Relion® product family

Grid Automation
Remote Monitoring and Control REC615
Technical Manual

Power and productivity
for a better world™

ABB

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Warranty

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

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Disclaimer

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 2004/108/EC) and concerning electrical equipment for use within specified voltage limits (Low-voltage directive 2006/95/EC). This conformity is the result of tests conducted by ABB in accordance with the product standards EN 50263 and 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.

Table of contents

Section 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 IEDs. The installation and commissioning personnel must have a basic knowledge in handling electronic equipment.

1.3 Product documentation

1.3.1 Product documentation set

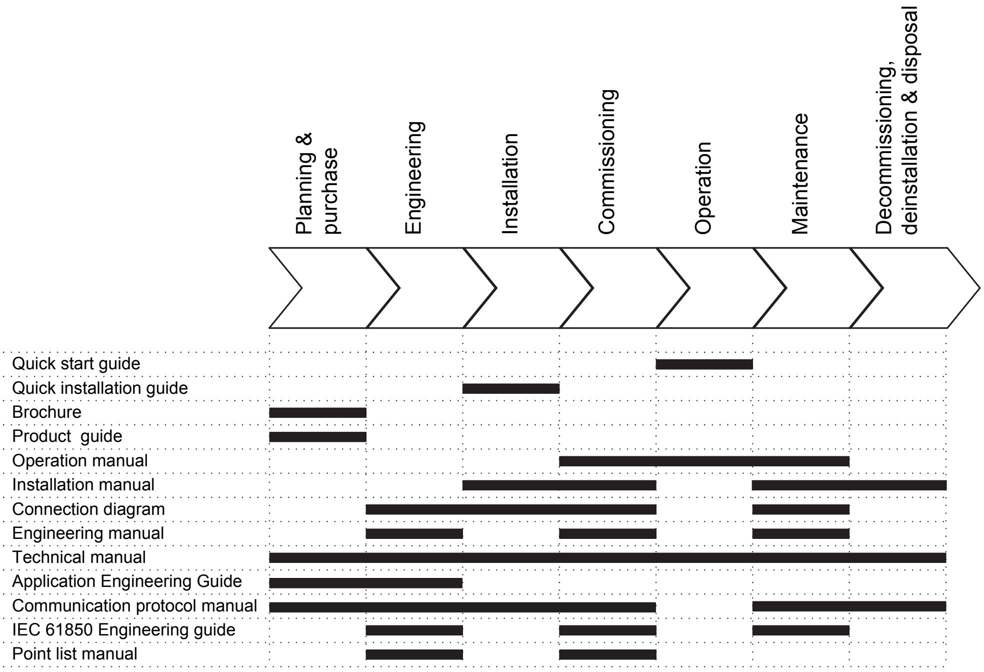

Figure 1: The intended use of documents during the product life cycle

Product series- and product-specific manuals can be downloaded from the ABB Website http://www.abb.com/relion.

1.3.2 Document revision history

Document revision/date	Product version	History
A/2013-09-17	1.0	First release
B/2014-06-13	1.0	Content updated
C/2015-03-06	1.1	Content updated to correspond to the product series version

Download the latest documents from the ABB Website http://www.abb.com/substationautomation.

1.3.3 Related documentation

Name of the document	Document ID
Application Engineering Guide	1MRS757802
Modbus Communication Protocol Manual	1MRS757803
DNP3 Communication Protocol Manual	1MRS757804
IEC 60870-5-101/104 Communication Protocol Manual	1MRS757805
IEC 61850 Engineering Guide	1MRS757809
Engineering Manual	1MRS757810
Installation Manual	1MRS757799
Operation Manual	1MRS757800

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.
- The example figures illustrate the IEC display variant.
- Menu paths are presented in bold.
  Select **Main menu/Settings**.
- LHMI messages are shown in Courier font.
  To save the changes in non-volatile memory, select `Yes` and press .
- 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".
- IED input/output messages and monitored data names are shown in Courier font.
  When the function starts, the `START` output is set to TRUE.

1.4.3 Functions, codes and symbols

All available functions are listed in the table. All of them may not be applicable to all products.

Table 1: Functions included in the relay

Function	IEC 61850	IEC 60617	IEC-ANSI
Protection			
Three-phase non-directional overcurrent protection, low stage, instance 1	PHLPTOC1	3I> (1)	51P-1 (1)
Three-phase non-directional overcurrent protection, high stage, instance 1	PHHPTOC1	3I>> (1)	51P-2 (1)
Three-phase non-directional overcurrent protection, instantaneous stage, instance 1	PHIPTOC1	3I>>> (1)	50P/51P (1)
Three-phase directional overcurrent protection, low stage, instance 1	DPHLPDOC1	3I> -> (1)	67-1 (1)
Three-phase directional overcurrent protection, low stage, instance 2	DPHLPDOC2	3I> -> (2)	67-1 (2)
Three-phase directional overcurrent protection, high stage, instance 1	DPHHPDOC1	3I>> -> (1)	67-2 (1)
Non-directional earth-fault protection, low stage, instance 1	EFLPTOC1	Io> (1)	51N-1 (1)
Non-directional earth-fault protection, high stage, instance 1	EFHPTOC1	Io>> (1)	51N-2 (1)
Non-directional earth-fault protection, instantaneous stage, instance 1	EFIPTOC1	Io>>> (1)	50N/51N (1)

Table continues on next page

Function	IEC 61850	IEC 60617	IEC-ANSI
Directional earth-fault protection, low stage, instance 1	DEFLPDEF1	Io> -> (1)	67N-1 (1)
Directional earth-fault protection, low stage, instance 2	DEFLPDEF2	Io> -> (2)	67N-1 (2)
Directional earth-fault protection, high stage, instance 1	DEFHPDEF1	Io>> -> (1)	67N-2 (1)
Transient/intermittent earth-fault protection, instance 1	INTRPTEF1	Io> -> IEF (1)	67NIEF (1)
Admittance based earth-fault protection, instance 1	EFPADM1	Yo> -> (1)	21YN (1)
Admittance based earth-fault protection, instance 2	EFPADM2	Yo> -> (2)	21YN (2)
Admittance based earth-fault protection, instance 3	EFPADM3	Yo> -> (3)	21YN (3)
Wattmetric based earth-fault protection, instance 1	WPWDE1	Po> -> (1)	32N (1)
Wattmetric based earth-fault protection, instance 2	WPWDE2	Po> -> (2)	32N (2)
Wattmetric based earth-fault protection, instance 3	WPWDE3	Po> -> (3)	32N (3)
Harmonics based earth-fault protection, instance 1	HAEFPTOC1	Io>HA (1)	51NHA (1)
Negative-sequence overcurrent protection, instance 1	NSPTOC1	I2> (1)	46 (1)
Negative-sequence overcurrent protection, instance 2	NSPTOC2	I2> (2)	46 (2)
Phase discontinuity protection, instance 1	PDNSPTOC1	I2/I1> (1)	46PD (1)
Residual overvoltage protection, instance 1	ROVPTOV1	Uo> (1)	59G (1)
Residual overvoltage protection, instance 2	ROVPTOV2	Uo> (2)	59G (2)
Three-phase undervoltage protection, instance 1	PHPTUV1	3U< (1)	27 (1)
Three-phase undervoltage protection, instance 2	PHPTUV2	3U< (2)	27 (2)
Three-phase undervoltage protection, instance 3	PHPTUV3	3U< (3)	27 (3)
Three-phase overvoltage protection, instance 1	PHPTOV1	3U> (1)	59 (1)
Three-phase overvoltage protection, instance 2	PHPTOV2	3U> (2)	59 (2)
Three-phase overvoltage protection, instance 3	PHPTOV3	3U> (3)	59 (3)
Positive-sequence undervoltage protection, instance 1	PSPTUV1	U1< (1)	47U+ (1)
Negative-sequence overvoltage protection, instance 1	NSPTOV1	U2> (1)	47O- (1)
Frequency protection, instance 1	FRPFRQ1	f>/f<,df/dt (1)	81 (1)

Table continues on next page

Function	IEC 61850	IEC 60617	IEC-ANSI
Frequency protection, instance 2	FRPFRQ2	f>/f<,df/dt (2)	81 (2)
Three-phase thermal protection for feeders, cables and distribution transformers, instance 1	T1PTTR1	3Ith>F (1)	49F (1)
Three-phase inrush detector, instance 1	INRPHAR1	3I2f> (1)	68 (1)
Master trip, instance 1	TRPPTRC1	Master Trip (1)	94/86 (1)
Master trip, instance 2	TRPPTRC2	Master Trip (2)	94/86 (2)
Multi-purpose protection, instance 1	MAPGAPC1	MAP (1)	MAP (1)
Multi-purpose protection, instance 2	MAPGAPC2	MAP (2)	MAP (2)
Multi-purpose protection, instance 3	MAPGAPC3	MAP (3)	MAP (3)
Multi-purpose protection, instance 4	MAPGAPC4	MAP (4)	MAP (4)
Multi-purpose protection, instance 5	MAPGAPC5	MAP (5)	MAP (5)
Multi-purpose protection, instance 6	MAPGAPC6	MAP (6)	MAP (6)
Load shedding and restoration, instance 1	LSHDPFRQ1	UFLS/R (1)	81LSH (1)
Fault locator, instance 1	SCEFRFLO1	FLOC (1)	21FL (1)
Power quality			
Current total demand distortion, instance 1	CMHAI1	PQM3I (1)	PQM3I (1)
Voltage total harmonic distortion, instance 1	VMHAI1	PQM3U (1)	PQM3V (1)
Voltage variation, instance 1	PHQVVR1	PQMU (1)	PQMV (1)
Voltage unbalance, instance 1	VSQVUB1	PQUUB (1)	PQVUB (1)
Control			
Circuit-breaker control, instance 1	CBXCBR1	I <-> O CB (1)	I <-> O CB (1)
Disconnector control, instance 1	DCXSWI1	I <-> O DCC (1)	I <-> O DCC (1)
Disconnector control, instance 2	DCXSWI2	I <-> O DCC (2)	I <-> O DCC (2)
Disconnector control, instance 3	DCXSWI3	I <-> O DCC (3)	I <-> O DCC (3)
Disconnector control, instance 4	DCXSWI4	I <-> O DCC (4)	I <-> O DCC (4)
Disconnector control, instance 5	DCXSWI5	I <-> O DCC (5)	I <-> O DCC (5)
Disconnector control, instance 6	DCXSWI6	I <-> O DCC (6)	I <-> O DCC (6)
Disconnector control, instance 7	DCXSWI7	I <-> O DCC (7)	I <-> O DCC (7)
Disconnector control, instance 8	DCXSWI8	I <-> O DCC (8)	I <-> O DCC (8)
Earthing switch indication, instance 1	ESSXSWI1	I <-> O ES (1)	I <-> O ES (1)
Earthing switch indication, instance 2	ESSXSWI2	I <-> O ES (2)	I <-> O ES (2)
Earthing switch indication, instance 3	ESSXSWI3	I <-> O ES (3)	I <-> O ES (3)
Earthing switch indication, instance 4	ESSXSWI4	I <-> O ES (4)	I <-> O ES (4)
Earthing switch indication, instance 5	ESSXSWI5	I <-> O ES (5)	I <-> O ES (5)
Earthing switch indication, instance 6	ESSXSWI6	I <-> O ES (6)	I <-> O ES (6)
Earthing switch indication, instance 7	ESSXSWI7	I <-> O ES (7)	I <-> O ES (7)
Earthing switch indication, instance 8	ESSXSWI8	I <-> O ES (8)	I <-> O ES (8)

Table continues on next page

Function	IEC 61850	IEC 60617	IEC-ANSI
Autoreclosing, instance 1	DARREC1	O -> I (1)	79 (1)
Synchronism and energizing check, instance 1	SECRSYN1	SYNC (1)	25 (1)
Automatic transfer switch, instance 1	ATSABTC1	ATSABTC (1)	ATSABTC (1)
Condition monitoring and supervision			
Circuit-breaker condition monitoring, instance 1	SSCBR1	CBCM (1)	CBCM (1)
Circuit-breaker condition monitoring, instance 2	SSCBR2	CBCM (2)	CBCM (2)
Trip circuit supervision, instance 1	TCSSCBR1	TCS (1)	TCM (1)
Trip circuit supervision, instance 2	TCSSCBR2	TCS (2)	TCM (2)
Fuse failure supervision, instance 1	SEQRFUF1	FUSEF (1)	60 (1)
Runtime counter for machines and devices, instance 1	MDSOPT1	OPTS (1)	OPTM (1)
Voltage presence, instance 1	PHSVPR1	PHSVPR(1)	PHSVPR(1)
Voltage presence, instance 2	PHSVPR2	PHSVPR(2)	PHSVPR(2)
Measurement			
Disturbance recorder, instance 1	RDRE1	DR (1)	DFR (1)
Three-phase current measurement, instance 1	CMMXU1	3I (1)	3I (1)
Sequence current measurement, instance 1	CSMSQI1	I1, I2, I0 (1)	I1, I2, I0 (1)
Residual current measurement, instance 1	RESCMMXU1	Io (1)	In (1)
Three-phase voltage measurement, instance 1	VMMXU1	3U (1)	3V (1)
Three-phase voltage measurement, instance 2	VMMXU2	3U (B) (1)	3V (B) (1)
Sequence voltage measurement, instance 1	VSMSQI1	U1, U2, U0 (1)	V1, V2, V0 (1)
Sequence voltage measurement, instance 2	VSMSQI2	U1, U2, U0 (B) (1)	V1, V2, V0 (B) (1)
Three-phase power and energy measurement, instance 1	PEMMXU1	P, E (1)	P, E (1)
Frequency measurement, instance 1	FMMXU1	f (1)	f (1)
Load profile, instance 1	LDPMSTA1	LOADPROF (1)	LOADPROF (1)
Other			
Minimum pulse timer (2 pcs), instance 1	TPGAPC1	TP (1)	TP (1)
Minimum pulse timer (2 pcs), instance 2	TPGAPC2	TP (2)	TP (2)
Minimum pulse timer (2 pcs, second resolution), instance 1	TPSGAPC1	TPS (1)	TPS (1)
Minimum pulse timer (2 pcs, minute resolution), instance 1	TPMGAPC1	TPM (1)	TPM (1)
Pulse timer (8 pcs), instance 1	PTGAPC1	PT (1)	PT (1)

Table continues on next page

Function	IEC 61850	IEC 60617	IEC-ANSI
Pulse timer (8 pcs), instance 2	PTGAPC2	PT (2)	PT (2)
Time delay off (8 pcs), instance 1	TOFGAPC1	TOF (1)	TOF (1)
Time delay off (8 pcs), instance 2	TOFGAPC2	TOF (2)	TOF (2)
Time delay on (8 pcs), instance 1	TONGAPC1	TON (1)	TON (1)
Time delay on (8 pcs), instance 2	TONGAPC2	TON (2)	TON (2)
Set reset (8 pcs), instance 1	SRGAPC1	SR (1)	SR (1)
Set reset (8 pcs), instance 2	SRGAPC2	SR (2)	SR (2)
Move (8 pcs), instance 1	MVGAPC1	MV (1)	MV (1)
Move (8 pcs), instance 2	MVGAPC2	MV (2)	MV (2)
Move (8 pcs), instance 3	MVGAPC3	MV (3)	MV (3)
Move (8 pcs), instance 4	MVGAPC4	MV (4)	MV (4)
Move (8 pcs), instance 5	MVGAPC5	MV (5)	MV (5)
Move (8 pcs), instance 6	MVGAPC6	MV (6)	MV (6)
Move (8 pcs), instance 7	MVGAPC7	MV (7)	MV (7)
Move (8 pcs), instance 8	MVGAPC8	MV (8)	MV (8)
Generic control point (16 pcs), instance 1	SPCGGIO1	SPCGGIO (1)	SPCGGIO (1)
Generic control point (16 pcs), instance 2	SPCGGIO2	SPCGGIO (2)	SPCGGIO (2)
Remote generic control points, instance 1	SPCRGGIO1	SPCRGGIO (1)	SPCRGGIO (1)
Local generic control points, instance 1	SPCLGGIO1	SPCLGGIO (1)	SPCLGGIO (1)
Generic up-down counters, instance 1	UDFCNT1	UDCNT (1)	UDCNT (1)
Generic up-down counters, instance 2	UDFCNT2	UDCNT (2)	UDCNT (2)
Generic up-down counters, instance 3	UDFCNT3	UDCNT (3)	UDCNT (3)
Analog value scaling function, instance 1	SCA4GAPC1	SCA4 (1)	SCA4 (1)
Analog value scaling function, instance 2	SCA4GAPC2	SCA4 (2)	SCA4 (2)
Analog value scaling function, instance 3	SCA4GAPC3	SCA4 (3)	SCA4 (3)
Analog value scaling function, instance 4	SCA4GAPC4	SCA4 (4)	SCA4 (4)
Analog value scaling function, instance 5	SCA4GAPC5	SCA4 (5)	SCA4 (5)
Analog value scaling function, instance 6	SCA4GAPC6	SCA4 (6)	SCA4 (6)
Analog value scaling function, instance 7	SCA4GAPC7	SCA4 (7)	SCA4 (7)
Analog value scaling function, instance 8	SCA4GAPC8	SCA4 (8)	SCA4 (8)
Analog value scaling function, instance 9	SCA4GAPC9	SCA4 (9)	SCA4 (9)

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Function	IEC 61850	IEC 60617	IEC-ANSI
Analog value scaling function, instance 10	SCA4GAPC10	SCA4 (10)	SCA4 (10)
Analog value scaling function, instance 11	SCA4GAPC11	SCA4 (11)	SCA4 (11)
Analog value scaling function, instance 12	SCA4GAPC12	SCA4 (12)	SCA4 (12)
Integer value moving function , instance 1	MVI4GAPC1	MVI4 (1)	MVI4 (1)
Integer value moving function , instance 2	MVI4GAPC2	MVI4 (2)	MVI4 (2)

Section 2 REC615 overview

2.1 Overview

REC615 is a dedicated grid automation relay designed for remote control and monitoring, protection, fault indication, power quality analysis and automation in medium-voltage secondary distribution systems, including networks with distributed power generation, with secondary equipment such as medium-voltage disconnectors, switches and ring-main units.

REC615 is a member of the Relion® product family. The relay has inherited features from the 615 series relays that are characterized by their compactness as well as environmentally friendly (RoHS compliance) and withdrawable-unit design. Re-engineered from the ground up, the relays have been designed to unleash the full potential of the IEC 61850 standard for communication and interoperability between substation automation devices.

With REC615, grid reliability can be enhanced, ranging from basic, non-directional overload protection to extended protection functionality with power quality analyses. REC615 meets today’s requirements for smart grids and supports the protection of cable feeders in isolated neutral, resistance-earthed, compensated and solidly earthed networks. REC615 is freely programmable with horizontal GOOSE communication, thus enabling sophisticated interlocking functions. REC615 includes sophisticated protection functionality to detect, isolate and restore power in all types of networks but especially in compensated networks. As part of an ABB smart grid solution, the relay provides superior fault location, isolation and restoration (FLIR) to lower the frequency and shorten the duration of faults.

The adaptable standard configurations allow the relay to be taken into use right after the application-specific parameters have been set, thus enabling rapid commissioning. The relay's existing I/O is further extendable with RIO600. REC615 supports the same configuration tools as the other relays in the Relion product family. The freely programmable relay contains six easily manageable setting groups.

One breaker and up to eight load-break switches can be controlled via the relay's front panel HMI or a remote system. The relay's large, easy-to-read LCD screen with single-line diagram offers local control and parametrization possibilities with dedicated push buttons for safe operation. Easy Web-based parametrization tool is also available with download possibility.

To protect the relay from unauthorized access and to maintain the integrity of information, the relay is provided with a four-level, role-based user authentication system, with individual passwords for the viewer, operator, engineer and administrator levels. The access control system applies to the front panel HMI, embedded Web browser-based HMI and Protection and Control IED Manager PCM600. In addition, the relay also includes cyber security features such as audit trail.

REC615 supports a variety of communication protocols for remote communication, such as IEC 60870-5-101/104, DNP3 level 2 and Modbus, simultaneously also supporting IEC 61850 with GOOSE messaging for high-speed protection, fault isolation and restoration.

2.1.1 Product version history

Product version	Product history
1.0	Product released: configurations A-C
1.1	• Fault locator • Transient/intermittent earth-fault protection • Operation time counter • Automatic transfer switch • Supervision of voltage presence status

2.2 Local HMI

The LHMI is used for setting, monitoring and controlling the IED. The LHMI comprises the display, buttons, LED indicators and communication port.

