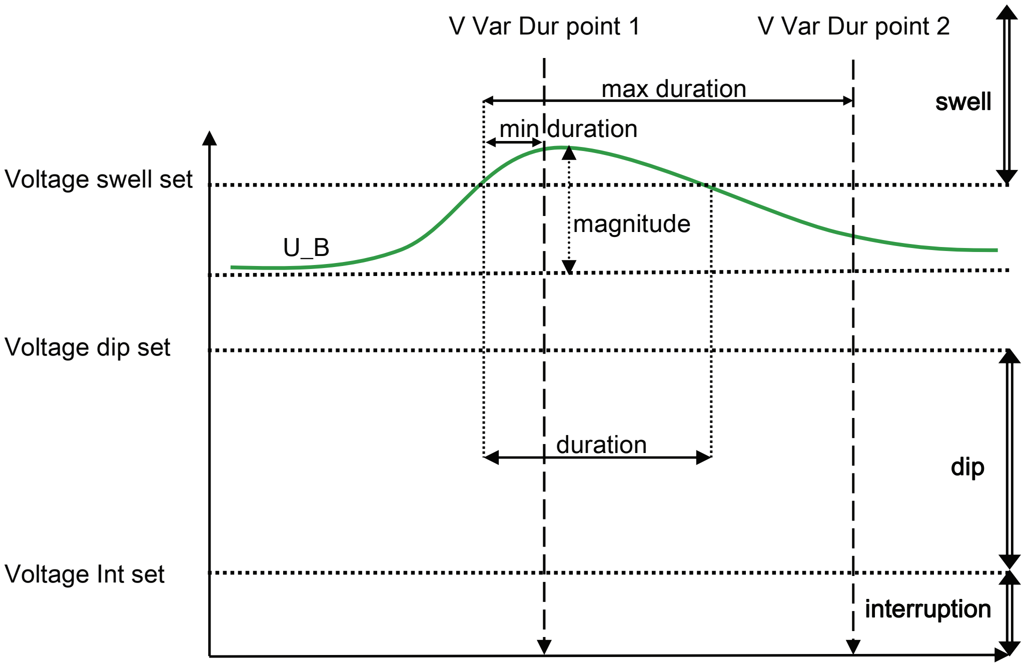


Figure 977: Duration and voltage magnitude limits for swell, dip and interruption measurement

Voltage dips disturb the sensitive equipment such as computers connected to the power system and may result in the failure of the equipment. Voltage dips are typically caused by faults occurring in the power distribution system. Typical reasons for the faults are lightning strikes and tree contacts. In addition to fault situations, the switching of heavy loads and starting of large motors also cause dips.

Voltage swells cause extra stress for the network components and the devices connected to the power system. Voltage swells are typically caused by the earth faults that occur in the power distribution system.

Voltage interruptions are typically associated with the switchgear operation related to the occurrence and termination of short circuits. The operation of a circuit breaker disconnects a part of the system from the source of energy. In the case of overhead networks, automatic reclosing sequences are often applied to the circuit breakers that interrupt fault currents. All these actions result in a sudden reduction of voltages on all voltage phases.

Due to the nature of voltage variations, the power quality standards do not specify any acceptance limits. There are only indicative values for, for example, voltage dips in the European standard EN 50160. However, the power quality standards like the international standard IEC 61000-4-30 specify that the voltage variation event is characterized by its duration and magnitude. Furthermore, IEEE Std 1159-1995 gives the recommended practice for monitoring the electric power quality.

Voltage variation measurement can be done to the phase-to-earth and phase-to-phase voltages. The power quality standards do not specify whether the measurement should be done to phase or phase-to-phase voltages. However, in some cases it is preferable to use phase-to-earth voltages for measurement. The measurement mode is always TRMS.

10.3.8 Signals

10.3.8.1 PHQVVR Input signals

Table 1634: PHQVVR Input signals

Name	Type	Default	Description
I3P	SIGNAL	-	Three-phase currents
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

10.3.8.2 PHQVVR Output signals

Table 1635: PHQVVR Output signals

Name	Type	Description
OPERATE	BOOLEAN	Voltage variation detected
START	BOOLEAN	Voltage variation present
SWELLST	BOOLEAN	Voltage swell active
DIPST	BOOLEAN	Voltage dip active
INTST	BOOLEAN	Voltage interruption active

10.3.9 PHQVVR Settings

Table 1636: PHQVVR Group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Reference voltage	10.0...200.0	%Un	0.1	57.7	Reference supply voltage in %
Voltage dip set 1	10.0...100.0	%	0.1	80.0	Dip limit 1 in % of reference voltage
VVa dip time 1	0.5...54.0	cycles	0.1	3.0	Voltage variation dip duration 1

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage dip set 2	10.0...100.0	%	0.1	80.0	Dip limit 2 in % of reference voltage
VVa dip time 2	10.0...180.0	cycles	0.1	30.0	Voltage variation dip duration 2
Voltage dip set 3	10.0...100.0	%	0.1	80.0	Dip limit 3 in % of reference voltage
VVa dip time 3	2000...60000	ms	10	3000	Voltage variation dip duration 3
Voltage swell set 1	100.0...140.0	%	0.1	120.0	Swell limit 1 in % of reference voltage
VVa swell time 1	0.5...54.0	cycles	0.1	0.5	Voltage variation swell duration 1
Voltage swell set 2	100.0...140.0	%	0.1	120.0	Swell limit 2 in % of reference voltage
VVa swell time 2	10.0...80.0	cycles	0.1	10.0	Voltage variation swell duration 2
Voltage swell set 3	100.0...140.0	%	0.1	120.0	Swell limit 3 in % of reference voltage
VVa swell time 3	2000...60000	ms	10	2000	Voltage variation swell duration 3
Voltage Int set	0.0...100.0	%	0.1	10.0	Interruption limit in % of reference voltage
VVa Int time 1	0.5...30.0	cycles	0.1	3.0	Voltage variation Int duration 1
VVa Int time 2	10.0...180.0	cycles	0.1	30.0	Voltage variation Int duration 2
VVa Int time 3	2000...60000	ms	10	3000	Voltage variation interruption duration 3
VVa Dur Max	100...3600000	ms	100	60000	Maximum voltage variation duration

Table 1637: PHQVVR Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Variation enable	1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int			7=Swell+dip+Int	Enable variation type

Table 1638: PHQVVR Non group settings (Advanced)

Parameter	Values (Range)	Unit	Step	Default	Description
Phase supervision	1=Ph A 2=Ph B 3=Ph A + B 4=Ph C 5=Ph A + C 6=Ph B + C 7=Ph A + B + C			7=Ph A + B + C	Monitored voltage phase
Phase mode	1=Three Phase			2=Single Phase	Three/Single phase mode

Parameter	Values (Range)	Unit	Step	Default	Description
	2=Single Phase				

10.3.10 PHQVVR Monitored data

Table 1639: PHQVVR Monitored data

Name	Type	Values (Range)	Unit	Description
ST_A	BOOLEAN	0=False 1=True		Start Phase A (Voltage Variation Event in progress)
ST_B	BOOLEAN	0=False 1=True		Start Phase B (Voltage Variation Event in progress)
ST_C	BOOLEAN	0=False 1=True		Start Phase C (Voltage Variation Event in progress)
INSTSWELLCNT	INT32	0...2147483647		Instantaneous swell operation counter
MOMSWELLCNT	INT32	0...2147483647		Momentary swell operation counter
TEMPSWELLCNT	INT32	0...2147483647		Temporary swell operation counter
MAXDURSWELLCNT	INT32	0...2147483647		Maximum duration swell operation counter
INSTDIPCNT	INT32	0...2147483647		Instantaneous dip operation counter
MOMDIPCNT	INT32	0...2147483647		Momentary dip operation counter
TEMPDIPCNT	INT32	0...2147483647		Temporary dip operation counter
MAXDURDIPCNT	INT32	0...2147483647		Maximum duration dip operation counter
MOMINTCNT	INT32	0...2147483647		Momentary interruption operation counter
TEMPINTCNT	INT32	0...2147483647		Temporary interruption operation counter
SUSTINTCNT	INT32	0...2147483647		Sustained interruption operation counter
MAXDURINTCNT	INT32	0...2147483647		Maximum duration interruption operation counter
PHQVVR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Variation Ph A	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation
Time	Timestamp			Time
Variation type	Enum	0=No variation 1=Swell 2=Dip 3=Swell + dip 4=Interruption 5=Swell + Int 6=Dip + Int 7=Swell+dip+Int		Variation type
Variation Ph A	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUref	Variation magnitude Phase C
Var Ph C rec time	Timestamp			Variation magnitude Phase C time stamp
Variation Dur Ph A	FLOAT32	0.000...3600.000	s	Variation duration Phase A
Var Dur Ph A time	Timestamp			Variation Ph A start time stamp
Variation Dur Ph B	FLOAT32	0.000...3600.000	s	Variation duration Phase B
Var Dur Ph B time	Timestamp			Variation Ph B start time stamp
Variation Dur Ph C	FLOAT32	0.000...3600.000	s	Variation duration Phase C
Var Dur Ph C time	Timestamp			Variation Ph C start time stamp
Var current Ph A	FLOAT32	0.00...60.00	xIn	Current magnitude Phase A preceding variation
Var current Ph B	FLOAT32	0.00...60.00	xIn	Current magnitude Phase B preceding variation
Var current Ph C	FLOAT32	0.00...60.00	xIn	Current magnitude Phase C preceding variation

10.3.11 Technical data

Table 1640: PHQVVR Technical data

Characteristic	Value
Operation accuracy	±1.5 % of the set value or ±0.2 % of reference voltage
Reset ratio	Typically 0.96 (Swell), 1.04 (Dip, Interruption)

10.4 Voltage unbalance VSQVUB (ANSI PQMV UB)

10.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage unbalance	VSQVUB	PQUUB	PQVUB

10.4.2 Function block

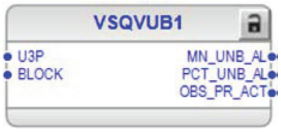


Figure 978: Function block

10.4.3 Functionality

The voltage unbalance function VSQVUB monitors voltage unbalance conditions in power transmission and distribution networks. It can be applied to identify a network and load unbalance that can cause sustained voltage unbalance. VSQVUB is also used to monitor the commitment of the power supply utility of providing a high-quality, that is, a balanced voltage supply on a continuous basis.

VSQVUB uses five different methods for calculating voltage unbalance. The methods are the negative-sequence voltage magnitude, zero-sequence voltage magnitude, ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude, ratio of the zero-sequence voltage magnitude to the positive-sequence voltage magnitude and ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude.

VSQVUB provides statistics which can be used to verify the compliance of the power quality with the European standard EN 50160 (2000). The statistics over selected period include a freely selectable percentile for unbalance. VSQVUB also includes an alarm functionality providing a maximum unbalance value and the date and time of occurrence.

VSQVUB contains a blocking functionality. It is possible to block a set of function outputs or the function itself.

10.4.4 Analog channel configuration

VSQVUB has one analog group input which must be properly configured.

Table 1641: Analog inputs

Input	Description
U3P	Three-phase voltages

See the preprocessing function blocks in this document for the possible signal sources.

There are a few special conditions which must be noted with the configuration.

Table 1642: Special conditions

Condition	Description
U3P connected to real measurements	The function can work with any two voltage channels connected but it is recommended to connect all three voltage channels.
	Further, if *VT connection* is "Delta" in that particular UTVTR, the *Unb detection method* cannot be set to "Zero Seq" or "Zero to Pos Seq".

Improper analog channel configuration causes a validation error if the analog channels are not completely configured or they do not match with certain settings. For troubleshooting, check the contents of this chapter and also the preprocessing blocks in this document. The configuration can be written to the protection relay once the mismatch is corrected.

10.4.5 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of VSQVUB can be described with a module diagram. All the modules in the diagram are explained in the next sections.

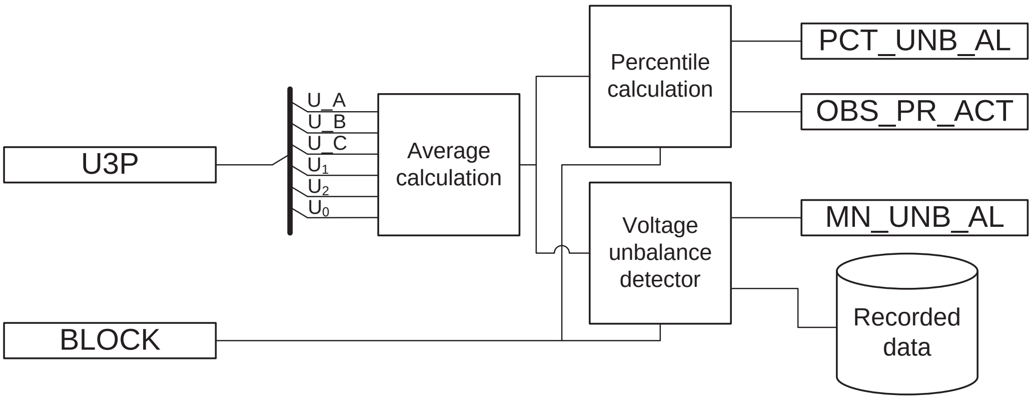


Figure 979: Functional module diagram

10.4.5.1 Average calculation

VSQVUB calculates two sets of measured voltage unbalance values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring. The ten-minute average is used for percentile calculation for a longer period.

The Average calculation module uses five different methods for the average calculation. The required method can be selected with the *Unb detection method* parameter.

When the "Neg Seq" mode is selected with *Unb detection method*, the voltage unbalance is calculated based on the negative-sequence voltage magnitude. Similarly, when the "Zero Seq" mode is selected, the voltage unbalance is calculated based on the zero-sequence voltage magnitude. When the "Neg to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the negative-sequence voltage magnitude to the positive-sequence magnitude. When the "Zero to Pos Seq" mode is selected, the voltage unbalance is calculated based on the ratio of the zero-sequence voltage magnitude to the positive-sequence magnitude. When the "Ph vectors Comp" mode is selected, the ratio of the maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of the phase voltage magnitude is used for voltage unbalance calculation.

The calculated three-second value and ten-minute value are available in the Monitored data view through the outputs `3S_MN_UNB` and `10MN_MN_UNB`.

3S_MN_UNB values are updated every three seconds and 10MIN_MN_UNB is updated every minute.

For VT connection = "Delta", the calculated zero-sequence voltage is always zero, hence, the setting *Unb detection method* = "Zero Seq" is not applicable in this VT configuration.

10.4.5.2 Voltage unbalance detector

The three-second average value is calculated and compared to the set value *Unbalance start val*. If the voltage unbalance exceeds this limit, the `MN_UNB_AL` output is activated.

The activation of the BLOCK input blocks MN_UNB_AL output.

10.4.5.3 Percentile calculation

The Percentile calculation module performs the statistics calculation for the level of voltage unbalance value for a settable duration. The operation of the Percentile calculation module can be described with a module diagram.

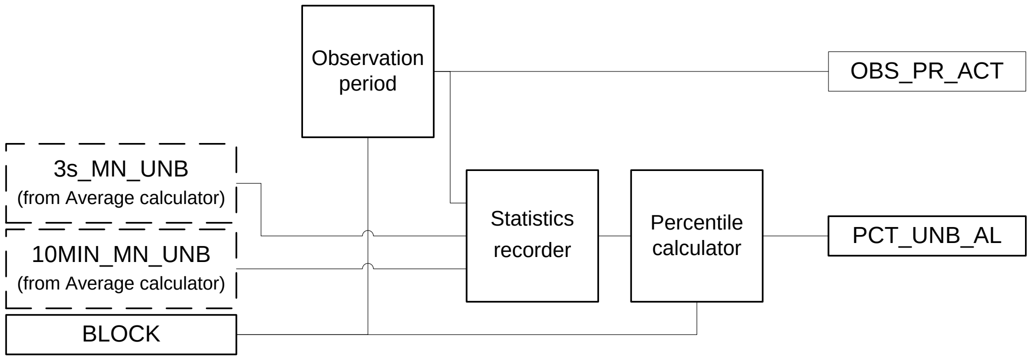


Figure 980: Percentile calculation

10.4.5.4 Observation period

The Observation period module calculates the length of the observation time for the Statistics recorder sub-module as well as determines the possible start of a new one. A new period can be started by timed activation using calendar time settings *Obs period Str year*, *Obs period Str month*, *Obs period Str day* and *Obs period Str hour*.

The observation period start time settings *Obs period Str year*, *Obs period Str month*, *Obs period Str day* and *Obs period Str hour* are used to set the calendar time in UTC. These settings have to be adjusted according to the local time and local daylight saving time.

A preferable way of continuous statistics recordings can be selected over a longer period (months, years). With the *Trigger mode* setting, the way the next possible observation time is activated after the former one has finished can be selected.

Table 1643: Trigger mode observation times

Trigger mode	Observation time
Single	Only one period of observation time is activated.
Periodic	The time gap between the two trigger signals is seven days.
Continuous	The next period starts right after the previous observation period is completed.

The length of the period is determined by the settings *Obs period selection* and *User Def Obs period*. The OBS_PR_ACT output is an indication signal which exhibits rising edge (TRUE) when the observation period starts and falling edge (FALSE) when the observation period ends.

If the *Percentile unbalance*, *Trigger mode* or *Obs period duration* settings change when OBS_PR_ACT is active, OBS_PR_ACT deactivates immediately.

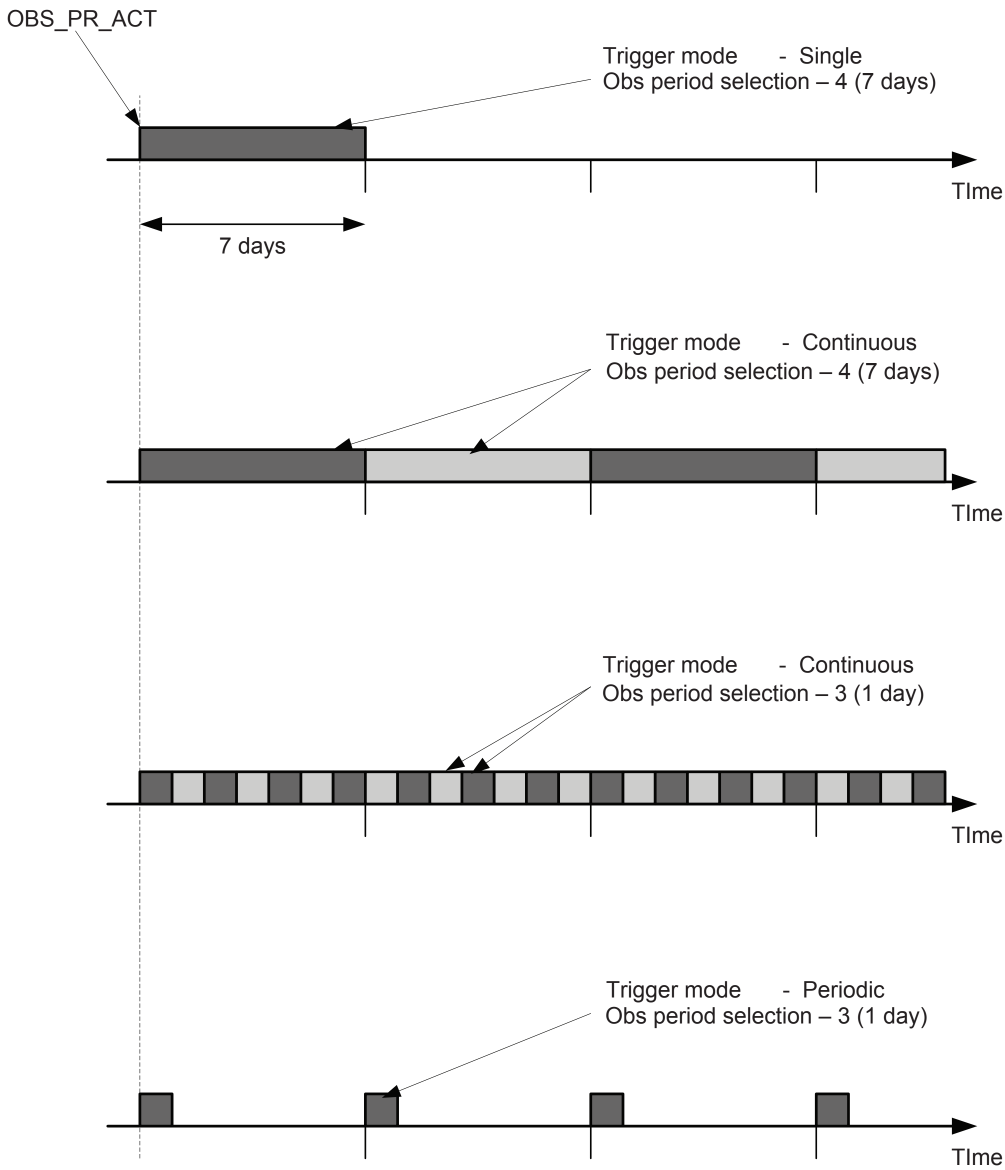


Figure 981: Periods for statistics recorder with different trigger modes and period settings

The BLOCK input blocks the OBS_PR_ACT output, which then disables the maximum value calculation of the Statistics recorder module. If the trigger mode is selected "Periodic" or "Continuous" and the blocking is deactivated before the next observation period is due to start, the scheduled period starts normally.

10.4.5.5 Statistics recorder

The Statistics recorder module provides readily calculated three-second or ten-minute values of the selected phase to the percentile calculator module based on the length of the active observation period. If the observation period is less than one day, the three-second average values are used. If the observation period is one day or longer, the ten-minute average values are used.

The maximum three-second or ten-minute mean voltage unbalance is recorded during the active observation period. The observation period start time *PR_STR_TIME*, observation period end time *PR_END_TIME*, maximum voltage unbalance value during observation period active, *MAX_UNB_VAL* and time of occurrence *MAX_UNB_TIME* are available through the Monitored data view. These outputs are updated once OBS_PR_ACT deactivates.

10.4.5.6 Percentile calculator

The purpose of the Percentile calculator module is to find the voltage unbalance level so that during the observation time 95 percent (default value of the *Percentile unbalance* setting) of all the measured voltage unbalance amplitudes are less than or equal to the calculated percentile.

The computed output value PCT_UNB_VAL, below which the percentile of the values lies, is available in the Monitored data view. The PCT_UNB_VAL output value is updated at the end of the observation period.

If the output PCT_UNB_VAL is higher than the defined setting *Unbalance start val* at the end of the observation period, an alarm output PCT_UNB_AL is activated. The PCT_UNB_AL output remains active for the whole period before the next period completes.

The BLOCK input blocks the output PCT_UNB_VAL.

10.4.5.7 Recorded data

The information required for a later fault analysis is stored when the Recorded data module is triggered. This happens when a voltage unbalance is detected by the Voltage unbalance detector module.

Three sets of recorded data are available in total. The sets are saved in data banks 1...3. The data bank 1 holds the most recent recorded data. Older data are moved to the subsequent banks (1 to 2 and 2 to 3) when a voltage unbalance is detected. When all three banks have data and a new variation is detected, the latest data set is placed into bank 1 and the data in bank 3 is overwritten by the data from bank 2.

The recorded data can be reset with the RESET binary input signal by navigating to the HMI reset (**Main menu** > **Clear** > **Reset recorded data** > **VSQVUBx**) or through tools via communications.

When a voltage unbalance is detected in the system, VSQVUB responds with the MN_UNB_AL alarm signal. During the alarm situation, VSQVUB stores the maximum magnitude and the time of occurrence and the duration of alarm MN_UNB_AL. The recorded data is stored when MN_UNB_AL is deactivated.

Table 1644: Recorded data

Parameter	Description
Alarm high mean Dur	Time duration for alarm high mean unbalance
Max unbalance Volt	Maximum three-second voltage
Time Max Unb Volt	Time stamp of voltage unbalance

10.4.6 Application

Voltage unbalance is one of the basic power quality parameters.

Ideally, in a three-phase or multiphase power system, the frequency and voltage magnitude of all the phases are equal and the phase displacement between any two consecutive phases is also equal. This is called a balanced source. Apart from the balanced source, usually the power system network and loads are also balanced, implying that network impedance and load impedance in each phase are equal. In some cases, the condition of a balance network and load is not met completely, which leads to a current and voltage unbalance in the system. Providing unbalanced supply voltage has a detrimental effect on load operation. For example, a small magnitude of a negative-sequence voltage applied to an induction motor results in a significant heating of the motor.

A balanced supply, balanced network and balanced load lead to a better power quality. When one of these conditions is disturbed, the power quality is deteriorated. VSQVUB monitors voltage unbalance conditions in power transmission and distribution networks. VSQVUB calculates two sets of measured values, a three-second and a ten-minute non-sliding average value. The three-second average value is used for continuous monitoring while the ten-minute average value is used for percentile calculation for a longer period of time. It can be applied to identify the network and load unbalance that may cause sustained voltage unbalance. A single-phase or phase-to-phase fault in the network or load side can create voltage unbalance but, as faults are usually isolated in a short period of time, the voltage unbalance is not a sustained one. Therefore, the voltage unbalance may not be covered by VSQVUB.

Another major application is the long-term power quality monitoring. This can be used to confirm a compliance to the standard power supply quality norms. The function provides a voltage unbalance level which corresponds to the 95 th percentile of the ten minutes' average values of voltage unbalance recorded over a period of up to one week. It means that for 95 percent of time during the observation period the voltage unbalance was less than or equal to the calculated percentile. An alarm can be obtained if this value exceeds the value that can be set.

The function uses five different methods for calculating voltage unbalance.

- Negative-sequence voltage magnitude
- Zero-sequence voltage magnitude
- Ratio of negative-sequence to positive-sequence voltage magnitude
- Ratio of zero-sequence to positive-sequence voltage magnitude
- Ratio of maximum phase voltage magnitude deviation from the mean voltage magnitude to the mean of phase voltage magnitude.

Usually, the ratio of the negative-sequence voltage magnitude to the positive-sequence voltage magnitude is selected for monitoring the voltage unbalance. However, other methods may also be used if required.

10.4.7 Signals

10.4.7.1 VSQVUB Input signals

Table 1645: VSQVUB Input signals

Name	Type	Default	Description
U3P	SIGNAL	-	Three-phase voltages
BLOCK	BOOLEAN	0=False	Block all outputs except measured values

10.4.7.2 VSQVUB Output signals

Table 1646: VSQVUB Output signals

Name	Type	Description
MN_UNB_AL	BOOLEAN	Alarm active when 3 sec voltage unbalance exceeds the limit
PCT_UNB_AL	BOOLEAN	Alarm active when percentile unbalance exceeds the limit
OBS_PR_ACT	BOOLEAN	Observation period is active

10.4.8 VSQVUB Settings

Table 1647: VSQVUB Non group settings (Basic)

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation On/Off
Unb detection method	1=Neg Seq 2=Zero Seq 3=Neg to Pos Seq 4=Zero to Pos Seq 5=Ph vectors Comp			3=Neg to Pos Seq	Set the operation mode for voltage unbalance calculation
Unbalance start Val	1...100	%	1	1	Voltage unbalance start value
Trigger mode	1=Single 2=Periodic 3=Continuous			3=Continuous	Specifies the observation period triggering mode
Percentile unbalance	1...100	%	1	95	The percent to which percentile value PCT_UNB_VAL is calculated
Obs period selection	1=1 Hour 2=12 Hours 3=1 Day 4=7 Days 5=User defined			5=User defined	Observation period for unbalance calculation

Table continues on the next page

Parameter	Values (Range)	Unit	Step	Default	Description
User Def Obs period	1...168	h	1	168	User define observation period for statistic calculation
Obs period Str year	2008...2076			2011	Calendar time for observation period start year in YYYY
Obs period Str month	0=reserved 1=January 2=February 3=March 4=April 5=May 6=June 7=July 8=August 9=September 10=October 11=November 12=December			1=January	Calendar time for observation period start month
Obs period Str day	1...31			1	Calendar time for observation period start day
Obs period Str hour	0...23	h		0	Calendar time for observation period start hour

10.4.9 VSQVUB Monitored data

Table 1648: VSQVUB Monitored data

Name	Type	Values (Range)	Unit	Description
3S_MN_UNB	FLOAT32	0.00...150.00	%	Non sliding 3 second mean value of voltage unbalance
10MIN_MN_UNB	FLOAT32	0.00...150.00	%	Sliding 10 minutes mean value of voltage unbalance
PCT_UNB_VAL	FLOAT32	0.00...150.00	%	Limit below which percentile unbalance of the values lie
MAX_UNB_VAL	FLOAT32	0.00...150.00	%	Maximum voltage unbalance measured in the observation period
MAX_UNB_TIME	Timestamp			Time stamp at which maximum voltage unbalance measured in the observation period
PR_STR_TIME	Timestamp			Time stamp of starting of the previous observation period
PR_END_TIME	Timestamp			Time stamp of end of previous observation period
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...150.00	%	Maximum 3 seconds unbalance voltage
Time Max Unb Volt	Timestamp			Time stamp of maximum voltage unbalance

Table continues on the next page

Name	Type	Values (Range)	Unit	Description
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...150.00	%	Maximum 3 seconds unbalance voltage
Time Max Unb Volt	Timestamp			Time stamp of maximum voltage unbalance
Alarm high mean Dur	FLOAT32	0.000...3600.000	s	Time duration for alarm high mean unbalance
Max unbalance Volt	FLOAT32	0.00...150.00	%	Maximum 3 seconds unbalance voltage
Time Max Unb Volt	Timestamp			Time stamp of maximum voltage unbalance
VSQVUB	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

10.4.10 Technical data

Table 1649: VSQVUB Technical data

Characteristic	Value
Operation accuracy	±1.5 % of the set value or ±0.002 × U_n
Reset ratio	Typically 0.96

11 General function block features

11.1 Definite time characteristics

11.1.1 Definite time operation

The DT mode is enabled when the *Operating curve type* setting is selected either as "ANSI Def. Time" or "IEC Def. Time". In the DT mode, the OPERATE output of the function is activated when the time calculation exceeds the set *Operate delay time* .

The user can determine the reset in the DT mode with the *Reset delay time* setting, which provides the delayed reset property when needed.

The *Type of reset curve* setting has no effect on the reset method when the DT mode is selected, but the reset is determined solely with the *Reset delay time* setting.

The purpose of the delayed reset is to enable fast clearance of intermittent faults, for example self-sealing insulation faults, and severe faults which may produce high asymmetrical fault currents that partially saturate the current transformers. It is typical for an intermittent fault that the fault current contains so called drop-off periods, during which the fault current falls below the set start current, including hysteresis. Without the delayed reset function, the operate timer would reset when the current drops off. In the same way, an apparent drop-off period of the secondary current of the saturated current transformer can also reset the operate timer.

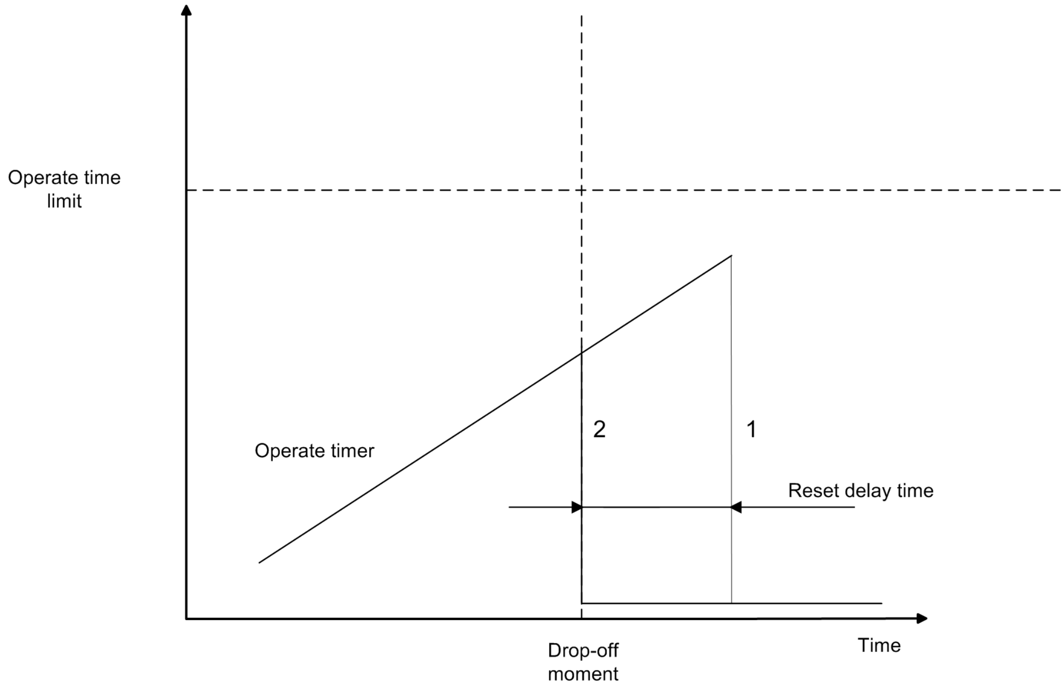


Figure 982: Operation of the counter in drop-off

In case 1, the reset is delayed with the *Reset delay time* setting and in case 2, the counter is reset immediately, because the *Reset delay time* setting is set to zero.