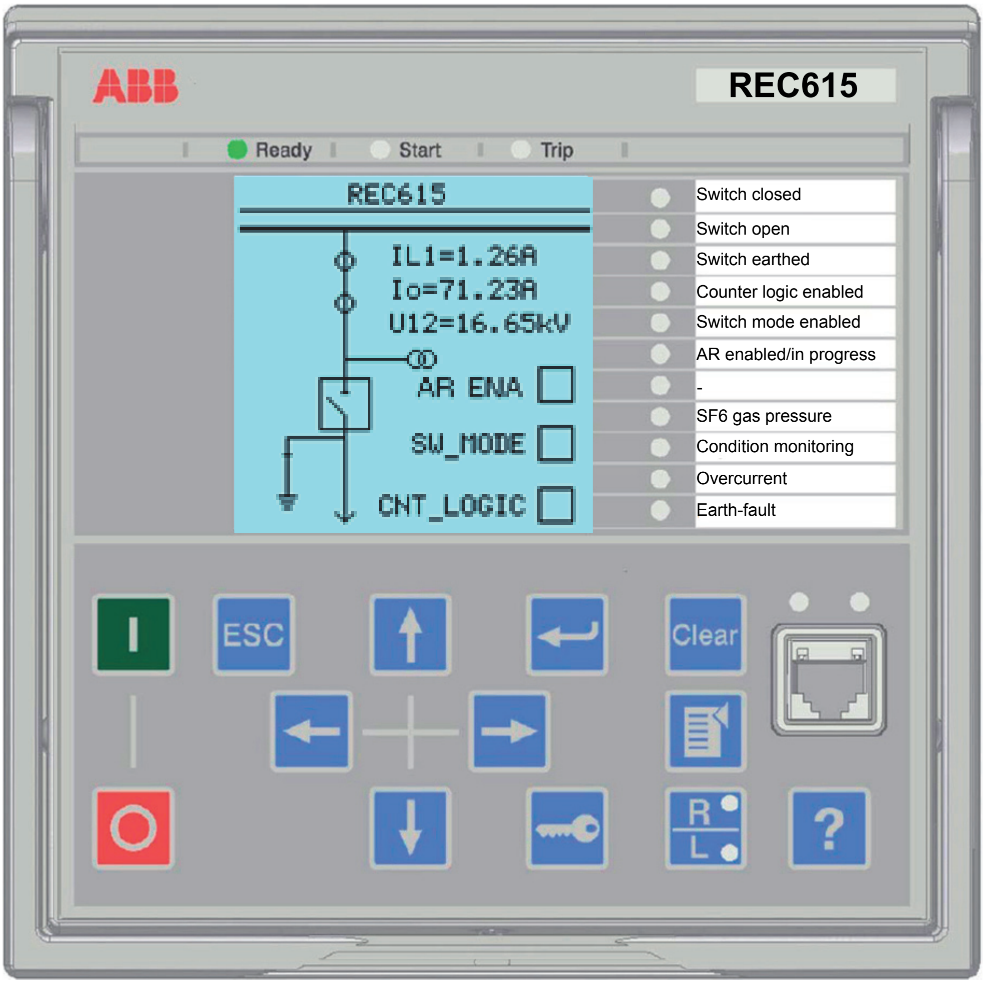


Figure 2: Example of the LHMI (IEC)

2.2.1 Display

The LHMI includes a graphical display that supports two character sizes. The character size depends on the selected language. The amount of characters and rows fitting the view depends on the character size.

Table 2: Small display

Character size[1)]	Rows in the view	Characters per row
Small, mono-spaced (6x12 pixels)	5	20
Large, variable width (13x14 pixels)	4	8 or more

1) Depending on the selected language

Table 3: Large display

Character size[1)]	Rows in the view	Characters per row
Small, mono-spaced (6x12 pixels)	10	20
Large, variable width (13x14 pixels)	8	8 or more

1) Depending on the selected language

The display view is divided into four basic areas.

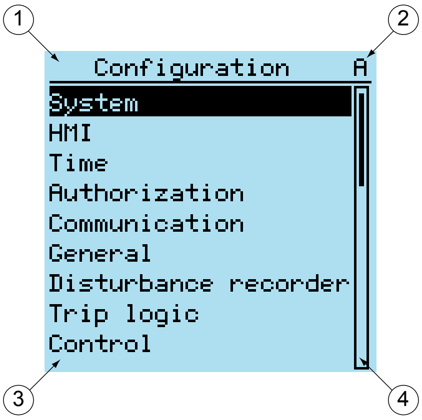


Figure 3: Display layout

1 Header

2 Icon

3 Content

4 Scroll bar (displayed when needed)

2.2.2 LEDs

The LHMI includes three protection indicators above the display: Ready, Start and Trip.

There are 11 matrix programmable LEDs on front of the LHMI. The LEDs can be configured with PCM600 and the operation mode can be selected with the LHMI, WHMI or PCM600.

2.2.3 Keypad

The LHMI keypad contains push-buttons which are used to navigate in different views or menus. With the push-buttons you can give open or close commands to objects in the primary circuit, for example, a circuit breaker, a contactor or a disconnector. The push-buttons are also used to acknowledge alarms, reset indications, provide help and switch between local and remote control mode.

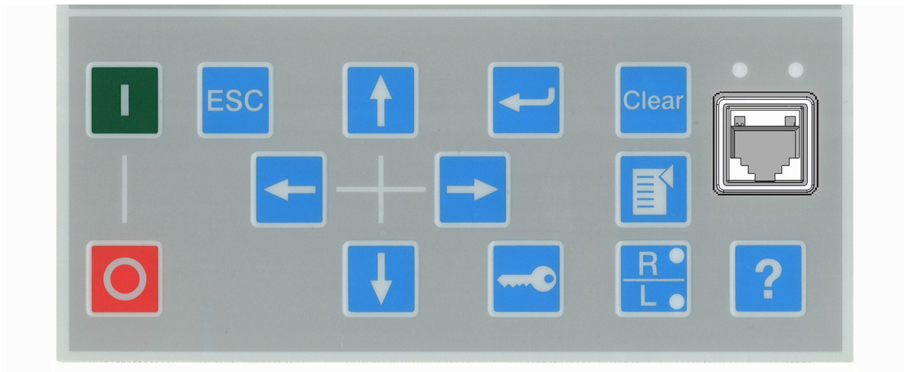


Figure 4: LHMI keypad with object control, navigation and command push-buttons and RJ-45 communication port

2.3 Web HMI

The WHMI allows secure access to the IED via a Web browser. The supported Web browser versions are Internet Explorer 7.0, 8.0 and 9.0.

WHMI is disabled by default.

Control operations are not allowed by WHMI.

WHMI offers several functions.

- Programmable LEDs and event lists
- System supervision
- Parameter settings
- Measurement display
- Disturbance records
- Phasor diagram
- Single-line diagram
- Importing/Exporting parameters

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

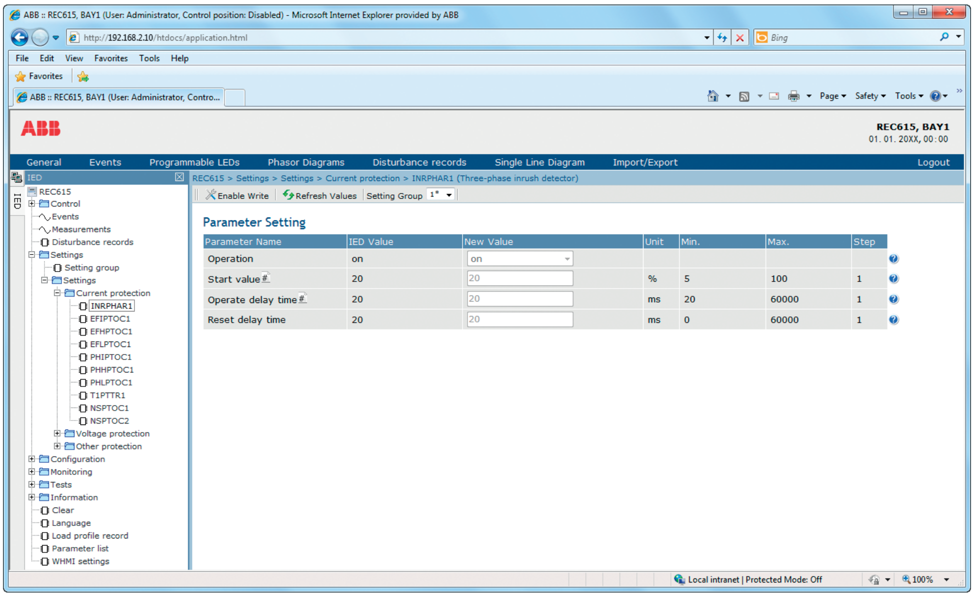


Figure 5: Example view of the WHMI

The WHMI can be accessed locally and remotely.

- Locally by connecting the laptop to the IED via the front communication port.
- Remotely over LAN/WAN.

2.4 Authorization

The user categories have been predefined for the LHMI and the WHMI, each with different rights and default passwords.

The default passwords can be changed with Administrator user rights.

If the IED-specific Administrator password is forgotten, ABB can provide a one-time reliable key to access the IED. For support, please contact ABB. The recovery of the Administrator password takes a few days.

User authorization is disabled by default for LHMI but WHMI always uses authorization.

Table 4: Predefined user categories

Username	User rights
VIEWER	Read only access
OPERATOR	• Selecting remote or local state with R/L (only locally) • Changing setting groups • Controlling • Clearing indications
ENGINEER	• Changing settings • Clearing event list • Clearing disturbance records • Changing system settings such as IP address, serial baud rate or disturbance recorder settings • Setting the IED to test mode • Selecting language
ADMINISTRATOR	• All listed above • Changing password • Factory default activation

For user authorization for PCM600, see PCM600 documentation.

2.4.1 Audit trail

The IED offers a large set of event-logging functions. Critical system and IED security-related events are logged to a separate nonvolatile audit trail for the administrator.

Audit trail is a chronological record of system activities that allows the reconstruction and examination of the sequence of system and security-related events and changes in the IED. Both audit trail events and process related events can be examined and analyzed in a consistent method with the help of Event List in LHMI and WHMI and Event Viewer in PCM600. The IED stores 2048 system events to the nonvolatile audit trail. Additionally, 1024 process events are stored in a nonvolatile event list. Both the audit trail and event list work according to the FIFO principle.

Audit trail events related to user authorization (login, logout, violation remote and violation local) are defined according to the selected set of requirements from IEEE 1686. The logging is based on predefined usernames or user categories. The user audit trail events are accessible with IEC 61850-8-1, PCM600, LHMI and WHMI.

Table 5: Audit trail events

Audit trail event	Description
Configuration change	Configuration files changed
Firmware change	Firmware changed
Firmware change fail	Firmware change failed
Attached to retrofit test case	Unit has been attached to retrofit case
Removed from retrofit test case	Removed from retrofit test case
Setting group remote	User changed setting group remotely
Setting group local	User changed setting group locally
Control remote	DPC object control remote
Control local	DPC object control local
Test on	Test mode on
Test off	Test mode off
Reset trips	Reset latched trips (TRPPTRC*)
Setting commit	Settings have been changed
Time change	Time changed directly by the user. Note that this is not used when the IED is synchronised properly by the appropriate protocol (SNTP, IRIG-B, IEEE 1588 v2).
View audit log	Administrator accessed audit trail
Login	Successful login from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Logout	Successful logout from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Firmware reset	Reset issued by user or tool
Audit overflow	Too many audit events in the time period
Violation remote	Unsuccessful login attempt from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.
Violation local	Unsuccessful login attempt from IEC 61850-8-1 (MMS), WHMI, FTP or LHMI.

PCM600 Event Viewer can be used to view the audit trail events and process related events. Audit trail events are visible through dedicated Security events view. Since only the administrator has the right to read audit trail, authorization must be used in PCM600. The audit trail cannot be reset but PCM600 Event Viewer can filter data. Audit trail events can be configured to be visible also in LHMI/WHMI Event list together with process related events.

To expose the audit trail events through Event list, define the authority logging level parameter via **Configuration/ Authorization/Authority logging.** Notice that this exposes audit trail events to all users.

Table 6: Comparison of authority logging levels

Audit trail event	Authority logging level					
	None	Configuration change	Setting group	Setting group, control	Settings edit	All
Configuration change		•	•	•	•	•
Firmware change		•	•	•	•	•
Firmware change fail		•	•	•	•	•
Attached to retrofit test case		•	•	•	•	•
Removed from retrofit test case		•	•	•	•	•
Setting group remote			•	•	•	•
Setting group local			•	•	•	•
Control remote				•	•	•
Control local				•	•	•
Test on				•	•	•
Test off				•	•	•
Reset trips				•	•	•
Setting commit					•	•
Time change						•
View audit log						•
Login						•
Logout						•
Firmware reset						•
Audit overflow						•
Violation local						•
Violation remote						•

2.5 Communication

The IED supports a range of communication protocols including IEC 61850, IEC 60870-5-101/IEC 60870-5-104, Modbus® and DNP3. Operational information and controls are available through these protocols. However, some communication functionality, for example, horizontal communication between the IEDs, is only enabled by the IEC 61850 communication protocol.

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 standard COMTRADE file format. The IED can send and receive binary signals from other IEDs (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. Further, the IED supports sending and receiving of analog values using GOOSE messaging. The IED meets the GOOSE performance requirements for tripping applications in distribution substations, as defined by the IEC 61850 standard.

The IED can simultaneously report events to four different clients on the station bus. If PCM600 reserves one client connection, only three client connections are left, for example, for IEC 61850 and Modbus.

All communication connectors, except for the front port connector, are placed on integrated optional communication modules. The IED can be connected to Ethernet-based communication systems via the RJ-45 connector (100Base-TX) or the fibre-optic LC connector (100Base-FX).

For the correct operation of redundant loop topology, 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 loop topology can cause problems to the network. The IED itself does not support link-down detection or RSTP. The ring recovery process is based on the aging of MAC addresses and link-up/link-down events can cause temporary breaks in communication. For better performance of the self-healing loop, it is recommended that the external switch furthest from the IED loop is assigned as the root switch (bridge priority = 0) and the bridge priority increases towards the IED loop. The end links of the IED loop can be attached to the same external switch or to two adjacent external switches. Self-healing Ethernet ring requires a communication module with at least two Ethernet interfaces for all IEDs.

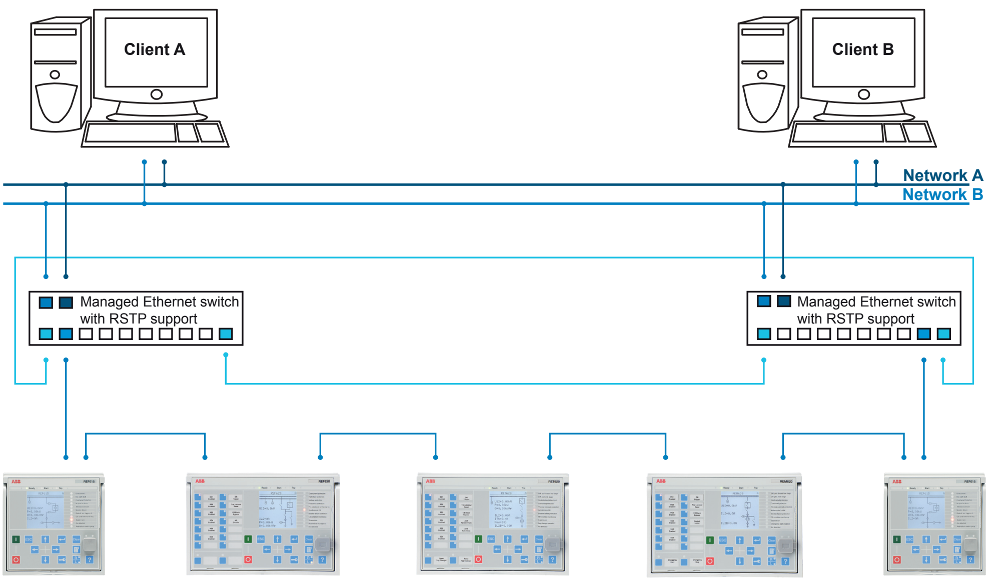


Figure 6: Self-healing Ethernet ring solution

The Ethernet ring solution supports the connection of up to 30 IEDs. If more than 30 IEDs are to be connected, it is recommended that the network is split into several rings with no more than 30 IEDs per ring.

Section 3 Basic functions

3.1 General parameters

Table 7: Analog input CT settings, phase currents

Parameter	Values (Range)	Unit	Step	Default	Description
Primary current	1.0...6000.0	A	0.1	100.0	Rated primary current
Secondary current	2=1A 3=5A			2=1A	Rated secondary current
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A amplitude correction factor
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B amplitude correction factor
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C amplitude correction factor
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the phase CTs

Table 8: Analog input sensor settings, phase currents

Parameter	Values (Range)	Unit	Step	Default	Description
Primary current	1.0...6000.0	A	0.1	80.0	Rated primary current
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A amplitude correction factor
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B amplitude correction factor
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C amplitude correction factor
Nominal Current	39...4000	A	1	80	Network Nominal Current (In)
Rated Secondary Value	1.000...50.000	mV/Hz	0.001	3.000	Rated Secondary Value (RSV) ratio
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the phase CTs[1)]

1) In this case sensors, although the tools and documentation mention CTs

Table 9: Analog input settings, residual current

Parameter	Values (Range)	Unit	Step	Default	Description
Primary current	1.0...6000.0	A	0.1	100.0	Primary current
Secondary current	1=0.2A 2=1A			2=1A	Secondary current
Amplitude corr.	0.900...1.100		0.001	1.000	Amplitude correction
Reverse polarity	0=False 1=True			0=False	Reverse the polarity of the residual CT

Table 10: Analog input VT settings, phase voltages

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...440.000	kV	0.001	20.000	Primary rated voltage
Secondary voltage	60...210	V	1	100	Secondary rated voltage
VT connection	1=Wye 2=Delta			2=Delta	Wye, delta, U12 or UL1[1)] VT connection
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A Voltage phasor magnitude correction of an external voltage transformer
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B Voltage phasor magnitude correction of an external voltage transformer
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C Voltage phasor magnitude correction of an external voltage transformer
Voltage input type	1=Voltage trafo			1=Voltage trafo	Type of the voltage input

1) The U12 and UL1 VT connections are not an option although the tools and documentation mention them

Table 11: Analog input sensor (SIM0001) settings, phase voltages

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...440.000	kV	0.001	20.000	Primary rated voltage
Secondary voltage	60...210	V	1	100	Secondary rated voltage
VT connection	1=Wye 2=Delta			2=Delta	Wye, delta, U12 or UL1[1)] VT connection
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A Voltage phasor magnitude correction of an external voltage transformer
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B Voltage phasor magnitude correction of an external voltage transformer
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C Voltage phasor magnitude correction of an external voltage transformer
Division ratio	1000...20000		1	10000	Voltage sensor division ratio
Voltage input type	1=Voltage trafo 3=CVD sensor			3=CVD sensor	Type of the voltage input

1) The U12 and UL1 VT connections are not an option although the tools and documentation mention them

Table 12: Analog input sensor (SIM0002) settings, phase voltages

Parameter	Values (Range)	Unit	Step	Default	Description
Primary voltage	0.100...440.000	kV	0.001	20.000	Primary rated voltage
VT connection	1=Wye			1=Wye	Wye, delta, U12 or UL1[1)] VT connection
Amplitude corr. A	0.900...1.100		0.001	1.000	Phase A Voltage phasor magnitude correction of an external voltage transformer[2)]
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Amplitude corr. B	0.900...1.100		0.001	1.000	Phase B Voltage phasor magnitude correction of an external voltage transformer[2)]
Amplitude corr. C	0.900...1.100		0.001	1.000	Phase C Voltage phasor magnitude correction of an external voltage transformer[2)]
Division ratio	1000...20000		1	10000	Voltage sensor division ratio
Voltage input type	3=CVD sensor			3=CVD sensor	Type of the voltage input

1) The U12 and UL1 VT connections are not an option although the tools and documentation mention them
2) In this case sensor, although the tools and documentation mention VTs

Table 13: Authorization settings

Parameter	Values (Range)	Unit	Step	Default	Description
Local override	0=False 1=True			1=True	Disable authority
Remote override	0=False 1=True			1=True	Disable authority
Local viewer				0	Set password
Local operator				0	Set password
Local engineer				0	Set password
Local administrator				0	Set password
Remote viewer				0	Set password
Remote operator				0	Set password
Remote engineer				0	Set password
Remote administrator				0	Set password
Authority logging	1=None 2=Configuration change 3=Setting group 4=Setting group, control 5=Settings edit 6=All			4=Setting group, control	Authority logging level

Table 14: Binary input settings

Parameter	Values (Range)	Unit	Step	Default	Description
Threshold voltage	18...176	Vdc	2	18	Binary input threshold voltage
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

Table 15: Ethernet front port 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

Table 16: Ethernet rear port settings

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

Table 17: General system 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[1)]				REC615	Bay name in system
IDMT Sat point	10...50	I/I>	1	50	Overcurrent IDMT saturation point

1) Used in the IEC main menu header and as part of the disturbance recording identification

Table 18: HMI settings

Parameter	Values (Range)	Unit	Step	Default	Description
FB naming convention	1=IEC61850 2=IEC60617 3=IEC-ANSI			1=IEC61850	FB naming convention used in IED
Default view	1=Measurements 2=Main menu 3=SLD page 1			1=Measurements	LHMI default view
Backlight timeout	1...60	min	1	3	LHMI backlight timeout
Web HMI mode	1=Active read only 2=Active 3=Disabled			3=Disabled	Web HMI functionality
Web HMI timeout	1...60	min	1	3	Web HMI login timeout
SLD symbol format	1=IEC 2=ANSI			1=IEC	Single Line Diagram symbol format
Autoscroll delay	0...30	s	1	0	Autoscroll delay for Measurements view

Table 19: Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Port 1	0=Not in use 1=IEC101 - COM1 2=IEC101 - COM2 3=IEC104 - Ethernet			0=Not in use	Port selection for instance 1
ClientIP 1				0.0.0.0	IP address of the client
Start Delay 1	0...20	char		4	Frame start delay for serial communication
End Delay 1	0...20	char		4	Frame end delay for serial communication
Device Address 1	1...65535			1	Link address of the instance 1
ASDU Address 1	1...65535			1	ASDU address of the instance 1
Link Mode 1	0=Balanced 1=Unbalanced			0=Balanced	Link mode setting for instance 1
COT Length 1	1...2			1	Cause of transmission length
IOA Length 1	1...3			2	Information Object Address length
Link Address Length 1	1...2			1	Link Address Length
ASDU Address Length 1	1...2			1	ASDU Address Length
Reply Size 1	1...128			1	Maximum Reply Window Size
Single Char Resp 1	0=Disabled 1=Enabled			0=Disabled	Single character response enabled/ disabled
Show Bad Time 1	0=Disabled 1=Enabled			1=Enabled	Enable/disable bad time quality indication in events
Hour Change Msg 1	0=Disabled 1=Enabled			0=Disabled	Enable/disable hour change message
Time Format 1	0=Short 24bit 1=Full 56bit			1=Full 56bit	Time stamp format 3 or 7 octet
Event Time 1	0=Local 1=UTC			1=UTC	Selects between UTC/Local time
Overflow Mode 1	0=Oldest +indication 1=Keep newest			0=Oldest +indication	Event buffer overflow handling mechanism
OvInd IOA 1	0...16777215			60000	Overflow indication address for interrogated data 1
OvInd NoGI IOA 1	0...16777215			60000	Overflow indication address for non-interrogated data 1
Event Order 1	0=Accurate time 1=Preserve chronology			0=Accurate time	Selects the event ordering principle
Selection Timeout 1	1...65	s		30	Selection timeout for control SBO operations
Cyclical Period 1	1...604800	s		10	Cyclical period in seconds
Inverted DIR bit 1	0=Disabled 1=Enabled			0=Disabled	Special mode for masters that require inverted DIR bit on Balanced IEC101 line. If enabled, this protocol instance will be non-compliant with the IEC 60870-5-101 standard.