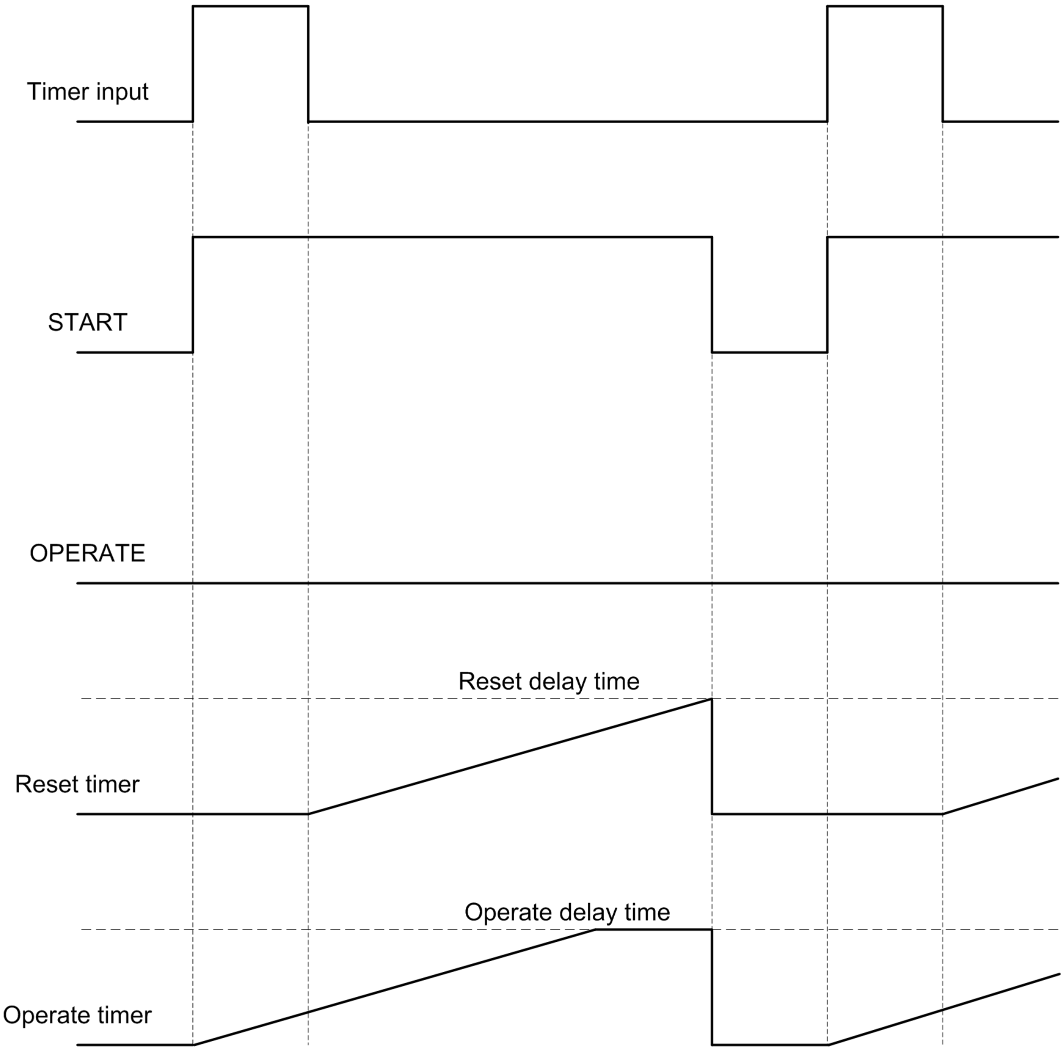


Figure 983: Drop-off period is longer than the set Reset delay time

When the drop-off period is longer than the set *Reset delay time*, as described in *Figure 983*, the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Start value*. The input signal is inactive when the current is below the set *Start value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the START output and the operate timer starts elapsing. The reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. When the reset (drop-off) timer elapses, the operate timer is reset. Since this happens before another start occurs, the OPERATE output is not activated.

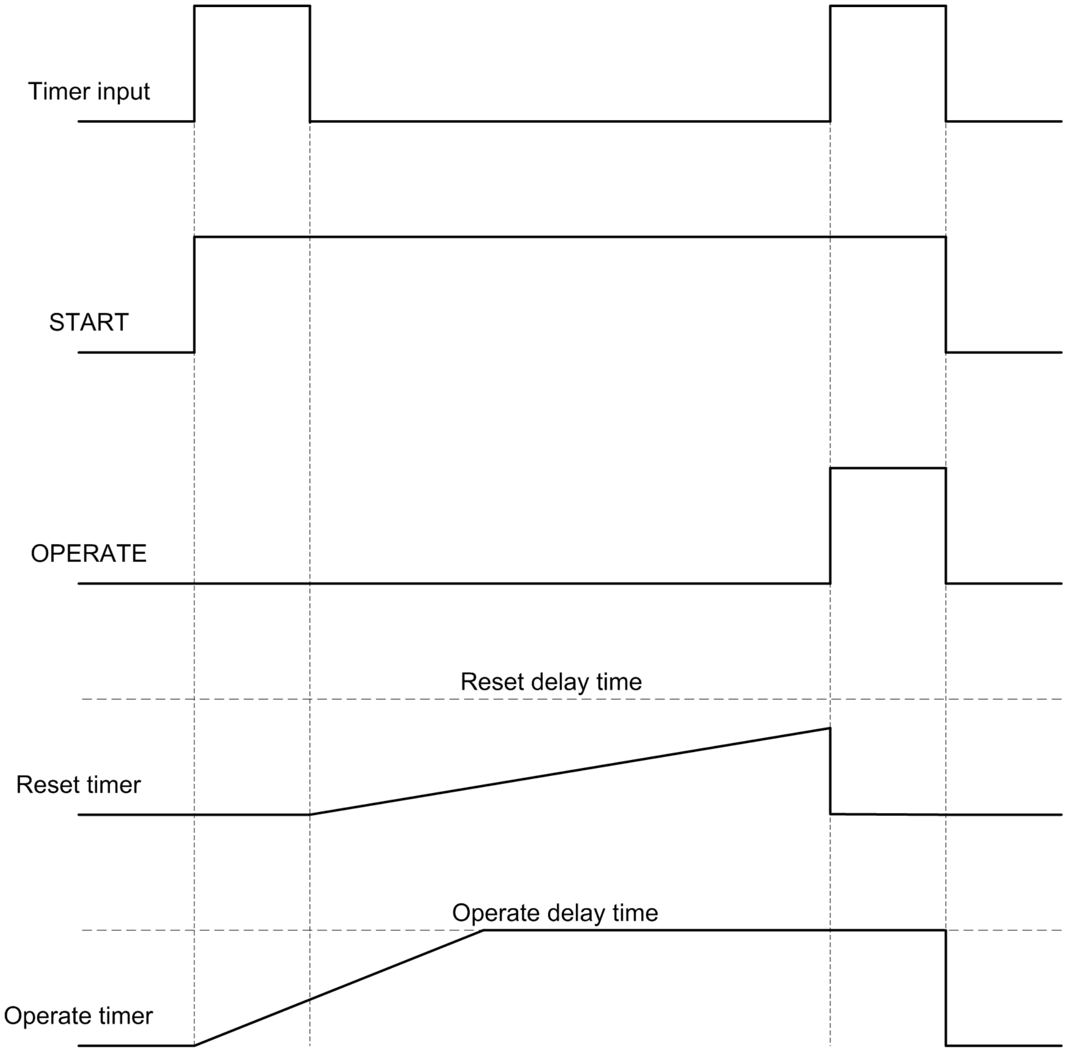


Figure 984: Drop-off period is shorter than the set Reset delay time

When the drop-off period is shorter than the set *Reset delay time*, as described in *Figure 984*, the input signal for the definite timer (here: timer input) is active, provided that the current is above the set *Start value*. The input signal is inactive when the current is below the set *Start value* and the set hysteresis region. The timer input rises when a fault current is detected. The definite timer activates the START output and the operate timer starts elapsing. The Reset (drop-off) timer starts when the timer input falls, that is, the fault disappears. Another fault situation occurs before the reset (drop-off) timer has elapsed. This causes the activation of the OPERATE output, since the operate timer already has elapsed.

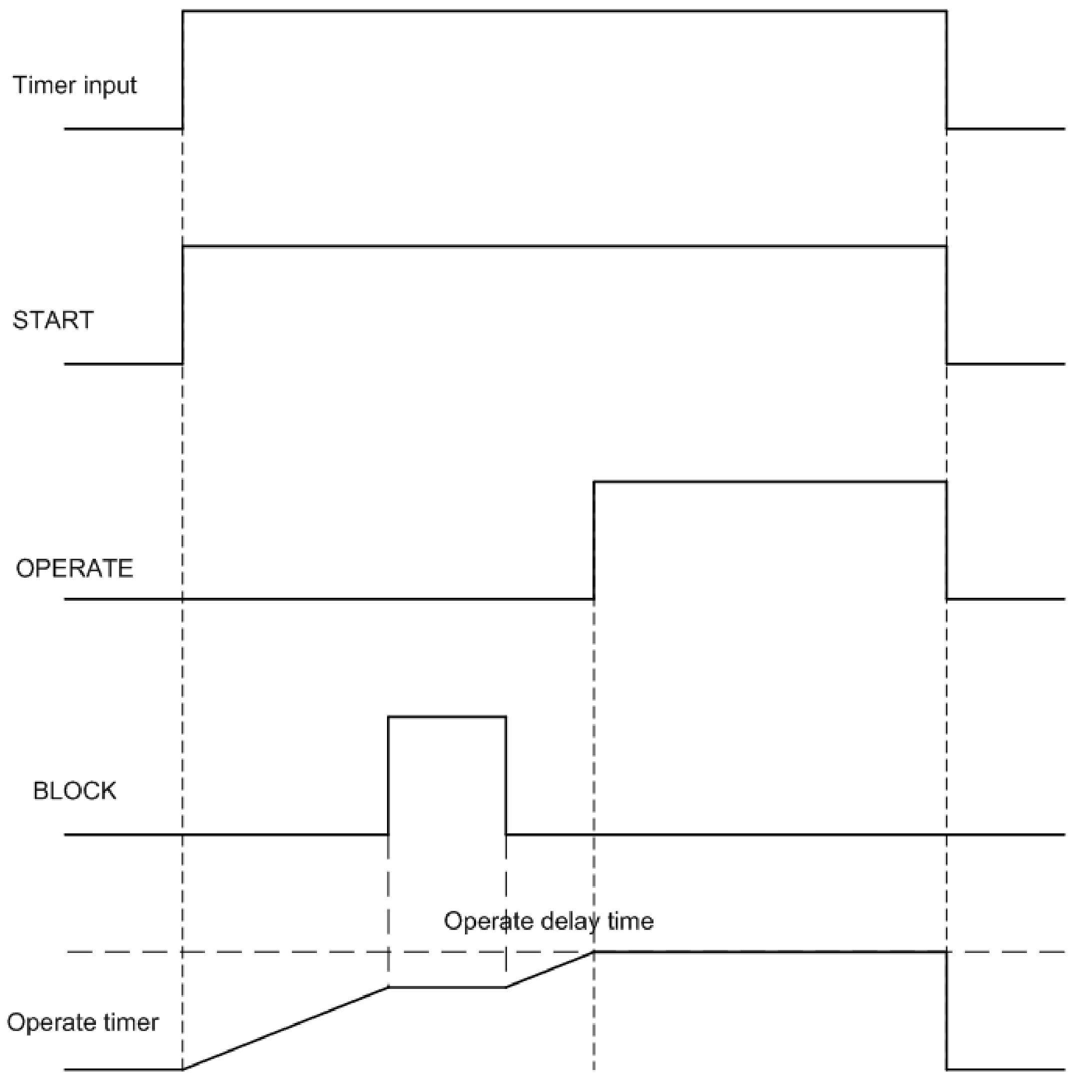


Figure 985: Operating effect of the BLOCK input when the selected blocking mode is "Freeze timer"

If the BLOCK input is activated when the operate timer is running, as described in *Figure 985*, the timer is frozen during the time BLOCK remains active. If the timer input is not active longer than specified by the *Reset delay time* setting, the operate timer is reset in the same way as described in *Figure 983*, regardless of the BLOCK input .

The selected blocking mode is "Freeze timer".

11.2 Current based inverse definite minimum time characteristics

11.2.1 IDMT curves for overcurrent protection

In inverse-time modes, the operation time depends on the momentary value of the current: the higher the current, the faster the operation time. The operation time calculation or integration starts immediately when the current exceeds the set *Start value* and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the overcurrent situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The curve scaling is determined with the *Time multiplier* setting.

There are two methods to level out the inverse-time characteristic.

- The *Minimum operate time* setting defines the minimum operating time for the IDMT curve, that is, the operation time is always at least the *Minimum operate time* setting.
- Alternatively, the *IDMT Sat point* is used for giving the leveling-out point as a multiple of the *Start value* setting. (Global setting: **Configuration** > **System** > ***IDMT Sat point***). The default parameter value is 50. This setting affects only the overcurrent and earth-fault IDMT timers.

IDMT operation time at currents over 50 x In is not guaranteed.

See *Chapter 3.12 Sensor inputs for currents and voltages* for Rogowski channel saturation details. Rogowski sensors do not saturate, but protection relay input does not have infinite range. 50 x In saturation is not achievable with some of the higher primary current settings.

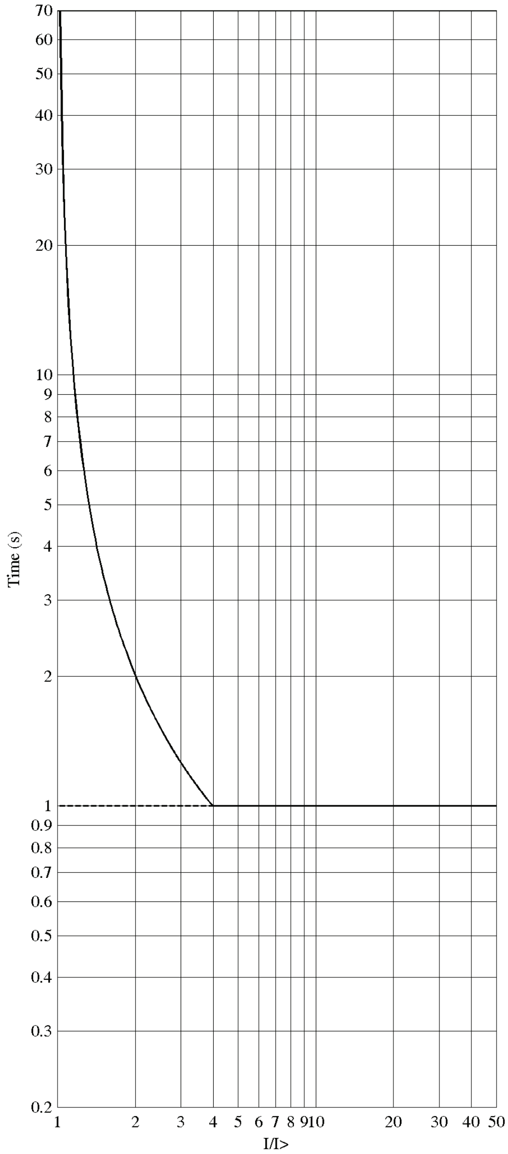


Figure 986: Operation time curve based on the IDMT characteristic leveled out with the Minimum operate time setting is set to 1000 milliseconds (the IDMT Sat point setting is set to maximum).

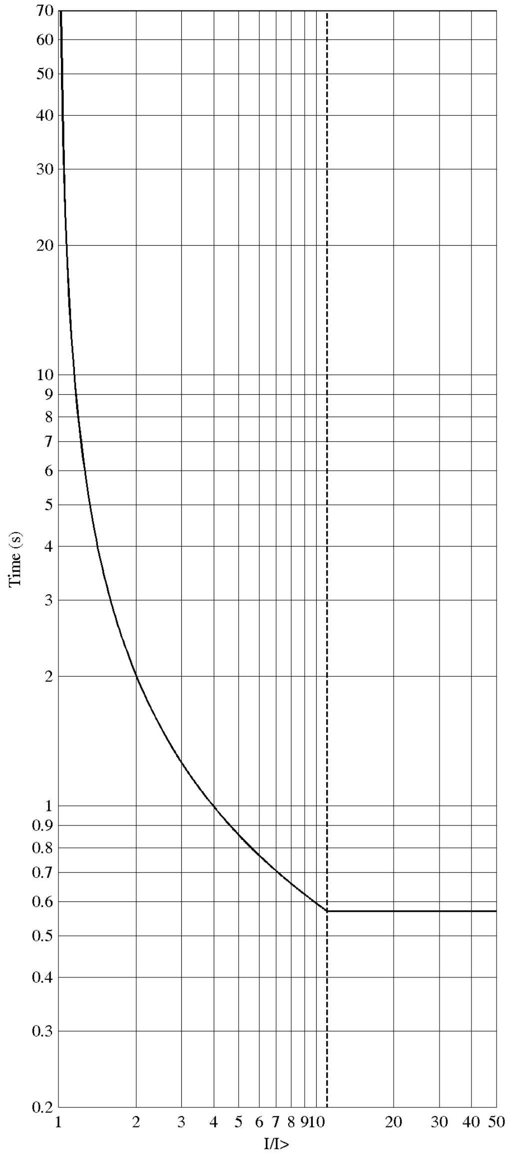


Figure 987: Operation time curve based on the IDMT characteristic leveled out with IDMT Sat point setting value "11" (the Minimum operate time setting is set to minimum).

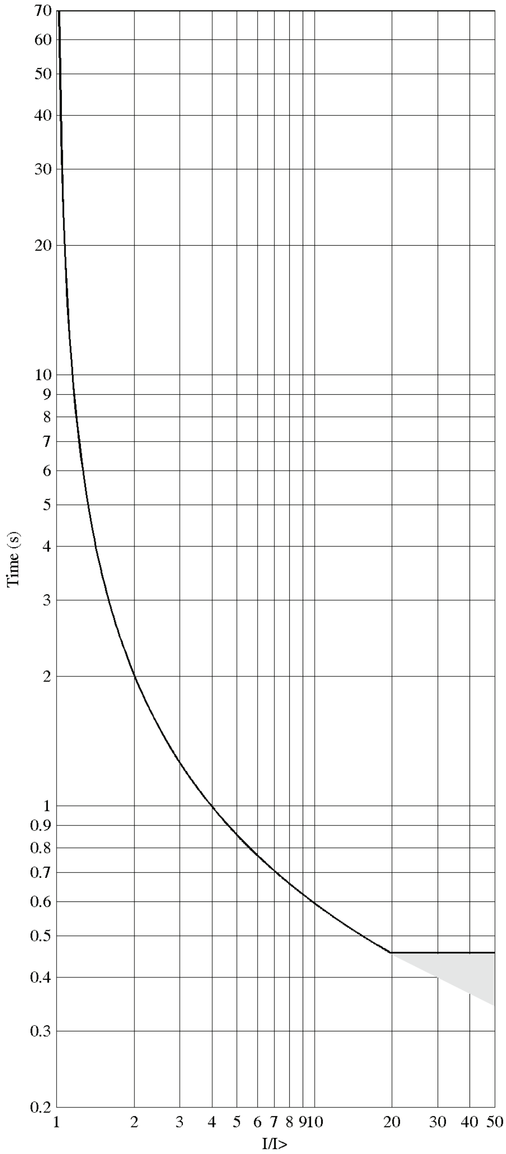


Figure 988: Example of how the inverse time characteristic is leveled out with currents over 50 x In and the Setting Start value setting "2.5 x In". (the IDMT Sat point setting is set to maximum and the Minimum operate time setting is set to minimum).

The grey zone in *Figure 988* shows the behavior of the curve in case the measured current is outside the guaranteed measuring range. Also, the maximum measured current of 50 x In gives the leveling-out point 50/2.5 = 20 x I/I>.

11.2.1.1 Standard inverse-time characteristics

For inverse-time operation, both IEC and ANSI/IEEE standardized inverse-time characteristics are supported.

The operate times for the ANSI and IEC IDMT curves are defined with the coefficients A, B and C.

The values of the coefficients can be calculated according to the formula:

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>} \right)^{c} - 1} + B \right) \cdot k$$

(Equation 393)

t[s]	Operate time in seconds
I	Measured current
I>	Set *Start value*
k	Set *Time multiplier*

Table 1650: Curve parameters for ANSI and IEC IDMT curves

Curve name	A	B	C
(1) ANSI Extremely Inverse	28.2	0.1217	2.0
(2) ANSI Very Inverse	19.61	0.491	2.0
(3) ANSI Normal Inverse	0.0086	0.0185	0.02
(4) ANSI Moderately Inverse	0.0515	0.1140	0.02
(6) Long Time Extremely Inverse	64.07	0.250	2.0
(7) Long Time Very Inverse	28.55	0.712	2.0
(8) Long Time Inverse	0.086	0.185	0.02
(9) IEC Normal Inverse	0.14	0.0	0.02
(10) IEC Very Inverse	13.5	0.0	1.0
(11) IEC Inverse	0.14	0.0	0.02
(12) IEC Extremely Inverse	80.0	0.0	2.0
(13) IEC Short Time Inverse	0.05	0.0	0.04
(14) IEC Long Time Inverse	120	0.0	1.0

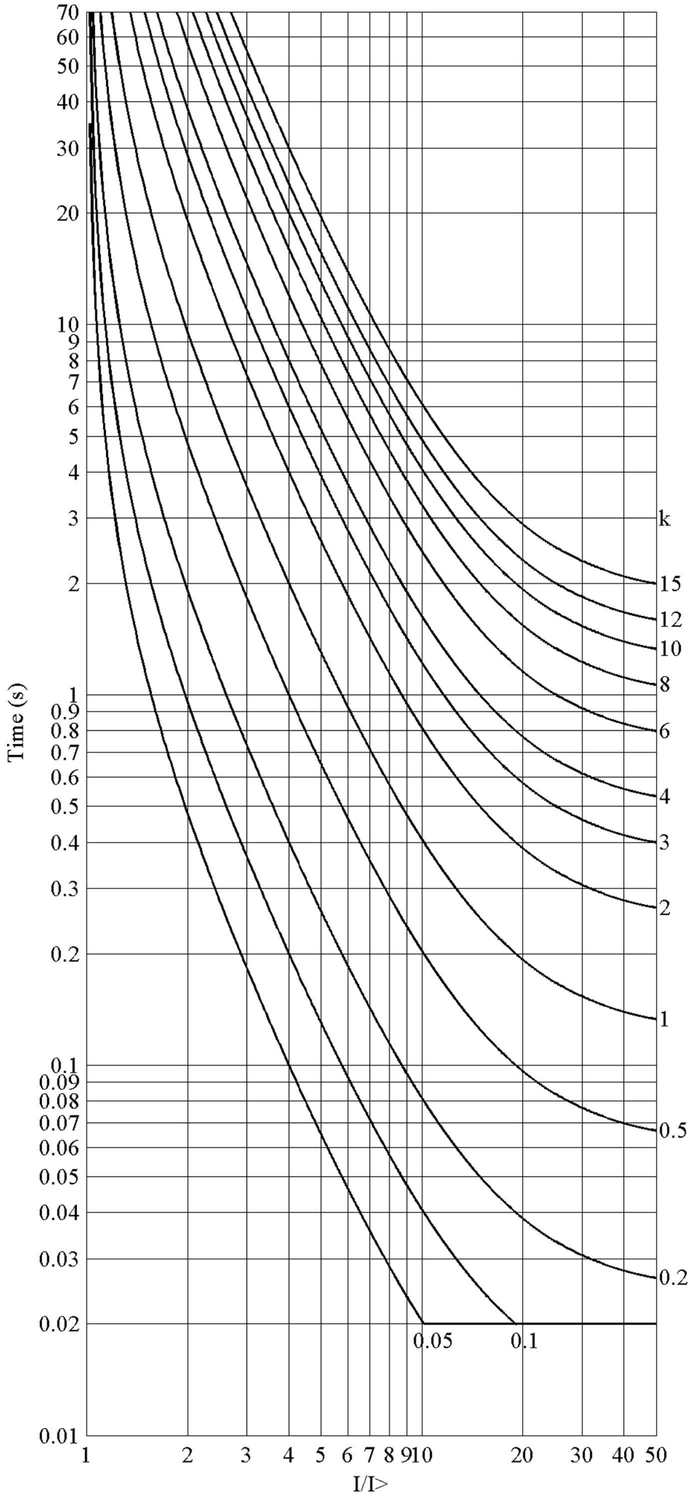


Figure 989: ANSI extremely inverse-time characteristics

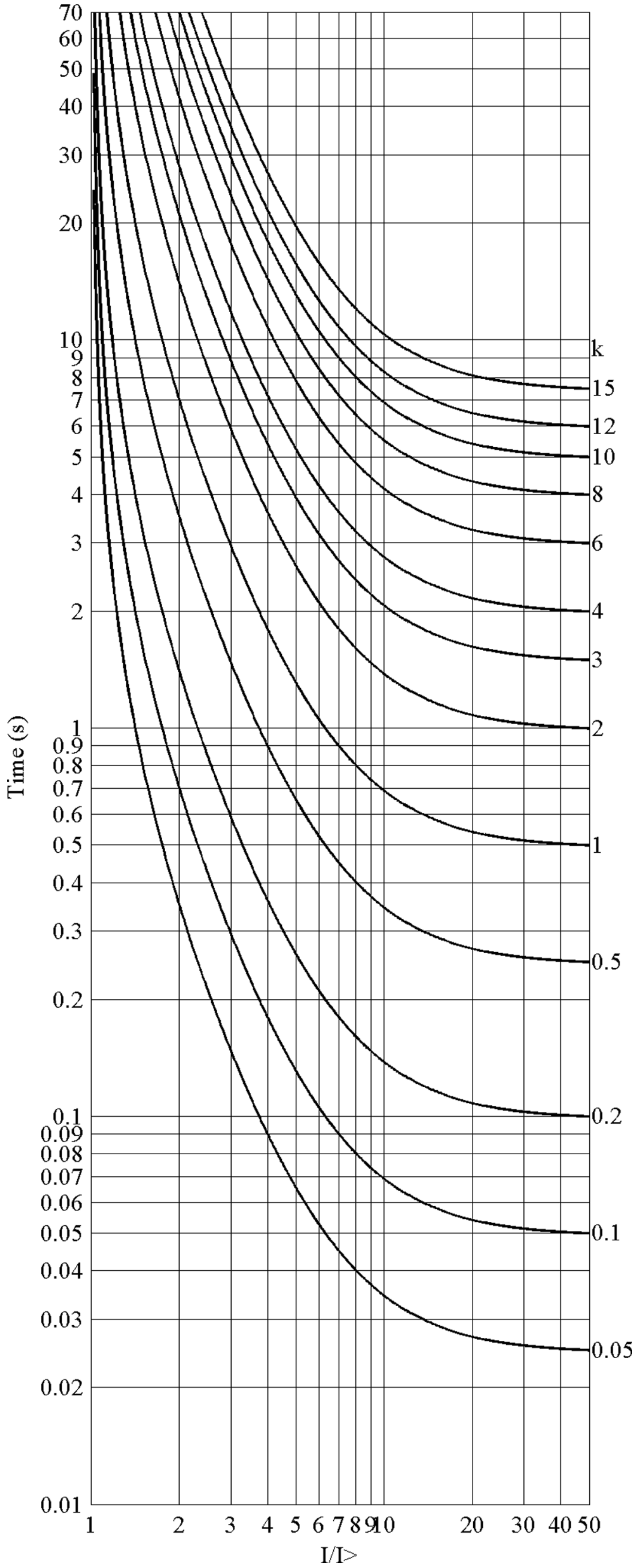


Figure 990: ANSI very inverse-time characteristics

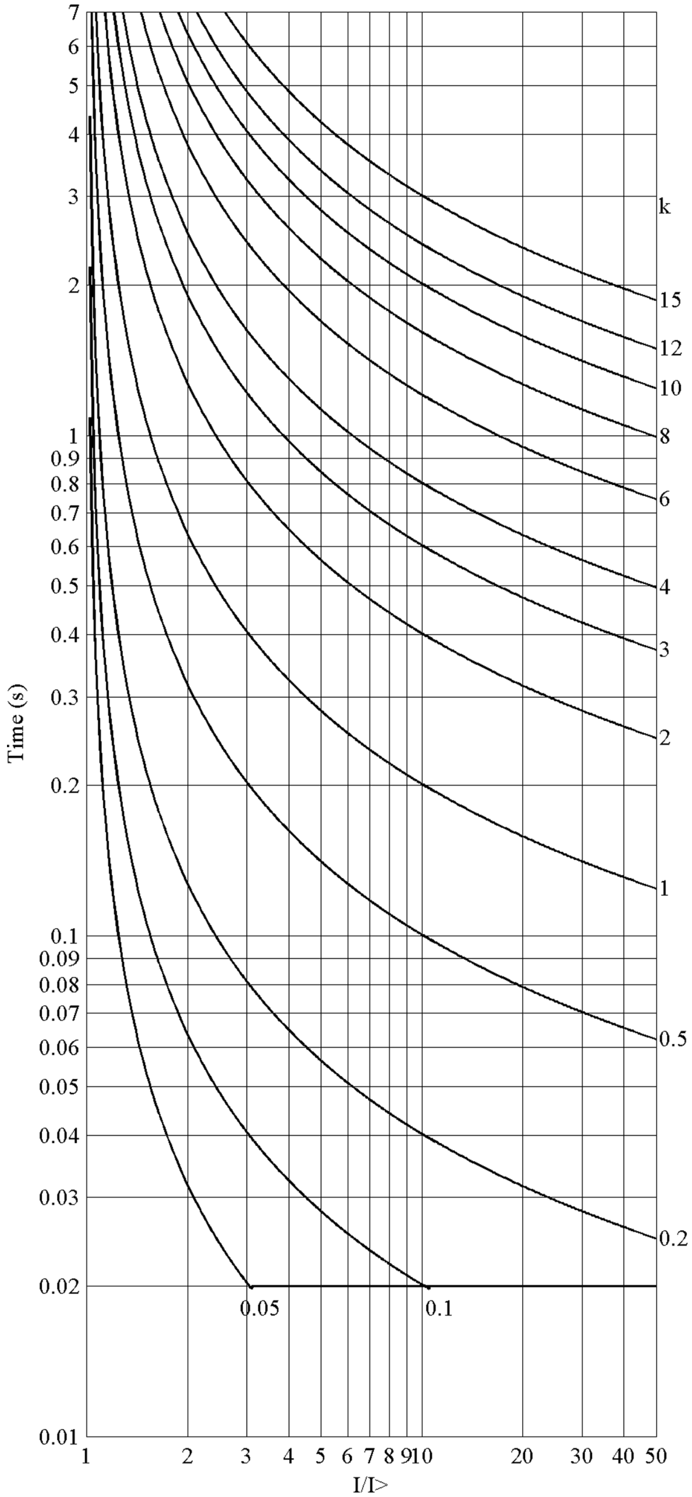


Figure 991: ANSI normal inverse-time characteristics

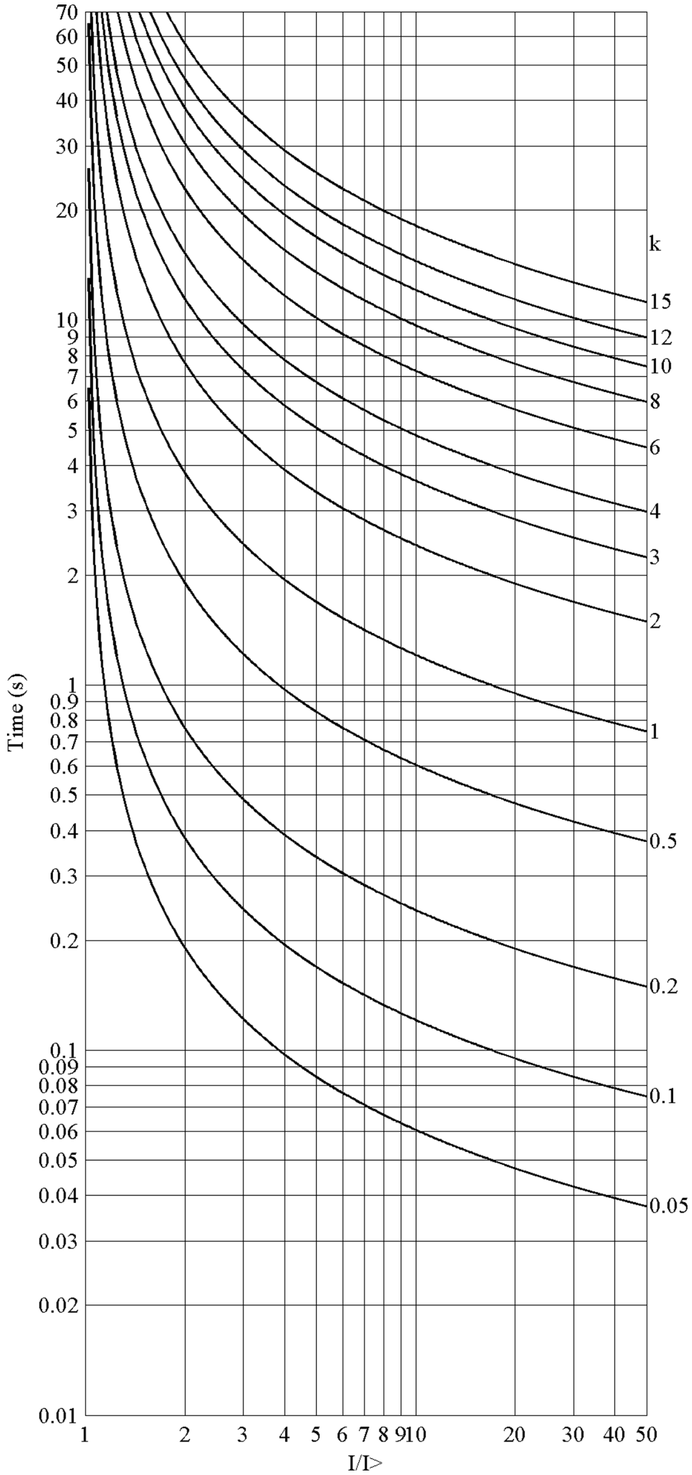


Figure 992: ANSI moderately inverse-time characteristics

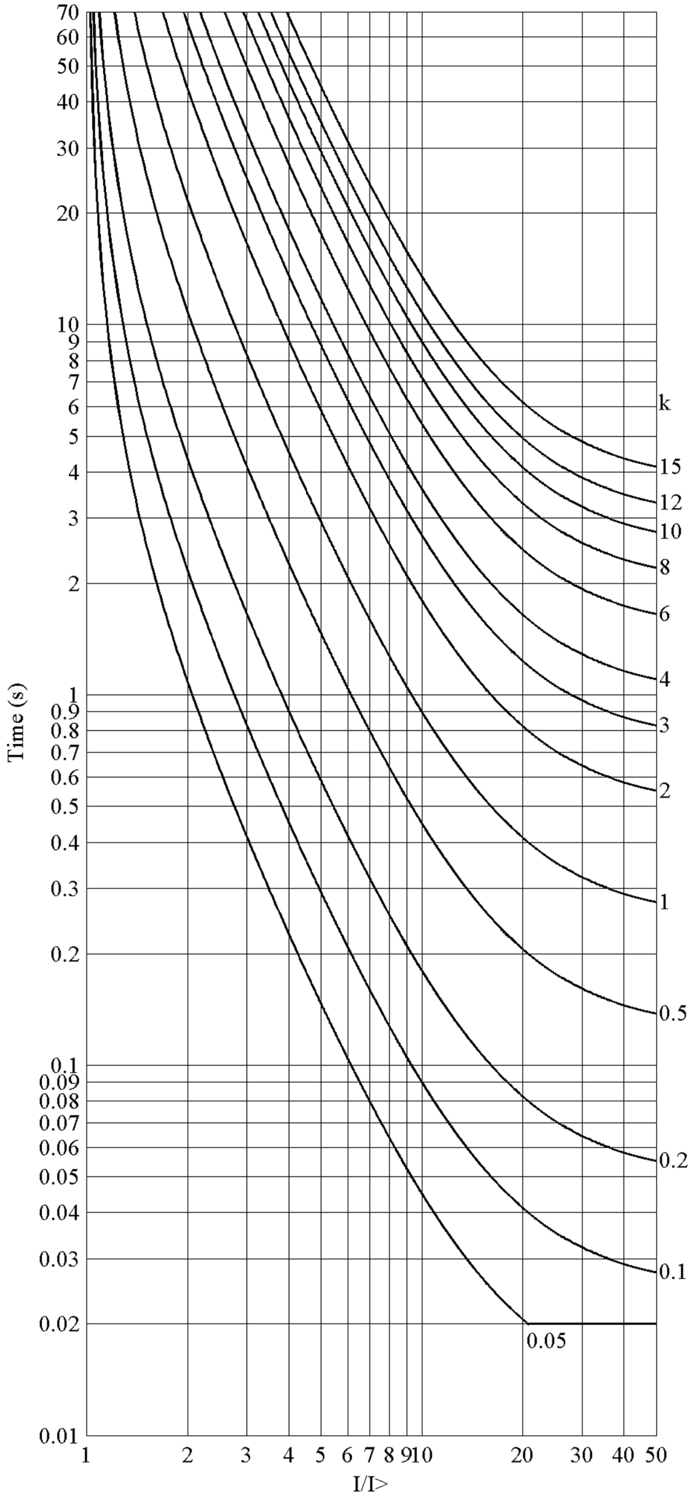


Figure 993: ANSI long-time extremely inverse-time characteristics

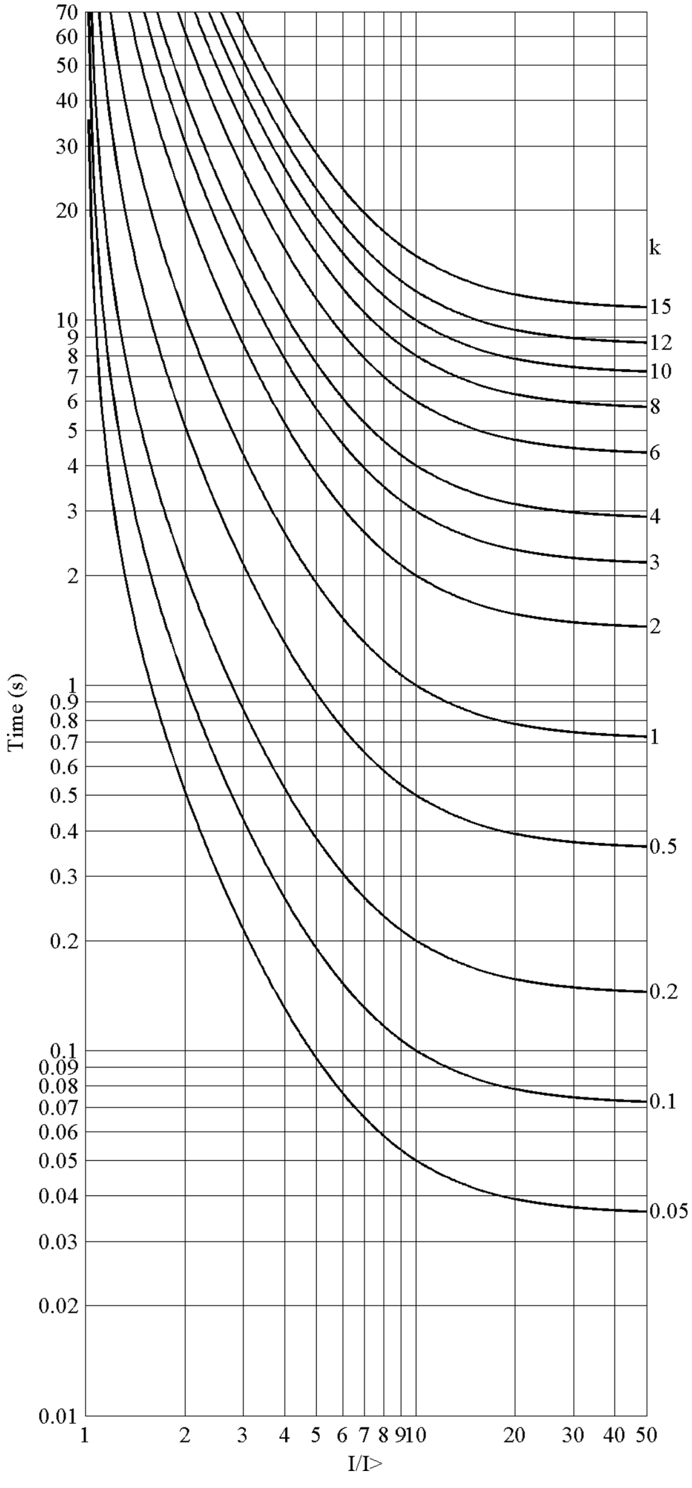


Figure 994: ANSI long-time very inverse-time characteristics

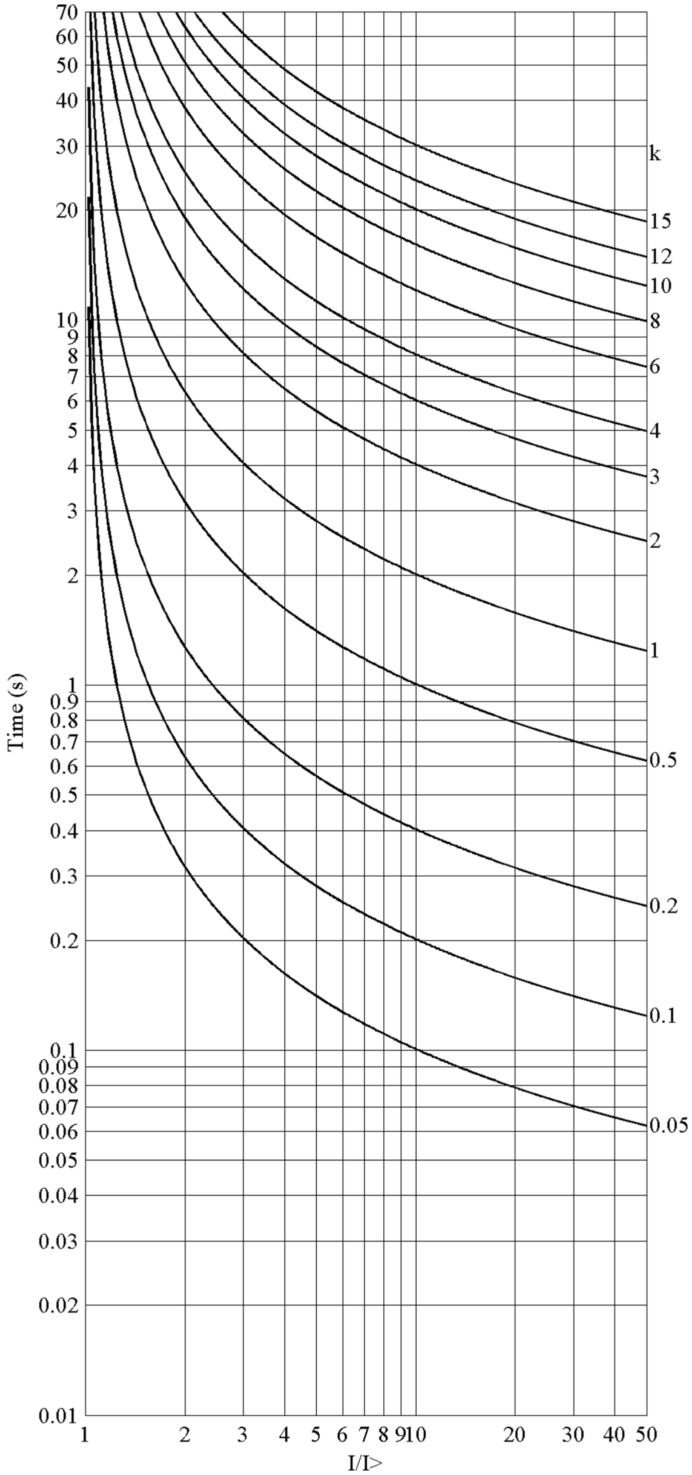


Figure 995: ANSI long-time inverse-time characteristics

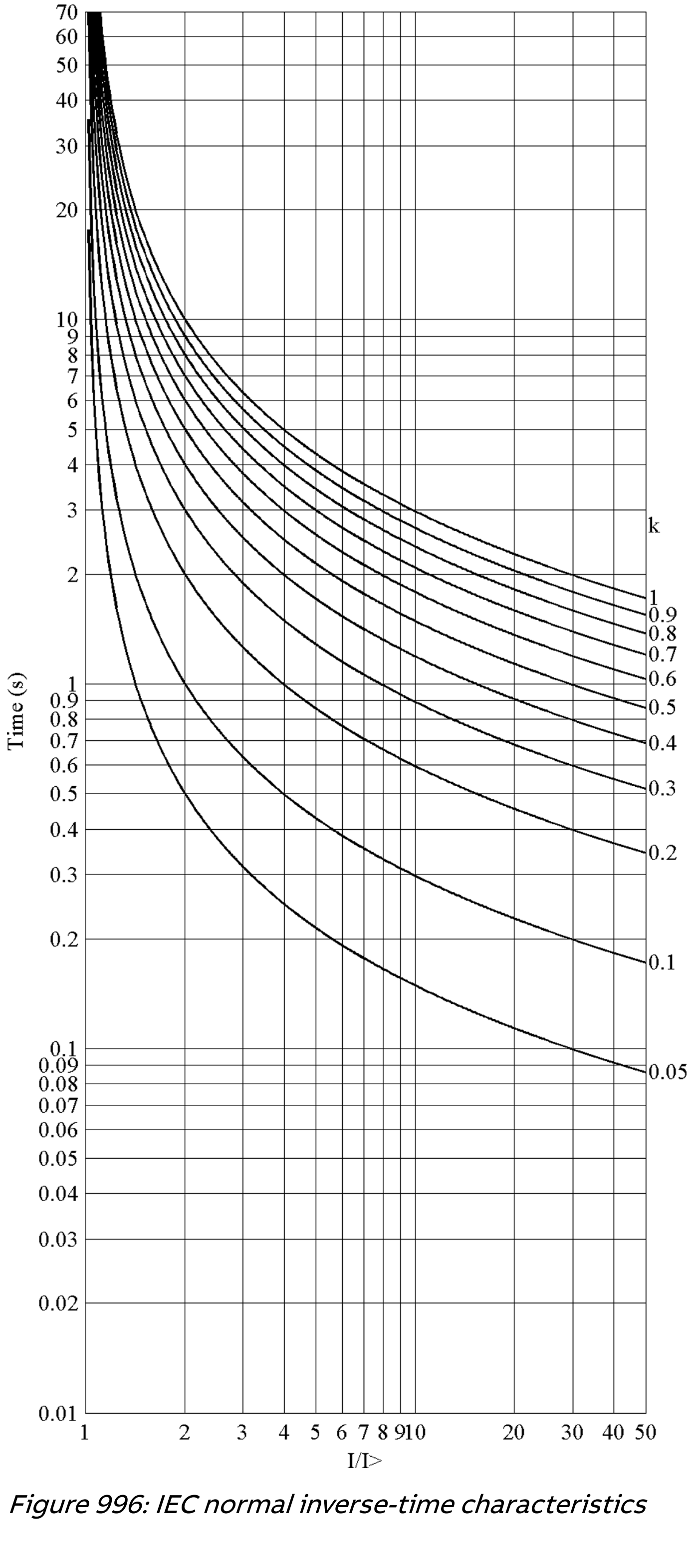


Figure 996: IEC normal inverse-time characteristics

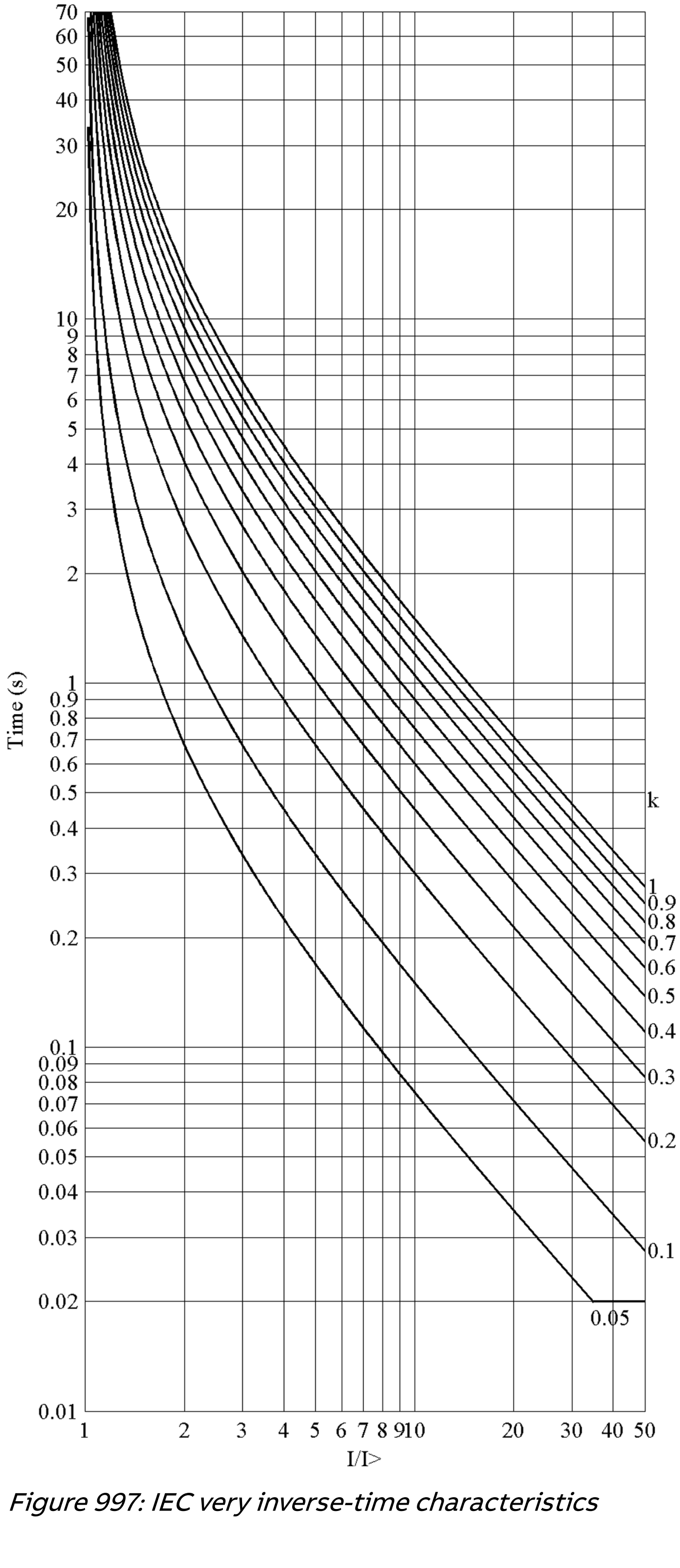


Figure 997: IEC very inverse-time characteristics

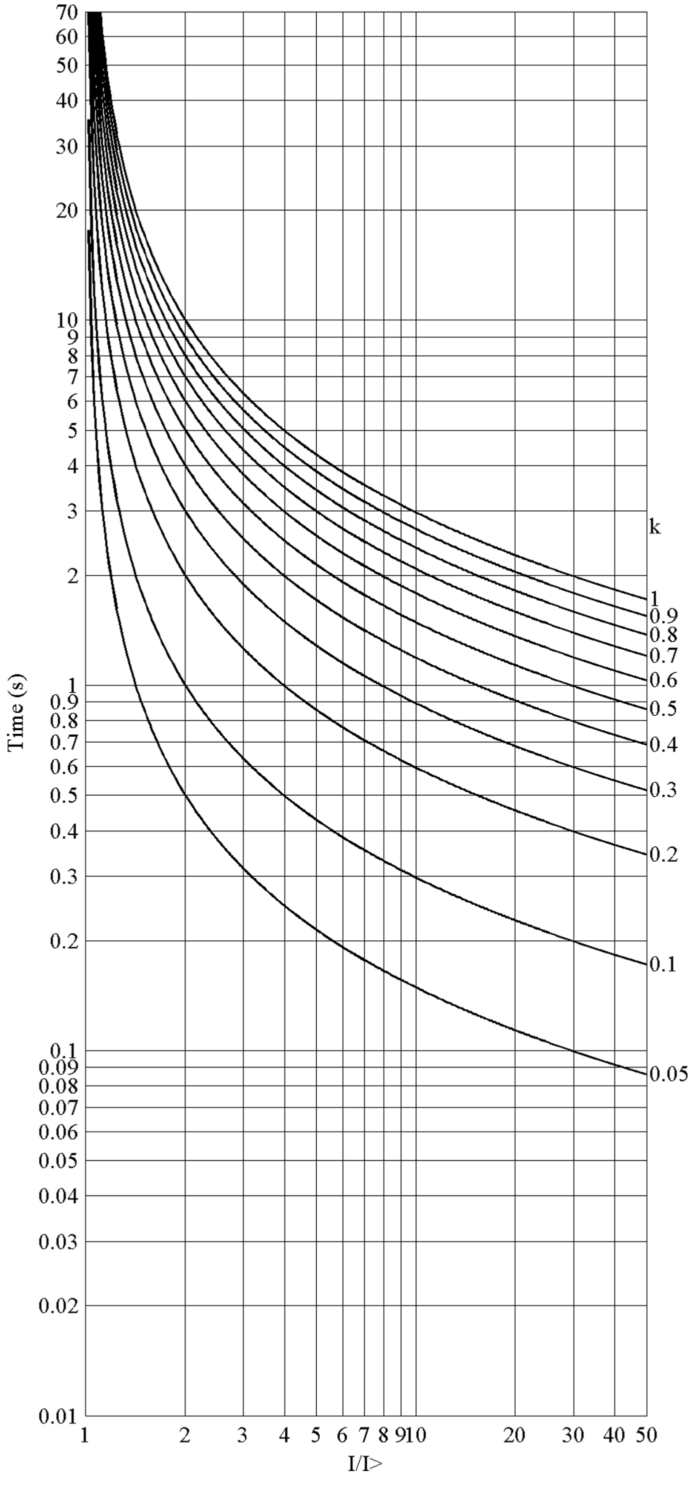


Figure 998: IEC inverse-time characteristics

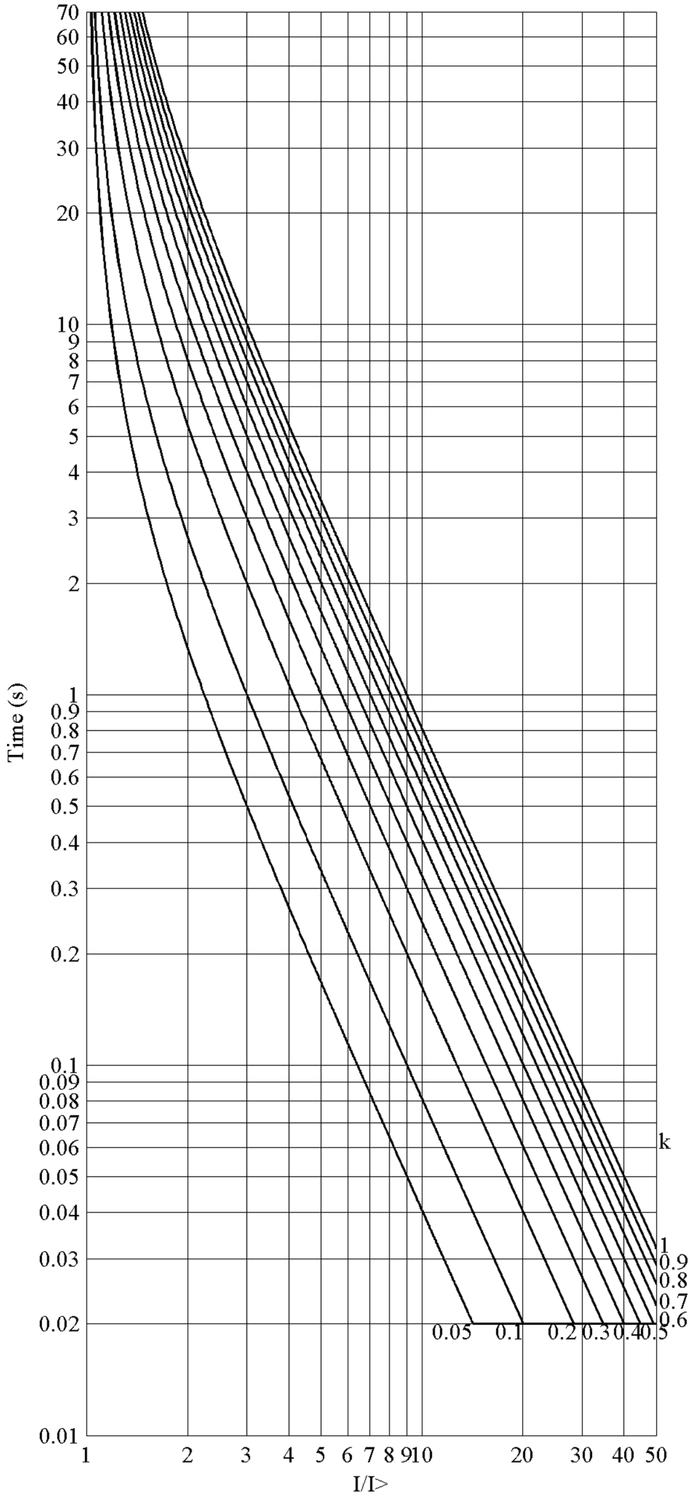


Figure 999: IEC extremely inverse-time characteristics

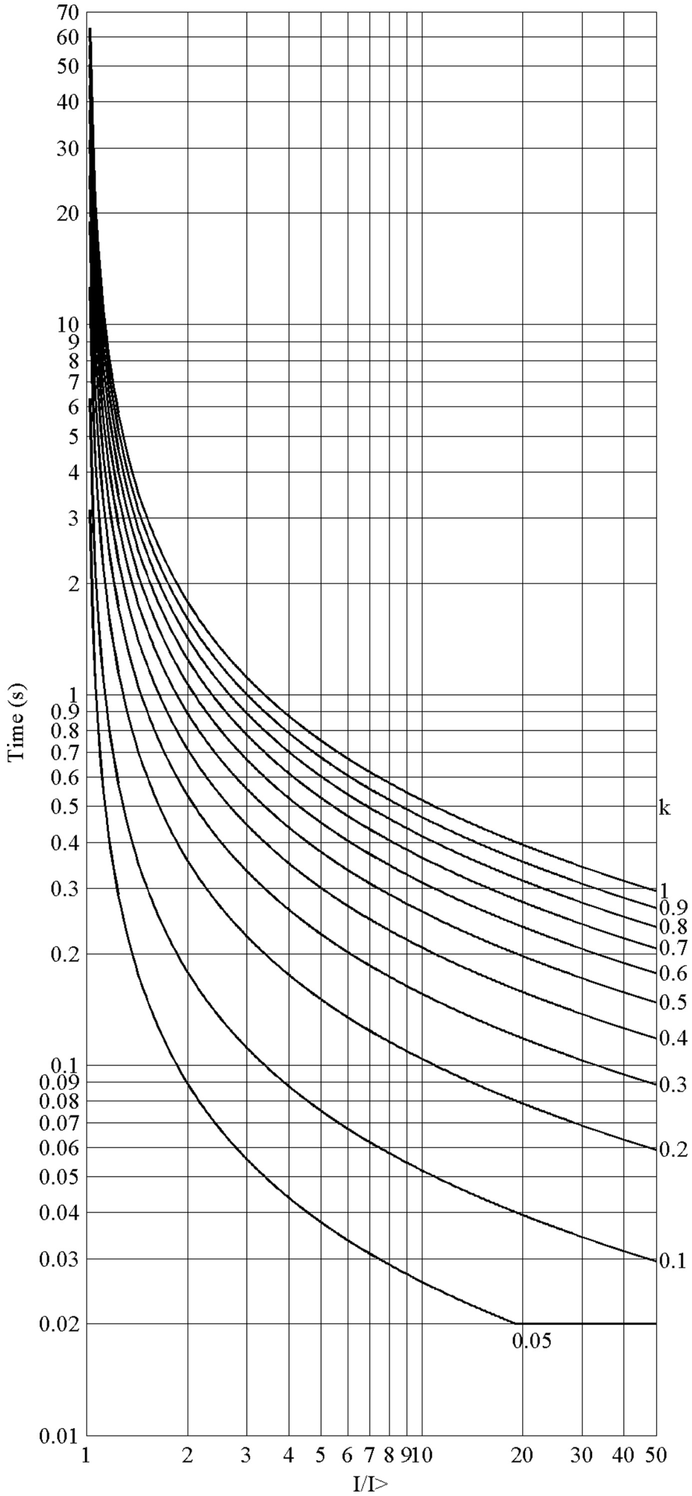


Figure 1000: IEC short-time inverse-time characteristics

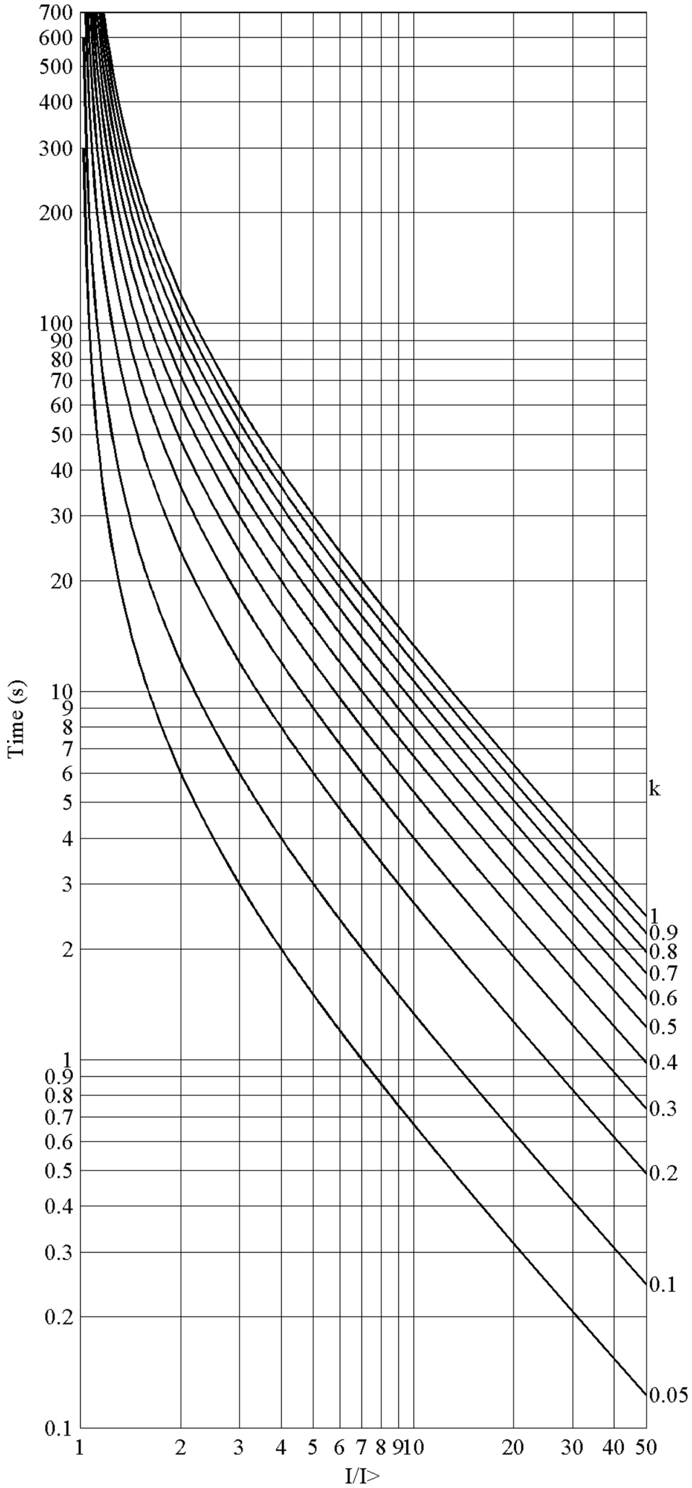


Figure 1001: IEC long-time inverse-time characteristics

11.2.1.2 User-programmable inverse-time characteristics

The user can define curves by entering parameters into the following standard formula:

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>} \right)^{c} - E} + B \right) \cdot k$$

(Equation 394)

t[s]	Operate time (in seconds)
A	Set *Curve parameter A*
B	Set *Curve parameter B*
C	Set *Curve parameter C*
E	Set *Curve parameter E*
I	Measured current
I>	Set *Start value*
k	Set *Time multiplier*

11.2.1.3 RI and RD-type inverse-time characteristics

The RI-type simulates the behavior of electromechanical relays. The RD-type is an earth-fault specific characteristic.