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Command delay 1	0...65535	ms		5000	Maximum delay for timestamped commands in milliseconds.
TX window (k) 1	1...20			12	IEC60870-5-104 transmit window (k)
RX window (w) 1	1...20			8	IEC60870-5-104 receive window (w)
TX timeout (t1) 1	1...60000	ms		30000	IEC60870-5-104 transmit timeout (t1)
RX timeout (t2) 1	1...60000	ms		10000	IEC60870-5-104 receive timeout (t1)
Test interval (t3) 1	1...60000	ms		20000	IEC60870-5-104 link test interval (t3)
Port 2	0=Not in use 1=IEC101 - COM1 2=IEC101 - COM2 3=IEC104 - Ethernet			0=Not in use	Port selection for instance 2
ClientIP 2				0.0.0.0	IP address of the client
Start Delay 2	0...20	char		4	Frame start delay for serial communication
End Delay 2	0...20	char		4	Frame end delay for serial communication
Device Address 2	1...65535			1	Link address of the instance 2
ASDU Address 2	1...65535			1	ASDU address of the instance 2
Link Mode 2	0=Balanced 1=Unbalanced			0=Balanced	Link mode setting for instance 2
COT Length 2	1...2			1	Cause of transmission length
IOA Length 2	1...3			2	Information Object Address length
Link Address Length 2	1...2			1	Link Address Length
ASDU Address Length 2	1...2			1	ASDU Address Length
Reply Size 2	1...128			1	Maximum Reply Window Size
Single Char Resp 2	0=Disabled 1=Enabled			0=Disabled	Single character response enabled/ disabled
Show Bad Time 2	0=Disabled 1=Enabled			1=Enabled	Enable/disable bad time quality indication in events
Hour Change Msg 2	0=Disabled 1=Enabled			0=Disabled	Enable/disable hour change message
Time Format 2	0=Short 24bit 1=Full 56bit			1=Full 56bit	Time stamp format 3 or 7 octet
Event Time 2	0=Local 1=UTC			1=UTC	Selects between UTC/Local time
Overflow Mode 2	0=Oldest +indication 1=Keep newest			0=Oldest +indication	Event buffer overflow handling mechanism
OvInd IOA 2	0...16777215			60000	Overflow indication address for interrogated data 2
OvInd NoGI IOA 2	0...16777215			60000	Overflow indication address for non-interrogated data 2
Event Order 2	0=Accurate time 1=Preserve chronology			0=Accurate time	Selects the event ordering principle
Selection Timeout 2	1...65	s		30	Selection timeout for control SBO operations

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Cyclical Period 2	1...604800	s		10	Cyclical period in seconds
Inverted DIR bit 2	0=Disabled 1=Enabled			0=Disabled	Special mode for masters that require inverted DIR bit on Balanced IEC101 line. If enabled, this protocol instance will be non-compliant with the IEC 60870-5-101 standard.
Command delay 2	0...65535	ms		5000	Maximum delay for timestamped commands in milliseconds.
TX window (k) 2	1...20			12	IEC60870-5-104 transmit window (k)
RX window (w) 2	1...20			8	IEC60870-5-104 receive window (w)
TX timeout (t1) 2	1...60000	ms		30000	IEC60870-5-104 transmit timeout (t1)
RX timeout (t2) 2	1...60000	ms		10000	IEC60870-5-104 receive timeout (t1)
Test interval (t3) 2	1...60000	ms		20000	IEC60870-5-104 link test interval (t3)

Table 20: IEC 61850-8-1 MMS 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

Table 21: Modbus settings

Parameter	Values (Range)	Unit	Step	Default	Description
Serial port 1	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for Serial interface 1
Parity 1	0=none 1=odd 2=even			2=even	Parity for Serial interface 1
Address 1	1...255			1	Modbus unit address on Serial interface 1
Link mode 1	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 1
Start delay 1	0...20	char		4	Start frame delay in chars on Serial interface 1
End delay 1	0...20	char		3	End frame delay in chars on Serial interface 1
Serial port 2	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for Serial interface 2
Parity 2	0=none 1=odd 2=even			2=even	Parity for Serial interface 2
Address 2	1...255			2	Modbus unit address on Serial interface 2
Link mode 2	1=RTU 2=ASCII			1=RTU	Modbus link mode on Serial interface 2
Start delay 2	0...20			4	Start frame delay in chars on Serial interface 2

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
End delay 2	0...20			3	End frame delay in chars on Serial interface 2
MaxTCPClients	0...5			5	Maximum number of Modbus TCP/IP clients
TCPWriteAuthority	0=No clients 1=Reg. clients 2=All clients			2=All clients	Write authority setting for Modbus TCP/IP clients
EventID	0=Address 1=UID			0=Address	Event ID selection
TimeFormat	0=UTC 1=Local			1=Local	Time format for Modbus time stamps
ClientIP1				000.000.000.000	Modbus Registered Client 1
ClientIP2				000.000.000.000	Modbus Registered Client 2
ClientIP3				000.000.000.000	Modbus Registered Client 3
ClientIP4				000.000.000.000	Modbus Registered Client 4
ClientIP5				000.000.000.000	Modbus Registered Client 5
CtlStructPWd1				****	Password for Modbus control struct 1
CtlStructPWd2				****	Password for Modbus control struct 2
CtlStructPWd3				****	Password for Modbus control struct 3
CtlStructPWd4				****	Password for Modbus control struct 4
CtlStructPWd5				****	Password for Modbus control struct 5
CtlStructPWd6				****	Password for Modbus control struct 6
CtlStructPWd7				****	Password for Modbus control struct 7
CtlStructPWd8				****	Password for Modbus control struct 8

Table 22: DNP3 settings

Parameter	Values (Range)	Unit	Step	Default	Description
DNP physical layer	1=Serial 2=TCP/IP			2=TCP/IP	DNP physical layer
Unit address	1...65519		1	1	DNP unit address
Master address	1...65519		1	3	DNP master and UR address
Serial port	0=Not in use 1=COM 1 2=COM 2			0=Not in use	COM port for serial interface, when physical layer is serial.
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	sec	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

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
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 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 TO	0...65535	ms	1	5000	Unsolicited response timeout
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
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...2		1	1	1=BI; 2=BI with status.
Default Var Obj 02	1...2		1	2	1=BI event; 2=BI event with time.
Default Var Obj 30	1...4		1	2	1=32 bit AI; 2=16 bit AI; 3=32 bit AI without flag; 4=16 bit AI without flag.
Default Var Obj 32	1...4		1	4	1=32 bit AI event; 2=16 bit AI event; 3=32 bit AI event with time; 4=16 bit AI event with time.

Table 23: COM1 serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 2=Fiber optic			0=No fiber	Fiber mode for COM1
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake 4=RS232 with handshake			1=RS485 2Wire	Serial mode for COM1
CTS delay	0...60000			0	CTS delay for COM1
RTS delay	0...60000			0	RTS delay for COM1
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM1

Table 24: COM2 serial communication settings

Parameter	Values (Range)	Unit	Step	Default	Description
Fiber mode	0=No fiber 2=Fiber optic			0=No fiber	Fiber mode for COM2
Serial mode	1=RS485 2Wire 2=RS485 4Wire 3=RS232 no handshake 4=RS232 with handshake			1=RS485 2Wire	Serial mode for COM2
CTS delay	0...60000			0	CTS delay for COM2
RTS delay	0...60000			0	RTS delay for COM2
Baudrate	1=300 2=600 3=1200 4=2400 5=4800 6=9600 7=19200 8=38400 9=57600 10=115200			6=9600	Baudrate for COM2

Table 25: Time settings

Parameter	Values (Range)	Unit	Step	Default	Description
Date				0	Date
Time				0	Time
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
Local time offset	-840...840	min		0	Local time offset in minutes
Synch source	0=None 1=SNTP 2=Modbus 5=IRIG-B 9=DNP 16=IEC60870-5-101 18=IEC60870-5-104			1=SNTP	Time synchronization source
IP SNTP primary				10.58.125.165	IP address for SNTP primary server
IP SNTP secondary				192.168.2.165	IP address for SNTP secondary server
DST on time				02:00	Daylight savings time on, time (hh:mm)
DST on date				01.05.	Daylight savings time on, date (dd:mm)
DST on day	0=Not in use 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			0=Not in use	Daylight savings time on, day of week
DST offset	-720...720	min		60	Daylight savings time offset, in minutes
DST off time				02:00	Daylight savings time off, time (hh:mm)
DST off date				25.09.	Daylight savings time off, date (dd:mm)
DST off day	0=Not in use 1=Mon 2=Tue 3=Wed 4=Thu 5=Fri 6=Sat 7=Sun			0=Not in use	Daylight savings time off, day of week

Table 26: Binary input signals in card location Xnnn

Name	Type	Description
Xnnn-Input m [1)]	BOOLEAN	See the application engineering guide for terminal connections

1) Xnnn = Slot ID, for example, X100, X110, as applicable

Table 27: Binary output signals in card location Xnnn

Name	Type	Default	Description
Xnnn-Pmm[1)2)]	BOOLEAN	0=False	See the application engineering guide for terminal connections

1) Xnnn = Slot ID, for example, X100, X110, as applicable
2) Pmm = For example, PO1, PO2, SO1, SO2, as applicable

Table 28: Binary input settings in card location Xnnn

Name [1)]	Value	Unit	Step	Default
Input m filter time	5…1000	ms		5
Input m inversion	0= False 1= True			0=False

1) Xnnn = Slot ID, for example, X100, X110, as applicable

3.2 Self-supervision

The IED's extensive self-supervision system continuously supervises the software and the electronics. It handles run-time fault situation and informs the user about a fault via the LHMI and through the communications channels.

There are two types of fault indications.

- Internal faults
- Warnings

3.2.1 Internal faults

When an IED internal fault is detected, IED protection operation is disabled, the green Ready LED begins to flash and the self-supervision output contact is activated.

Internal fault indications have the highest priority on the LHMI. None of the other LHMI indications can override the internal fault indication.

An indication about the fault is shown as a message on the LHMI. The text `Internal Fault` with an additional text message, a code, date and time, is shown to indicate the fault type.

Different actions are taken depending on the severity of the fault. The IED tries to eliminate the fault by restarting. After the fault is found to be permanent, the IED stays in the internal fault mode. All other output contacts are released and locked for the internal fault. The IED continues to perform internal tests during the fault situation.

If an internal fault disappears, the green Ready LED stops flashing and the IED returns to the normal service state. The fault indication message remains on the display until manually cleared.

The self-supervision signal output operates on the closed circuit principle. Under normal conditions the relay is energized and the contact gap 3-5 in slot X100 is closed. If the auxiliary power supply fail or an internal fault is detected, the contact gap 3-5 is opened.

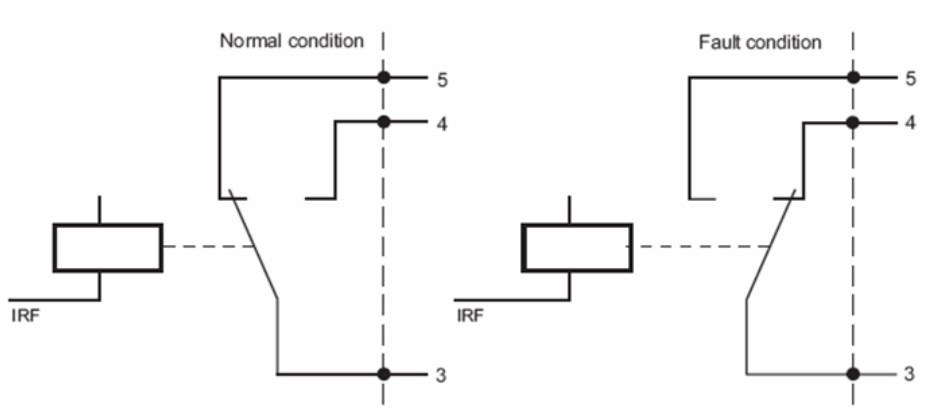


Figure 7: Output contact

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

Table 29: Internal fault indications and codes

Fault indication	Fault code	Additional information
Internal Fault System error	2	An internal system error has occurred.
Internal Fault File system error	7	A file system error has occurred.
Internal Fault Test	8	Internal fault test activated manually by the user.
Internal Fault SW watchdog error	10	Watchdog reset has occurred too many times within an hour.
Internal Fault SO-relay(s),X100	43	Faulty Signal Output relay(s) in card located in slot X100.
Internal Fault SO-relay(s),X110	44	Faulty Signal Output relay(s) in card located in slot X110.
Internal Fault SO-relay(s),X130	46	Faulty Signal Output relay(s) in card located in slot X130.
Internal Fault PO-relay(s),X100	53	Faulty Power Output relay(s) in card located in slot X100.
Internal Fault Conf. error,X000	62	Card in slot X000 is wrong type.
Internal Fault Conf. error,X100	63	Card in slot X100 is wrong type or does not belong to the original composition.

Table continues on next page

Fault indication	Fault code	Additional information
Internal Fault Conf. error,X110	64	Card in slot X110 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf. error,X120	65	Card in slot X120 is wrong type, is missing or does not belong to the original composition.
Internal Fault Conf.error,X130	66	Card in slot X130 is wrong type, is missing or does not belong to the original composition.
Internal Fault Card error,X000	72	Card in slot X000 is faulty.
Internal Fault Card error,X100	73	Card in slot X100 is faulty.
Internal Fault Card error,X110	74	Card in slot X110 is faulty.
Internal Fault Card error,X120	75	Card in slot X120 is faulty.
Internal Fault Card error,X130	76	Card in slot X130 is faulty.
Internal Fault LHMI module	79	LHMI module is faulty. The fault indication may not be seen on the LHMI during the fault.
Internal Fault RAM error	80	Error in the RAM memory on the CPU card.
Internal Fault ROM error	81	Error in the ROM memory on the CPU card.
Internal Fault EEPROM error	82	Error in the EEPROM memory on the CPU card.
Internal Fault FPGA error	83	Error in the FPGA on the CPU card.
Internal Fault RTC error	84	Error in the RTC on the CPU card.

For further information on internal fault indications, see the operation manual.

3.2.2 Warnings

In case of a warning, the IED continues to operate except for those protection functions possibly affected by the fault, and the green Ready LED remains lit as during normal operation.

Warnings are indicated with the text `Warning` and the name of the warning, a numeric code and the date and time on the LHMI. The warning indication message can be manually cleared.

If a warning appears, record the name and code so that it can be provided to ABB customer service.

Table 30: Warning indications and codes

Warning indication	Warning code	Additional information
Warning Watchdog reset	10	A watchdog reset has occurred.
Warning Power down det.	11	The auxiliary supply voltage has dropped too low.
Warning IEC61850 error	20	Error when building the IEC 61850 data model.
Warning Modbus error	21	Error in the Modbus communication.
Warning DNP3 error	22	Error in the DNP3 communication.
Warning Dataset error	24	Error in the Data set(s).
Warning Report cont. error	25	Error in the Report control block(s).
Warning GOOSE contr. error	26	Error in the GOOSE control block(s).
Warning SCL config error	27	Error in the SCL configuration file or the file is missing.
Warning Logic error	28	Too many connections in the configuration.
Warning SMT logic error	29	Error in the SMT connections.
Warning GOOSE input error	30	Error in the GOOSE connections.
ACT error	31	Error in the ACT connections.
Warning GOOSE Rx. error	32	Error in the GOOSE message receiving.
Warning AFL error	33	Analog channel configuration error.
Warning Unack card comp.	40	A new composition has not been acknowledged/accepted.

For further information on warning indications, see the operation manual.

3.3 Programmable LEDs

3.3.1 Function block

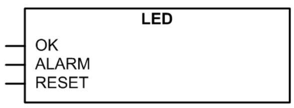


Figure 8: Function block

3.3.2 Functionality

The programmable LEDs reside on the right side of the display on the LHMI.

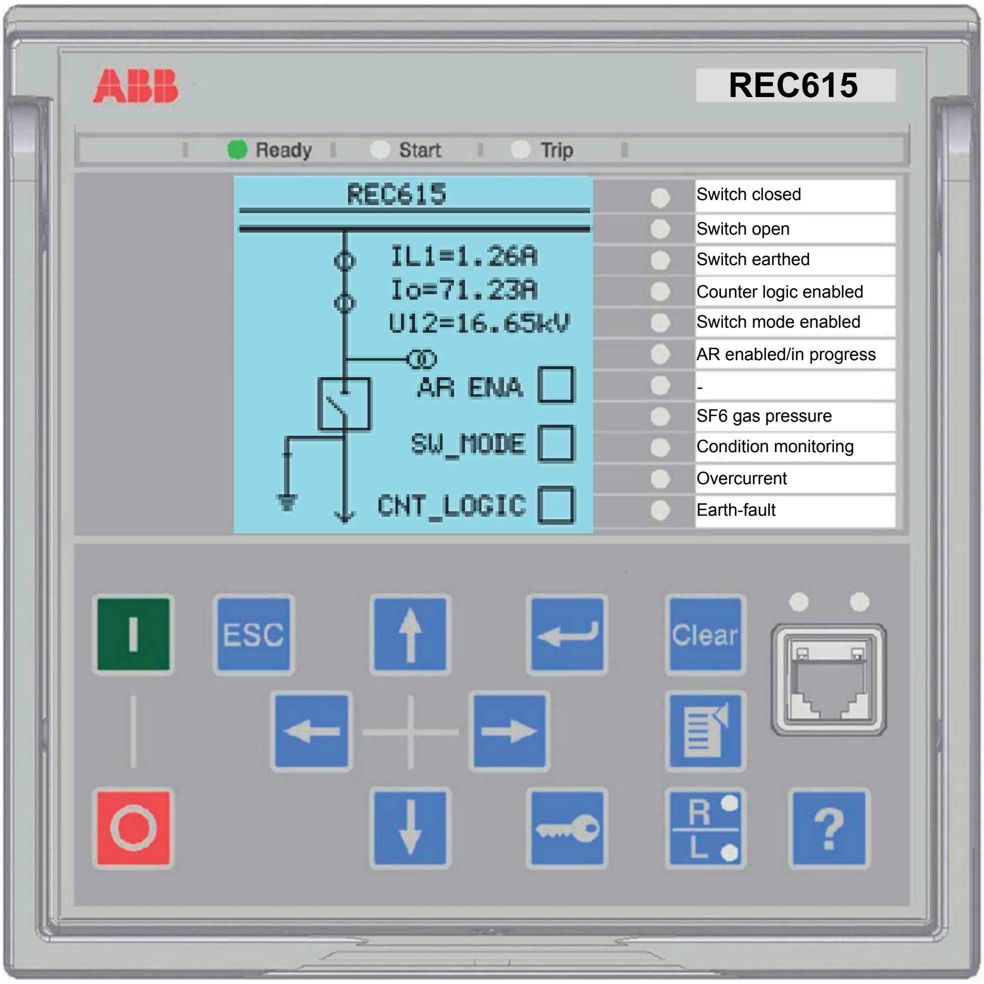


Figure 9: Programmable LEDs on the right side of the display

All the programmable LEDs in the HMI of the IED 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 color* 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* color setting to "Green" changes the color behavior of the `OK` inputs to red.

The `ALARM` input has a higher priority than the `OK` input.

Each LED is seen in the Application Configuration tool as an individual function block. Each LED has 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 under the **Clear** menu.

The menu structure for the programmable LEDs is presented in Figure 10. 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.

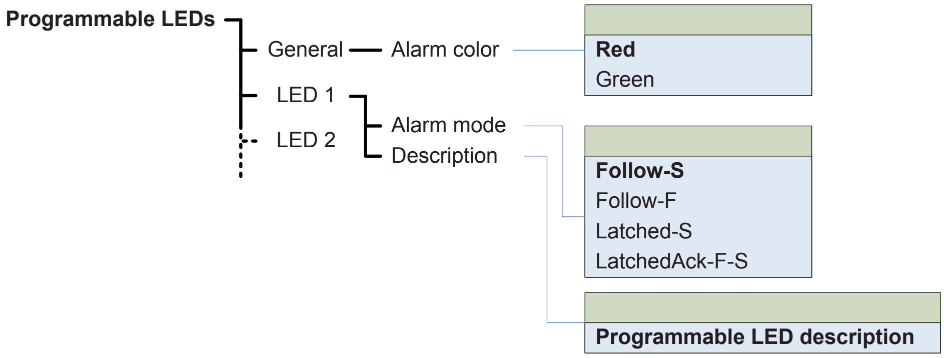


Figure 10: Menu structure

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.

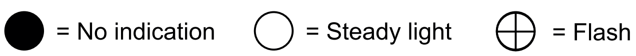


Figure 11: Symbols used in the sequence diagrams

"Follow-S": Follow Signal, ON

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

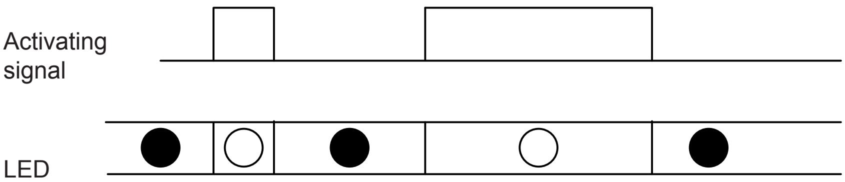


Figure 12: Operating sequence "Follow-S"

"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, the alarm disappears.