The RI-type is calculated using the formula

$$t[s] = \left(\frac{k}{0.339 - 0.236 \times \frac{I>}{I}} \right)$$

(Equation 395)

The RD-type is calculated using the formula

$$t[s] = 5.8 - 1.35 \times \mathrm{In}\left(\frac{I}{k \times I>} \right)$$

(Equation 396)

t[s]	Operate time (in seconds)
k	Set *Time multiplier*
I	Measured current
I>	Set *Start value*

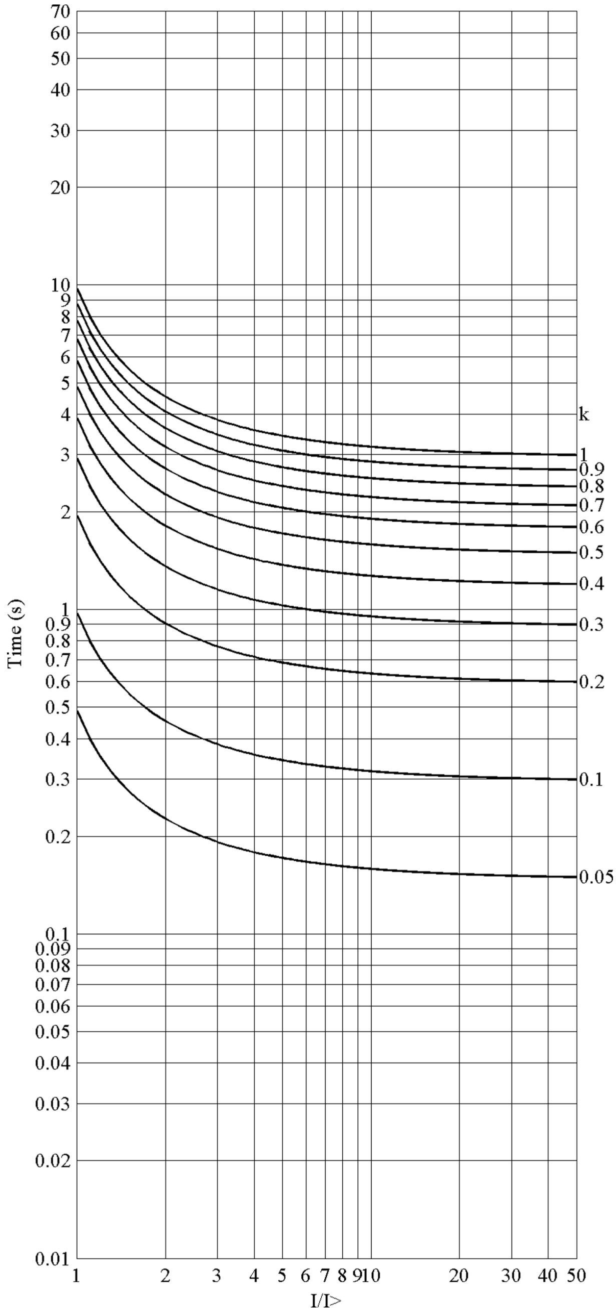


Figure 1002: RI-type inverse-time characteristics

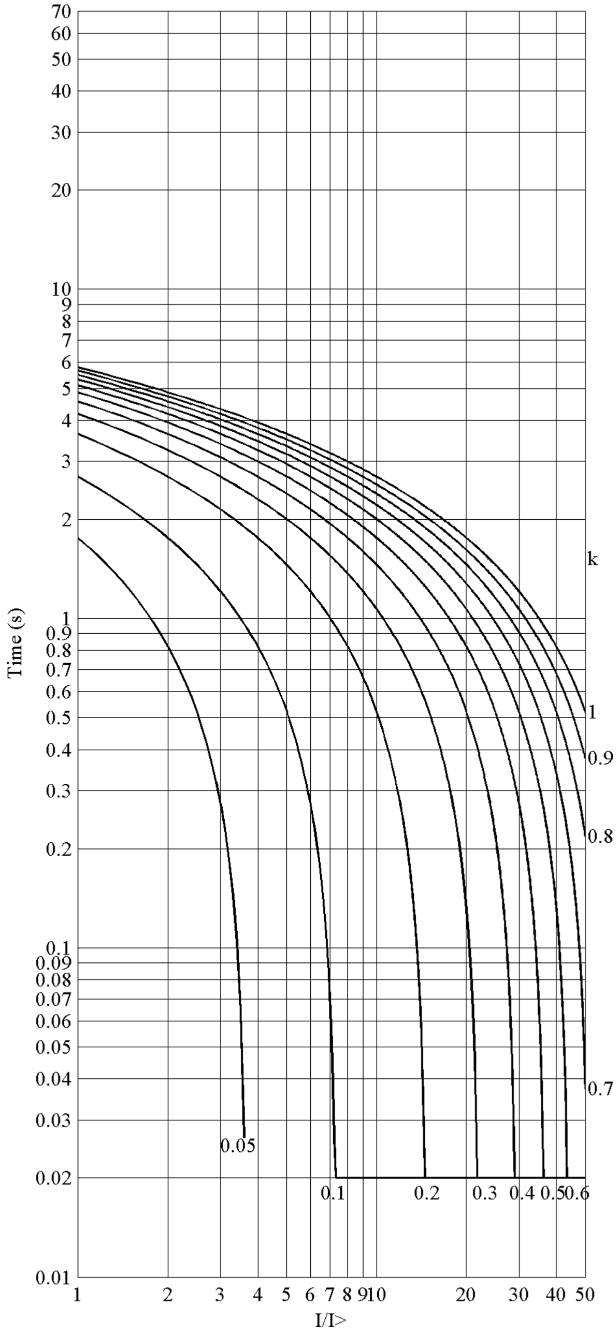


Figure 1003: RD-type inverse-time characteristics

11.2.1.4 UK rectifier inverse-time characteristic

The UK rectifier type simulates the rectifier bridge.

The operate times are defined with the coefficients A, B and C.

The values of the coefficients can be calculated according to the formula

$$t[s] = \left(\frac{A}{\left(\frac{I}{I>} \right)^{c} - 1} + B \right) \cdot k$$

t[s] Operate time in seconds

I Measured current

I> Set *Start value*

k Set *Time multiplier*

Table 1651: Curve parameters for UK rectifier

Operating curve type	A	B	C
(20) UK rectifier	45900	0	5.6

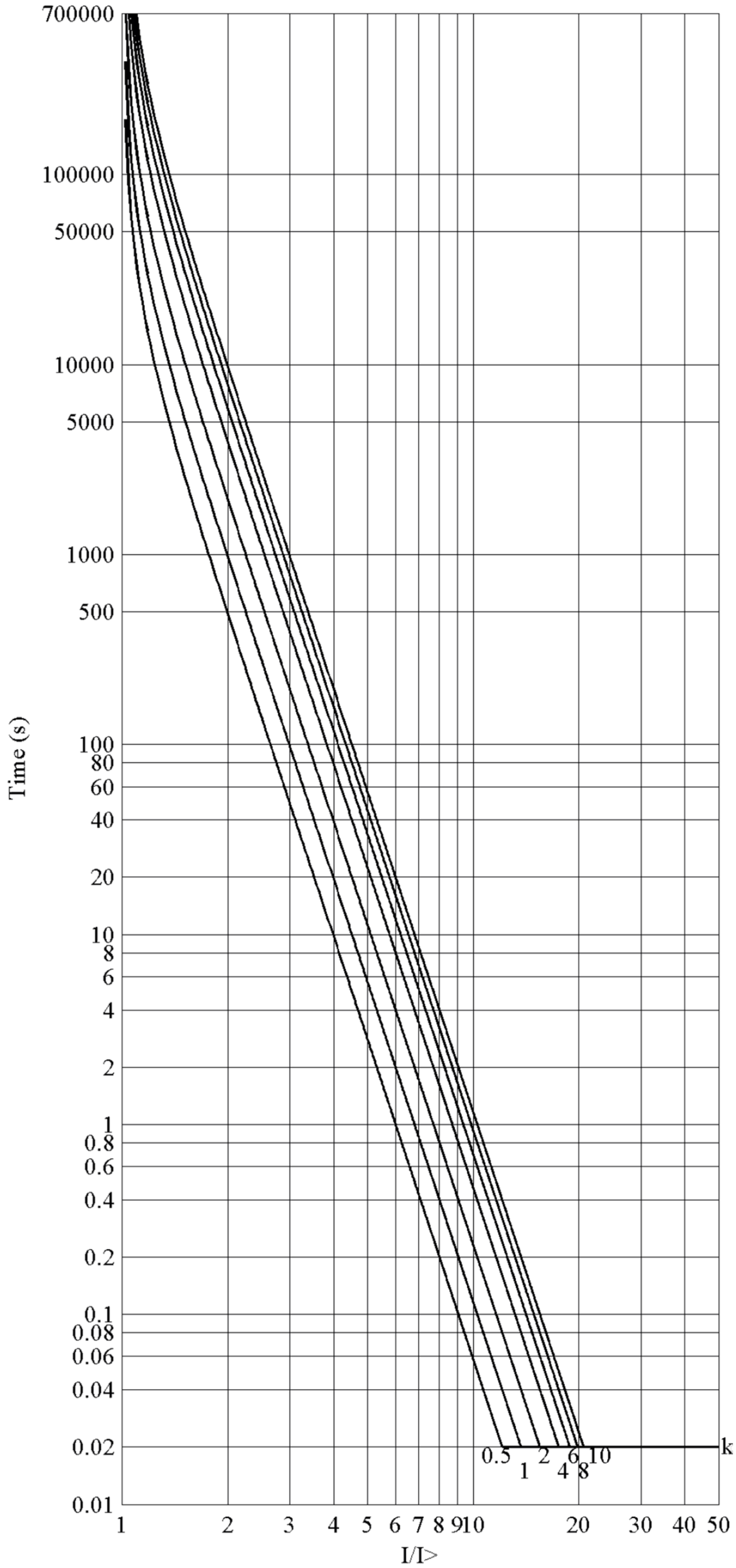


Figure 1004: UK rectifier inverse-time characteristic

11.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting.

Table 1652: Values for reset mode

Setting name	Possible values
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset

Immediate reset

If the *Type of reset curve* setting in a drop-off case is selected as "Immediate", the inverse timer resets immediately.

Definite time reset

The definite type of reset in the inverse-time mode can be achieved by setting the *Type of reset curve* parameter to “Def time reset”. As a result, the operate inverse-time counter is frozen for the time determined with the *Reset delay time* setting after the current drops below the set *Start value*, including hysteresis. The integral sum of the inverse-time counter is reset, if another start does not occur during the reset delay.

If the *Type of reset curve* setting is selected as “Def time reset”, the current level has no influence on the reset characteristic.

Inverse reset

Inverse reset curves are available only for ANSI and user-programmable curves. If you use other curve types, immediate reset occurs.

Standard delayed inverse reset

The reset characteristic required in ANSI (IEEE) inverse-time modes is provided by setting the *Type of reset curve* parameter to “Inverse reset”. In this mode, the time delay for reset is given with the following formula using the coefficient D, which has its values defined in the table below.

$$t[s] = \left| \frac{D}{\left(\frac{I}{I>}\right)^2 - 1} \right| \cdot k$$

(Equation 397)

t[s]	Reset time (in seconds)
k	Set *Time multiplier*

Table continues on the next page

I	Measured current
I>	Set *Start value*

Table 1653: Coefficients for ANSI delayed inverse reset curves

Curve name	D
(1) ANSI Extremely Inverse	29.1
(2) ANSI Very Inverse	21.6
(3) ANSI Normal Inverse	0.46
(4) ANSI Moderately Inverse	4.85
(6) Long Time Extremely Inverse	30
(7) Long Time Very Inverse	13.46
(8) Long Time Inverse	4.6

The delayed inverse reset time depends also on the protection function's start duration value START_DUR. The reset time on the drop-off moment can be calculated by multiplying t[s] with START_DUR.

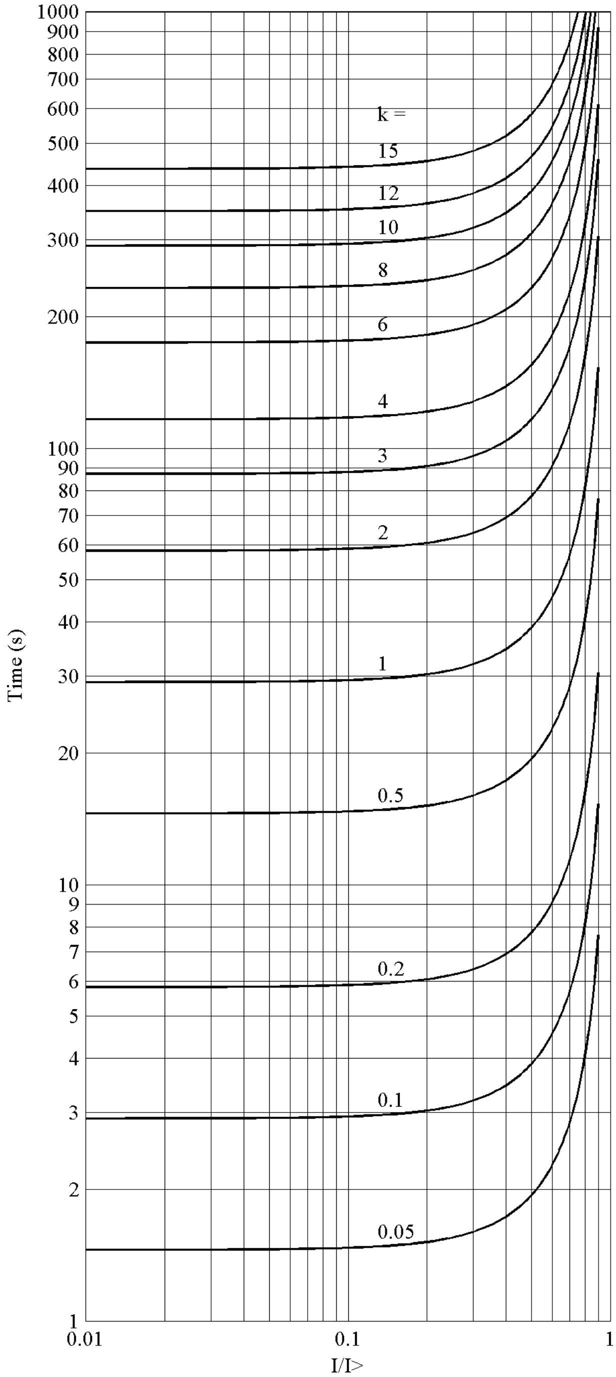


Figure 1005: ANSI extremely inverse reset time characteristics

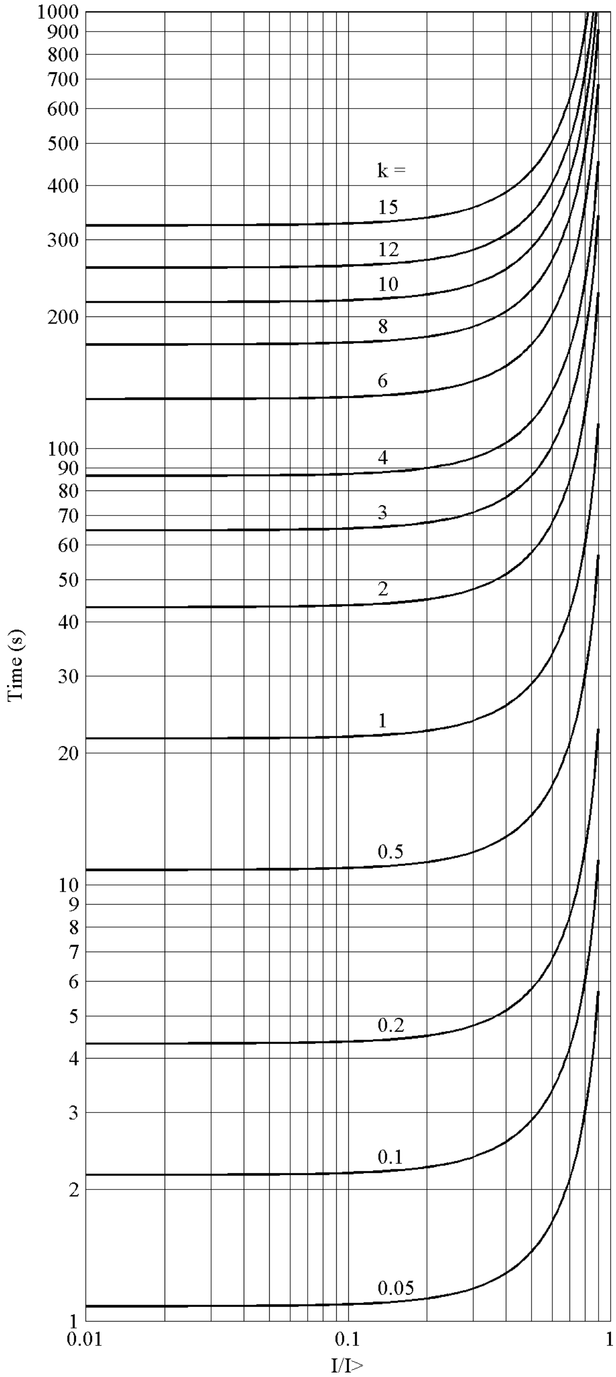


Figure 1006: ANSI very inverse reset time characteristics

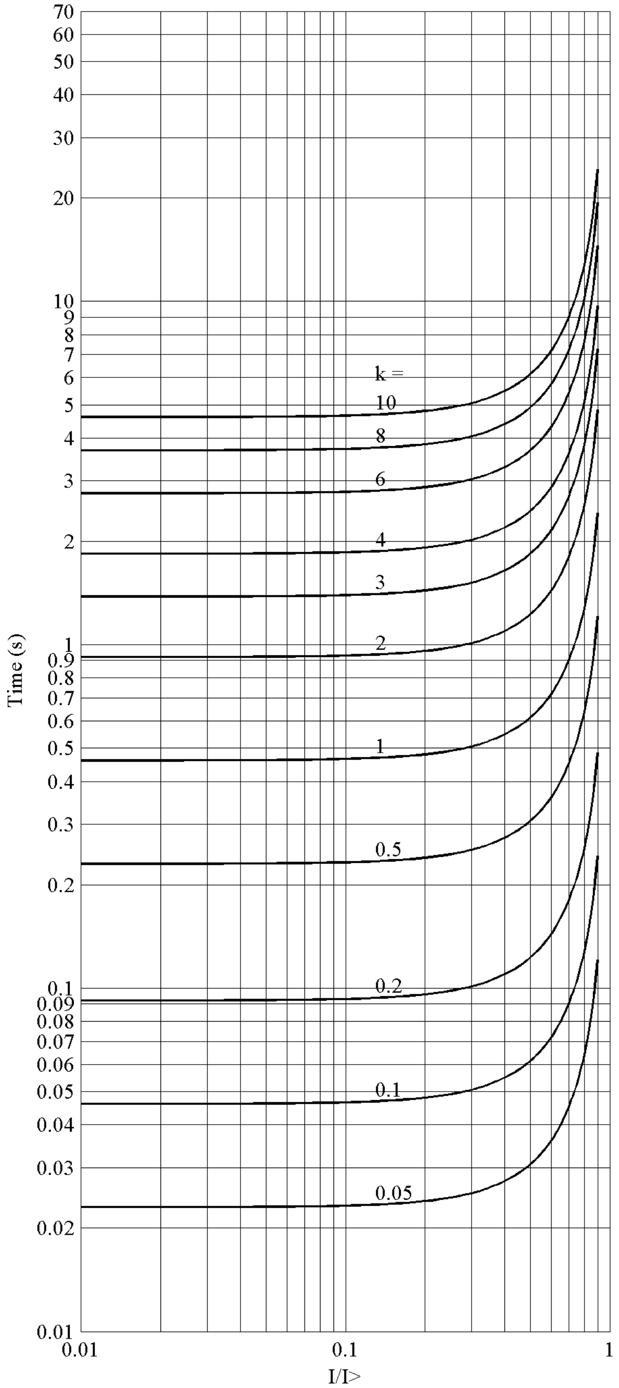


Figure 1007: ANSI normal inverse reset time characteristics

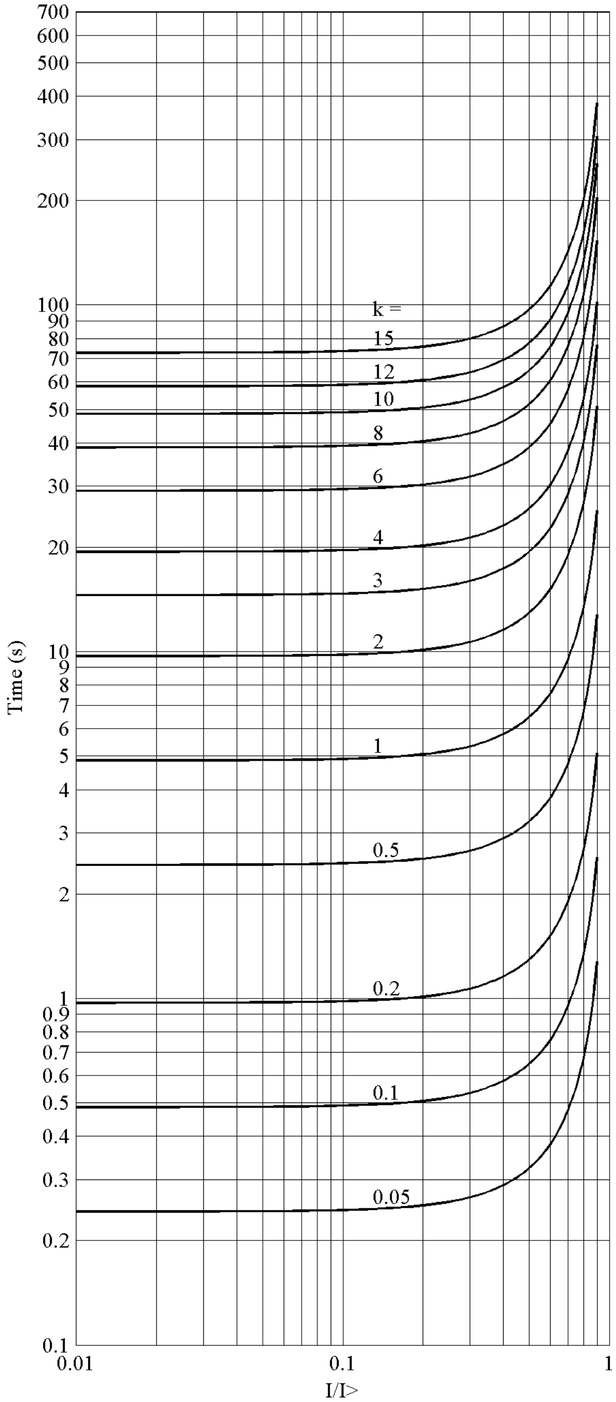


Figure 1008: ANSI moderately inverse reset time characteristics

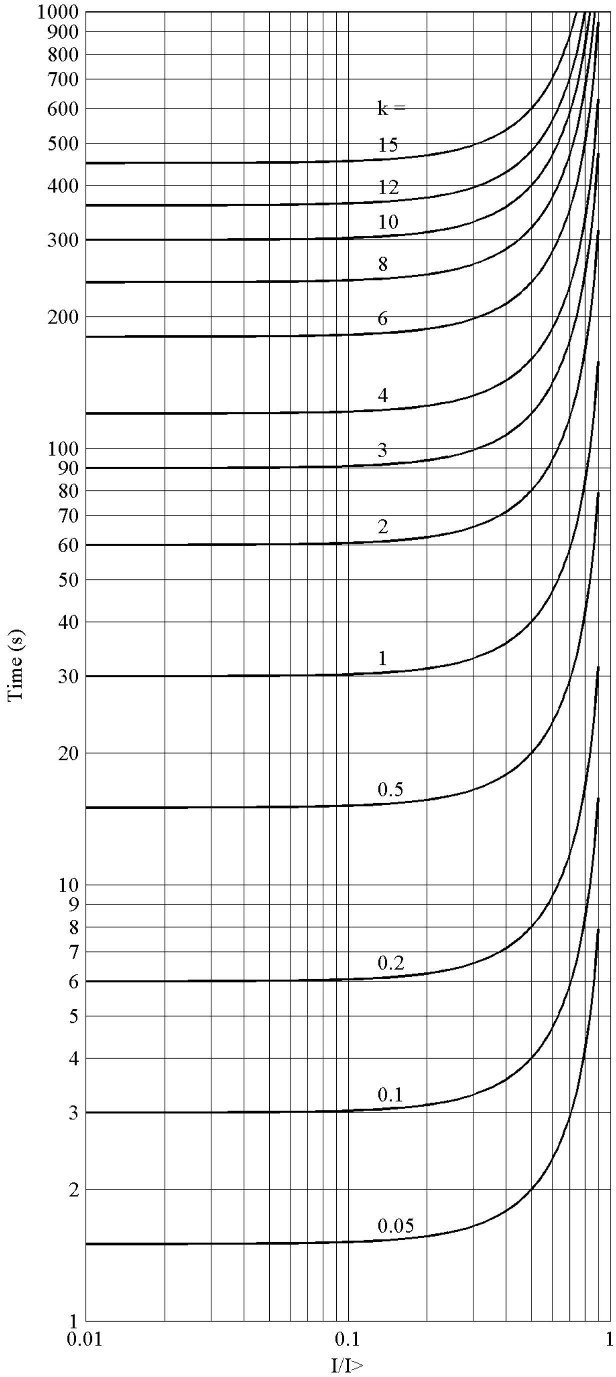


Figure 1009: ANSI long-time extremely inverse reset time characteristics

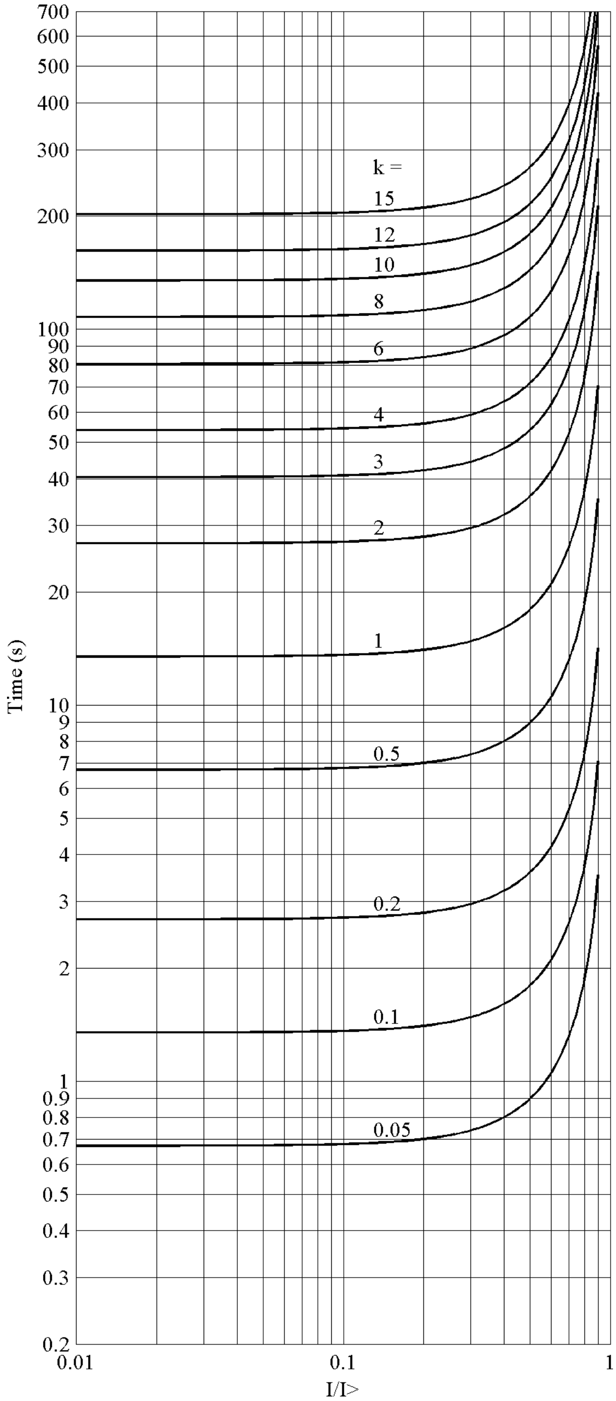


Figure 1010: ANSI long-time very inverse reset time characteristics

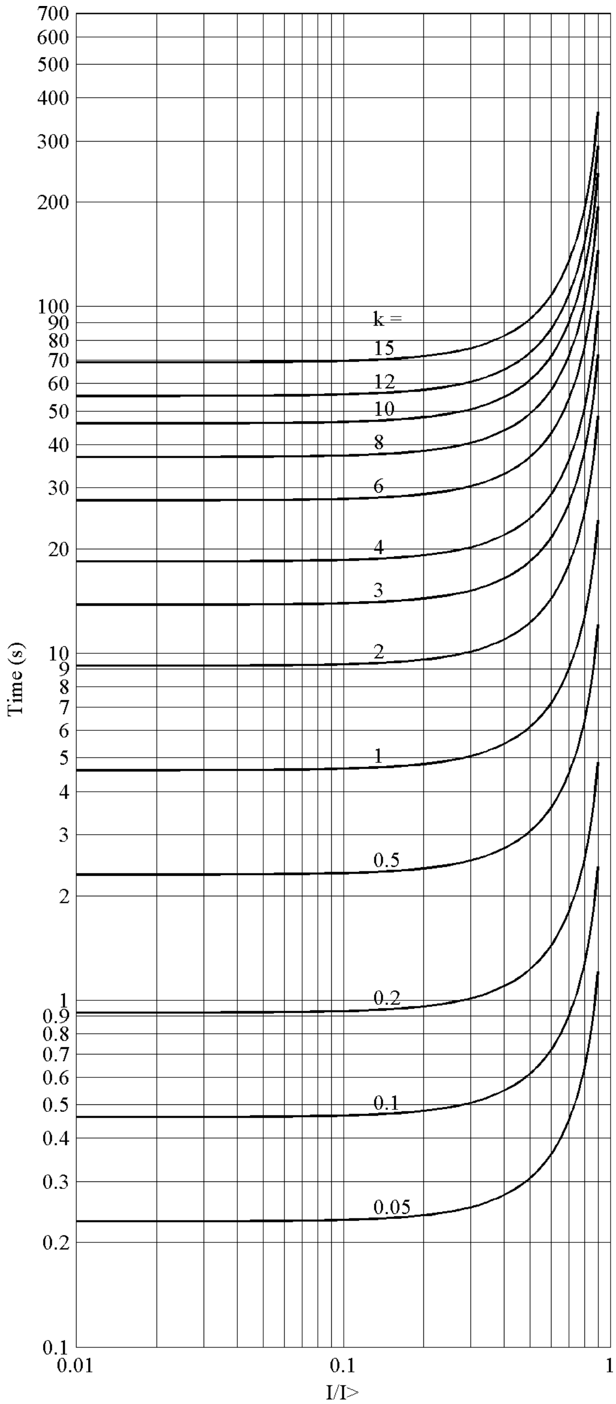


Figure 1011: ANSI long-time inverse reset time characteristics

The delayed inverse-time reset is not available for IEC-type inverse time curves.

User-programmable delayed inverse reset

The user can define the delayed inverse reset time characteristics with the following formula using the set *Curve parameter D*.

$$t[s] = \left| \frac{D}{\left(\frac{I}{I>}\right)^2 - 1} \right| \cdot k$$

(Equation 398)

The delayed inverse reset time depends also on the protection function's start duration value START_DUR. The reset time on the drop-off moment can be calculated by multiplying t[s] with START_DUR.

t[s]	Reset time (in seconds)
k	Set *Time multiplier*
D	Set *Curve parameter D*
I	Measured current
I>	Set *Start value*

11.2.3 Inverse-timer freezing

When the BLOCK input is active, the internal value of the time counter is frozen at the value of the moment just before the freezing. Freezing of the counter value is chosen when the user does not wish the counter value to count upwards or to be reset. This may be the case, for example, when the inverse-time function of a protection relay needs to be blocked to enable the definite-time operation of another protection relay for selectivity reasons, especially if different relaying techniques (old and modern relays) are applied.

The selected blocking mode is "Freeze timer".

The activation of the BLOCK input also lengthens the minimum delay value of the timer.

Activating the BLOCK input alone does not affect the operation of the START output. It still becomes active when the current exceeds the set *Start value*, and inactive when the current falls below the set *Start value* and the set *Reset delay time* has expired.

11.3 Voltage based inverse definite minimum time characteristics

11.3.1 IDMT curves for overvoltage protection

In inverse-time modes, the operate time depends on the momentary value of the voltage, the higher the voltage, the faster the operate time. The operate time calculation or integration starts immediately when the voltage exceeds the set value of the *Start value* setting and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the overvoltage situation exceeds the value set by the inverse time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time for the IDMT mode, that is, it is possible to limit the IDMT based operate time for not becoming too short. For example:

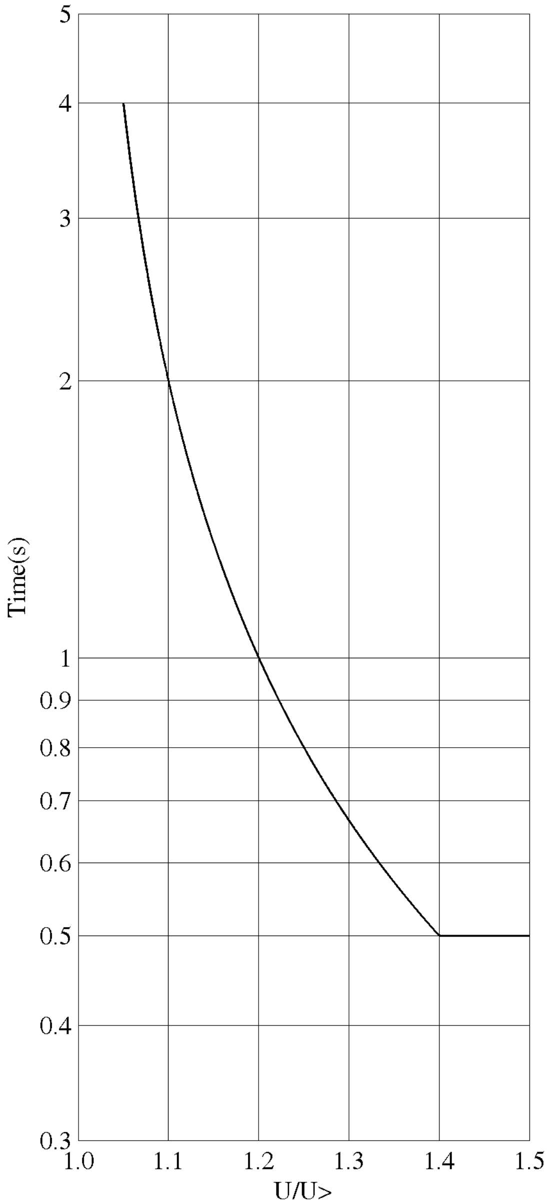


Figure 1012: Operate time curve based on IDMT characteristic with Minimum operate time set to 0.5 second

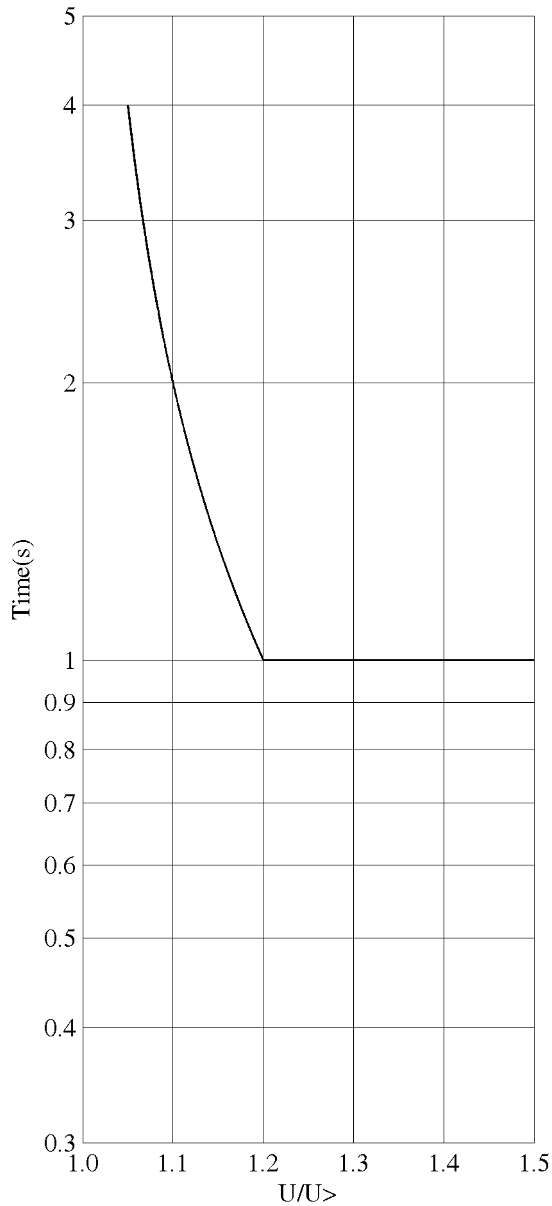


Figure 1013: Operate time curve based on IDMT characteristic with Minimum operate time set to 1 second

11.3.1.1 Standard inverse-time characteristics for overvoltage protection

The operate times for the standard overvoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse operate time can be calculated with the formula:

$$t\left[s\right] = \frac{k \cdot A}{\left(B \times \frac{U - U>}{U>} - C\right)^{E}} + D$$

(Equation 399)

t [s]	Operate time in seconds
U	Measured voltage
U>	Set value of *Start value*
k	Set value of *Time multiplier*

Table 1654: Curve coefficients for the standard overvoltage IDMT curves

Curve name	A	B	C	D	E
(17) Inverse Curve A	1	1	0	0	1
(18) Inverse Curve B	480	32	0.5	0.035	2
(19) Inverse Curve C	480	32	0.5	0.035	3

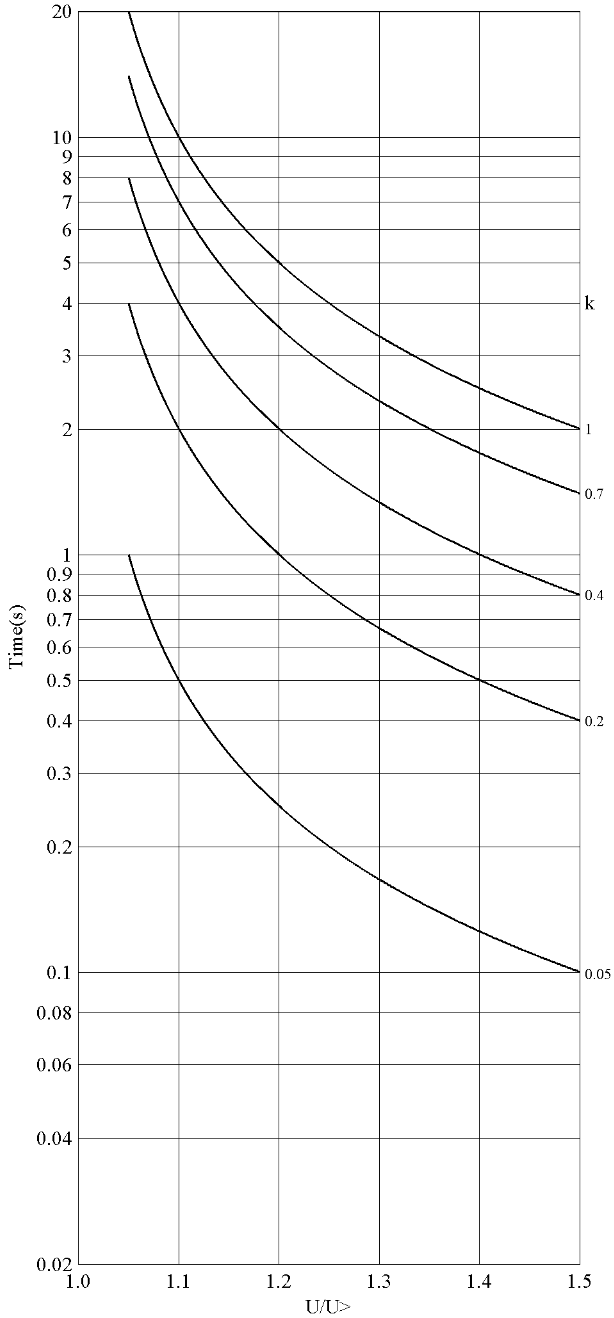


Figure 1014: Inverse curve A characteristic of overvoltage protection

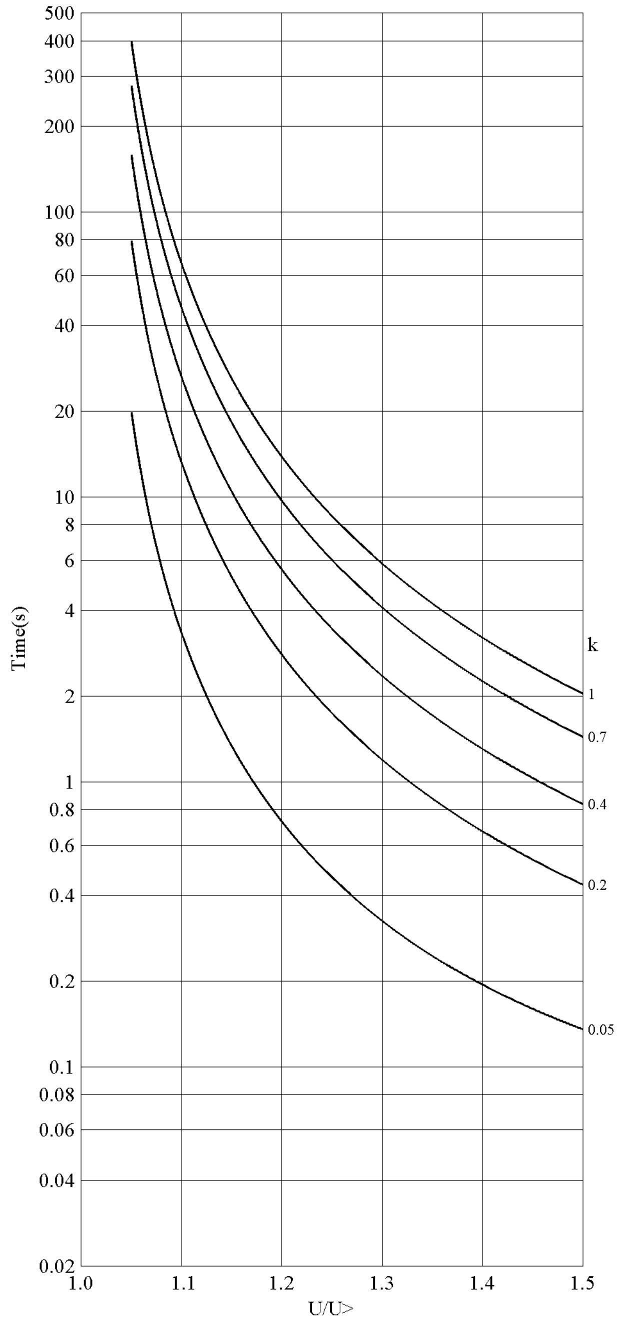


Figure 1015: Inverse curve B characteristic of overvoltage protection

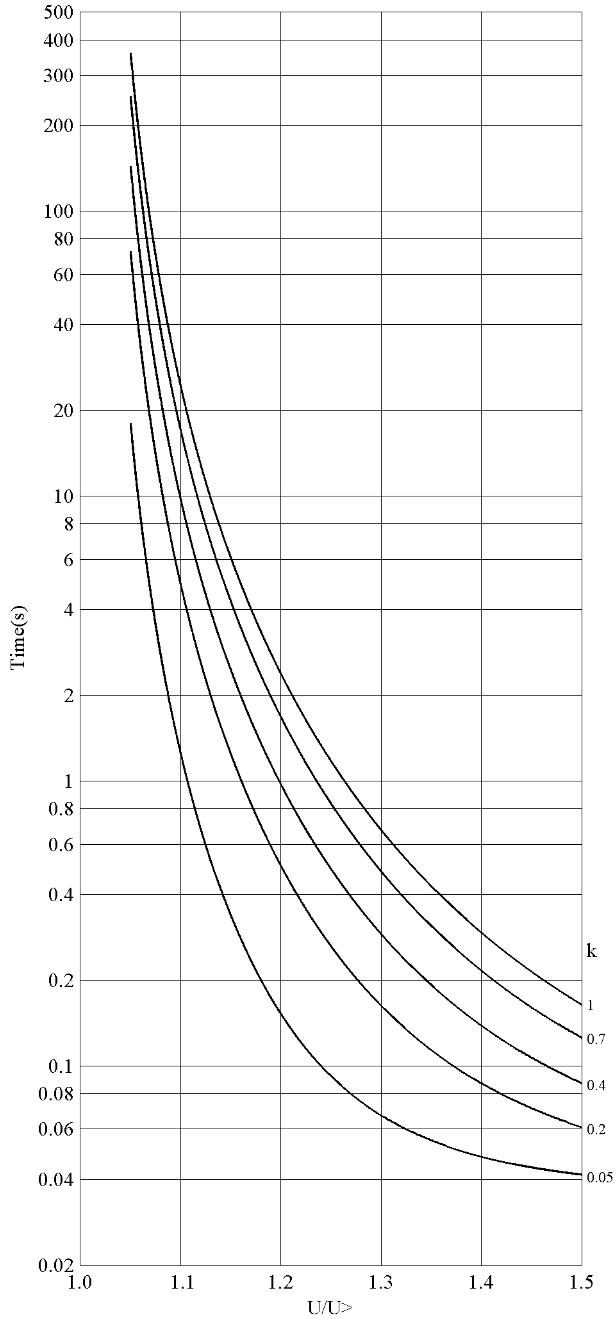


Figure 1016: Inverse curve C characteristic of overvoltage protection

11.3.1.2 User programmable inverse-time characteristics for overvoltage protection

The user can define the curves by entering the parameters using the standard formula:

$$t[s] = \frac{k \cdot A}{\left(B \times \frac{U - U>}{U>} - C\right)^{E}} + D$$

(Equation 400)

t[s]	Operate time in seconds
A	Set value of *Curve parameter A*
B	Set value of *Curve parameter B*
C	Set value of *Curve parameter C*
D	Set value of *Curve parameter D*
E	Set value of *Curve parameter E*
U	Measured voltage
U>	Set value of *Start value*
k	Set value of *Time multiplier*

11.3.1.3 IDMT curve saturation of overvoltage protection

For the overvoltage IDMT mode of operation, the integration of the operate time does not start until the voltage exceeds the value of *Start value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared to *Start value*. For example, due to the curve equation B and C, the characteristics equation output is saturated in such a way that when the input voltages are in the range of *Start value* to *Curve Sat Relative* in percent over *Start value*, the equation uses *Start value* * (1.0 + *Curve Sat Relative /* 100) for the measured voltage. Although, the curve A has no discontinuities when the ratio U/U> exceeds the unity, *Curve Sat Relative* is also set for it. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning the discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum operate time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

11.3.2 IDMT curves for undervoltage protection

In the inverse-time modes, the operate time depends on the momentary value of the voltage, the lower the voltage, the faster the operate time. The operate time calculation or integration starts immediately when the voltage goes below the set value of the *Start value* setting and the `START` output is activated.

The `OPERATE` output of the component is activated when the cumulative sum of the integrator calculating the undervoltage situation exceeds the value set by the inverse-time mode. The set value depends on the selected curve type and the setting values used. The user determines the curve scaling with the *Time multiplier* setting.

The *Minimum operate time* setting defines the minimum operate time possible for the IDMT mode. For setting a value for this parameter, the user should carefully study the particular IDMT curve.

11.3.2.1 Standard inverse-time characteristics for undervoltage protection

The operate times for the standard undervoltage IDMT curves are defined with the coefficients A, B, C, D and E.

The inverse operate time can be calculated with the formula:

$$t\left[s\right] = \frac{k \cdot A}{\left(B \times \frac{U< - U}{U<} - C\right)^{E}} + D$$

(Equation 401)

t [s]	Operate time in seconds
U	Measured voltage
U<	Set value of the *Start value* setting
k	Set value of the *Time multiplier* setting

Table 1655: Curve coefficients for standard undervoltage IDMT curves

Curve name	A	B	C	D	E
(21) Inverse Curve A	1	1	0	0	1
(22) Inverse Curve B	480	32	0.5	0.055	2

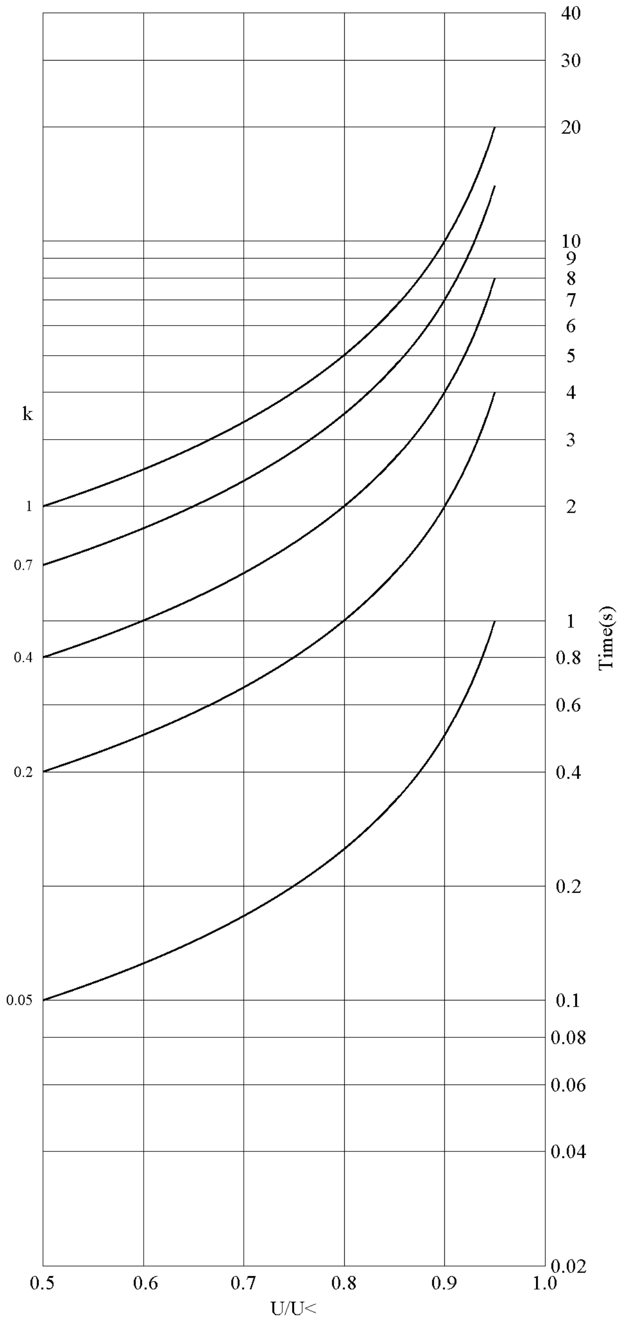


Figure 1017: : Inverse curve A characteristic of undervoltage protection

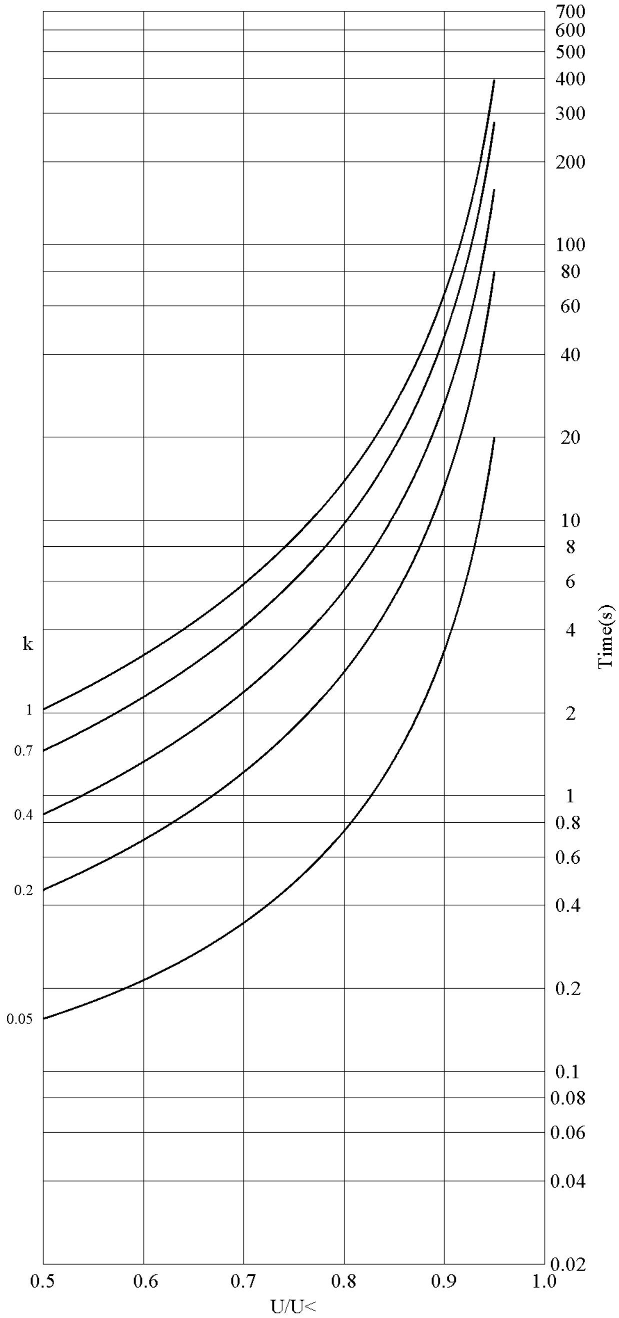


Figure 1018: Inverse curve B characteristic of undervoltage protection

11.3.2.2 User-programmable inverse-time characteristics for undervoltage protection

The user can define curves by entering parameters into the standard formula:

$$t[s] = \frac{k \cdot A}{\left(B \times \frac{U< -U}{U<} - C\right)^E} + D$$

(Equation 402)

t[s]	Operate time in seconds
A	Set value of *Curve parameter A*
B	Set value of *Curve parameter B*
C	Set value of *Curve parameter C*
D	Set value of *Curve parameter D*
E	Set value of *Curve parameter E*
U	Measured voltage
U<	Set value of *Start value*
k	Set value of *Time multiplier*

11.3.2.3 IDMT curve saturation of undervoltage protection

For the undervoltage IDMT mode of operation, the integration of the operate time does not start until the voltage falls below the value of *Start value*. To cope with discontinuity characteristics of the curve, a specific parameter for saturating the equation to a fixed value is created. The *Curve Sat Relative* setting is the parameter and it is given in percents compared with *Start value*. For example, due to the curve equation B, the characteristics equation output is saturated in such a way that when input voltages are in the range from *Start value* to *Curve Sat Relative* in percents under *Start value*, the equation uses *Start value* * (1.0 - *Curve Sat Relative*/ 100) for the measured voltage. Although, the curve A has no discontinuities when the ratio U/U> exceeds the unity, *Curve Sat Relative* is set for it as well. The *Curve Sat Relative* setting for curves A, B and C is 2.0 percent. However, it should be noted that the user must carefully calculate the curve characteristics concerning also discontinuities in the curve when the programmable curve equation is used. Thus, the *Curve Sat Relative* parameter gives another degree of freedom to move the inverse curve on the voltage ratio axis and it effectively sets the maximum operate time for the IDMT curve because for the voltage ratio values affecting by this setting, the operation time is fixed, that is, the definite time, depending on the parameters but no longer the voltage.

11.4 Frequency measurement and protection

All the function blocks that use frequency quantity as their input signal share the common features related to the frequency measurement algorithm. The frequency estimation is done from one phase (phase-to-phase or phase voltage) or from the positive phase sequence (PPS). The voltage groups with three-phase inputs use PPS as the source. The frequency measurement range is 0.6...1.5 × F_n. (For REG615 the range is 0.2...1.4 × F_n when *Frequency adaptivity* is enabled.) The df/dt measurement range always starts from 0.6 × F_n. When the frequency exceeds these limits, it is regarded as out of range and a minimum or maximum value is held as the measured value respectively with appropriate quality information. The frequency estimation requires 160 ms to stabilize after a bad quality signal. Therefore, a delay of 160 ms is added to the transition from the bad quality. The bad quality of the signal can be due to restrictions like:

- The source voltage is below 0.02 × U_n at F_n.
- The source voltage waveform is discontinuous.
- The source voltage frequency rate of change exceeds 15 Hz/s (including stepwise frequency changes).

When the bad signal quality is obtained, the nominal or zero (depending on the *Def frequency Sel* setting) frequency value is shown with appropriate quality information in the measurement view. The frequency protection functions are blocked when the quality is bad, thus the timers and the function outputs are reset. When the frequency is out of the function block's setting range but within the measurement range, the protection blocks are running. However, the OPERATE outputs are blocked until the frequency restores to a valid range.

11.5 Frequency adaptivity and generator start-up protection

Frequency adaptivity enables sensitive and selective protection during the start-up and shutdown phase of the generator when low frequency and low voltage amplitude exist at the same time. Sensitive protection is necessary because, for example, the fault current level in generator internal fault during start-up or shutdown (when field excitation is not present) may not exceed even the nominal current level.

Frequency adaptivity can be enabled by setting *Frequency adaptivity* and setting one UTVTR *Frequency adaptivity* to "Main frequency source". One additional UTVTR or ILTCTR can be set to "Backup frequency source". For main or backup frequency source, all three-phases must be connected. Each TxTR block that is set to Frequency adaptivity mode enable outputs measurements adapted to either main or backup source frequency depending on their availability.

See the Preprocessing blocks chapter for more information.

Harmonics calculation is limited to 2nd, 3rd and 5th harmonic when frequency adaptivity is enabled.

The frequency adaptivity uses the positive-sequence voltage in the frequency tracking and adapts the DFT, RMS, peak-to-peak and peak measurement accuracies of the current and voltage inputs by using the tracked frequency in the operation range of 0.2...1.5 xFn. Frequency adaptation starts when the generator terminal positive-sequence voltage level exceeds 0.04 xUn (minimum level). If frequency adaptivity backup source is currents their positive sequence must exceed 0.07 xIn to be usable as backup source. Backup source threshold limit is valid at nominal frequency and threshold increases when frequency deviates from nominal (up to 0.35 xIn or 0.2 xUn at 0.2 xFn or 0.11 xIn or 0.06 xUn at 1.5 xFn). As the Synchronism and energizing check (SECRSYN) bus voltage U12b voltage input always expects *Rated frequency*, the frequency adaptivity does not apply for this input.

If the generator terminal positive-sequence voltage is below the minimum level, the relay is not able to maintain frequency adaptation. The non-adaptive situation is indicated by function Protection output FRQ_ADP_FAIL. When frequency adaptivity uses backup frequency source, the FRQ_ADP_BU output is activated. The tracked frequency is retained for 3 seconds until the FRQ_ADP_FAIL output is activated and Rated frequency is expected. Outputs FRQ_ADP_FAIL, FRQ_ADP_BU and FRQ_ADP_WARN can be used in the application configuration, if necessary.

See function block Protection for more information.

The operation accuracy of the protection functions in the range of 0.2...1.5 xFn can be assumed to be according to the technical data given separately for each function. Slight deviations in operation accuracy are possible outside the frequency range specified in technical data. Operate time accuracy and reset times given in technical data are only valid in the frequency range specified for each function.

The specified operate times are expected to increase at lower frequency due to longer network cycles.

Frequency adaptivity depends on the availability of voltages or currents. The generator start-up protection can be also extended by using wide peak-to-peak measurement mode (operational from 2 Hz upward) with designated start-up overcurrent protection function (PHLPTOC). Before the generator is connected with the rest of the network by closing the circuit breaker, the designated start-up overcurrent function should be either blocked or its start value increased, as the *Start value* setting is typically lower than the nominal current.

11.6 Measurement modes

In many current or voltage dependent function blocks, there are various alternative measuring principles.

- RMS
- DFT which is a numerically calculated fundamental component of the signal
- Peak-to-peak
- Peak-to-peak with peak backup
- Wide peak-to-peak

Consequently, the measurement mode can be selected according to the application.

In extreme cases, for example with high overcurrent or harmonic content, the measurement modes function in a slightly different way. The operation accuracy is defined with the frequency range of f/fn=0.95...1.05. In peak-to-peak and RMS measurement modes, the harmonics of the phase currents are not suppressed, whereas in the fundamental frequency measurement the suppression of harmonics is at least -50 dB at the frequency range of f= n x fn, where n = 2, 3, 4, 5,...

RMS

The RMS measurement principle is selected with the *Measurement mode* setting using the value "RMS". RMS consists of both AC and DC components. The AC component is the effective mean value of the positive and negative peak values. RMS is used in applications where the effect of the DC component must be taken into account.