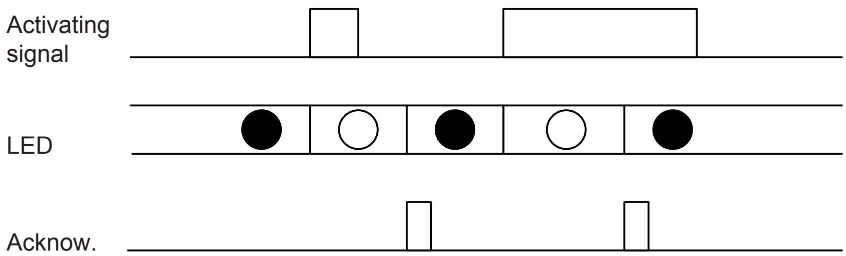


Figure 13: Operating sequence "Latched-S"

"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.

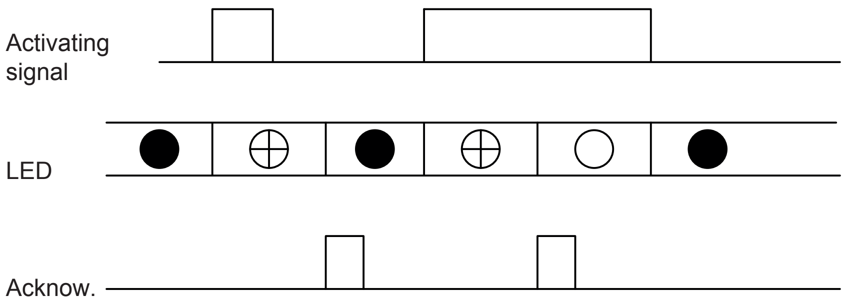


Figure 14: Operating sequence "LatchedAck-F-S"

3.3.3 Signals

Table 31: Input signals

Name	Type	Default	Description
OK	BOOLEAN	0=False	Ok input for LED 1
ALARM	BOOLEAN	0=False	Alarm input for LED 1
RESET	BOOLEAN	0=False	Reset input for LED 1
OK	BOOLEAN	0=False	Ok input for LED 2
ALARM	BOOLEAN	0=False	Alarm input for LED 2
RESET	BOOLEAN	0=False	Reset input for LED 2
OK	BOOLEAN	0=False	Ok input for LED 3
ALARM	BOOLEAN	0=False	Alarm input for LED 3
RESET	BOOLEAN	0=False	Reset input for LED 3
OK	BOOLEAN	0=False	Ok input for LED 4
ALARM	BOOLEAN	0=False	Alarm input for LED 4
RESET	BOOLEAN	0=False	Reset input for LED 4
OK	BOOLEAN	0=False	Ok input for LED 5
ALARM	BOOLEAN	0=False	Alarm input for LED 5
RESET	BOOLEAN	0=False	Reset input for LED 5
OK	BOOLEAN	0=False	Ok input for LED 6
ALARM	BOOLEAN	0=False	Alarm input for LED 6
RESET	BOOLEAN	0=False	Reset input for LED 6
OK	BOOLEAN	0=False	Ok input for LED 7
ALARM	BOOLEAN	0=False	Alarm input for LED 7
RESET	BOOLEAN	0=False	Reset input for LED 7
OK	BOOLEAN	0=False	Ok input for LED 8
ALARM	BOOLEAN	0=False	Alarm input for LED 8
RESET	BOOLEAN	0=False	Reset input for LED 8
OK	BOOLEAN	0=False	Ok input for LED 9
ALARM	BOOLEAN	0=False	Alarm input for LED 9
RESET	BOOLEAN	0=False	Reset input for LED 9
OK	BOOLEAN	0=False	Ok input for LED 10
ALARM	BOOLEAN	0=False	Alarm input for LED 10
RESET	BOOLEAN	0=False	Reset input for LED 10
OK	BOOLEAN	0=False	Ok input for LED 11
ALARM	BOOLEAN	0=False	Alarm input for LED 11
RESET	BOOLEAN	0=False	Reset input for LED 11

3.3.4 Settings

Table 32: Non group settings

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 programmable LED 1
Description				Programmable LEDs LED 1	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 2
Description				Programmable LEDs LED 2	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 3
Description				Programmable LEDs LED 3	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 4
Description				Programmable LEDs LED 4	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 5
Description				Programmable LEDs LED 5	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 6
Description				Programmable LEDs LED 6	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 7
Description				Programmable LEDs LED 7	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 8

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Description				Programmable LEDs LED 8	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 9
Description				Programmable LEDs LED 9	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 10
Description				Programmable LEDs LED 10	Programmable LED description
Alarm mode	0=Follow-S 1=Follow-F 2=Latched-S 3=LatchedAck-F-S			0=Follow-S	Alarm mode for programmable LED 11
Description				Programmable LEDs LED 11	Programmable LED description

3.3.5 Monitored data

Table 33: Monitored data

Name	Type	Values (Range)	Unit	Description
Programmable LED 1	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 1
Programmable LED 2	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 2
Programmable LED 3	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 3
Programmable LED 4	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 4
Programmable LED 5	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 5
Programmable LED 6	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 6
Programmable LED 7	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 7
Programmable LED 8	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 8

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Programmable LED 9	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 9
Programmable LED 10	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 10
Programmable LED 11	Enum	0=None 1=Ok 3=Alarm		Status of programmable LED 11

3.4 LED indication control

3.4.1 Function block

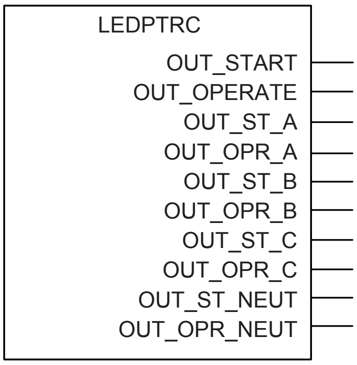


Figure 15: Function block

3.4.2 Functionality

The IED includes a global conditioning function LEDPTRC that is used with the protection indication LEDs.

LED indication control should never be used for tripping purposes. There is a separate trip logic function TRPPTRC available in the IED 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 always internally connected to Start and Trip LEDs. 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 IED configuration (available as output signals `OUT_ST_NEUT` and `OUT_OPR_NEUT`).

3.5 Time synchronization

The IED has an internal real-time clock which can be either free-running or synchronized from an external source. The real-time clock is used for time stamping events, recorded data and disturbance recordings.

The IED is provided with a 48-hour capacitor back-up that enables the real-time clock to keep time in case of an auxiliary power failure.

Setting *Synch Source* determines the method how the real-time clock is synchronized. If set to “None”, the clock is free-running and the settings *Date* and *Time* can be used to set the time manually. Other setting values activate a communication protocol that provides the time synchronization. Only one synchronization method can be active at a time but SNTP provides time master redundancy.

The IED supports SNTP, IRIG-B, DNP3, Modbus and IEC 60870-5-101/104 to update the real-time clock. IRIG-B with GPS provides the best accuracy, ±1 ms. The accuracy using SNTP is +2...3 ms.

When Modbus TCP or DNP3 over TCP/IP is used, SNTP or IRIG-B time synchronization should be used for better synchronization accuracy.

When the SNTP server IP setting is changed, the IED must be rebooted to activate the new IP address. The SNTP server IP settings are normally defined in the engineering phase via the SCL file.

With the legacy protocols, the synchronization message must be received within four minutes from the previous synchronization. Otherwise bad synchronisation status is raised for the IED. With SNTP, it is required that the SNTP server responds to a request within 12 ms, otherwise the response is considered invalid.

The IED 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. While using the secondary SNTP server, the IED tries to switch back to the primary server on every third SNTP request attempt. If both the SNTP servers are offline, event time stamps have the time invalid status. The time is requested from the SNTP server every 60 seconds.

IRIG-B time synchronization requires the IRIG-B format B004/B005 according to the 200-04 IRIG-B standard. Older IRIG-B standards refer to these as B000/B001 with IEEE-1344 extensions. The synchronization time can be either UTC time or local time. As no reboot is necessary, the time synchronization starts immediately after the IRIG-B sync source is selected and the IRIG-B signal source is connected.

ABB has tested the IRIG-B with the following clock masters:

- Tekron TTM01 GPS clock with IRIG-B output
- Meinberg TCG511 controlled by GPS167
- Datum ET6000L
- Arbiter Systems 1088B

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

3.6 Parameter setting groups

3.6.1 Function block

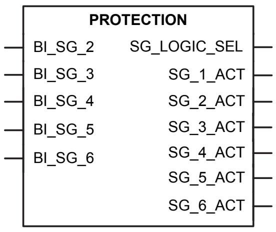


Figure 16: Function block

3.6.2 Functionality

The IED 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 34: 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.

The setting group (SG) is changed whenever switching the *SG operation mode* setting from "Operator" to either "Logic mode 1" or "Logic mode 2." Thus, it is recommended to select the preferred operation mode at the time of installation and commissioning and not change it throughout the IED's service. Changing the *SG operation mode* setting from "Logic mode 1" to "Logic mode 2" or from "Logic mode 2" to "Logic mode 1" does not affect the setting group (SG).

For example, six setting groups can be controlled with three binary inputs. The *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 35: 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 36: 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

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

3.7 Fault records

The IED has the capacity to store the records of 128 latest fault events. Fault records include fundamental or RMS current values. The records enable the user to analyze recent power system events. Each fault record (FLTMSTA) 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 and ends if any protection function 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.

Start duration that has the value of 100% indicates that a protection function has operated during the fault and if none of the protection functions has been operated, Start duration shows always values less than 100%.

The Fault recorded data Protection and Start duration is 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.

If some functions in 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. In case frequency cannot be measured, nominal frequency is used for frequency and zero for Frequency gradient and validity is set accordingly.

Measuring mode for phase current and residual current values can be selected with the *Measurement mode* setting parameter.

Table 37: FLTMSTA Non group settings

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
A measurement mode	1=RMS 2=DFT 3=Peak-to-Peak			2=DFT	Selects used measurement mode phase currents and residual current

Table 38: FLTMSTA 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	Enum	0=Unknown 1=PHLPTOC1 6=PHHPTOC1 12=PHIPTOC1 17=EFLPTOC1 22=EFHPTOC1 30=EFIPTOC1 35=NSPTOC1 36=NSPTOC2 41=PDNSPTOC1 44=T1PTTR1 50=DEFLPDEF1 51=DEFLPDEF2 53=DEFHPDEF1 56=EFPADM1 57=EFPADM2 58=EFPADM3 59=FRPFRQ1 60=FRPFRQ2 65=LSHDPFRQ1 71=DPHLPDOC1 72=DPHLPDOC2 74=DPHHPDOC1 77=MAPGAPC1 78=MAPGAPC2 79=MAPGAPC3 100=ROVPTOV1 101=ROVPTOV2 104=PHPTOV1 105=PHPTOV2 106=PHPTOV3 108=PHPTUV1 109=PHPTUV2 110=PHPTUV3 112=NSPTOV1 116=PSPTUV1 117=PSPTUV2 -37=HAEFPTOC1 -35=WPWDE3 -34=WPWDE2 -33=WPWDE1 80=MAPGAPC4 81=MAPGAPC5 82=MAPGAPC6		Protection function
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...999999.999	s	Breaker clear time
Active group	INT32	1...6		Active setting group
Shot pointer	INT32	0...7		Autoreclosing shot pointer value
Max current IL1	FLOAT32	0.000...50.000	xIn	Maximum phase A current

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Max current IL2	FLOAT32	0.000...50.000	xIn	Maximum phase B current
Max current IL3	FLOAT32	0.000...50.000	xIn	Maximum phase C current
Max current Io	FLOAT32	0.000...50.000	xIn	Maximum residual current
Current IL1	FLOAT32	0.000...50.000	xIn	Phase A current
Current IL2	FLOAT32	0.000...50.000	xIn	Phase B current
Current IL3	FLOAT32	0.000...50.000	xIn	Phase C current
Current Io	FLOAT32	0.000...50.000	xIn	Residual current
Current Io-Calc	FLOAT32	0.000...50.000	xIn	Calculated residual current
Current Ps-Seq	FLOAT32	0.000...50.000	xIn	Positive sequence current
Current Ng-Seq	FLOAT32	0.000...50.000	xIn	Negative sequence current
Voltage UL1	FLOAT32	0.000...4.000	xUn	Phase A voltage
Voltage UL2	FLOAT32	0.000...4.000	xUn	Phase B voltage
Voltage UL3	FLOAT32	0.000...4.000	xUn	Phase C voltage
Voltage U12	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage
Voltage U23	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage
Voltage U31	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage
Voltage Uo	FLOAT32	0.000...4.000	xUn	Residual voltage
Voltage Zro-Seq	FLOAT32	0.000...4.000	xUn	Zero sequence voltage
Voltage Ps-Seq	FLOAT32	0.000...4.000	xUn	Positive sequence voltage
Voltage Ng-Seq	FLOAT32	0.000...4.000	xUn	Negative sequence voltage
Voltage UL1B	FLOAT32	0.000...4.000	xUn	Phase A voltage (b)
Voltage UL2B	FLOAT32	0.000...4.000	xUn	Phase B voltage (b)
Voltage UL3B	FLOAT32	0.000...4.000	xUn	Phase B voltage (b)
Voltage U12B	FLOAT32	0.000...4.000	xUn	Phase A to phase B voltage (b)
Voltage U23B	FLOAT32	0.000...4.000	xUn	Phase B to phase C voltage (b)
Voltage U31B	FLOAT32	0.000...4.000	xUn	Phase C to phase A voltage (b)
Voltage UoB	FLOAT32	0.000...4.000	xUn	Residual voltage (b)
Voltage Zro-SeqB	FLOAT32	0.000...4.000	xUn	Zero sequence voltage (b)
Voltage Ps-SeqB	FLOAT32	0.000...4.000	xUn	Positive sequence voltage (b)

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Voltage Ng-SeqB	FLOAT32	0.000...4.000	xUn	Negative sequence voltage (b)
PTTR thermal level	FLOAT32	0.00...99.99		PTTR calculated temperature of the protected object relative to the operate level
PDNSPTOC1 rat. I2/I1	FLOAT32	0.00...999.99	%	PDNSPTOC1 ratio I2/I1
Frequency	FLOAT32	30.00...80.00	Hz	Frequency
Frequency gradient	FLOAT32	-10.00...10.00	Hz/s	Frequency gradient
Conductance Yo	FLOAT32	-1000.00...1000.00	mS	Conductance Yo
Susceptance Yo	FLOAT32	-1000.00...1000.00	mS	Susceptance Yo
Angle Uo - Io	FLOAT32	-180.00...180.00	deg	Angle residual voltage - residual current
Angle U23 - IL1	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage - phase A current
Angle U31 - IL2	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage - phase B current
Angle U12 - IL3	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage - phase C current
Angle UoB - IoB	FLOAT32	-180.00...180.00	deg	Angle residual voltage - residual current (b)
Angle U23B - IL1B	FLOAT32	-180.00...180.00	deg	Angle phase B to phase C voltage - phase A current (b)
Angle U31B - IL2B	FLOAT32	-180.00...180.00	deg	Angle phase C to phase A voltage - phase B current (b)
Angle U12B - IL3B	FLOAT32	-180.00...180.00	deg	Angle phase A to phase B voltage - phase C current (b)

3.8 Non-volatile memory

In addition to the setting values, the IED can store some data in the non-volatile memory.

- Up to 1024 events are stored. The stored events are visible in LHMI, WHMI and Event viewer tool in PCM600.
- Recorded data
    - Fault records (up to 128)
    - Maximum demands
- Circuit breaker condition monitoring

- Latched alarm and trip LEDs' status
- Trip circuit lockout
- Counter values

3.9 Binary input

3.9.1 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 IED.

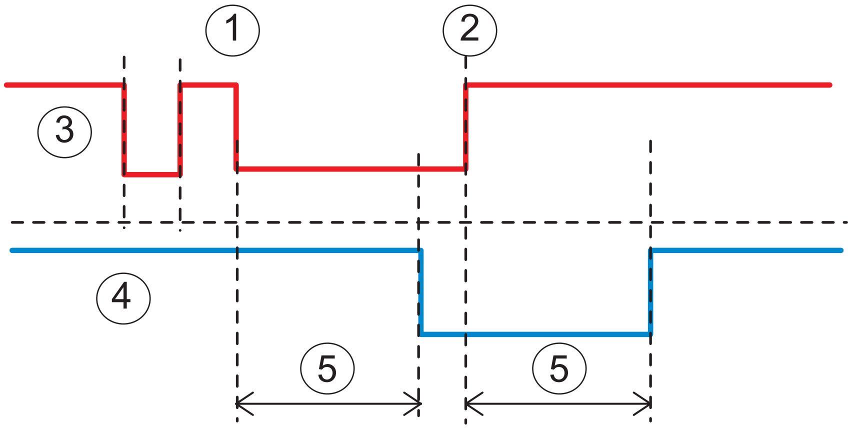


Figure 17: Binary input filtering

1 t_0

2 t_1

3 Input signal

4 Filtered input signal

5 Filter time

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 39: Input filter parameter values

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

3.9.2 Binary input inversion

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

Table 40: Binary input states

Control voltage	Input # invert	State of binary input
No	0	False (0)
Yes	0	True (1)
No	1	True (0)
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.

3.9.3 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 41: Oscillation parameter values

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

3.10 Binary outputs

The IED 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 IED 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 IED 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 IED for breaker failure protection function.

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

3.10.1 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.

3.10.1.1 Dual single-pole power outputs PO1 and PO2

Dual (series-connected) single-pole (normally open/form A) power output contacts PO1 and PO2 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 slot X100 of the power supply module.

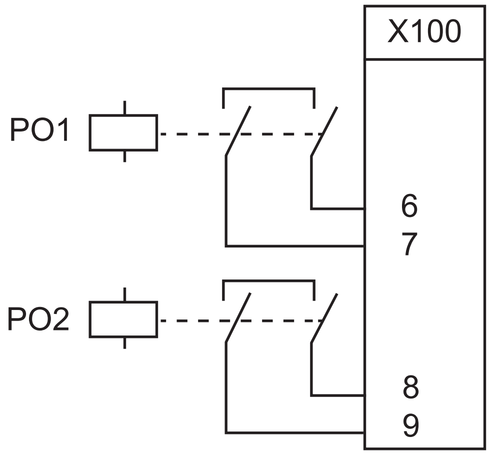


Figure 18: Dual single-pole power output contacts PO1 and PO2

3.10.1.2 Double-pole power outputs PO3 and PO4 with trip circuit supervision

The power outputs PO3 and PO4 are double-pole normally open/form A power outputs with trip circuit supervision.

When the two poles of the contacts are connected in series, they have the same technical specification as PO1 for breaking duty. The trip circuit supervision hardware and associated functionality which can supervise the breaker coil both during closing and opening condition are also provided. Contacts PO3 and PO4 are almost always used for energizing the breaker trip coils.

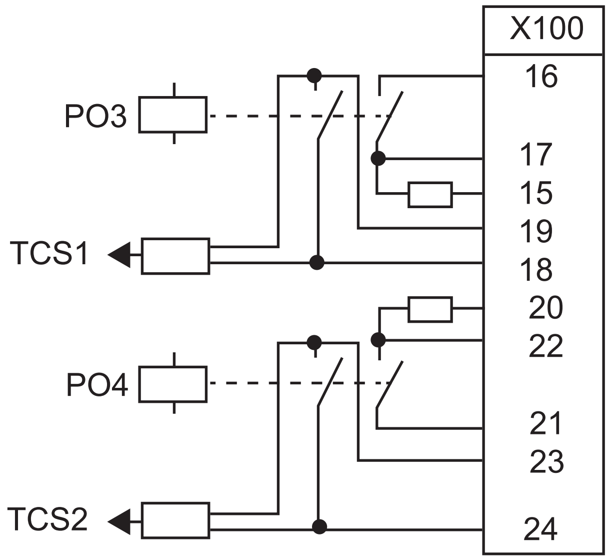


Figure 19: Double-pole power outputs PO3 and PO4 with trip circuit supervision

Power outputs PO3 and PO4 are included in the power supply module located in slot X100 of the IED.

3.10.2 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.

3.10.2.1 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 IED.

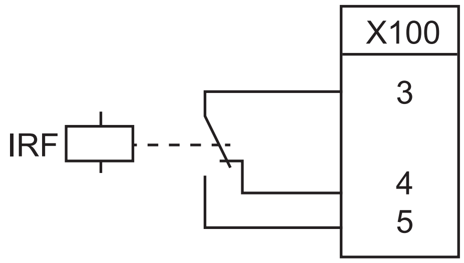


Figure 20: Internal fault signal output IRF

3.10.2.2 Signal outputs SO1 and SO2 in power supply module

Signal outputs (normally open/form A or change-over/form C) SO1 (dual parallel form C) and SO2 (single contact/form A) are part of the power supply module of the IED.

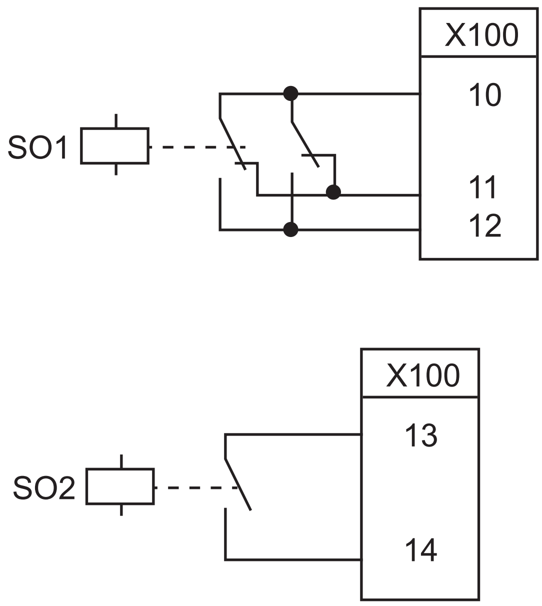


Figure 21: Signal outputs SO1 and SO2 in power supply module

3.10.2.3 Signal outputs SO1, SO2, SO3 and SO4 in BIO0005

The optional card BIO0005 provides the signal outputs SO1, SO2 SO3 and SO4. Signal outputs SO1 and SO2 are dual, parallel form C contacts; SO3 is a single form C contact, and SO4 is a single form A contact.