RMS is calculated according to the formula:

$$I_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} I_i^2}$$

(Equation 403)

n	Number of samples in a calculation cycle
I_i	Current sample value

DFT

The DFT measurement principle is selected with the *Measurement mode* setting using the value "DFT". In the DFT mode, the fundamental frequency component of the measured signal is numerically calculated from the samples. In some applications, for example, it can be difficult to accomplish sufficiently sensitive settings and accurate operation of the low stage, which may be due to a considerable amount of harmonics on the primary side currents. In such a case, the operation can be based solely on the fundamental frequency component of the current. In addition, the DFT mode has slightly higher CT requirements than the peak-to-peak mode, if used with high and instantaneous stages.

Peak-to-peak

The peak-to-peak measurement principle is selected with the *Measurement mode* setting using the value "Peak-to-Peak". It is the fastest measurement mode, in which the measurement quantity is made by calculating the average from the positive and negative peak values. The DC component is not included. The retardation time is short. The damping of the harmonics is quite low and practically determined by the characteristics of the anti-aliasing filter of the protection relay inputs. Consequently, this mode is usually used in conjunction with high and instantaneous stages, where the suppression of harmonics is not so important. In addition, the peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.

Peak-to-peak with peak backup

The peak-to-peak with peak backup measurement principle is selected with the *Measurement mode* setting using the value "P-to-P+backup". It is similar to the peak-to-peak mode, with the exception that it has been enhanced with the peak backup. In the peak-to-peak with peak backup mode, the function starts with two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set *Start value*. The peak backup is enabled only when the function is used in the DT mode in high and instantaneous stages for faster operation.

Wide peak-to-peak

The wide peak-to-peak measurement principle is available in products where it is necessary for overcurrent protection to operate already starting from as low frequency as 2 Hz during the generator start-up or shutdown phase. The wide peakto-peak measurement principle is selected with the *Measurement mode* setting "Wide P-to-P".

The measurement mode calculates the average from the positive and negative peak values over the 500 ms wide measurement window, independently of the *Frequency adaptivity* setting value. Retardation and reset times are longer due to the length of the measurement window. The frequency of the fault current affects the operate time. The damping of the harmonics is quite low and practically determined by the characteristics of the anti-aliasing filter of the protection relay current inputs.

When using measurement mode “Wide P-to-P”, the protection relay accepts only *Operate delay time* setting value 800 ms or longer and *Operating curve type* 5=”ANSI Def. Time” or 15=”IEC Def. Time”.

Operation accuracy in the frequency range 2...85 Hz is ±1.5% or ±0.003 × I_n. Operate time accuracy in definite time mode is ±1.0% of the set value or ±60 ms when I_{Fault} = 2 × set *Start value* and the fault current frequency is 10...85 Hz.

11.7 Calculated measurements

Calculated residual current and voltage

The residual current is calculated from the phase currents according to equation:

$$\overline{Io} = -(\overline{I}_A + \overline{I}_B + \overline{I}_C)$$

(Equation 404)

The residual voltage is calculated from the phase-to-earth voltages when the VT connection is selected as “Wye” with the equation:

$$\overline{Uo} = (\overline{U}_A + \overline{U}_B + \overline{U}_C)/3$$

(Equation 405)

Sequence components

The phase-sequence current components are calculated from the phase currents according to:

$$\overline{I}_0 = (\overline{I}_A + \overline{I}_B + \overline{I}_C)/3$$

(Equation 406)

$$\overline{I}_1 = (\overline{I}_A + a \cdot \overline{I}_B + a^2 \cdot \overline{I}_C)/3$$

(Equation 407)

$$\overline{I}_2 = (\overline{I}_A + a^2 \cdot \overline{I}_B + a \cdot \overline{I}_C)/3$$

(Equation 408)

The phase-sequence voltage components are calculated from the phase-to-earth voltages when *VT connection* is selected as “Wye” with the equations:

$$\overline{U}_0 = (\overline{U}_A + \overline{U}_B + \overline{U}_C)/3$$

(Equation 409)

$$\overline{U}_1 = (\overline{U}_A + a \cdot \overline{U}_B + a^2 \cdot \overline{U}_C)/3$$

(Equation 410)

$$\overline{U}_2 = (\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C)/3$$

(Equation 411)

When *VT connection* is selected as “Delta”, the positive and negative phase sequence voltage components are calculated from the phase-to-phase voltages according to the equations:

$$\overline{U}_1 = (\overline{U}_{AB} - a^2 \cdot \overline{U}_{BC})/3$$

(Equation 412)

$$\overline{U}_2 = (\overline{U}_{AB} - a \cdot \overline{U}_{BC})/3$$

(Equation 413)

The phase-to-earth voltages are calculated from the phase-to-phase voltages when *VT connection* is selected as "Delta" according to the equations.

$$\overline{U}_A = \overline{U}_0 + \left(\overline{U}_{AB} - \overline{U}_{CA}\right)/3$$

(Equation 414)

$$\overline{U}_B = \overline{U}_0 + \left(\overline{U}_{BC} - \overline{U}_{AB}\right)/3$$

(Equation 415)

$$\overline{U}_C = \overline{U}_0 + \left(\overline{U}_{CA} - \overline{U}_{BC}\right)/3$$

(Equation 416)

If the $\overline{U}_0$ channel is not valid, it is assumed to be zero.

The phase-to-phase voltages are calculated from the phase-to-earth voltages when *VT connection* is selected as "Wye" according to the equations.

$$\overline{U}_{AB} = \overline{U}_A - \overline{U}_B$$

(Equation 417)

$$\overline{U}_{BC} = \overline{U}_B - \overline{U}_C$$

(Equation 418)

$$\overline{U}_{CA} = \overline{U}_C - \overline{U}_A$$

(Equation 419)

11.8 Test mode

11.8.1 Functionality

The mode of all the logical nodes in the relay's IEC 61850 data model can be set with *Test mode*. *Test mode* activation method can be changed via parameter **Configuration** > **System** > **Test mode selection**. Available activation methods are "Local", "Local+remote, maintenance", "Local+Remote, all levels" and "Binary input". By default, *Test mode* activation method is "Local" which means the test mode can be activated only via LHMI through parameter **Tests** > **IED test** > **Test mode**. The remote activation method via binary input or via IEC 61850 communication is possible (LD0.LLN0.Mod). When the binary input is selected as the test mode activation method, the behavior can be configured with the application configuration.

Table 1656: Test mode

Test mode	Description	Protection BEH_BLK	Protection BEH_TST
Normal mode	Normal operation	FALSE	FALSE
IED blocked	Protection working as in “Normal mode” but ACT configuration can be used to block physical outputs to process. Control function commands blocked.	TRUE	FALSE
IED test	Protection works as in “Normal mode” but protection functions work in parallel with test parameters	FALSE	TRUE
IED test and blocked	Protection works as in “Normal mode” but protection functions work in parallel with the test parameter. The ACT configuration can be used to block physical outputs to process. The control function command is blocked.	TRUE	TRUE

See function block Protection for more details.

The behavior data objects in all logical nodes follow LD0.LLN0.Mod value. If "Normal mode" is selected, the behavior data objects follow the mode (.Mod) data object of the corresponding logical device.

Vertical and horizontal communication is not blocked by the “IED blocked” or “IED test and blocked” modes.

11.8.2 Application configuration and Test mode

The breaker and disconnector outputs from control commands to process are blocked with ”IED blocked” and “IED test and blocked” modes. If physical outputs need to be blocked from the protection, the application configuration must be used to block these signals. The blocking scheme needs to use BEH_BLK output of PROTECTION function block.

BEH_BLK signal can be used to

- Connect to TRPPTRC BLOCK input. This is the best option when all protection signaling goes through the master trip function.
- Connect to necessary protection function BLOCK inputs.
- Create logic condition for physical outputs to block state changes when BEH_BLK is active.

11.8.3 Control mode

The mode of all logical nodes located under CTRL logical device can be set with *Control mode*. The *Control mode* parameter is available via the HMI or PCM600 path **Configuration** > **Control** > **General**. By default, *Control mode* can only be set locally through LHMI. *Control mode* inherits its value from *Test mode* but *Control mode* ”On”, “Blocked” and “Off” can also be set independently. *Control mode* is also available via IEC 61850 communication (CTRL.LLN0.Mod).

Table 1657: Control mode

Control mode	Description	Control BEH_BLK
On	Normal operation	FALSE
Blocked	Control function commands blocked	TRUE
Off	Control functions disabled	FALSE

See function block Control for more details.

The behavior data objects under CTRL logical device follow CTRL.LLN0.Mod value. If "On" is selected, behavior data objects follow the mode of the corresponding logical device.

11.8.4 Application configuration and Control mode

The physical outputs from commands to process are blocked with “Blocked“ mode. If physical outputs need to be blocked totally, meaning also commands from the binary inputs, the application configuration must be used to block these signals. Blocking scheme uses BEH_BLK output of CONTROL function block.

11.8.5 Authorization

By default, *Test mode* and *Control mode* can only be changed from LHMI. It is possible to write test mode by remote client if it is needed in configuration. This is done via LHMI by setting parameter *Test mode selection* via **Configuration** > **System**. Remote operation is possible only when the relay's control position is in remote position. Local and remote control can be selected with R/L button or via Control function block in application configuration.

When using the Signal Monitoring tool to force online values, the following conditions need to be met.

- *Remote force* is set to “All levels”
- *Test mode* is enabled
- The relay's control position is in remote position.

Table 1658: Test mode selection

Test mode selection	LHMI	61850-8-1-MMS	WHMI	Binary input
Local	Yes	No access	No access	No access
Local+Remote, Mainte-nance	Yes	Command originator cat-egory maintenance	No access	No access
Local+Remote, All levels	Yes	All originator categories	Yes	No access
Binary input	No access	No access	No access	Yes

11.8.6 LHMI indications

The Home button flashes green with low frequency indicating that one of the test mode options, that is, “IED blocked”, “IED test and blocked” or "IED test", is activated.

12 Requirements for measurement transformers

12.1 Current transformers

12.1.1 Current transformer requirements for overcurrent protection

For reliable and correct operation of the overcurrent protection, the CT has to be chosen carefully. The distortion of the secondary current of a saturated CT may endanger the operation, selectivity, and co-ordination of protection. However, when the CT is correctly selected, a fast and reliable short circuit protection can be enabled.

The selection of a CT depends not only on the CT specifications but also on the network fault current magnitude, desired protection objectives, and the actual CT burden. The protection settings of the protection relay should be defined in accordance with the CT performance as well as other factors.

12.1.1.1 Current transformer accuracy class and accuracy limit factor

The rated accuracy limit factor (F_n) is the ratio of the rated accuracy limit primary current to the rated primary current. For example, a protective current transformer of type 5P10 has the accuracy class 5P and the accuracy limit factor 10. For protective current transformers, the accuracy class is designed by the highest permissible percentage composite error at the rated accuracy limit primary current prescribed for the accuracy class concerned, followed by the letter "P" (meaning protection).

Table 1659: Limits of errors according to IEC 60044-1 for protective current transformers

Accuracy class	Current error at rated primary current (%)	Phase displacement at rated primary current		Composite error at rated accuracy limit primary current (%)
		minutes	centiradians	
5P	±1	±60	±1.8	5
10P	±3	–	–	10

The accuracy classes 5P and 10P are both suitable for non-directional overcurrent protection. The 5P class provides a better accuracy. This should be noted also if there are accuracy requirements for the metering functions (current metering, power metering, and so on) of the protection relay.

The CT accuracy primary limit current describes the highest fault current magnitude at which the CT fulfils the specified accuracy. Beyond this level, the secondary current of the CT is distorted and it might have severe effects on the performance of the protection relay.

In practise, the actual accuracy limit factor (F_a) differs from the rated accuracy limit factor (F_n) and is proportional to the ratio of the rated CT burden and the actual CT burden.

The actual accuracy limit factor is calculated using the formula:

$$F_a \approx F_n \times \frac{|S_{in} + S_n|}{|S_{in} + S|}$$

F_n	the accuracy limit factor with the nominal external burden S_n
S_{in}	the internal secondary burden of the CT
S	the actual external burden

12.1.1.2 Non-directional overcurrent protection

Current transformer selection

Non-directional overcurrent protection does not set high requirements on the accuracy class or on the actual accuracy limit factor (F_a) of the CTs. It is, however, recommended to select a CT with F_a of at least 20.

The nominal primary current I_{1n} should be chosen in such a way that the thermal and dynamic strength of the current measuring input of the protection relay is not exceeded. This is always fulfilled when

$I_{1n} > I_{kmax} / 100$,

I_{kmax} is the highest fault current.

The saturation of the CT protects the measuring circuit and the current input of the protection relay. For that reason, in practice, even a few times smaller nominal primary current can be used than given by the formula.

Recommended start current settings

If I_{kmin} is the lowest primary current at which the highest set overcurrent stage is to operate, the start current should be set using the formula:

Current start value < $0.7 \times (I_{kmin} / I_{1n})$

I_{1n} is the nominal primary current of the CT.

The factor 0.7 takes into account the protection relay inaccuracy, current transformer errors, and imperfections of the short circuit calculations.

The adequate performance of the CT should be checked when the setting of the high set stage overcurrent protection is defined. The operate time delay caused by the CT saturation is typically small enough when the overcurrent setting is noticeably lower than F_a.

When defining the setting values for the low set stages, the saturation of the CT does not need to be taken into account and the start current setting is simply according to the formula.

Delay in operation caused by saturation of current transformers

The saturation of CT may cause a delayed protection relay operation. To ensure the time selectivity, the delay must be taken into account when setting the operate times of successive protection relays.

With definite time mode of operation, the saturation of CT may cause a delay that is as long as the time constant of the DC component of the fault current, when the current is only slightly higher than the starting current. This depends on the accuracy limit factor of the CT, on the remanence flux of the core of the CT, and on the operate time setting.

With inverse time mode of operation, the delay should always be considered as being as long as the time constant of the DC component.

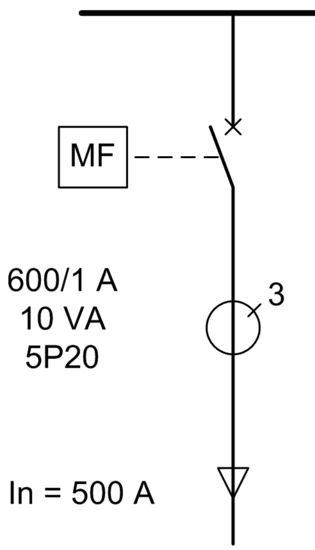
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the starting current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor F_a should be chosen using the formula:

F_a > 20 × *Current start value* / I_{1n}

The *Current start value* is the primary start current setting of the protection relay.

12.1.1.3 Example for non-directional overcurrent protection

The following figure describes a typical medium voltage feeder. The protection is implemented as three-stage definite time non-directional overcurrent protection.



3I>	1200 A	2.00 x I_{2n}
	0.75 s	0.75 s
3I>>	1800A	3.00 x I_{2n}
	0.50 s	0.50 s
3I>>>	3500 A	5.83 x I_{2n}
	0.20 s	0.20 s

Figure 1019: Example of three-stage overcurrent protection

The maximum three-phase fault current is 41.7 kA and the minimum three-phase short circuit current is 22.8 kA. The actual accuracy limit factor of the CT is calculated to be 59.

The start current setting for low-set stage (3I>) is selected to be about twice the nominal current of the cable. The operate time is selected so that it is selective with the next protection relay (not visible in *Figure 1019*). The settings for the high-set stage and instantaneous stage are defined also so that grading is ensured with the downstream protection. In addition, the start current settings have to be defined so that the protection relay operates with the minimum fault current and it does not operate with the maximum load current. The settings for all three stages are as in *Figure 1019*.

For the application point of view, the suitable setting for instantaneous stage (I>>>) in this example is 3 500 A (5.83 × I_{2n}). I_{2n} is the 1.2 multiple with nominal primary current of the CT. For the CT characteristics point of view, the criteria given by the current transformer selection formula is fulfilled and also the protection relay setting is considerably below the F_a. In this application, the CT rated burden could have been selected much lower than 10 VA for economical reasons.

12.1.2 Current transformer requirements for transformer differential protection

The more important the object to be protected, the more attention has to be paid to the current transformers. It is not normally possible to dimension the current transformer so that they repeat the currents with high DC components without saturating when the residual flux of the current transformer is high. TR2PTDF and TR3PTDF operate reliably even though the current transformers are partially saturated.

The accuracy class recommended for current transformers to be used with TR2PTDF and TR3PTDF is 5P or X-type. In the 5P type, the limit of the current error at the rated primary current is 1 percent and the limit of the phase displacement is 60 minutes. The limit of the composite error at the rated accuracy limit primary current is 5 percent.

The approximate value of the accuracy limit factor F_a corresponding to the actual current transformer burden can be calculated on the basis of the rated accuracy limit factor F_n at the rated burden, the rated burden S_n, the internal burden $S_{in}$and the actual burden S_a of the current transformer.

$$F_a = F_n \times \frac{S_{in} + S_n}{S_{in} + S_a}$$

(Equation 420)

F_a	The approximate value of the accuracy limit factor (ALF) corresponding to the actual CT burden
F_n	The rated accuracy limit factor at the rated burden of the current transformer
S_n	The rated burden of the current transformer
S_{in}	The internal burden of the current transformer
S_a	The actual burden of the current transformer

Class X defines the CT knee-point voltage U_{kn} as a sinusoidal voltage applied to the CT secondary (primary open) which, when increased by 10 %, causes the CT magnetizing current to increase by 50 %. The relationship between the actual accuracy limit factor F_a and the CT knee-point voltage, assuming resistive burden, is $U_{kn} = k * F_a * I_n * (R_{in} + R_a)$ where I_n = CT rated secondary current, R_{in} = CT internal resistance and R_a = CT's actual burden in ohms. Factor k depends on the CT magnetizing curve. The value k = 1.0 is used in IEC 61869-2:2012.

Example 1

The rated burden S_n of the current transformer 5P20 is 10 VA, the secondary rated current is 5A, the internal resistance R_{in}= 0.07 Ω and the accuracy limit factor F_n corresponding to the rated burden is 20 (5P20). Thus the internal burden of the current transformer is S_{in}= $(5A)^2$ * 0.07 Ω = 1.75 VA. The input impedance of the protection relay at a rated current of 5A is < 20 mΩ. If the measurement conductors have a resistance of 0.113 Ω, the actual burden of the current transformer is S_a=$(5A)^2$ * (0.113 + 0.020) Ω = 3.33 VA. Thus the accuracy limit factor F_a corresponding to the actual burden is approximately 46.

The CT burden can grow considerably at the rated current 5A. The actual burden of the current transformer decreases at the rated current of 1A while the repeatability simultaneously improves.

At faults occurring in the protected area, the currents may be very high compared to the rated currents of the current transformers. Due to the instantaneous stage of the differential function block, it is sufficient that the current transformers are capable of repeating the current required for instantaneous tripping during the first cycle.

Thus the current transformers usually are able to reproduce the asymmetric fault current without saturating within the next 10 ms after the occurrence of the fault to secure that the operate times of the protection relay comply with the retardation time.

The accuracy limit factors corresponding to the actual burden of the phase current transformer to be used in differential protection fulfill the requirement.

$$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{-T_m/T_{dc}}) + 1)$$

(Equation 421)

Ik_{max}	The maximum through-going fault current (in I_r) at which the protection is not allowed to operate
T_{dc}	The primary DC time constant related to Ik_{max}
ω	The angular frequency, that is, 2*π*fn
T_m	The time-to-saturate, that is, the duration of the saturation free transformation
K_r	The remanence factor 1/(1-r), where r is the maximum remanence flux in p.u. from saturation flux

The accuracy limit factors corresponding to the actual burden of the phase current transformer is used in differential protection.

The parameter *r* is the maximum remanence flux density in the CT core in p.u. from saturation flux density. The value of the parameter *r* depends on the magnetic material used and on the construction of the CT. For instance, if the value of *r* = 0.4, the remanence flux density can be 40 percent of the saturation flux density. The manufacturer of the CT has to be contacted when an accurate value for the parameter *r* is needed. The value *r* = 0.4 is recommended to be used when an accurate value is not available.

The required minimum time-to-saturate T_m in TR2PTDF and TR3PTDF is half fundamental cycle period (10 ms when fn = 50Hz).

Two typical cases are considered for the determination of the sufficient accuracy limit factor (F_a):

1. A fault occurring at the substation bus:

   The protection must be stable at a fault arising during a normal operating situation. Re-energizing the transformer against a bus fault leads to very high fault currents and thermal stress and therefore re-energizing is not preferred in this case. Thus, the remanence can be neglected.

   The maximum through-going fault current Ik_{max} is typically 10 I_r for a substation main transformer. At a short circuit fault close to the supply transformer, the DC time constant (T_{dc}) of the fault current is almost the same as that of the transformer, the typical value being 100 ms.

Ik_{max}	10 I_r
T_{dc}	100 ms
ω	100π Hz
T_m	10 ms
K_r	1

   When the values are substituted in *Equation 421*, the result is:

   $$F_a > K_r \times Ik_{\max} \times (T_{dc} \times \omega \times (1 - e^{-T_m / T_{dc}}) + 1) \approx 40$$

2. Re-energizing against a fault occurring further down in the network:

   The protection must be stable also during re-energization against a fault on the line. In this case, the existence of remanence is very probable. It is assumed to be 40 percent here.

   On the other hand, the fault current is now smaller and since the ratio of the resistance and reactance is greater in this location, having a full DC offset is not possible. Furthermore, the DC time constant (T_{dc}) of the fault current is now smaller, assumed to be 50 ms here.

   Assuming a maximum fault current being 30 percent lower than in the bus fault and a DC offset 90 percent of the maximum.

Ik_{max}	0.7* 10 = 7 (I_r)
T_{dc}	50 ms
ω	100π Hz
T_m	10 ms
K_r	1/(1-0.4) = 1.6667

   When the values are substituted in the equation, the result is:

   $$F_a > K_r \times Ik_{\max} \times 0.9 \times (T_{dc} \times \omega \times (1 - e^{-T_m / T_{dc}}) + 1) \approx 40$$

   If the actual burden of the current transformer (S_a) in *Equation 420* cannot be reduced low enough to provide a sufficient value for F_a, there are two alternatives to deal with the situation:

   - a CT with a higher rated burden S_n can be chosen (which also means a higher rated accuracy limit F_n)

- a CT with a higher nominal primary current I_{1n} (but the same rated burden) can be chosen

Example 2

Assuming that the actions according to alternative two above are taken in order to improve the actual accuracy limit factor:

$$F_a = \frac{IrCT}{IrTR} \times F_n$$

(Equation 422)

IrTR	1000 A (rated secondary side current of the power transformer)
IrCT	1500 A (rated primary current of the CT on the transformer secondary side)
F_n	30 (rated accuracy limit factor of the CT)
F_a	(IrCT / IrTR) * Fn (actual accuracy limit factor due to oversizing the CT) = (1500/1000) * 30 = 45

In TR2PTDF and TR3PTDF, it is important that the accuracy limit factors F_a of the phase current transformers at both sides correspond with each other, that is, the burdens of the current transformers on both sides are to be as equal as possible. If high inrush or start currents with high DC components pass through the protected object when it is connected to the network, special attention is required for the performance and the burdens of the current transformers and for the settings of the function block.

13 Protection relay's physical connections

13.1 Module diagrams

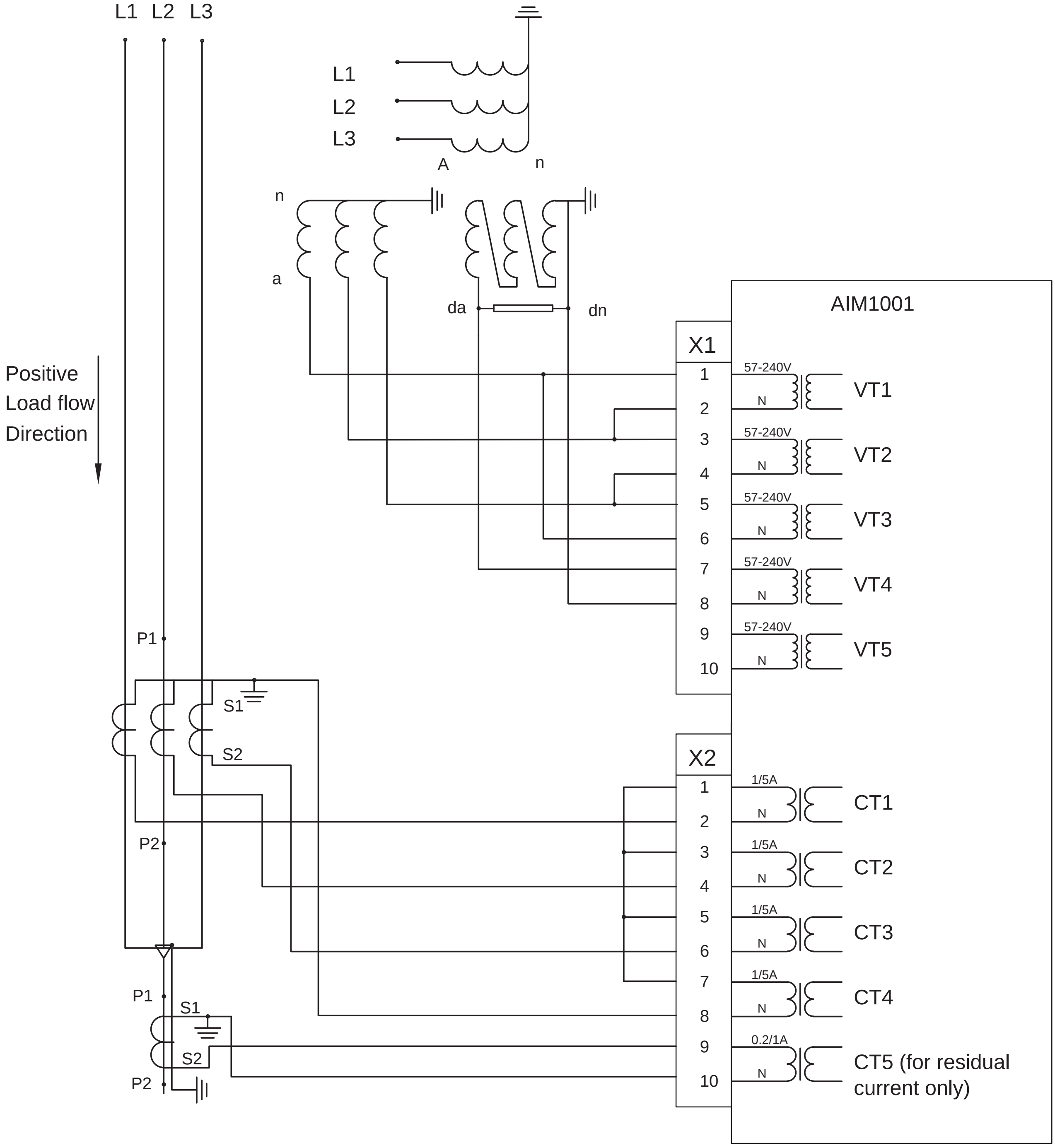


Figure 1020: AIM1001 module

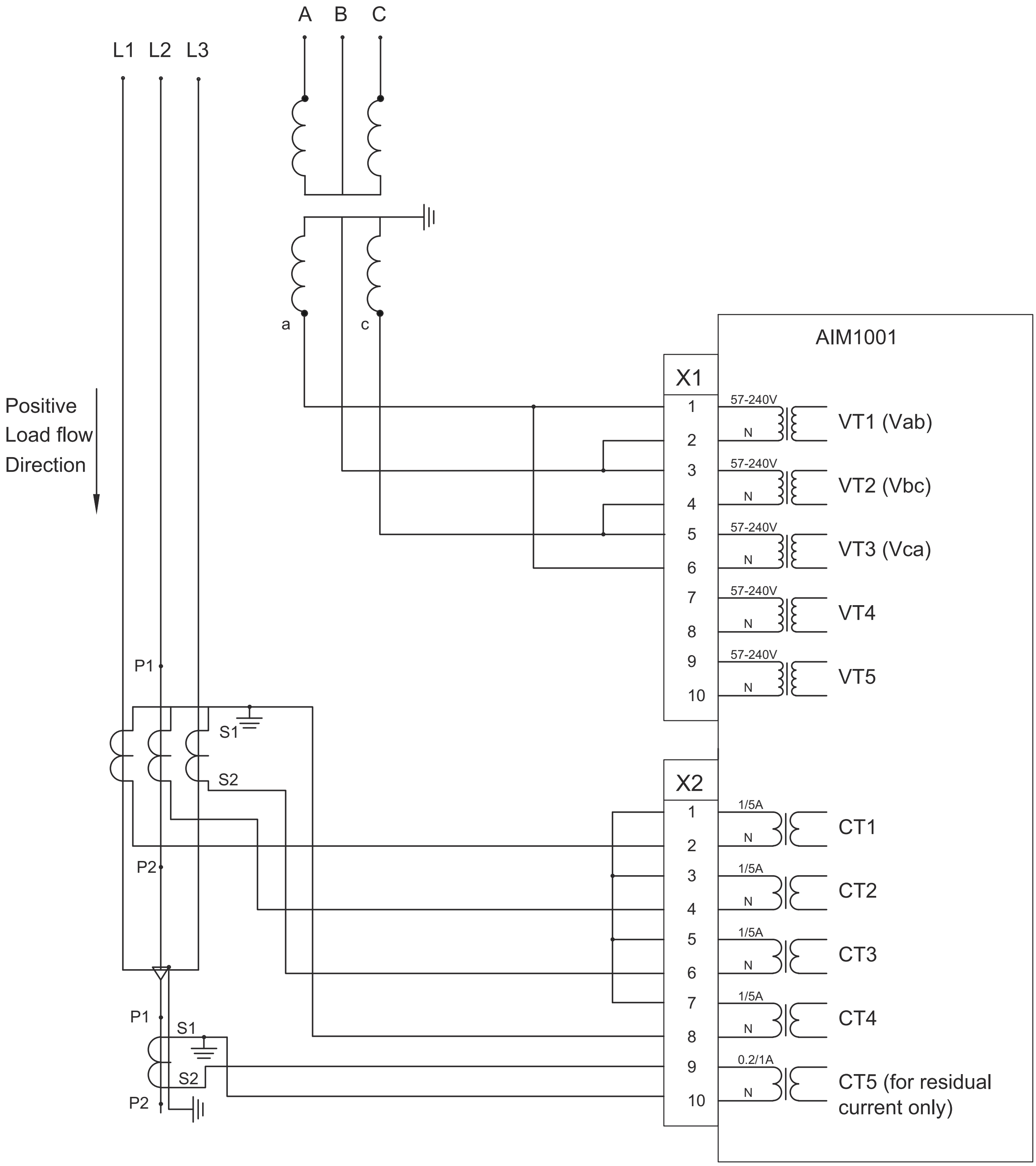


Figure 1021: AIM1001 module (two phase-to-phase VTs)

The two phase-to-phase VT connection is often referred as “open delta” (ANSI) or as “V” (IEC) connection. The relay measures all three phase-to-phase voltages using only two primary VTs. The relay will calculate the phase-to-ground voltages internally, with the assumption that the three-phase system is balanced, i.e. residual voltage is zero.

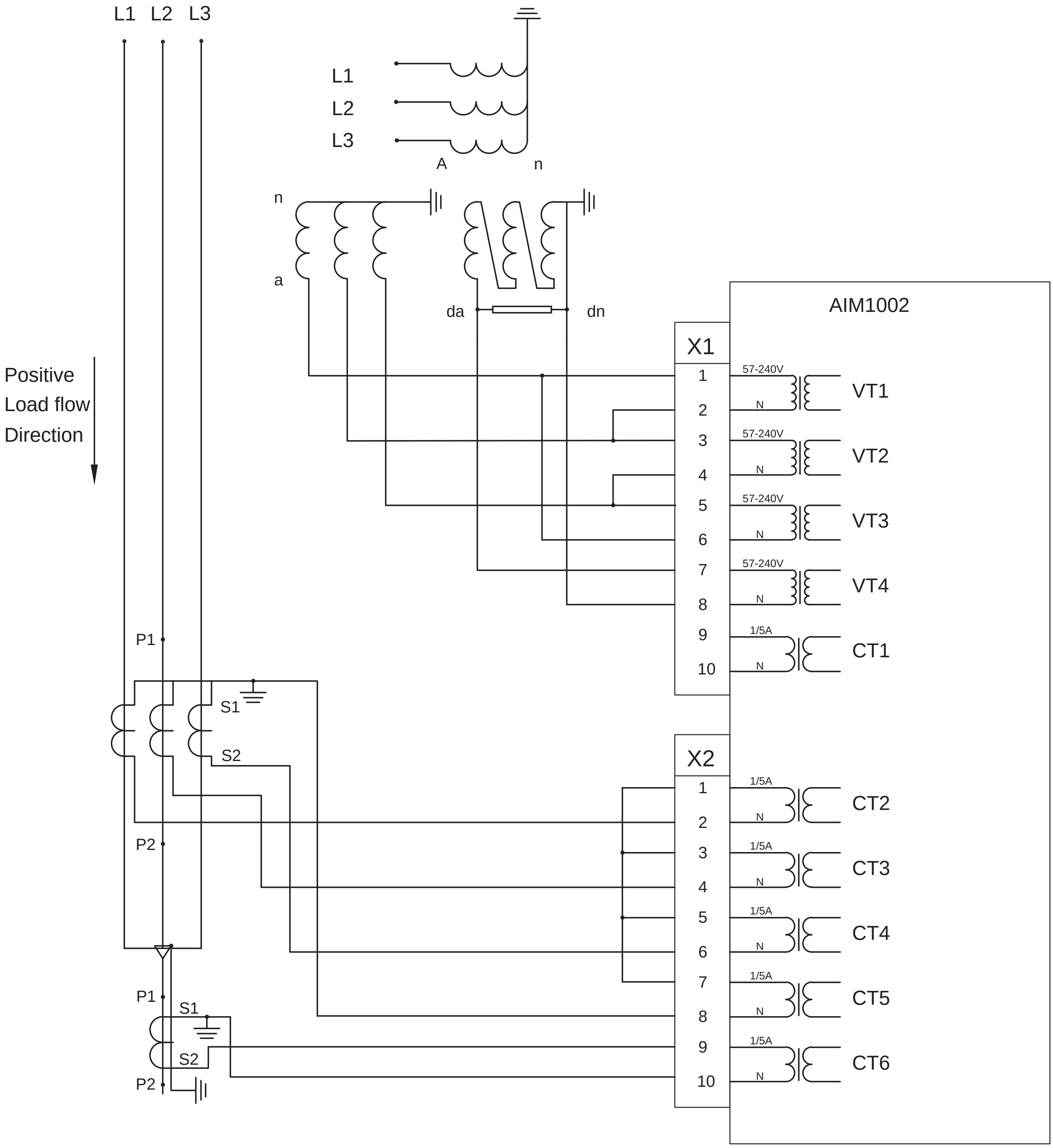


Figure 1022: AIM1002 module

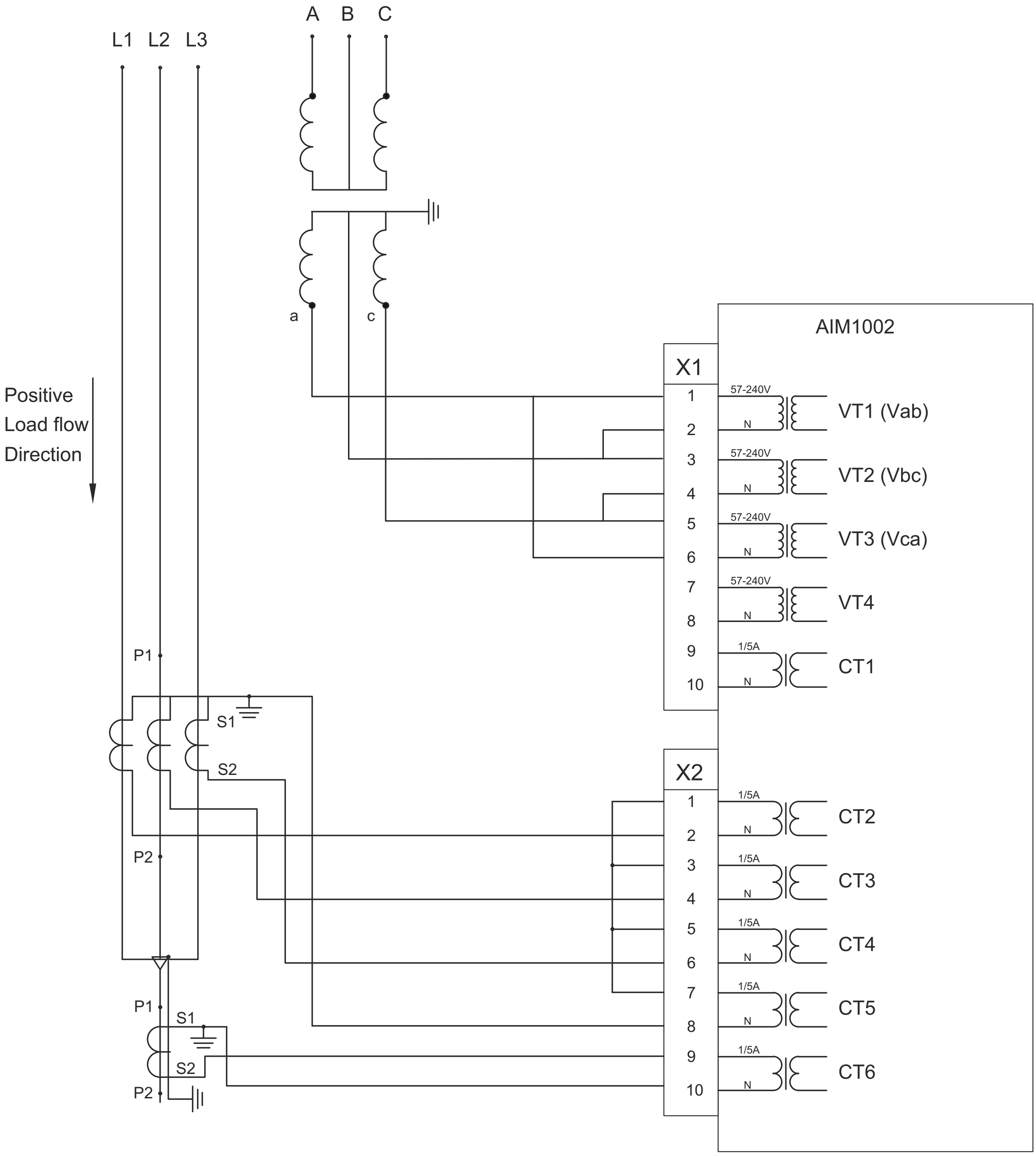


Figure 1023: AIM1002 module (two phase-to-phase VTs)

The two phase-to-phase VT connection is often referred as “open delta” (ANSI) or as “V” (IEC) connection. The relay measures all three phase-to-phase voltages using only two primary VTs. The relay will calculate the phase-to-ground voltages internally, with the assumption that the three-phase system is balanced, i.e. residual voltage is zero.

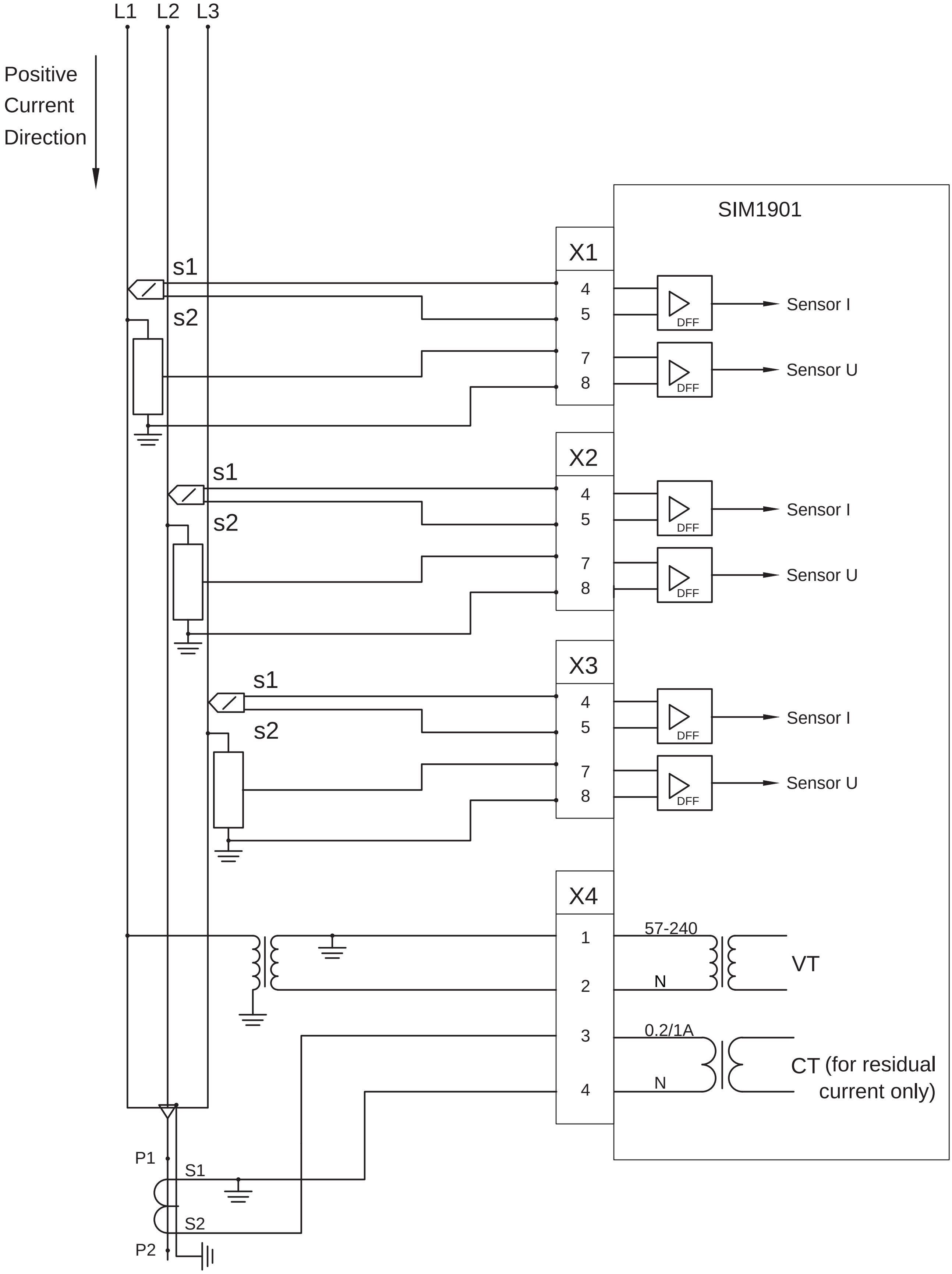


Figure 1024: SIM1901 module (VT primary connection phase-to-earth)

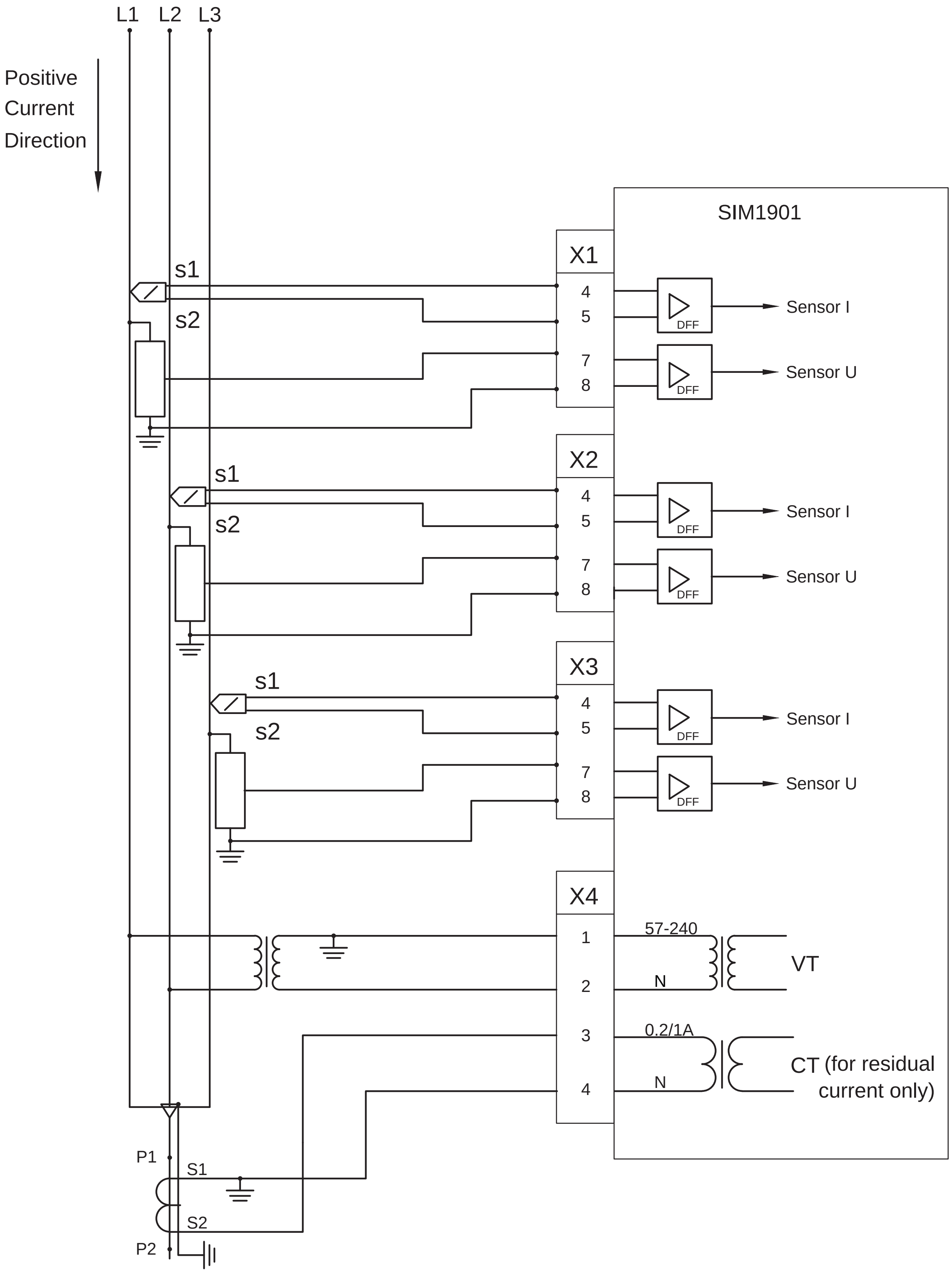


Figure 1025: SIM1901 module (VT primary connection phase-to-phase)

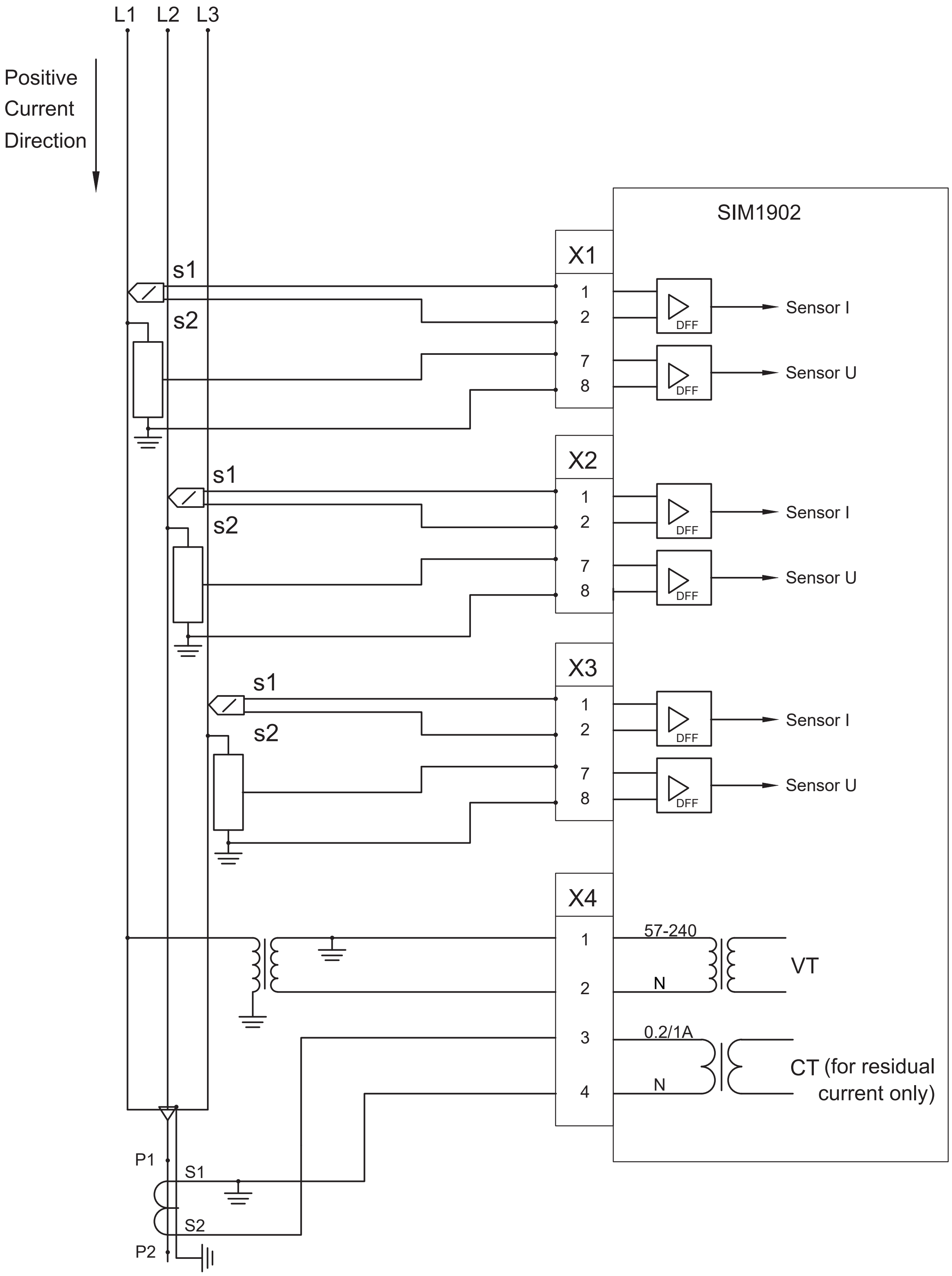


Figure 1026: SIM1902 module (VT primary connection phase-to-earth)

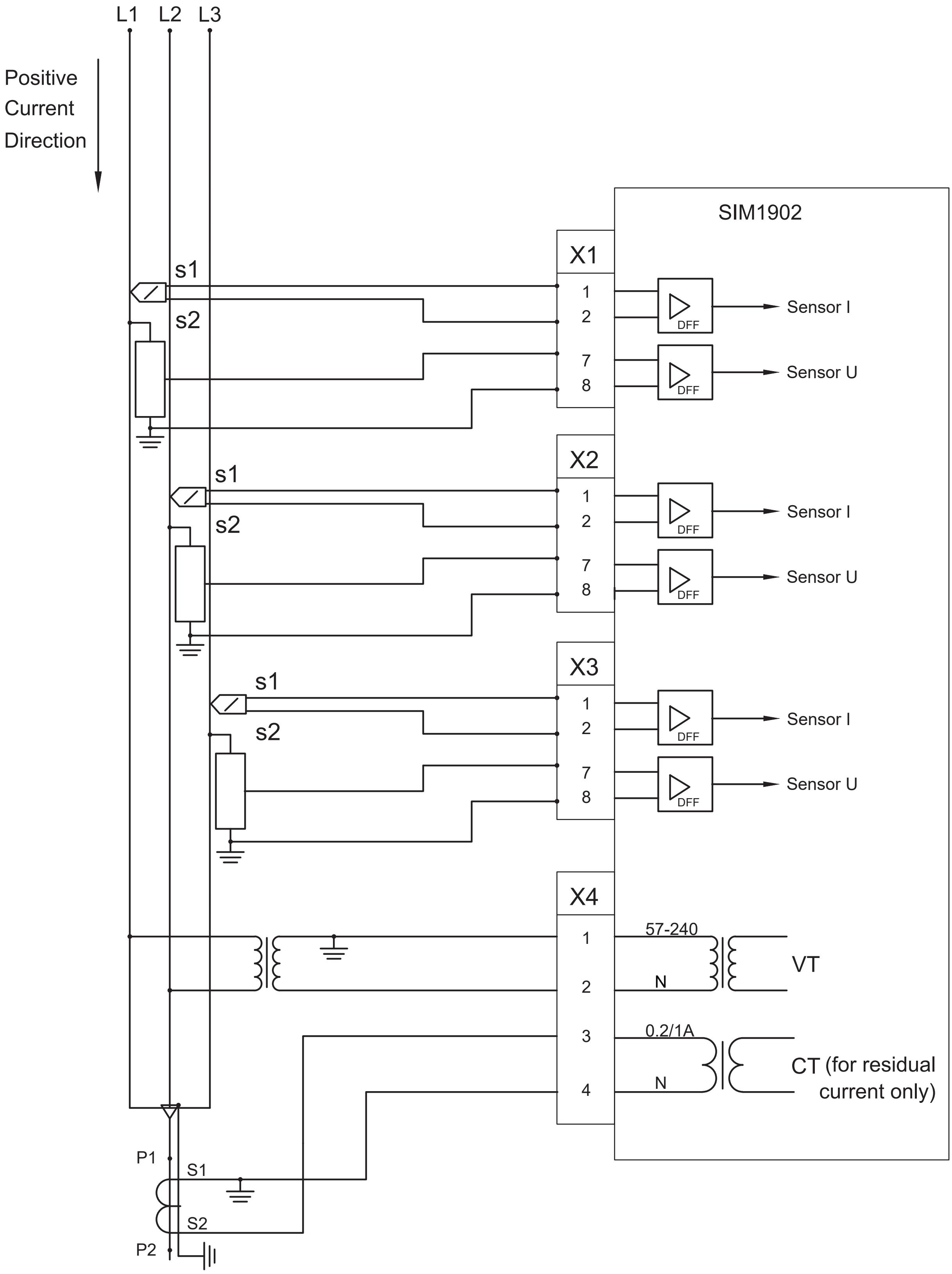


Figure 1027: SIM1902 module (VT primary connection phase-to-phase)

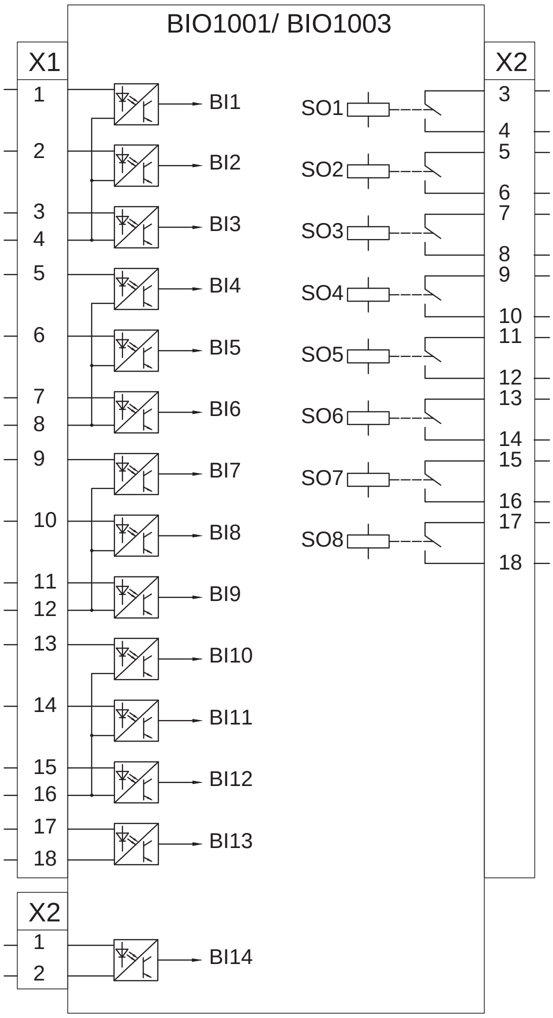


Figure 1028: BIO1001/BIO1003 modules

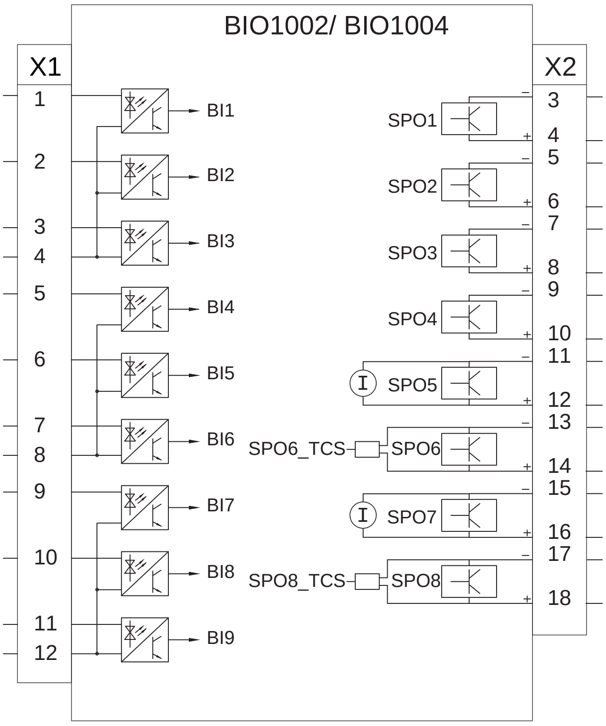


Figure 1029: BIO1002/BIO1004 modules

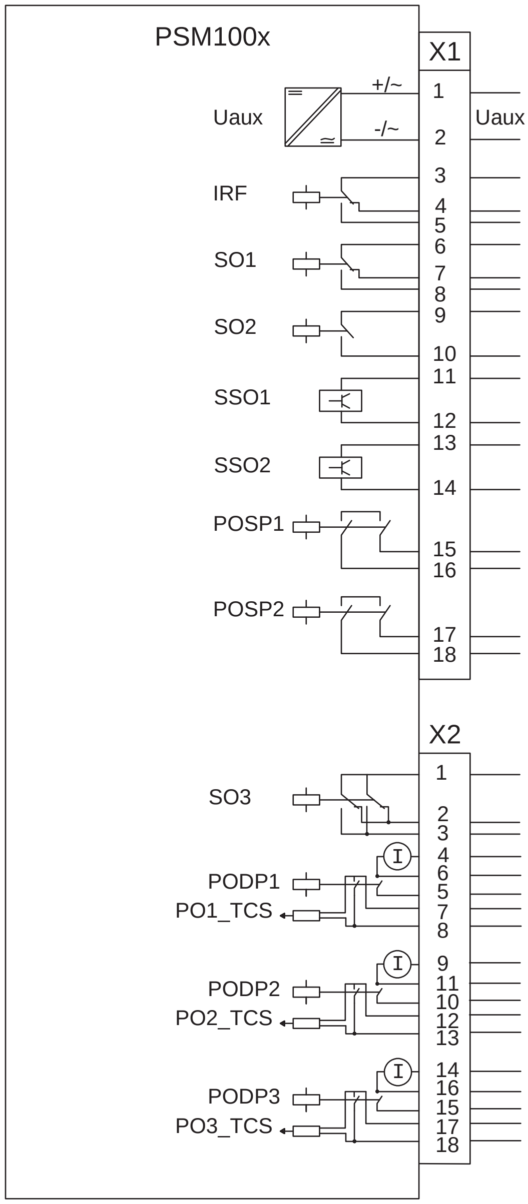


Figure 1030: PSM100x module

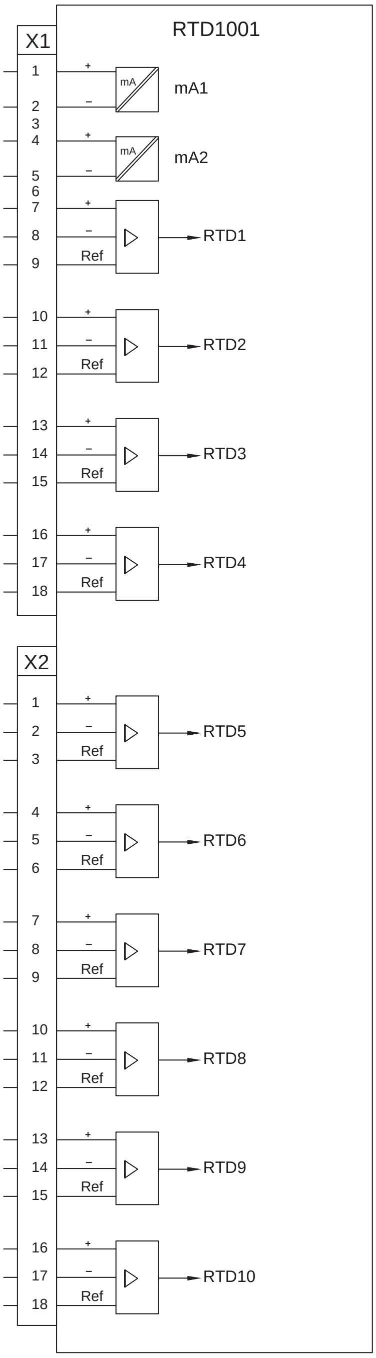


Figure 1031: RTD1001 module

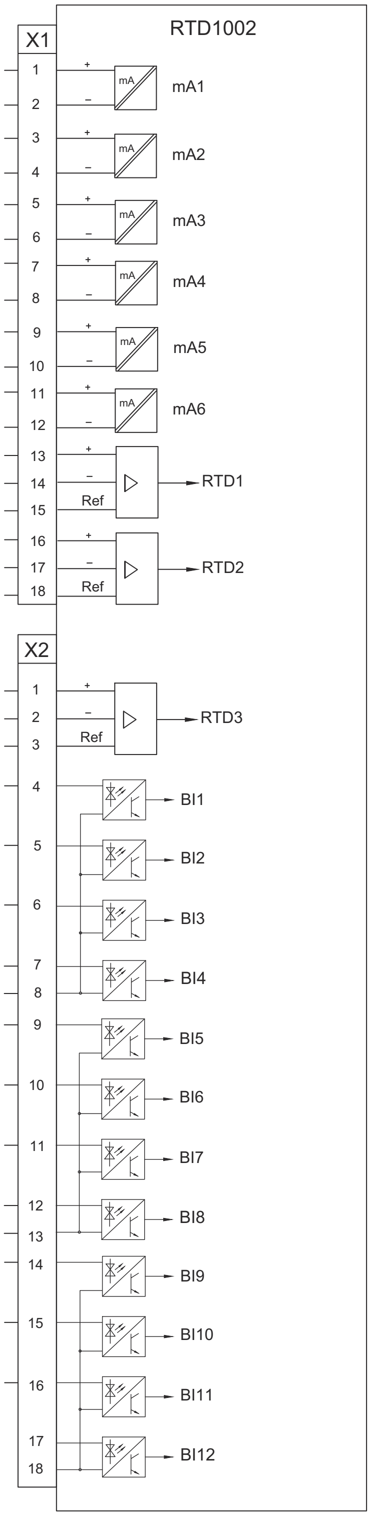


Figure 1032: RTD1002 module

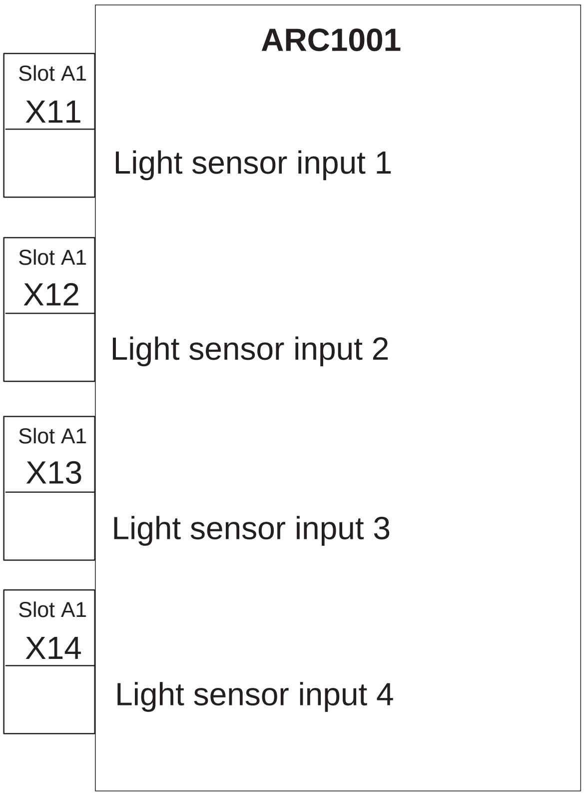


Figure 1033: Arc module

13.2 Communication modules

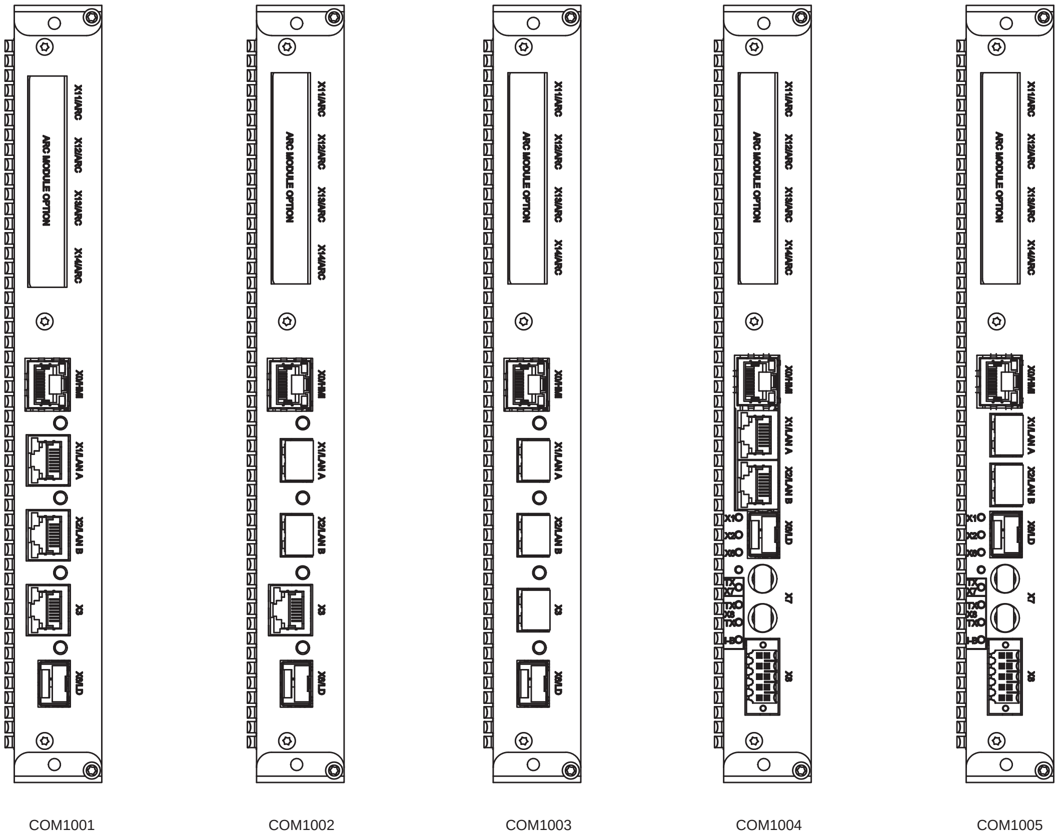


Figure 1034: Communication module options

The Ethernet ports marked with LAN A and LAN B are used with redundant Ethernet protocols HSR and PRP. The third station bus Ethernet port without the LAN A or LAN B label is an interlink port which is used to connect a device to the common redundant Ethernet channel.