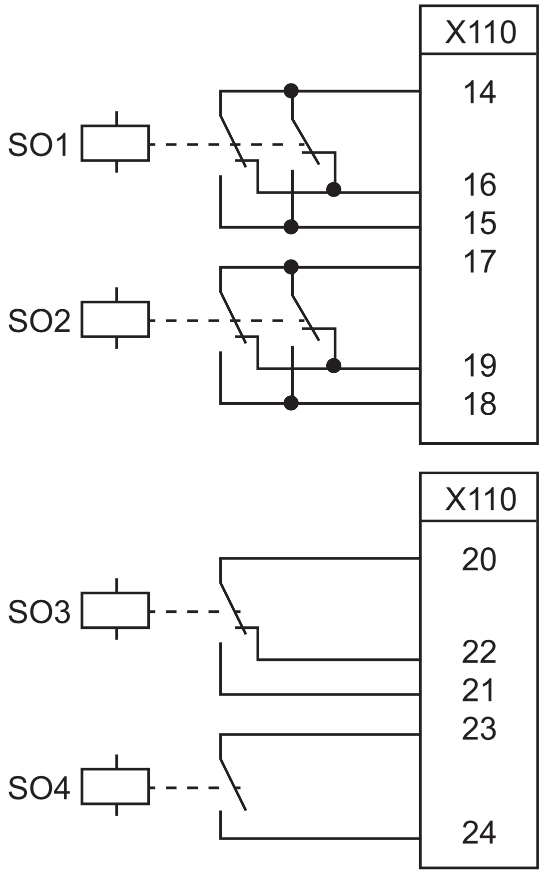


Figure 22: Signal output in BIO0005

3.10.2.4 Signal outputs SO1, SO2 and SO3 in BIO0006

BIO0006 module is provided with signal outputs SO1, SO2 (dual parallel/form C) and SO3 (single/form C contact).

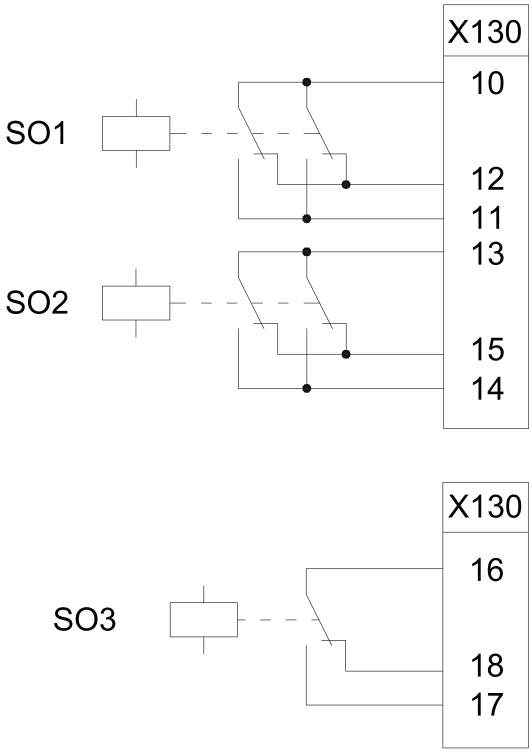


Figure 23: Signal outputs in BIO0006

3.11 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.

3.11.1 GOOSERCV_BIN function block

3.11.1.1 Function block

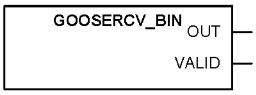


Figure 24: Function block

3.11.1.2 Functionality

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

3.11.1.3 Signals

Table 42: GOOSERCV_BIN Input signals

Name	Type	Default	Description
IN	BOOLEAN	0	Input signal

Table 43: GOOSERCV_BIN Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal
VALID	BOOLEAN	Output signal

3.11.2 GOOSERCV_DP function block

3.11.2.1 Function block

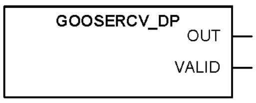


Figure 25: Function block

3.11.2.2 Functionality

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

3.11.2.3 Signals

Table 44: GOOSERCV_DP Input signals

Name	Type	Default	Description
IN	Dbpos	00	Input signal

Table 45: GOOSERCV_DP Output signals

Name	Type	Description
OUT	Dbpos	Output signal
VALID	BOOLEAN	Output signal

3.11.3 GOOSERCV_MV function block

3.11.3.1 Function block

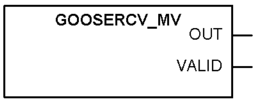


Figure 26: Function block

3.11.3.2 Functionality

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

3.11.3.3 Signals

Table 46: GOOSERCV_MV Input signals

Name	Type	Default	Description
IN	FLOAT32	0	Input signal

Table 47: GOOSERCV_MV Output signals

Name	Type	Description
OUT	FLOAT32	Output signal
VALID	BOOLEAN	Output signal

3.11.4 GOOSERCV_INT8 function block

3.11.4.1 Function block

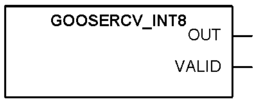


Figure 27: Function block

3.11.4.2 Functionality

The GOOSERCV_INT8 function is used to connect the GOOSE 8 bit integer inputs to the application.

3.11.4.3 Signals

Table 48: GOOSERCV_INT8 Input signals

Name	Type	Default	Description
IN	INT8	0	Input signal

Table 49: GOOSERCV_INT8 Output signals

Name	Type	Description
OUT	INT8	Output signal
VALID	BOOLEAN	Output signal

3.11.5 GOOSERCV_INTL function block

3.11.5.1 Function block

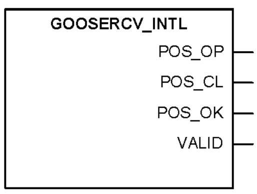


Figure 28: Function block

3.11.5.2 Functionality

The GOOSERCV_INTL function 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.

3.11.5.3 Signals

Table 50: GOOSERCV_INTL Input signals

Name	Type	Default	Description
IN	Dbpos	00	Input signal

Table 51: 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

3.11.6 GOOSERCV_CMV function block

3.11.6.1 Function block

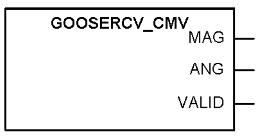


Figure 29: Function block

3.11.6.2 Functionality

The GOOSERCV_CMV function 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) value for the application. Default value (0) is used if VALID output indicates invalid status.

The ANG output passes the received GOOSE (angle) value for the application. Default value (0) is used if VALID output indicates invalid status.

3.11.6.3 Signals

Table 52: GOOSERCV_CMV Input signals

Name	Type	Default	Description
MAG_IN	FLOAT32	0	Input signal (amplitude)
ANG_IN	FLOAT32	0	Input signal (angle)

Table 53: GOOSERCV_CMV Output signals

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

3.11.7 GOOSERCV_ENUM function block

3.11.7.1 Function block

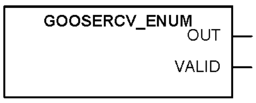


Figure 30: Function block

3.11.7.2 Functionality

The GOOSERCV_ENUM function block is used to connect GOOSE enumerator inputs to the application.

3.11.7.3 Signals

Table 54: GOOSERCV_ENUM Input signals

Name	Type	Default	Description
IN	Enum	0	Input signal

Table 55: GOOSERCV_ENUM Output signals

Name	Type	Description
OUT	Enum	Output signal
VALID	BOOLEAN	Output signal

3.11.8 GOOSERCV_INT32 function block

3.11.8.1 Function block

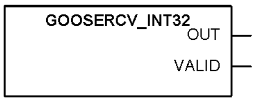


Figure 31: Function block

3.11.8.2 Functionality

The GOOSERCV_INT32 function block is used to connect GOOSE 32 bit integer inputs to the application.

3.11.8.3 Signals

Table 56: GOOSERCV_INT32 Input signals

Name	Type	Default	Description
IN	INT32	0	Input signal

Table 57: GOOSERCV_INT32 Output signals

Name	Type	Description
OUT	INT32	Output signal
VALID	BOOLEAN	Output signal

3.12 Type conversion function blocks

3.12.1 QTY_GOOD function block

3.12.1.1 Function block

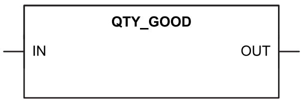


Figure 32: Function block

3.12.1.2 Functionality

The QTY_GOOD function block 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 (logic function output, binary input, application function output or received GOOSE signal). 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.

3.12.1.3 Signals

Table 58: QTY_GOOD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 59: QTY_GOOD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.12.2 QTY_BAD function block

3.12.2.1 Function block

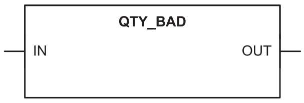


Figure 33: Function block

3.12.2.2 Functionality

The QTY_BAD function block 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 (logic function output, binary input, application function output or received GOOSE signal). 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.

3.12.2.3 Signals

Table 60: QTY_BAD Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 61: QTY_BAD Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.12.3 T_HEALTH function block

3.12.3.1 Function block

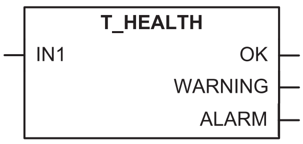


Figure 34: Function block

3.12.3.2 Functionality

The T_HEALTH function 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 IED.

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 IED or it is invalid, the default value (0) is used and the `ALARM` is activated in the T_HEALTH function block.

3.12.3.3 Signals

Table 62: T_HEALTH Input signals

Name	Type	Default	Description
IN	Any	0	Input signal

Table 63: T_HEALTH Output signals

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

3.12.4 T_F32_INT8 function block

3.12.4.1 Function block

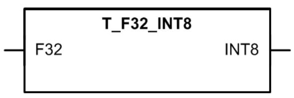


Figure 35: Function block

3.12.4.2 Functionality

T_F32_INT8 is a type conversion function.

The function converts 32-bit floating type values to 8-bit integer type. The rounding operation is included. Output value saturates if the input value is below the minimum or above the maximum value.

3.12.4.3 Signals

Table 64: T_F32_INT8 Input signals

Name	Type	Default	Description
F32	FLOAT32	0.0	Input signal

Table 65: T_F32_INT8 Output signal

Name	Type	Description
INT8	INT8	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.12.5 QTY_GOOSE_COMM function block

3.12.5.1 Function block

Figure 36: QTY_GOOSE_COMM function block

3.12.5.2 Functionality

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

The `OUT` 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.

3.12.5.3 Signals

Table 66: QTY_GOOSE_COMM Input signals

Name	Type	Default	Description
IN		0	Input signal

Table 67: QTY_GOOSE_COMM Output signals

Name	Type	Description
OUT	BOOLEAN	Output signal

3.12.6 T_DIR function block

3.12.6.1 Functionality

The T_DIR function evaluates enumerated data of the FAULT_DIR data attribute of the directional functions. T_DIR can only be used with GOOSE. The DIR input can be connected to the GOOSERCV_ENUM function block, which is receiving the LD0.<function>.Str.dirGeneral or LD0.<function>.Dir.dirGeneral data attribute sent by another IED.

In case the GOOSERCV_ENUM function block does not receive the value from the sending IED or it is invalid , the default value (0) is used in function outputs.

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

3.12.6.2 Signals

Table 68: T_DIR Input signals

Name	Type	Default	Description
DIR	Enum	0	Input signal

Table 69: T_DIR Output signals

Name	Type	Default	Description
FWD	BOOLEAN	0	Direction forward
REV	BOOLEAN	0	Direction backward

3.13 Configurable logic blocks

3.13.1 Standard configurable logic blocks

3.13.1.1 OR function block

Function block

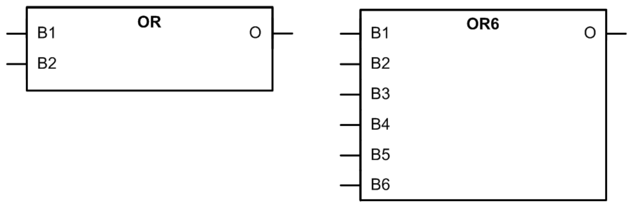


Figure 37: Function blocks

Functionality

OR and OR6 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 and OR6 has six inputs.

Signals

Table 70: OR Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2

Table 71: 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 72: OR Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Table 73: OR6 Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.2 AND function block

Function block

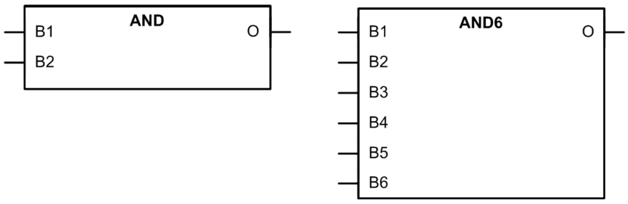


Figure 38: Function blocks

Functionality

AND and AND6 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 and AND6 has six inputs.

Signals

Table 74: AND Input signals

Name	Type	Default	Description
B1	BOOLEAN	1	Input signal 1
B2	BOOLEAN	1	Input signal 2

Table 75: 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 76: AND Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Table 77: AND6 Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.3 XOR function block

Function block

Figure 39: Function block

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.

Signals

Table 78: XOR Input signals

Name	Type	Default	Description
B1	BOOLEAN	0	Input signal 1
B2	BOOLEAN	0	Input signal 2

Table 79: XOR Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.4 NOT function block

Function block

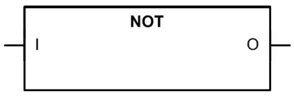


Figure 40: Function block

Functionality

NOT is used to generate combinatory expressions with Boolean variables.

NOT inverts the input signal.

Signals

Table 80: NOT Input signal

Name	Type	Default	Description
I	BOOLEAN	0	Input signal

Table 81: NOT Output signal

Name	Type	Description
O	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.5 MAX3 function block

Function block

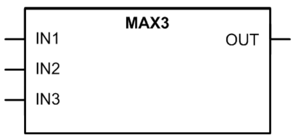


Figure 41: Function block

Functionality

The maximum function MAX3 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, MAX3 output value is set to -2^21.

Signals

Table 82: MAX3 Input signals

Name	Type	Default	Description
IN1	FLOAT32	0	Input signal 1
IN2	FLOAT32	0	Input signal 2
IN3	FLOAT32	0	Input signal 3

Table 83: MAX3 Output signal

Name	Type	Description
OUT	FLOAT32	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.6 MIN3 function block

Function block

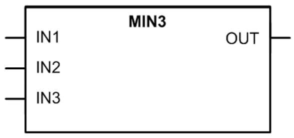


Figure 42: Function block

Functionality

The minimum function MIN3 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, MIN3 output value is set to 2^21.

Signals

Table 84: MIN3 Input signals

Name	Type	Default	Description
IN1	FLOAT32	0	Input signal 1
IN2	FLOAT32	0	Input signal 2
IN3	FLOAT32	0	Input signal 3

Table 85: MIN3 Output signal

Name	Type	Description
OUT	FLOAT32	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.7 R_TRIG function block

Function block

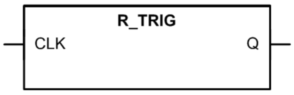


Figure 43: Function block

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.

Signals

Table 86: R_TRIG Input signals

Name	Type	Default	Description
CLK	BOOLEAN	0	Input signal

Table 87: R_TRIG Output signal

Name	Type	Description
Q	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.8 F_TRIG function block

Function block

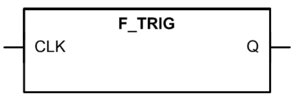


Figure 44: Function block

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.

Signals

Table 88: F_TRIG Input signals

Name	Type	Default	Description
CLK	BOOLEAN	0	Input signal

Table 89: F_TRIG Output signal

Name	Type	Description
Q	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.9 T_POS_XX function blocks

Function block

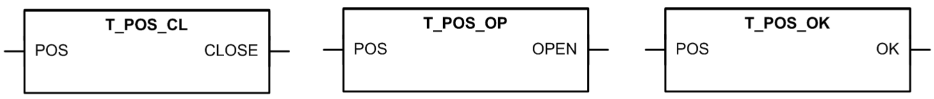


Figure 45: Function blocks

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 90: Cross reference between circuit breaker position and the output of the function block

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

Signals

Table 91: T_POS_CL Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 92: T_POS_OP Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 93: T_POS_OK Input signals

Name	Type	Default	Description
POS	Double binary	0	Input signal

Table 94: T_POS_CL Output signal

Name	Type	Description
CLOSE	BOOLEAN	Output signal

Table 95: T_POS_OP Output signal

Name	Type	Description
OPEN	BOOLEAN	Output signal

Table 96: T_POS_OK Output signal

Name	Type	Description
OK	BOOLEAN	Output signal

Settings

The function does not have any parameters available in LHMI or Protection and Control IED Manager (PCM600).

3.13.1.10 SWITCHR function block

Function block

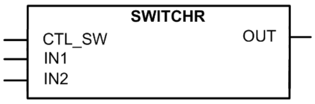


Figure 46: Function block

Functionality

SWITCHR switching block for REAL data type is operated by the `CTL_SW` input, selects the output value `OUT` between the `IN1` and `IN2` inputs.

CTL_SW	OUT
FALSE	IN2
TRUE	IN1

Signals

Table 97: SWITCHR Input signals

Name	Type	Default	Description
CTL_SW	BOOLEAN	1	Control Switch
IN1	REAL	0.0	Real input 1
IN2	REAL	0.0	Real input 2

Table 98: SWITCHR Output signals

Name	Type	Description
OUT	REAL	Real switch output

3.13.2 Minimum pulse timer

3.13.2.1 Minimum pulse timer TPGAPC

Function block

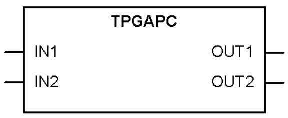


Figure 47: Function block

Functionality

The Minimum pulse timer TPGAPC function 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.

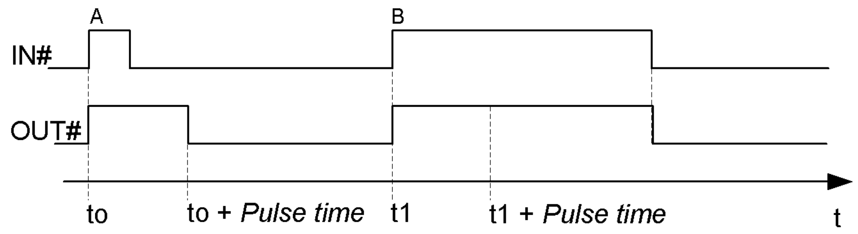


Figure 48: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 99: Input signals

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

Table 100: TPGAPC Output signals

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

Settings

Table 101: TPGAPC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse time	0...60000	ms	1	150	Minimum pulse time

3.13.2.2 Minimum pulse timer TPSGAPC

Function block

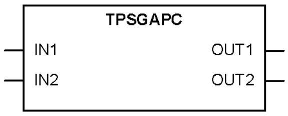


Figure 49: Function block

Functionality

The Minimum second pulse timer 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.

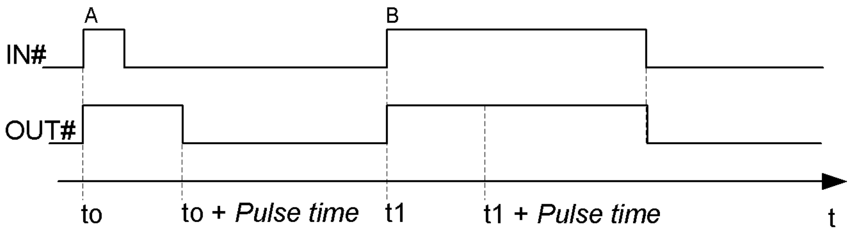


Figure 50: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 102: Input signals

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

Table 103: TPSGAPC Output signals

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

Settings

Table 104: TPSGAPC Non group settings

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

3.13.2.3 Minimum pulse timer TPMGAPC

Function block

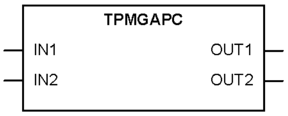


Figure 51: Function block

Functionality

The Minimum minute pulse timer 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.

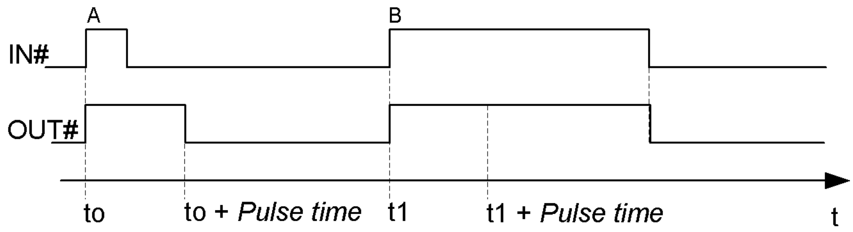


Figure 52: A = Trip pulse is shorter than Pulse time setting, B = Trip pulse is longer than Pulse time setting

Signals

Table 105: Input signals

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

Table 106: TPMGAPC Output signals

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

Settings

Table 107: TPMGAPC Non group settings

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

3.13.3 Pulse timer function block PTGAPC

3.13.3.1 Function block

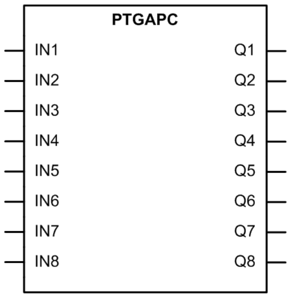


Figure 53: Function block

3.13.3.2 Functionality

The pulse timer function block 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.