Table 1660: Ports in communication modules

Port	Type	Description
X0	RJ-45	HMI
X1	RJ-45 or LC	Ethernet (LAN A)
X2	RJ-45 or LC	Ethernet (LAN B)
X3	RJ-45 or LC	Ethernet (Interlink)
X6	SFP - LC	Protection communication [1]
X7	FO - ST	Serial communication
X8	TP [2]	Serial communication/IRIG-B

[1] If a galvanic pilot wire is used as the protection communication link, the pilot wire modem RPW600 is required. A single-mode SFP transceiver and corresponding fiber-optic cable is used to connect REX640 with the RPW600 modem. The recommended minimum length of this cable is 3 m.

[2] 2- or 4-wire twisted pair

Table 1661: Station bus communication interfaces included in communication modules

Module ID	RJ-45	LC	EIA_485	ST
COM1001	3	–	–	–
COM1002	1	2	–	–
COM1003	–	3	–	–
COM1004	2	–	1	1
COM1005	–	2	1	1

13.3 Arc sensor interface

Light sensor input connections for the arc protection are available on the optional hardware module in Slot A1. The module supports connection of up to four sensors. The sensors can be lens or loop types or a free mixture.

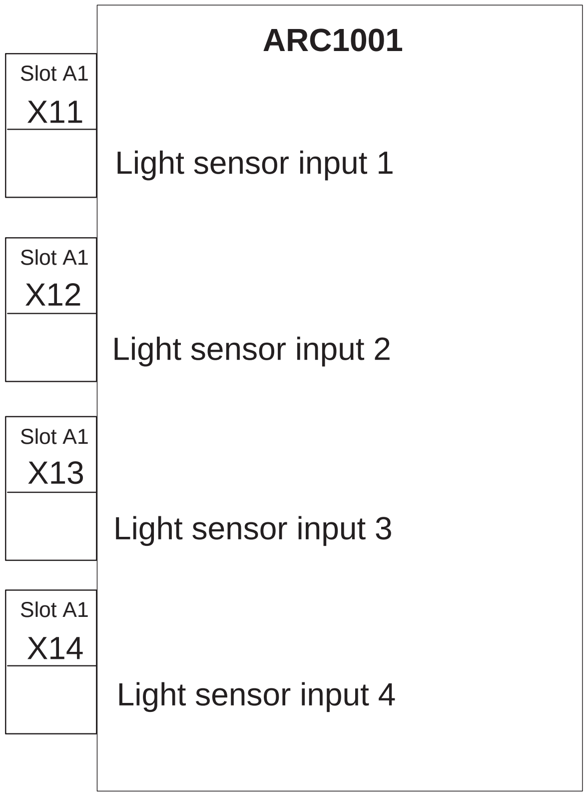


Figure 1035: ARC module

The ARCSARC function must be instantiated in the application configuration to enable the sensor inputs.

Table 1662: ARCSARC instances and arc sensor inputs

Instance	Sensor input activation
ARCSARC1	Light sensor input 1
ARCSARC2	Light sensor input 2
ARCSARC3	Light sensor input 3
ARCSARC4	Light sensor input 4

14 Technical data

Table 1663: Dimensions of the relay

Description		Value
Width		304.0 mm (11.9685 in)
Height		264.8 mm (10.4252 in)
Depth	With compression type CT/VT connectors	242.2 mm (9.5354 in)
	With ring lug type CT/VT connectors	254.1 mm (10.0039 in)
	With grounding bar	274.0 mm (10.7874 in)
Weight box		6.9...8.8 kg (15.2...19.4 lb)

Table 1664: Dimensions of the HMI

Description	Value
Width	212.5 mm (8.3661 in)
Height	177.5 mm (6.9882 in)
Depth	57.6 mm (2.2677 in)
Weight	1.6 kg (3.5 lb)
Display element size	Seven inches
Display element resolution[1]	800 x 480 pixels

Table 1665: Power supply for the relay

Description	PSM1001	PSM1002	PSM1003
Nominal auxiliary voltage U_n	24, 30, 48, 60 V DC	100, 110, 120, 220, 240 V AC, 50 and 60 Hz	110, 125 V DC
		48, 60, 110, 125, 220, 250 V DC	
Maximum interruption time in the auxiliary DC voltage without resetting the relay	50 ms at U_n		
Auxiliary voltage variation	50...120 % of U_n (12...72 V DC)	38...110 % of U_n (38...264 V AC)	70...120 % of U_n (77...150 V DC)

Table continues on the next page

[1] The HMI display element can contain dark and/or bright dots up to five pieces in random locations, or up to two adjacent dots in two different locations. Also slight imperfections like scratches and dust particles on the display element surface can appear. These are not affecting the usability of the HMI and are within the normal display element manufacturing tolerances.

Description	PSM1001	PSM1002	PSM1003
		80...120 % of U_n (38.4...300 V DC)	
Start-up threshold	16 V DC (24 V DC × 67%)		77 V DC (110 V DC × 70 %)
Burden of auxiliary voltage supply under quiescent (P_q)/ operating condition	DC <18.0 W (nominal)/ <25.0 W (max.)	DC <20.0 W (nominal)/ <25.0 W (max.) AC <20.0 W (nominal)/ <25.0 W (max.)	DC <17.0 W (nominal)/ <25.0 W (max.)
Ripple in the DC auxiliary voltage	Max 15 % of the DC value (at frequency of 100 Hz)		
Fuse type	T8A/250 V	T4A/250 V	
Permissible frequency band	50/60Hz +-10%		

Table 1666: Power supply for the LHMI

Description	Value
Nominal auxiliary voltage U_n	100, 110, 120, 220, 240 V AC, 50 and 60 Hz
	24, 48, 60, 110, 125, 220, 250 V DC
Auxiliary voltage variation	38...110 % of U_n (38...264 V AC)
	80...120 % of U_n (19.2...300 V DC)
Start-up threshold	19.2 V DC (24 V DC × 80 %)
Burden of auxiliary voltage supply under quiescent (P_q)/operating condition	DC <6.0 W (nominal)/<14.0 W (max.) AC <7.0 W (nominal)/<12.0 W (max.)
Ripple in the DC auxiliary voltage	Max 15 % of the DC value (at frequency of 100 Hz)
Fuse type	T3.15A/250V

Table 1667: Energizing inputs

Description		Value	
Rated frequency		50/60 Hz	
Current inputs	Rated current, I_n	0.2/1 A	1/5 A[2]
	Thermal withstand capability: • Continuously • For 1 s	4 A 100 A	20 A 500 A
	Dynamic current withstand: • Half-wave value	250 A	1250 A
	Input impedance	<100 mΩ	<20 mΩ

Table continues on the next page

2 Residual current and/or phase current.

Description		Value
Voltage inputs	Rated voltage	57...240 V AC
	Voltage withstand: • Continuous • For 10 s	288 V AC 360 V AC
	Burden at rated voltage	<0.05 VA

Table 1668: Table 9: Energizing Inputs (SIM1901)

Description		Value
Current sensor input	Rated current voltage	75 mV ... 9000 mV [3]
	Continuous voltage withstand	125 V
	Input impedance at 50/60Hz	2...3 MΩ [4]
Voltage sensor input	Rated secondary voltage	346 mV…1733 mV [5]
	Continuous voltage withstand	50 V
	Input impedance at 50/60Hz	3 MΩ

Table 1669: Energizing Inputs (SIM1902)

Description		Value
Current sensor input	Rated current voltage	75 mV ... 9000 mV [6]
	Continuous voltage withstand	125 V
	Input impedance at 50/60Hz	2 MΩ
Voltage sensor input	Rated secondary voltage	346 mV…2339 mV [7]
	Continuous voltage withstand	50 V
	Input impedance at 50/60Hz	2 MΩ

Table 1670: Binary inputs

Description	Value
Operating range	±20 % of the rated voltage
Rated voltage	24...250 V DC
Current drain	1.6...1.9 mA
Power consumption	31.0...570.0 mW

Table continues on the next page

[3] Equals the current range of 40 … 4000 A with 80A, 3mV/Hz Rogowski
[4] Depending on the used nominal current (hardware gain)
[5] Covers 6 kV … 30 kV sensors with division ratio of 10 000:1. Secondary voltages 600mV/√3 … 3 V / √3. Range up to 2 x Rated.
[6] Equals the current range of 40 … 4000 A with 80A, 3mV/Hz Rogowski
[7] Covers 6 kV … 40.5 kV sensors with division ratio of 10 000:1. Secondary voltages 600mV/√3 … 4.05V / √3. Range up to 2 x Rated.

Description	Value
Threshold voltage	16...176 V DC
Ripple in the DC auxiliary voltage	Max 15 % of the DC value (at frequency of 100 Hz)
Wetting current	220 mA, impulse period 5ms 0…120 mA[10], impulse period 8ms

Adjust the binary input threshold voltage correctly. It is recommended to set the threshold voltage to 70 % of the nominal auxiliary voltage. The factory default is 16 V to ensure the binary inputs' operation regardless of the auxiliary voltage used (24, 48, 60, 110, 125, 220 or 250 V DC). However, the default value is not optimal for the higher auxiliary voltages. The binary input threshold voltage should be set as high as possible to prevent any inadvertent activation of the binary inputs due to possible external disturbances. At the same time, the threshold should be set so that the correct operation is not jeopardized in case of undervoltage of the auxiliary voltage.

Table 1671: RTD/mA inputs and mA outputs

Description		Value	
RTD inputs	Supported RTD sensors	100 Ω platinum 250 Ω platinum 100 Ω nickel 120 Ω nickel 250 Ω nickel	TCR 0.00385 (DIN 43760) TCR 0.00385 TCR 0.00618 (DIN 43760) TCR 0.00618 TCR 0.00618
	Supported resistance range	0...4 kΩ	
	Maximum lead resistance (three-wire measurement)	100 Ω per lead	
	Isolation	2 kV (inputs to protective earth)	
	Response time	<1 s	
	RTD/resistance sensing current	<1 mA rms	
	Operation accuracy	Resistance	Temperature
		± 2.0 % or ±1 Ω	±1°C
mA inputs	Supported current range	±0…20 mA	
	Current input impedance	44 Ω ±0.1 %	
	Operation accuracy	±0.5 % or ±0.01 mA	
mA outputs	Supported current range	±0…20 mA	

Table continues on the next page

[10] Adjustable only in RTD1002 module

Description		Value
	Maximum loop impedance	700 Ω
	Operation accuracy	±0.1 mA

Table 1672: Signal outputs and IRF output

Description	Value
Rated voltage	250 V AC/DC
Maximum continuous burden (resistive load, AC)	1250 VA
Continuous contact carry	5 A
Make and carry for 3.0 s	10 A
Make and carry 0.5 s	15 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at 48/110/220 V DC	1 A/0.25 A/0.15 A
Minimum contact load	10 mA at 5 V AC/DC

Table 1673: Single-pole power output relays

Description	Value
Rated voltage	250 V AC/DC
Maximum continuous burden (resistive load, AC)	2000 VA
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at 48/110/220 V DC	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC

Table 1674: Static signal output (SSO) relays

Description	Value
Rated voltage	250 V AC/DC
Maximum continuous burden (resistive load, AC)	250 VA
Continuous contact carry	1 A
Make and carry for 3.0 s	5 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at 110 V DC	0.25 A
Minimum load current	1 mA
Maximum operation frequency at 50% duty cycle	10 Hz

Table 1675: Double-pole power output relays with TCS function

Description	Value
Rated voltage	250 V AC/DC
Maximum continuous burden (resistive load, AC)	2000 VA
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at 48/110/220 V DC (two contacts connected in series)	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC
Trip-circuit supervision (TCS): • Control voltage range • Current drain through the supervision circuit • Minimum voltage over the TCS contact	 20...250 V AC/DC ~1.5 mA 20 V AC/DC (15...20 V)

Table 1676: Static power output (SPO) relays

Description	Value
Rated voltage	250 V DC
Maximum continuous burden (resistive load, DC)	2000 VA
Continuous contact carry	5 A, 60 s 5 A continuous (one output active at a time per module) 1 A continuous (multiple outputs simultaneously active in the same module)
Make and carry for 0.2 s	30 A
Breaking capacity when the control-circuit time constant L/R<40 ms, at 48/110/220 V DC two contacts connected in series	16 A/6 A/3 A
Minimum load current	1 mA
Trip-circuit supervision (TCS) SP06 and SP08: • Control voltage range • Current drain through the supervision circuit • Minimum voltage over the TCS contact	 20...250 V DC ~1.5 mA 20 V DC
SP05 and SP07: Current drain through the circuit	~3 mA

Table 1677: Serial interface

Type	Connector
Screw terminal X8	10-pin 2-row connector
Serial port X7	Optical ST-connector

Table 1678: USB interface, HMI

Type	Description
USB	Hi-Speed USB Type A

Table 1679: Ethernet interfaces (connectors X0, X1, X2 and X3)

Connector	Media	Reach[1]	Rate	Wavelength	Permitted path attenuation[2]
RJ-45	CAT 6 S/FTP	100 m	100 mbits/s	–	–
LC	MM 62.5/125 or 50/125 µm glass fiber core	2 km	100 mbits/s	1300 nm	<8 dB

Table 1680: Maximum processing delay time

SMVSENDER internal processing time (us)	50 Hz nominal frequency	60 Hz nominal frequency
Average processing delay time	1800	1520
Maximum processing delay time	2000	1720

Table 1681: Protection communication link (connector X6)

Connector	Part number[3]	Fiber type	Reach[1]	Wavelength	Permitted path attenuation[2]
LC (SFP)	2RCA045621	MM 62.5/125 or 50/125 µm	2 km	1310 nm	<8 dB
LC (SFP)	2RCA045622	SM 9/125 µm	20 km	1310 nm	<13 dB
LC (SFP)	2RCA045623	SM 9/125 µm	50 km	1310 nm	<26 dB

[1] Maximum length depends on the cable attenuation and quality, the amount of splices and connectors in the path.
[2] Maximum allowed attenuation caused by connectors and cable together.
[3] Only these ABB verified SFP modules are supported in the protection communication link (port X6 in the communication module).

Table 1682: IRIG-B (connector X8)

Description	Value
IRIG time code format	B004, B005[4]
Isolation	500V 1 min
Modulation	Unmodulated
Logic level	5 V TTL
Current consumption	<1.0 mA
Power consumption	<0.5 W

Table 1683: Lens sensor and optical fiber for arc protection

Description	Value
Normal service temperature range of the lens	–40...+100°C
Maximum service temperature range of the lens, max 1 h	+140°C
Minimum permissible bending radius of the connection fiber	100 mm
Arc sensor loop maximum attenuation	25dB

Table 1684: Degree of protection of the protection relay

Description	Value
Front/connector side	IP 20 (with ring-lug signal connectors IP 00 or IP 10 depending on wiring)
Top and bottom	IP 30
Rear	IP 40

Table 1685: Degree of protection of the HMI

Description	Value
Front	IP 54
Other sides	IP 20

Table 1686: Environmental conditions

Description	Value
Operating temperature range	–25...+55ºC (continuous)
Short-time service temperature range	–40...+85ºC (<16 h)[5, 6]
Relative humidity	<93 %, non-condensing
Atmospheric pressure	86...106 kPa

Table continues on the next page

4 According to the 200-04 IRIG standard
5 Degradation in MTBF and HMI performance outside the temperature range of –25...+55 ºC.
6 For relays with an LC communication interface the maximum operating temperature is +70 ºC.

Description	Value
Altitude	Up to 2000 m
Transport and storage temperature range	–40...+85ºC

15 Protection relay and functionality tests

Table 1687: Electromagnetic compatibility tests

Description	Type test value	Reference
1 MHz/100 kHz burst disturbance test • Common mode • Differential mode	2.5 kV 2.5 kV	IEC 61000-4-18 IEC 60255-26, class III IEEE C37.90.1-2012
3 MHz, 10 MHz and 30 MHz burst disturbance test • Common mode	2.5 kV	IEC 61000-4-18 IEC 60255-26, class III
Electrostatic discharge test • Contact discharge • Air discharge	8 kV 15 kV	IEC 61000-4-2 IEC 60255-26 IEEE C37.90.3-2001
Radio frequency interference test	10 V (rms) f = 150 kHz...80 MHz 10 V/m (rms) f = 80...2700 MHz 10 V/m f = 900 MHz 20 V/m (rms) f = 80...1000 MHz	IEC 61000-4-6 IEC 60255-26, class III IEC 61000-4-3 IEC 60255-26, class III ENV 50204 IEC 60255-26, class III IEEE C37.90.2-2004
Fast transient disturbance test • Communication • Other ports	2 kV 4 kV	IEC 61000-4-4 IEC 60255-26 IEEE C37.90.1-2012
Surge immunity test • Communication • Other ports	1 kV, line-to-earth 4 kV, line-to-earth 2 kV, line-to-line	IEC 61000-4-5 IEC 60255-26
Power frequency (50 Hz) magnetic field immunity test • Continuous • 1...3 s	300 A/m 1000 A/m	IEC 61000-4-8 IEC 60255-26
Pulse magnetic field immunity test	1000 A/m 6.4/16 µs	IEC 61000-4-9

Table continues on the next page

Description	Type test value	Reference
Damped oscillatory magnetic field immunity test • 2 s • 1 MHz	100 A/m 400 transients/s	IEC 61000-4-10
Voltage dips and short interruptions	0%/50 ms Criterion A 40%/200 ms Criterion C 70%/500 ms Criterion C 0%/5000 ms Criterion C	IEC 61000-4-11 IEC 61000-4-29 IEC 60255-26
Power frequency immunity test • Common mode • Differential mode	Binary inputs only 300 V rms 150 V rms	IEC 61000-4-16 IEC 60255-26, class A
Emission tests • Conducted 0.15. 0.50 MHz 0.5...30 MHz • Radiated 30...230 MHz 230...1000 MHz 1…3 GHz 3…6 GHz	<79 dB (µV) quasi peak <66 dB (µV) average <73 dB (µV) quasi peak <60 dB (µV) average <40 dB (µV/m) quasi peak, measured at 10 m distance <47 dB (µV/m) quasi peak, measured at 10 m distance <76 dB (µV/m) peak <56 dB (µV/m) average, measured at 3 m distance <80 dB (µV/m) peak <60 dB (µV/m) average, measured at 3 m distance	EN 55011, class A IEC 60255-26 CISPR 11 CISPR 12

Table 1688: Safety-related tests

Description	Type test value	Reference
Overvoltage category	III	IEC 60255-27
Pollution degree	2	IEC 60255-27
Insulation class	Class I	IEC 60255-27
Dielectric tests	500 V, 50 Hz, 1 min, RS-485 and IRIG-B 1 kV, 50 Hz, 1 min, across open contacts 1.5 kV, 50 Hz, 1 min, Ethernet RJ-45	IEC 60255-27

Table continues on the next page

Description	Type test value	Reference
	2 kV, 50 Hz, 1 min, all other circuits	
Impulse voltage test	1 kV, 1.2/50 µs, 0.5 J, RS-485 and IRIG-B 2.4 kV, 1.2/50 µs, 0.5 J, Ethernet RJ-45 5 kV, 1.2/50 µs, 0.5 J, all other circuits	IEC 60255-27
Insulation resistance measurements	>100 MΩ, 500 V DC	IEC 60255-27
Protective bonding resistance	<0.1 Ω, 4 A, 60 s	IEC 60255-27
Maximum temperature of parts and materials	Tested	IEC 60255-27
Flammability of insulating materials, components and fire enclosures	Evaluated / Tested	IEC 60255-27
Single-fault condition	Tested	IEC 60255-27

Table 1689: Mechanical tests

Description	Requirement	Reference
Vibration tests (sinusoidal)	Class 2	IEC 60068-2-6 (test Fc) IEC 60255-21-1
Shock and bump test	Class 2	IEC 60068-2-27 (test Ea shock) IEC 60068-2-29 (test Eb bump) IEC 60255-21-2

Table 1690: Environmental tests

Description	Type test value	Reference
Dry heat test	96 h at +55°C 16 h at +85°C [1]	IEC 60068-2-2
Dry cold test	96 h at –25°C 16 h at –40°C	IEC 60068-2-1
Damp heat test	6 cycles (12 h + 12 h) at +25…+55°C, humidity >93%	IEC 60068-2-30
Change of temperature test	5 cycles (3 h + 3 h) at -25...+55°C	IEC60068-2-14
Storage test	96 h at –40°C	IEC 60068-2-1

[1] For relays with an LC communication interface the maximum operating temperature is +70°C.

Description	Type test value	Reference
	96 h at +85°C	IEC 60068-2-2

Table 1691: Product safety

Description	Reference
LV directive	2006/95/EC
Standard	EN 60255-27 (2014) EN 60255-1 (2009)

Table 1692: EMC compliance

Description	Reference
EMC directive	2014/30/EU
Standard	EN 60255-26 (2013)

Table 1693: RoHS compliance

Description
Complies with RoHS Directive 2011/65/EU

16 Applicable standards and regulations

EN 60255-1

EN 60255-26

EN 60255-27

EMC council directive 2004/108/EC

EU directive 2002/96/EC/175

IEC 60255

Low-voltage directive 2006/95/EC

IEC 61850

BS EN 60255-26: 2013

BS EN 61000-6-2: 2005

BS EN 61000-6-4: 2019

BS EN 60255-1: 2010

BS EN 60255-27: 2014

17 Glossary

100BASE-FX	A physical medium defined in the IEEE 802.3 Ethernet standard for local area networks (LANs) that uses fiber optic cabling
100BASE-TX	A physical medium defined in the IEEE 802.3 Ethernet standard for local area networks (LANs) that uses twisted-pair cabling category 5 or higher with RJ-45 connectors
ACT	1. Application Configuration tool in PCM600 2. Trip status in IEC 61850
AD	Active directory
AIM	Analog input module
AIS	Air-insulated switchgear
AR	Autoreclosing
ASC	Arc suppression coil
AVR	Automatic voltage regulator
BCD	Binary coded decimal
CAT 6	Cable standard for gigabit Ethernet and other network protocols that is backward compatible with CAT 5/5e and CAT 3 cable standards
CB	Circuit breaker
CBB	Cycle building block
CBCT	Core balance current transformer
CBFP	Circuit breaker failure protection
COM600S	Substation Management Unit. An all-in-one communication gateway, automation platform and user interface solution for utility and industrial distribution substations.
COMTRADE	Common format for transient data exchange for power systems. Defined by the IEEE Standard.
CR	Carrier receive signal
CS	Carrier send signal
CT	Current transformer
DAN	Doubly attached node
DC	1. Direct current 2. Disconnector 3. Double command
DCB	Directional comparison blocking scheme
DCS	Distributed control system
DCUB	Directional comparison unblocking scheme
DFT	Discrete fourier transform
DG	Distributed generation

DHCP	Dynamic host configuration protocol
DIP switch	A set of on-off switches arranged in a standard dual inline package
DNP3	A distributed network protocol originally developed by Westronic. The DNP3 Users Group has the ownership of the protocol and assumes responsibility for its evolution.
DO	Data object (IEC61850)
DST	Daylight-saving time
DT	Definite time
DUTT	Direct underreach transfer trip
EEPROM	Electrically erasable programmable read-only memory
EMC	Electromagnetic compatibility
Ethernet	A standard for connecting a family of frame-based computer networking technologies into a LAN
FLC	Full load current
FPGA	Field-programmable gate array
FPN	Flexible product naming
FTP	File transfer protocol
FTPS	FTP Secure
GCB	Generator circuit breaker
GFC	General fault criteria
GIS	1. Gas-insulated switchgear 2. Geoinformation systems
GND	Ground/earth
GNSS	Global navigation satellite systems
GOOSE	Generic object-oriented substation event
GPS	Global positioning system
HF	High frequency
HMI	Human machine interface
HSR	High-availability seamless redundancy
HTTPS	Hypertext transfer protocol secure
HV	High voltage
IDMT	Inverse definite minimum time
IEC	International electrotechnical commission
IEC 60870-5-101	Companion standard for basic telecontrol tasks
IEC 60870-5-103	1. Communication standard for protective equipment 2. A serial master/slave protocol for point-to-point communication
IEC 60870-5-104	Network access for IEC 60870-5-101
IEC 61850	International standard for substation communication and modeling
IEC 61850-8-1	A communication protocol based on the IEC 61850 standard series
IEC 61850-9-2	A communication protocol based on the IEC 61850 standard series

IEC 61850-9-2 LE	Lite Edition of IEC 61850-9-2 offering process bus interface
IED	Intelligent electronic device
IEEE 1588	Standard for a Precision Clock Synchronization Protocol for networked measurement and control systems
IRF	1. Internal fault 2. Internal relay fault
IRIG-B	Inter-Range Instrumentation Group's time code format B
L/R	Local/Remote
LAN	Local area network
LC	Connector type for glass fiber cable, IEC 61754-20
LD	Logical device
LDC	Line drop compensation
LE	Light edition
LED	Light-emitting diode
LF	Low frequency
LHMI	Local human machine interface
LN	Logical node (IEC61850)
LOG	Loss of grid
LOM	Loss of mains
LV	Low voltage
M/F	Master/Follower
MAC	Media access control
MCB	Miniature circuit breaker
MCC	Minimizing circulating current
MM	1. Multimode 2. Multimode optical fiber
MMS	1. Manufacturing message specification 2. Metering management system
Modbus	A serial communication protocol developed by the Modicon company in 1979. Originally used for communication in PLCs and RTU devices.
Modbus ASCII	Link mode using 7-bit ASCII characters
Modbus RTU	Link mode using 8-bit binary characters
MSB	Most significant bit
MV	Medium voltage
NC	Normally closed
NPS	Negative phase sequence
NRP	Negative reactance principle
NSCB	Non-source circuit breaker
OSB	Out of step blocking

P2P	peer-to-peer
PC	1. Personal computer 2. Polycarbonate
PCM600	Protection and control IED manager
Peak-to-peak	1. The amplitude of a waveform between its maximum positive value and its maximum negative value 2. A measurement principle where the measurement quantity is made by calculating the average from the positive and negative peak values without including the DC component. The peak-to-peak mode allows considerable CT saturation without impairing the performance of the operation.
Peak-to-peak with peak back-up	A measurement principle similar to the peak-to-peak mode but with the function starting on two conditions: the peak-to-peak value is above the set start current or the peak value is above two times the set start value
PGU	Power generating unit
PLC	Programmable logic controller
PMS	Power management system
PO	Power output
PODP	Power output, double pole
POSP	Power output, single pole
POTT	Permissive overreach transfer trip
PPS	Pulse per second
PRP	Parallel redundancy protocol
PST	Parameter setting tool
PTP	Precision time protocol
PUTT	Permissive underreach transfer trip
RAM	Random access memory
RCA	Also known as MTA or base angle. Characteristic angle.
RIO600	Remote I/O unit
RJ-45	Galvanic connector type
RMS	Root-mean-square (value)
ROM	Read-only memory
RS-485	Serial link according to EIA standard RS485
RSTP	Rapid spanning tree protocol
RTC	Real-time clock
RTD	Resistance temperature detector
Rx	Receive/Received
SA	Substation automation
SAN	Single attached node
SBO	Select-before-operate
SCADA	Supervision, control and data acquisition

SCB	1. Shunt capacitor bank 2. Source circuit breaker
SCL	XML-based system configuration description language defined by IEC 61850
SCM	Smart control module
SHMI	Switchgear HMI
SI	Sensor input
SIM	Sensor input module
SLD	Single-line diagram
SM	1. Single mode 2. Single-mode optical fiber
SMT	Signal matrix tool in PCM600
SMV	Sampled measured values
SNTP	Simple network time protocol
SOTF	Switch onto fault
SPO	Static power output
SSO	Static signal output
ST	Connector type for glass fiber cable
TCP	Transmission control protocol
TCS	Trip-circuit supervision
TP	Disturbance data recorded with or without trip bit
Tx	Transmit/Transmitted
UART	Universal asynchronous receiver-transmitter
UDP	User datagram protocol
USB	Universal serial bus
UTC	Coordinated universal time
VDR	Voltage-depended resistor
VT	Voltage transformer
WAN	Wide area network
WEI	Weak-end infeed logic
WHMI	Web human-machine interface

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