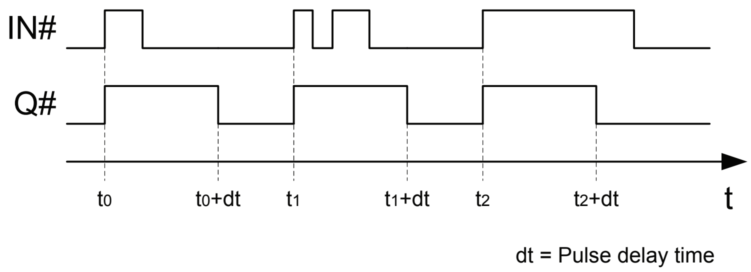


Figure 54: Timer operation

3.13.3.3 Signals

Table 108: 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 109: 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

3.13.3.4 Settings

Table 110: PTGAPC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Pulse delay time 1	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 2	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 3	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 4	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 5	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 6	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 7	0...3600000	ms	10	0	Pulse delay time
Pulse delay time 8	0...3600000	ms	10	0	Pulse delay time

3.13.3.5 Technical data

Table 111: PTGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.13.4 Time-delay-off function block TOFGAPC

3.13.4.1 Function block

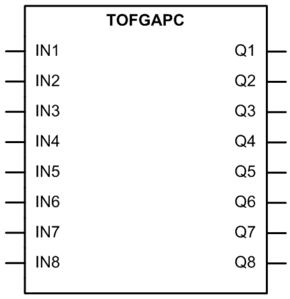


Figure 55: Function block

3.13.4.2 Functionality

The time-delay-off function block TOFGAPC can be used, for example, for a drop-off-delayed output related to the input signal. TOFGAPC 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.

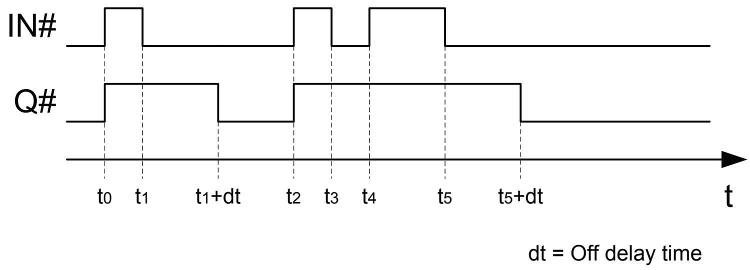


Figure 56: Timer operation

3.13.4.3 Signals

Table 112: 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
Table continues on next page			

Name	Type	Default	Description
IN6	BOOLEAN	0=False	Input 6 status
IN7	BOOLEAN	0=False	Input 7 status
IN8	BOOLEAN	0=False	Input 8 status

Table 113: 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

3.13.4.4 Settings

Table 114: TOFGAPC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Off delay time 1	0...3600000	ms	10	0	Off delay time
Off delay time 2	0...3600000	ms	10	0	Off delay time
Off delay time 3	0...3600000	ms	10	0	Off delay time
Off delay time 4	0...3600000	ms	10	0	Off delay time
Off delay time 5	0...3600000	ms	10	0	Off delay time
Off delay time 6	0...3600000	ms	10	0	Off delay time
Off delay time 7	0...3600000	ms	10	0	Off delay time
Off delay time 8	0...3600000	ms	10	0	Off delay time

3.13.4.5 Technical data

Table 115: TOFGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.13.5 Time-delay-on function block TONGAPC

3.13.5.1 Function block

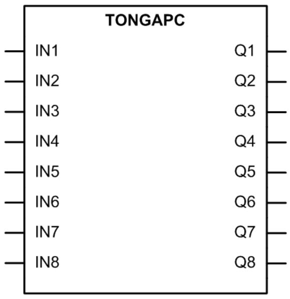


Figure 57: Function block

3.13.5.2 Functionality

The time-delay-on function block 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.

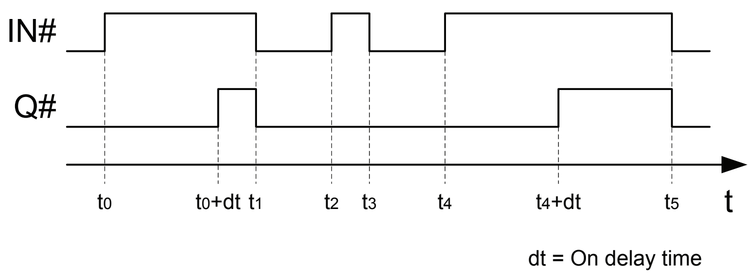


Figure 58: Timer operation

3.13.5.3 Signals

Table 116: 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
Table continues on next page			

Name	Type	Default	Description
IN6	BOOLEAN	0=False	Input 6
IN7	BOOLEAN	0=False	Input 7
IN8	BOOLEAN	0=False	Input 8

Table 117: TONGAPC Output signals

Name	Type	Description
Q1	BOOLEAN	Output 1
Q2	BOOLEAN	Output 2
Q3	BOOLEAN	Output 3
Q4	BOOLEAN	Output 4
Q5	BOOLEAN	Output 5
Q6	BOOLEAN	Output 6
Q7	BOOLEAN	Output 7
Q8	BOOLEAN	Output 8

3.13.5.4 Settings

Table 118: TONGAPC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
On delay time 1	0...3600000	ms	10	0	On delay time
On delay time 2	0...3600000	ms	10	0	On delay time
On delay time 3	0...3600000	ms	10	0	On delay time
On delay time 4	0...3600000	ms	10	0	On delay time
On delay time 5	0...3600000	ms	10	0	On delay time
On delay time 6	0...3600000	ms	10	0	On delay time
On delay time 7	0...3600000	ms	10	0	On delay time
On delay time 8	0...3600000	ms	10	0	On delay time

3.13.5.5 Technical data

Table 119: TONGAPC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

3.13.6 Set-reset function block SRGAPC

3.13.6.1 Function block

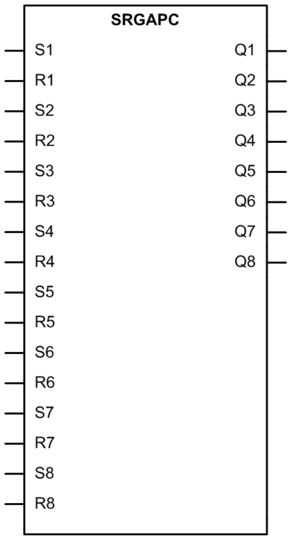


Figure 59: Function block

3.13.6.2 Functionality

The SRGAPC function block 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. SRGAPC 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 120: Truth table for SRGAPC

S#	R#	Q#
0	0	0[1)]
0	1	0
1	0	1
1	1	1

1) Keep state/no change

3.13.6.3 Signals

Table 121: 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

Table 122: 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

3.13.6.4 Settings

Table 123: SRGAPC Non group settings

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

3.13.7 Move function block MVGAPC

3.13.7.1 Function block

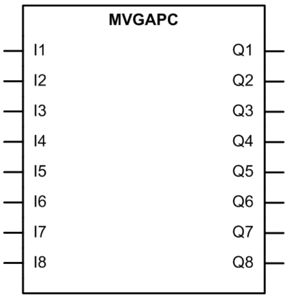


Figure 60: Function block

3.13.7.2 Functionality

The move function block 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.

3.13.7.3 Signals

Table 124: MV Input signals

Name	Type	Default	Description
I1	BOOLEAN	0	I1 status
I2	BOOLEAN	0	I2 status
I3	BOOLEAN	0	I3 status
I4	BOOLEAN	0	I4 status
I5	BOOLEAN	0	I5 status
I6	BOOLEAN	0	I6 status
I7	BOOLEAN	0	I7 status
I8	BOOLEAN	0	I8 status

Table 125: 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

3.13.8 Integer value moving function block MVI4GAPC

3.13.8.1 Function block

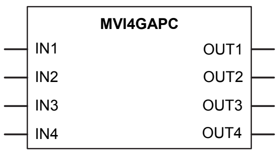


Figure 61: Function block symbol

3.13.8.2 Functionality

The move function block 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.

3.13.8.3 Signals

Table 126: 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 127: 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

3.13.9 Analog value scaling function block SCA4GAPC

3.13.9.1 Function block

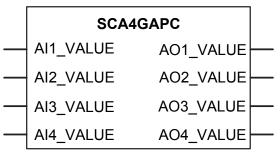


Figure 62: Function block symbol

3.13.9.2 Functionality

The analog value-moving function block 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.

3.13.9.3 Signals

Table 128: 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 129: 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

3.13.9.4 Settings

Table 130: SCA4GAPC Non group 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

3.13.10 Local/remote control function block CONTROL

3.13.10.1 Function block

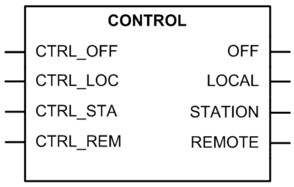


Figure 63: Function block

3.13.10.2 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.

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

Table 131: Truth table for CONTROL

Input				Output
CTRL_OFF	CTRL_LOC	CTRL_STA [1)]	CTRL_REM	
TRUE	any	any	any	OFF = TRUE
FALSE	TRUE	any	any	LOCAL = TRUE
FALSE	FALSE	TRUE	any	STATION = TRUE
FALSE	FALSE	FALSE	TRUE	REMOTE = TRUE
FALSE	FALSE	FALSE	FALSE	OFF = TRUE

1) If station authority is not in use, the `CTRL_STA` input is interpreted as `CTRL_REM`.

The station authority check based on the IEC 61850 command originator category in control command can be enabled by setting the value of the *Station authority* setting to "Station, Remote" (The command originator validation is performed only if the *LR control* setting is set to "Binary input"). The station authority check is not in use by default.

3.13.10.3 Signals

Table 132: 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

Table 133: 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

3.13.10.4 Settings

Table 134: 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=Not used 2=Station, Remote			1=Not used	Control command originator category usage

3.13.10.5 Monitored data

Table 135: 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 18=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		Latest command response
LR state	Enum	0=Off 1=Local 2=Remote 3=Station		LR state monitoring for PCM

3.13.11 Generic control points function block SPCGGIO

3.13.11.1 Function block

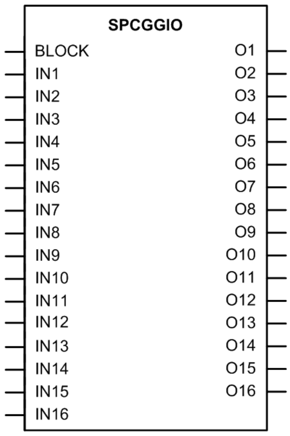


Figure 64: Function block

3.13.11.2 Functionality

The generic control points function SPCGGIO contains 16 independent control points. SPCGGIO 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 SPCGGIO 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”.

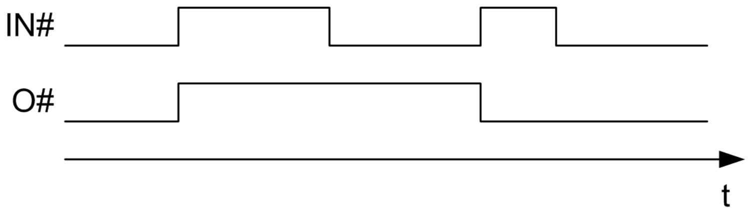


Figure 65: Operation in "Toggle" mode

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 SPCGGIO toggled operation mode is always working as persistent mode. The output O# follows the value written to the input IN#.

3.13.11.3 Signals

Table 136: SPCGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating 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 137: SPCGGIO 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

3.13.11.4 Settings

Table 138: SPCGGIO Non group settings

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 -1=Off			1=Toggle	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			1=Toggle	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			1=Toggle	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 3	Generic control point description
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 7	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 11	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCGGIO1 Output 16	Generic control point description

3.13.12 Remote generic control points SPCRGGIO

3.13.12.1 Function block

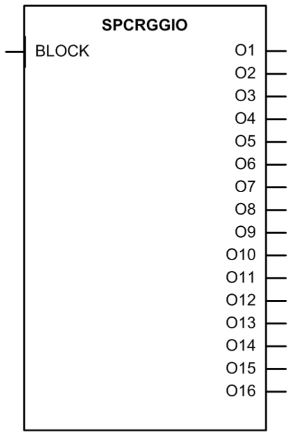


Figure 66: Function block

3.13.12.2 Functionality

The remote control function block SPCRGGIO is dedicated only for remote controlling, that is, SPCRGGIO cannot be controlled locally. The remote control is provided through communications.

3.13.12.3 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off". The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are *Enable* and *Disable*.

SPCRGGIO has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. SPCRGGIO also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the IED is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or SPCRGGIO can only be accessed remotely through communication. SPCRGGIO follows the local or remote (L/R) state if the setting *Loc Rem restriction* is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The `BLOCK` input can be used for blocking the output functionality. The `BLOCK` input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input `BLOCK` is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the `BLOCK` input resets the output to the FALSE state.

3.13.12.4 Signals

Table 139: SPCRGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 140: SPCRGGIO 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

3.13.12.5 Settings

Table 141: SPCRGGIO Non group settings

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 -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 6	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 7	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 14	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 15	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCRGGIO1 Output 16	Generic control point description

3.13.13 Local generic control points SPCLGGIO

3.13.13.1 Function block

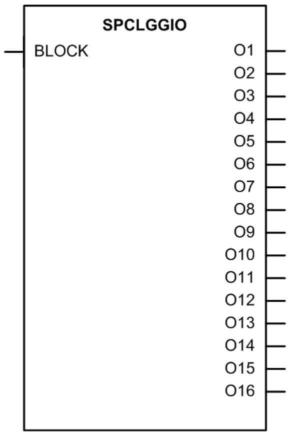


Figure 67: Function block

3.13.13.2 Functionality

The local control function block SPCLGGIO is dedicated only for local controlling, that is, SPCLGGIO cannot be controlled remotely. The local control is done through the buttons in the front panel.

3.13.13.3 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

SPCLGGIO has the *Operation mode*, *Pulse length* and *Description* settings available to control all 16 outputs. By default, the *Operation mode* setting is set to "Off". This disables the controllable signal output. SPCLGGIO also has a general setting *Loc Rem restriction*, which enables or disables the local or remote state functionality.

When the *Operation mode* is set to "Toggle", the corresponding output toggles between "True" and "False" for every input pulse received. The state of the output is stored in a nonvolatile memory and restored if the IED is restarted.

When the *Operation mode* is set to "Pulsed", the corresponding output can be used to produce the predefined length of pulses. Once activated, the output remains active for the duration of the set pulse length. When activated, the additional activation command does not extend the length of pulse. Thus, the pulse needs to be ended before the new activation can occur.

The *Description* setting can be used for storing signal names for each output.

Each control point or SPCLGGIO can only be accessed through the LHMI control. SPCLGGIO follows the local or remote (L/R) state if the *Loc Rem restriction* setting is "true". If the *Loc Rem restriction* setting is "false", local or remote (L/R) state is ignored, that is, all controls are allowed regardless of the local or remote state.

The `BLOCK` input can be used for blocking the output functionality. The `BLOCK` input operation depends on the *Operation mode* setting. If the *Operation mode* setting is set to "Toggle", the output state cannot be changed when the input `BLOCK` is TRUE. If the *Operation mode* setting is set to "Pulsed", the activation of the `BLOCK` input resets the output to the FALSE state.

3.13.13.4 Signals

Table 142: SPCLGGIO Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 143: SPCLGGIO 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

Table continues on next page

Name	Type	Description
O14	BOOLEAN	Output 14 status
O15	BOOLEAN	Output 15 status
O16	BOOLEAN	Output 16 status

3.13.13.5 Settings

Table 144: SPCLGGIO Non group settings

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 -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 1	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 2	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 3	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 4	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 5	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 6	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 7	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 8	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 9	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 10	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 11	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 12	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 13	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 14	Generic control point description

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 15	Generic control point description
Operation mode	0=Pulsed 1=Toggle -1=Off			-1=Off	Operation mode for generic control point
Pulse length	10...3600000	ms	10	1000	Pulse length for pulsed operation mode
Description				SPCLGGIO1 Output 16	Generic control point description

3.13.14 Generic up-down counter UDFCNT

3.13.14.1 Function block

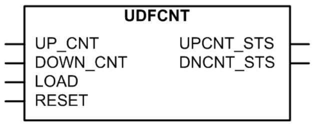


Figure 68: Function block

3.13.14.2 Functionality

The multipurpose 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.

3.13.14.3 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 multipurpose generic up-down counter can be described with a module diagram. All the modules in the diagram are explained in the next sections.

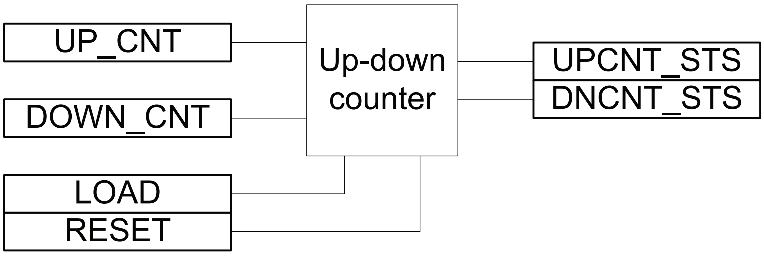


Figure 69: Functional module diagram

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.

3.13.14.4 Signals

Table 145: 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 146: UDFCNT Output signals

Name	Type	Description
UPCNT_STS	BOOLEAN	Status of the up counting
DNCNT_STS	BOOLEAN	Status of the down counting

3.13.14.5 Settings

Table 147: UDFCNT Non group settings

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 1=Reset			0=Cancel	Resets counter value
Load counter	0=Cancel 1=Load			0=Cancel	Loads the counter to preset value

3.13.14.6 Monitored data

Table 148: UDFCNT Monitored data

Name	Type	Values (Range)	Unit	Description
CNT_VAL	INT128	0...2147483647		Output counter value

3.14 Factory settings restoration

In case of configuration data loss or any other file system error that prevents the IED 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.

3.15 Load profile record LDPMSTA

3.15.1 Functionality

The IED 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 larger 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.

3.15.1.1 Quantities

Selectable quantities are product-dependent.

Table 149: Quantity Description

Disabled	Quantity not selected
IL1	Phase 1 current
IL2	Phase 2 current
IL3	Phase 3 current
Io	Neutral/earth/residual current
U12	Phase-to-phase 12 voltage
U23	Phase-to-phase 23 voltage
U31	Phase-to-phase 31 voltage
UL1	Phase-to-earth 1 voltage
UL2	Phase-to-earth 2 voltage
UL3	Phase-to-earth 3 voltage
U12B	Phase-to-phase 12 voltage, B side
U23B	Phase-to-phase 23 voltage, B side
U31B	Phase-to-phase 31 voltage, B side
UL1B	Phase-to-earth 1 voltage, B side
UL2B	Phase-to-earth 2 voltage, B side
UL3B	Phase-to-earth 3 voltage, B side
S	Apparent power
P	Real power
Q	Reactive power
PF	Power factor

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.

3.15.1.2 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 150. When the recording buffer is fully occupied, the oldest data are overwritten by the newest data.

Table 150: 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
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

3.15.1.3 Uploading of record

The IED 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".

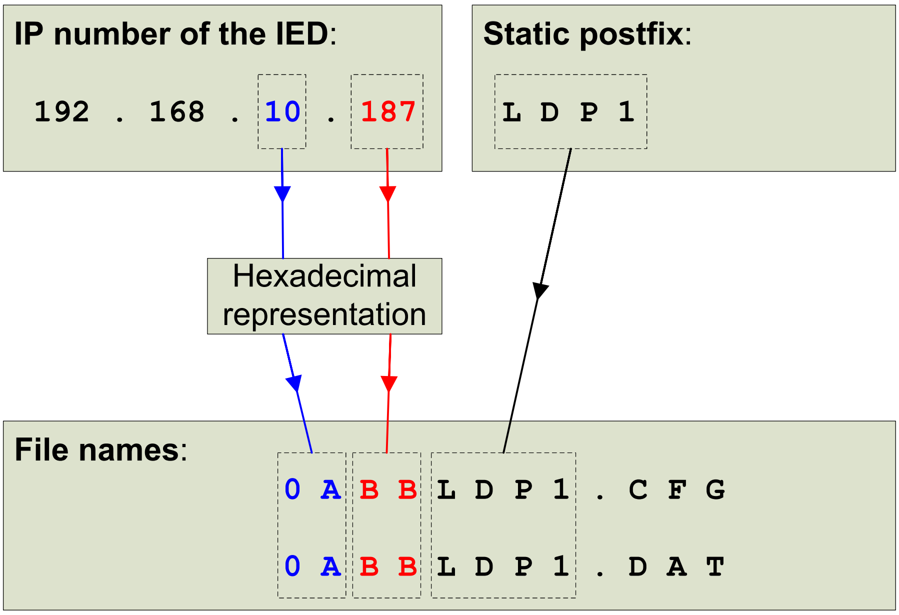


Figure 70: Load profile record file naming

3.15.1.4 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.

3.15.2 Configuration

The load profile record can be configured with the PCM600 tool 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.

Each IED can be mapped to each of the quantity channels of the load profile record. The mapping is done with the *Quantity selection* setting of the corresponding quantity channel.

The IP number of the IED and the content of the *Bay name* setting are both included in the COMTRADE configuration file for identification purposes.

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 IED. The levels for MEM_WARN and MEM_ALARM are set by two parameters *Mem.warn level* and *Mem. Alarm level*.

3.15.3 Signals

Table 151: LDPMSTA Output signals

Name	Type	Description
MEM_WARN	BOOLEAN	Recording memory warning status
MEM_ALARM	BOOLEAN	Recording memory alarm status

3.15.4 Settings

Table 152: LDPMSTA Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Quantity Sel 1	0=Disabled 1=IL1 2=IL2 3=IL3 4=Io 9=U12 10=U23 11=U31 12=UL1 13=UL2 14=UL3 15=U12B 16=U23B 17=U31B 18=UL1B 19=UL2B 20=UL3B 21=S 22=P 23=Q 24=PF			0=Disabled	Select quantity to be recorded

3.15.5 Monitored data

Table 153: LDPMSTA Monitored data

Name	Type	Values (Range)	Unit	Description
Rec. memory used	INT32	0...100	%	How much recording memory is currently used

Section 4 Protection functions

4.1 Three-phase current protection

4.1.1 Three-phase non-directional overcurrent protection PHxPTOC

4.1.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
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/51P

4.1.1.2 Function block

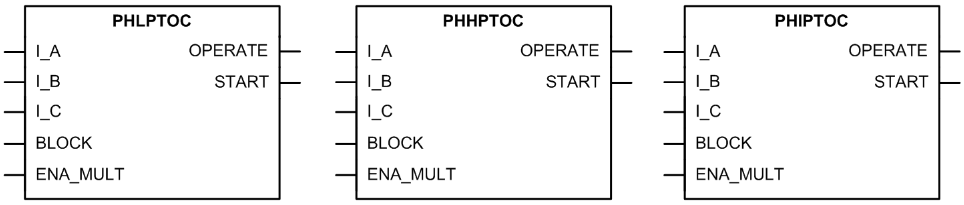


Figure 71: Function block

4.1.1.3 Functionality

The three-phase overcurrent protection 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, if desired.

4.1.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of three-phase non-directional overcurrent protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

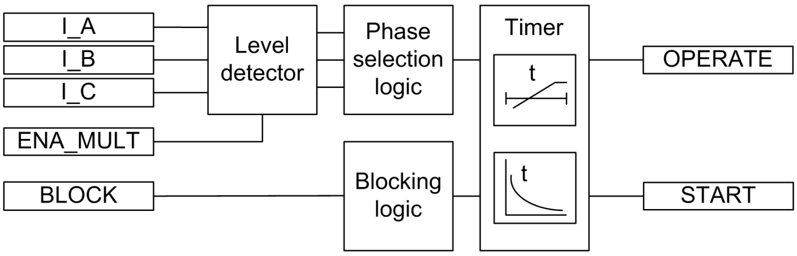


Figure 72: Functional module diagram. I_A, I_B and I_C represent phase currents.

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 IED 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.

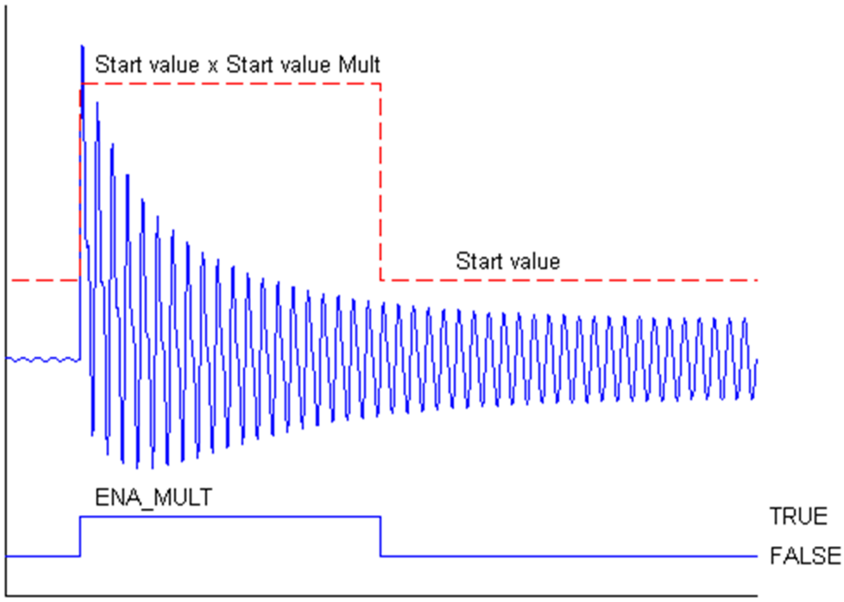


Figure 73: Start value behavior with `ENA_MULT` *input activated*

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. 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 the IDMT curves for overcurrent protection section 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 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, 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.

4.1.1.5 Measurement modes

The function operates on four alternative measurement modes: "RMS", "DFT", "Peak-to-Peak" and "P-to-P + backup". The measurement mode is selected with the setting *Measurement mode*.

Table 154: 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

For a detailed description of the measurement modes, see the Measurement modes section in this manual.

4.1.1.6 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 IED 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 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 155: 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	

Table continues on next page

Operating curve type	PHLPTOC	PHHPTOC
(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	

PHIPTOC supports only definite time characteristic.

For a detailed description of timers, see the General function block features section in this manual.

Table 156: 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.

4.1.1.7 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 74. 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 IED 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.

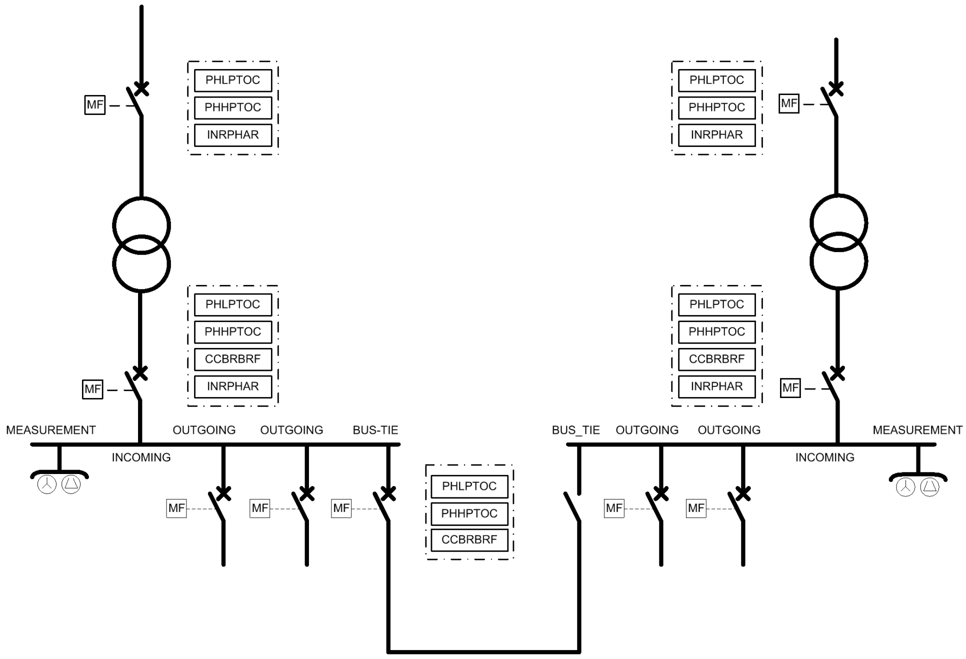


Figure 74: Example of traditional time selective transformer overcurrent protection

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 75 shows this arrangement.

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 75 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 157: 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.

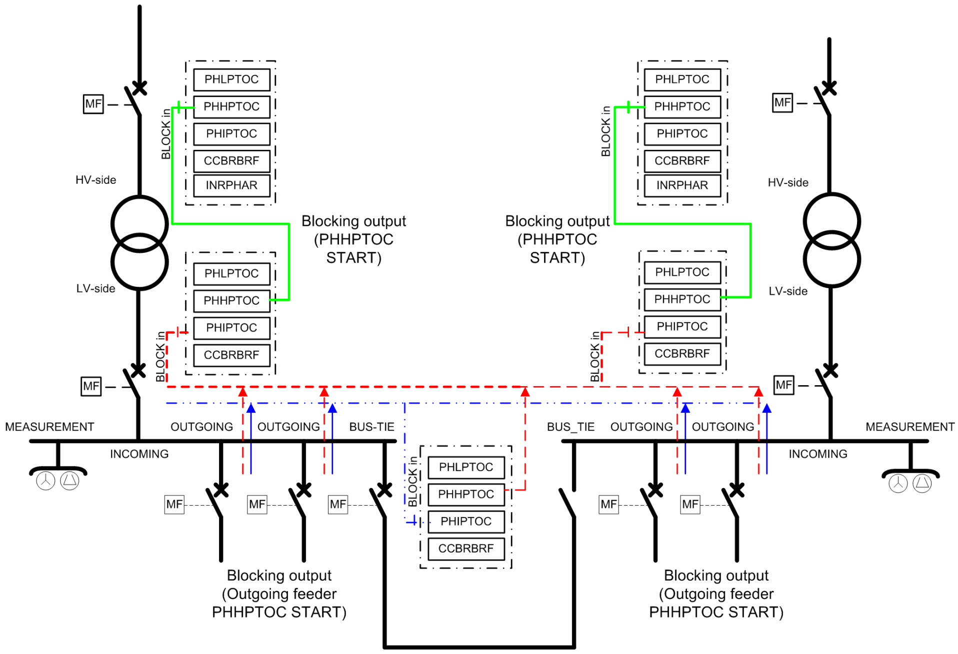


Figure 75: Numerical overcurrent protection functionality for a typical sub-transmission/distribution substation (feeder protection not shown).Blocking output = digital output signal from the start of a protection stage, Blocking in = digital input signal to block the operation of a protection stage

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 practically zero. Also, the effects of switching inrush currents on the setting values can be reduced by using the IED 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 the Measurement modes chapter 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 76 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.

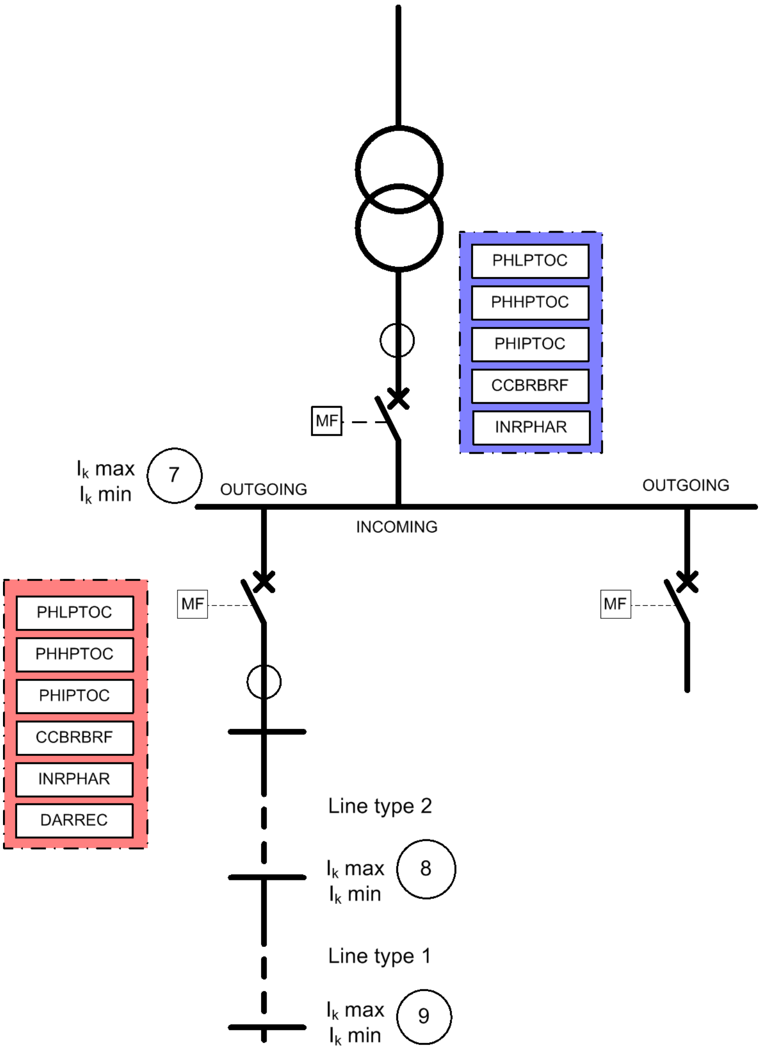


Figure 76: Functionality of numerical multiple-stage overcurrent protection

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 77, the coordination plan shows an example of operation characteristics in the LV-side incoming feeder and radial outgoing feeder.

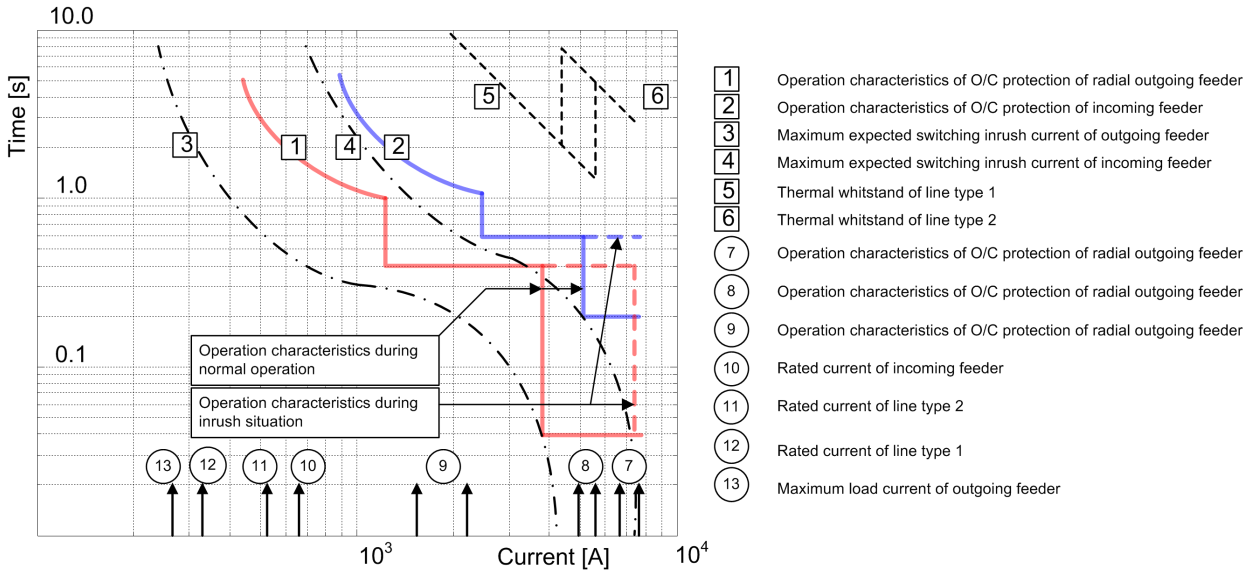


Figure 77: Example coordination of numerical multiple-stage overcurrent protection

4.1.1.8 Signals

Table 158: PHLPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 159: PHHPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 160: PHIPTOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 161: PHLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 162: PHHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 163: PHIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.1.1.9 Settings

Table 164: PHLPTOC Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	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	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
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. 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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 165: PHLPTOC Non group settings

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
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

Table 166: *PHHPTOC Group settings*

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	0.05...15.00		0.01	1.00	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. 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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 167: *PHHPTOC Non group settings*

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
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

Table 168: *PHIPTOC Group settings*

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...200000	ms	10	20	Operate delay time

Table 169: PHIPTOC Non group settings

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
Reset delay time	0...60000	ms	1	20	Reset delay time

4.1.1.10 Monitored data

Table 170: 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 2=blocked 3=test 4=test/blocked 5=off		Status

Table 171: 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

Table 172: 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

4.1.1.11 Technical data

Table 173: 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)2)		Minimum	Typical	Maximum
	PHIPTOC: I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	16 ms 11 ms	19 ms 12 ms	23 ms 14 ms
	PHHPTOC and PHLPTOC: I_{Fault} = 2 x set *Start value*	22 ms	24 ms	25 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 3) ±5.0% of the theoretical value or ±40 ms 3)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		

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) 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) Valid for FPHLPTOC

4.1.1.12 Technical revision history

Table 174: PHIPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting.
C	Minimum and default values changed to 20 ms for the *Operate delay time* setting. Minimum value changed to 1.00 x I_n for the *Start value* setting.

Table 175: PHHPTOC Technical revision history

Technical revision	Change
C	*Measurement mode* "P-to-P + backup" replaced with "Peak-to-Peak"
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

Table 176: PHLPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

4.1.2 Three-phase directional overcurrent protection DPHxPDOC

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> ->	67-1
Three-phase directional overcurrent protection - High stage	DPHHPDOC	3I>> ->	67-2

4.1.2.2 Function block

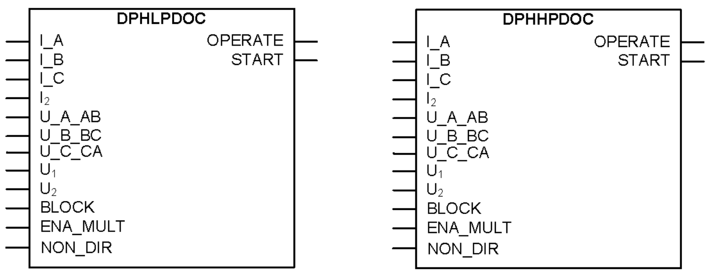


Figure 78: Function block

4.1.2.3 Functionality

The three-phase overcurrent protection 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, if desired.

4.1.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of directional overcurrent protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

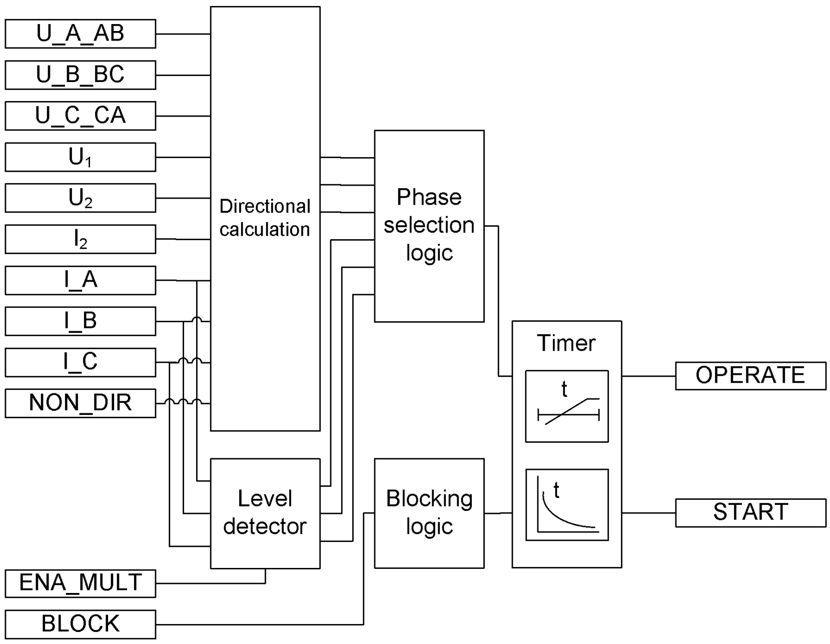


Figure 79: Functional module diagram

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 177: 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 IED 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.

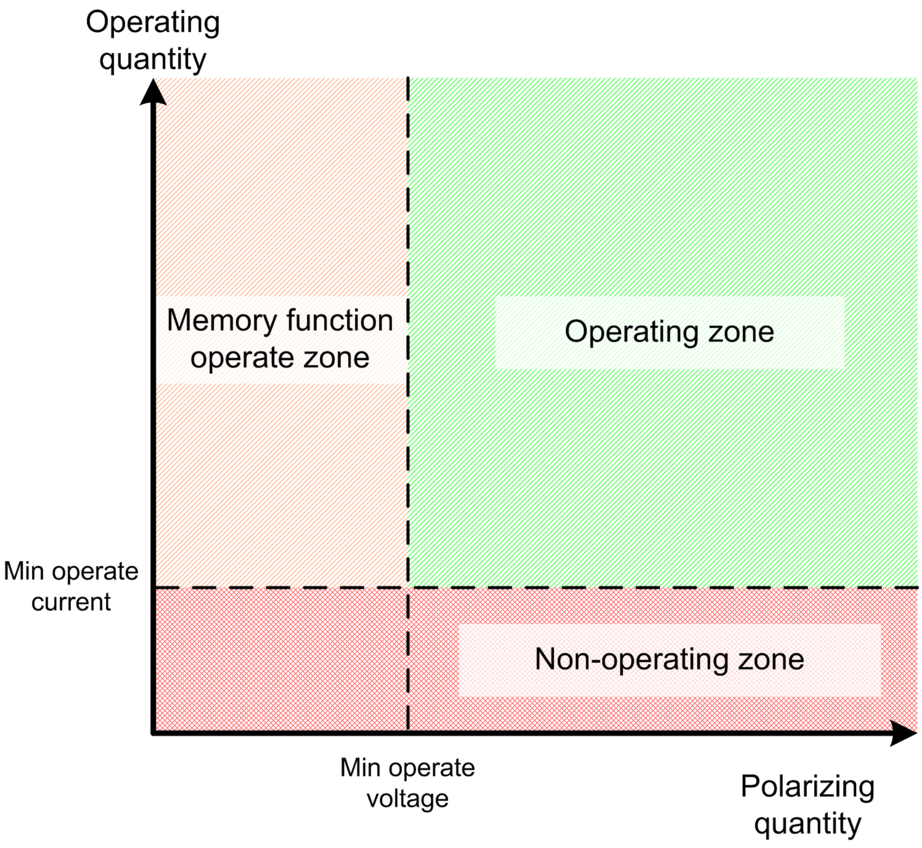


Figure 80: Operating zones at minimum magnitude levels

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 IED 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.

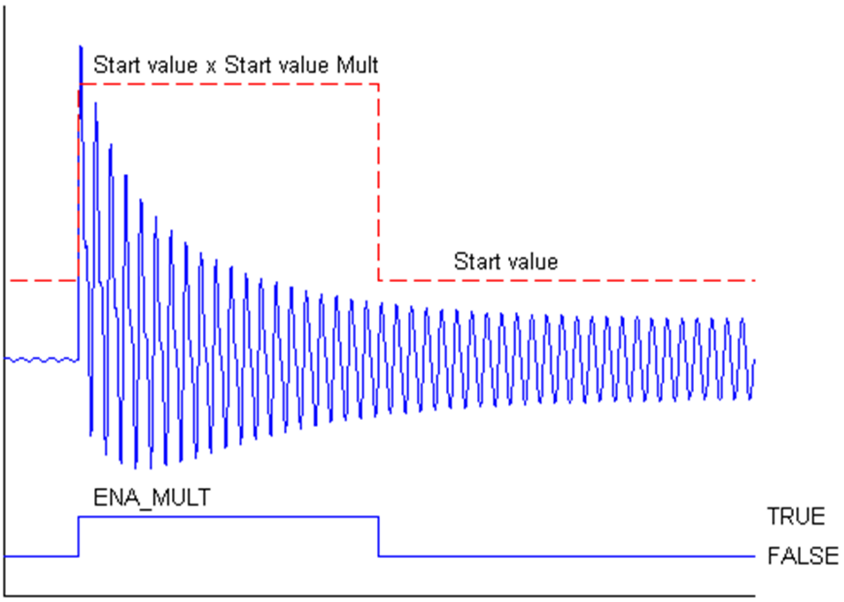


Figure 81: Start value behavior with ENA_MULT input activated

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.

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. 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 the IDMT curves for overcurrent protection section 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 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, 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.

4.1.2.5 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 178: Measurement modes supported by DPHxPDOC stages

Measurement mode	DPHLPDOC	DPHHPDOC
RMS	x	x
DFT	x	x
Peak-to-Peak	x	x

4.1.2.6 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.

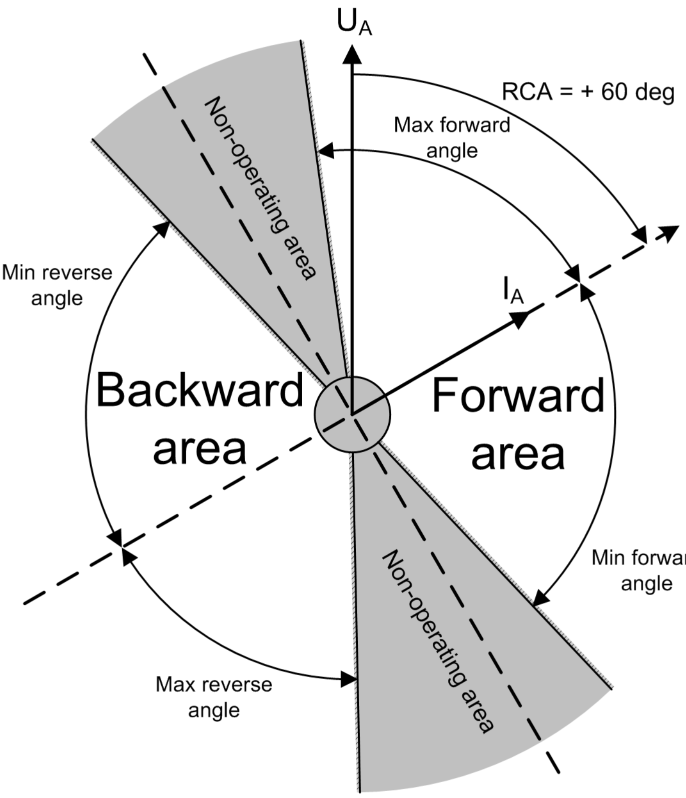


Figure 82: Configurable operating sectors

Table 179: 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
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 180: 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 181: Equations for calculating angle difference for self-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_A$	$ANGLE\_A = \varphi(\underline{U}_A) - \varphi(\underline{I}_A) - \varphi_{RCA}$
B	$\underline{I}_B$	$\underline{U}_B$	$ANGLE\_B = \varphi(\underline{U}_B) - \varphi(\underline{I}_B) - \varphi_{RCA}$
C	$\underline{I}_C$	$\underline{U}_C$	$ANGLE\_C = \varphi(\underline{U}_C) - \varphi(\underline{I}_C) - \varphi_{RCA}$
A - B	$\underline{I}_A - \underline{I}_B$	$\underline{U}_{AB}$	$ANGLE\_A = \varphi(\underline{U}_{AB}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA}$
B - C	$\underline{I}_B - \underline{I}_C$	$\underline{U}_{BC}$	$ANGLE\_B = \varphi(\underline{U}_{BC}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA}$
C - A	$\underline{I}_C - \underline{I}_A$	$\underline{U}_{CA}$	$ANGLE\_C = \varphi(\underline{U}_{CA}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA}$

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.

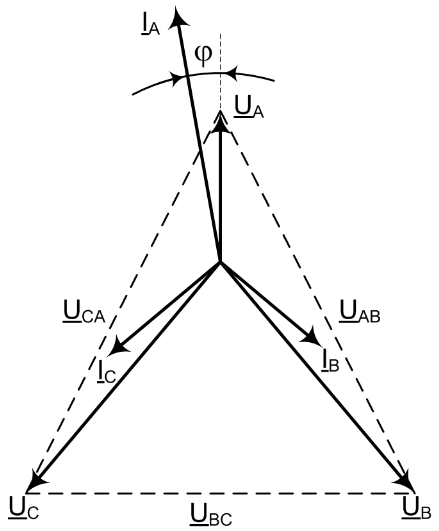


Figure 83: Single-phase earth fault, phase A

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.

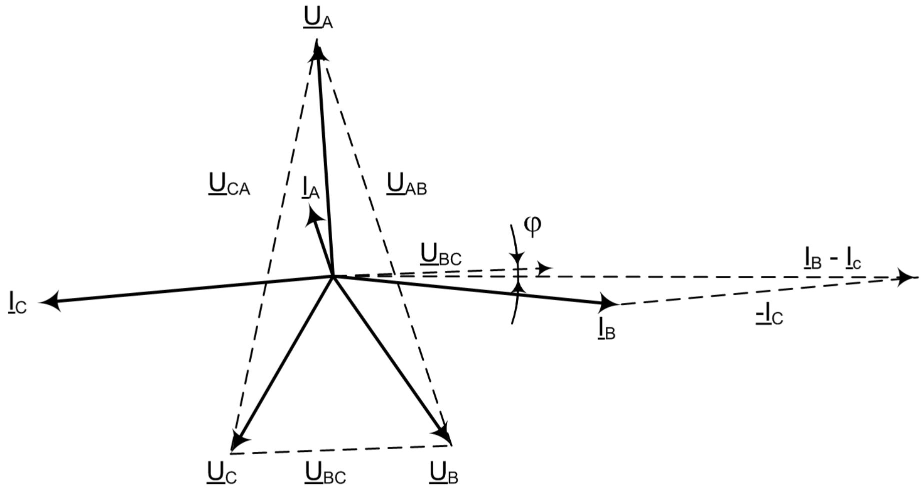


Figure 84: Two-phase short circuit, short circuit is between phases B and C

Cross-polarizing as polarizing quantity

Table 182: Equations for calculating angle difference for cross-polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_{BC}$	$ANGLE\_A = \varphi(\underline{U}_{BC}) - \varphi(\underline{I}_A) - \varphi_{RCA} + 90^o$
B	$\underline{I}_B$	$\underline{U}_{CA}$	$ANGLE\_B = \varphi(\underline{U}_{CA}) - \varphi(\underline{I}_B) - \varphi_{RCA} + 90^o$
C	$\underline{I}_C$	$\underline{U}_{AB}$	$ANGLE\_C = \varphi(\underline{U}_{AB}) - \varphi(\underline{I}_C) - \varphi_{RCA} + 90^o$
A - B	$\underline{I}_A$ - $\underline{I}_B$	$\underline{U}_{BC}$ - $\underline{U}_{CA}$	$ANGLE\_A = \varphi(\underline{U}_{BC} - \underline{U}_{CA}) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 90^o$
B - C	$\underline{I}_B$ - $\underline{I}_C$	$\underline{U}_{CA}$ - $\underline{U}_{AB}$	$ANGLE\_B = \varphi(\underline{U}_{CA} - \underline{U}_{AB}) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} + 90^o$
C - A	$\underline{I}_C$ - $\underline{I}_A$	$\underline{U}_{AB}$ - $\underline{U}_{BC}$	$ANGLE\_C = \varphi(\underline{U}_{AB} - \underline{U}_{BC}) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 90^o$

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.

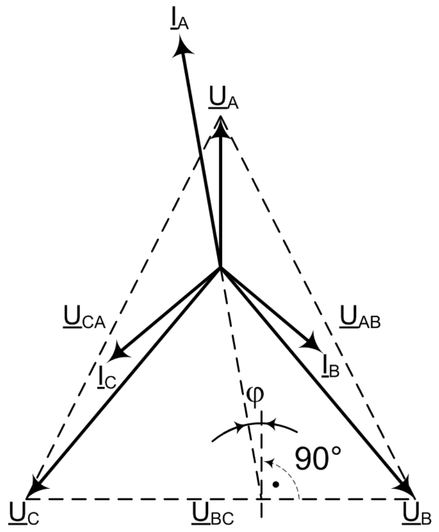


Figure 85: Single-phase earth fault, phase A

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.

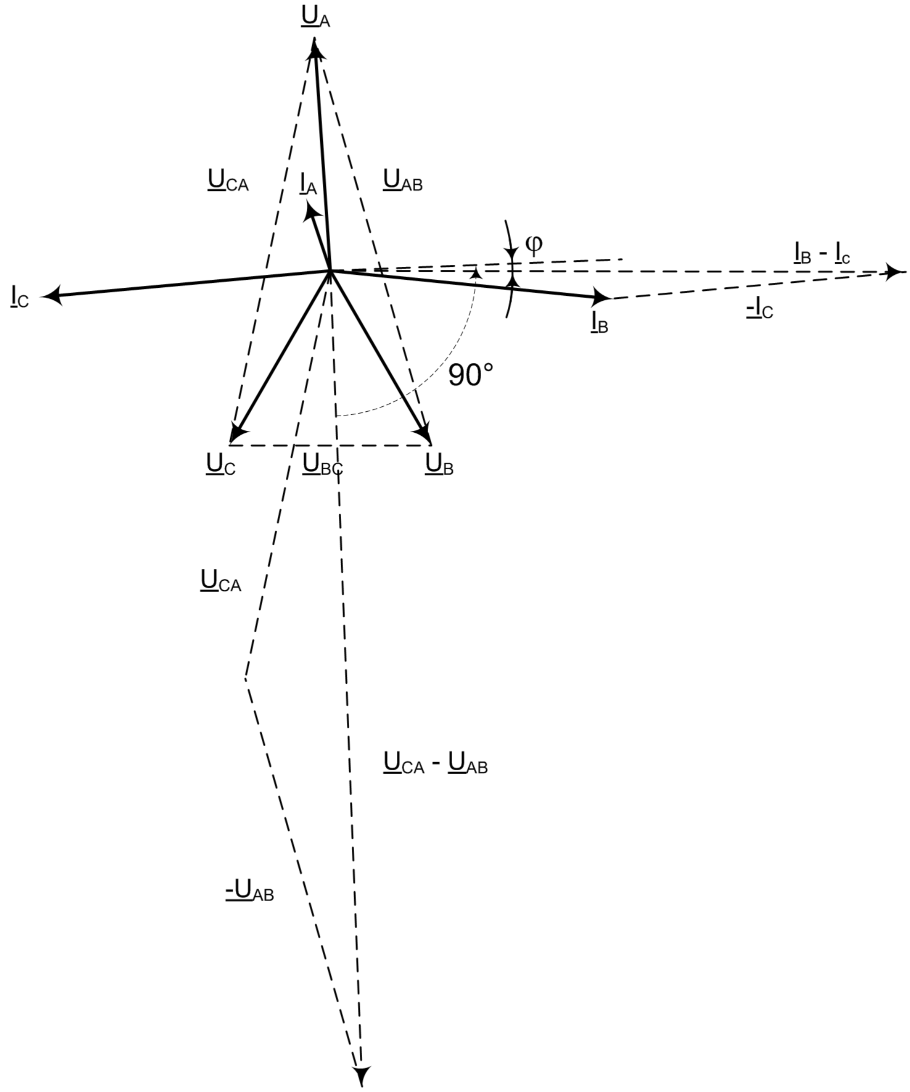


Figure 86: Two-phase short circuit, short circuit is between phases B and C

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 1)

This means that the actuating polarizing quantity is -$\underline{U}_2$.

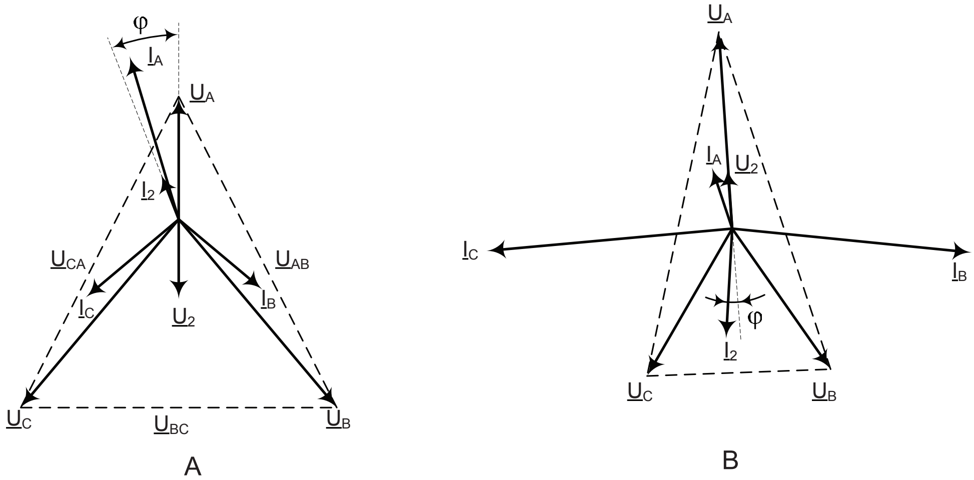


Figure 87: Phasors in a single-phase earth fault, phases A-N, and two-phase short circuit, phases B and C, when the actuating polarizing quantity is the negative-sequence voltage -U2

Positive sequence voltage as polarizing quantity

Table 183: Equations for calculating angle difference for positive-sequence quantity polarizing method

Faulted phases	Used fault current	Used polarizing voltage	Angle difference
A	$\underline{I}_A$	$\underline{U}_1$	$ANGLE\_A = \varphi(\underline{U}_1) - \varphi(\underline{I}_A) - \varphi_{RCA}$
B	$\underline{I}_B$	$\underline{U}_1$	$ANGLE\_B = \varphi(\underline{U}_1) - \varphi(\underline{I}_B) - \varphi_{RCA} - 120^\circ$
C	$\underline{I}_C$	$\underline{U}_1$	$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C) - \varphi_{RCA} + 120^\circ$
A - B	$\underline{I}_A$ - $\underline{I}_B$	$\underline{U}_1$	$ANGLE\_A = \varphi(\underline{U}_1) - \varphi(\underline{I}_A - \underline{I}_B) - \varphi_{RCA} + 30^\circ$
B - C	$\underline{I}_B$ - $\underline{I}_C$	$\underline{U}_1$	$ANGLE\_B = \varphi(\underline{U}_1) - \varphi(\underline{I}_B - \underline{I}_C) - \varphi_{RCA} - 90^\circ$
C - A	$\underline{I}_C$ - $\underline{I}_A$	$\underline{U}_1$	$ANGLE\_C = \varphi(\underline{U}_1) - \varphi(\underline{I}_C - \underline{I}_A) - \varphi_{RCA} + 150^\circ$

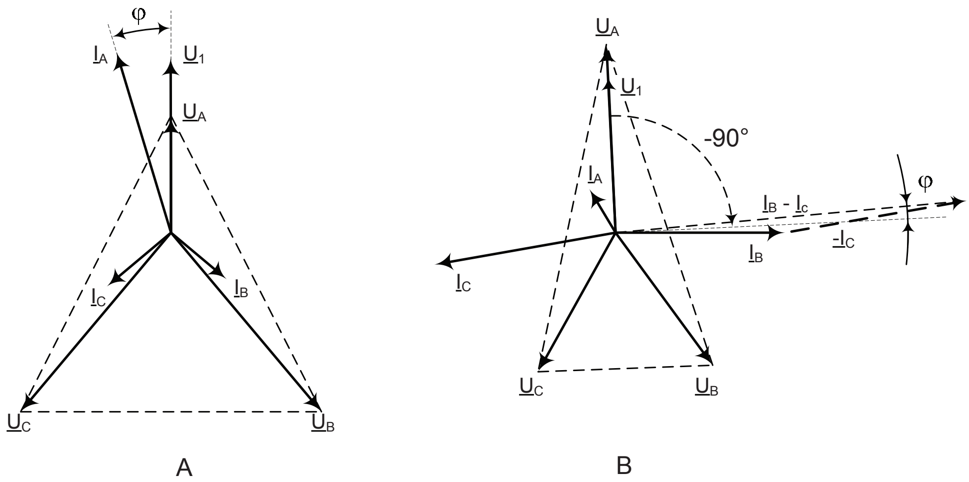


Figure 88: Phasors in a single-phase earth fault, phase A to ground, and a two-phase short circuit, phases B-C, are short-circuited when the polarizing quantity is the positive-sequence voltage U_1

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 IED using the parameter in the HMI menu: **Configuration/System/Phase rotation**. The default parameter value is "ABC".

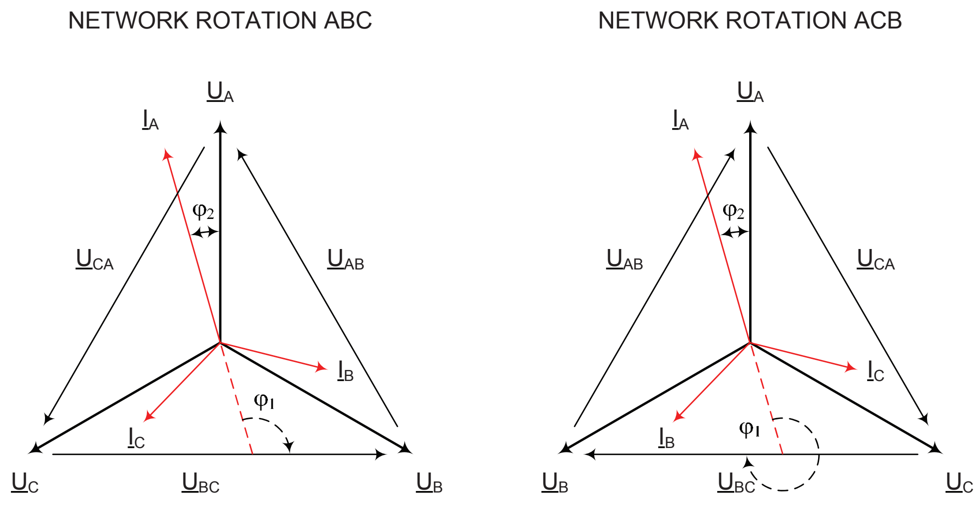


Figure 89: Examples of network rotating direction

4.1.2.7 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 IEDs 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 IEDs 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 IEDs 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 IEDs 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.

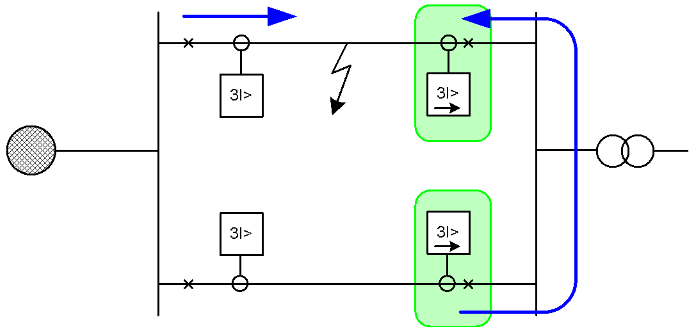


Figure 90: Overcurrent protection of parallel lines using directional IEDs

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.

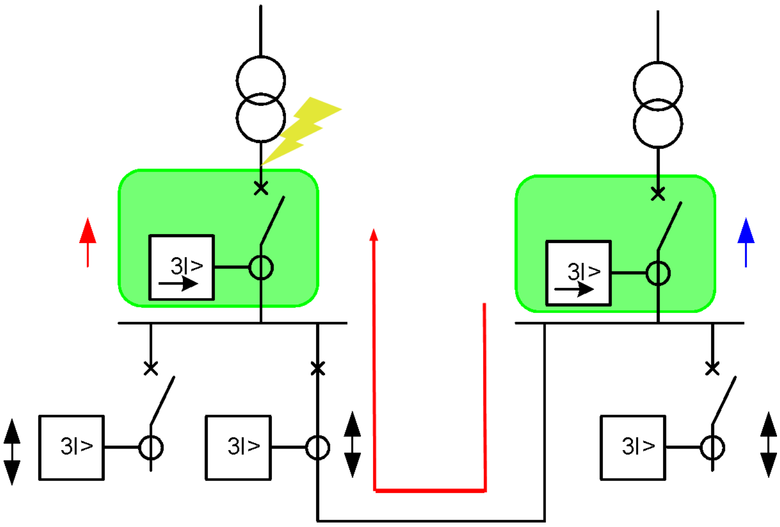


Figure 91: Overcurrent protection of parallel operating transformers

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 IEDs 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.

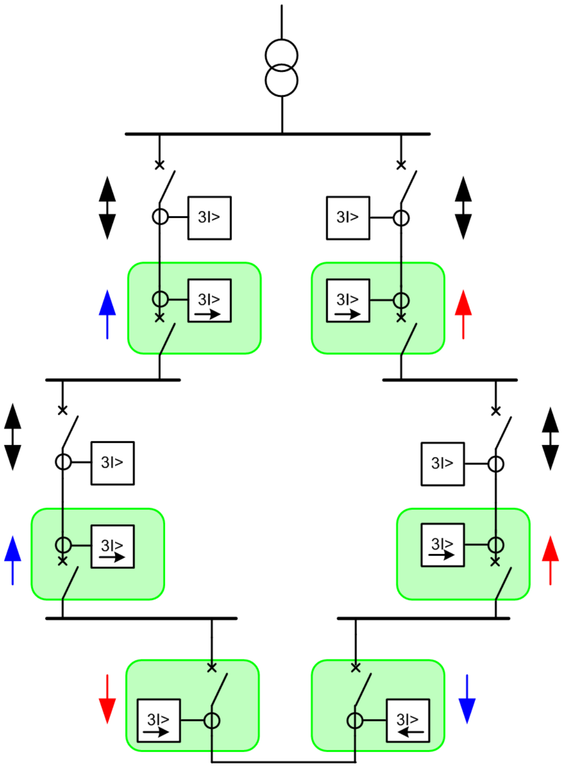


Figure 92: Closed ring network topology where feeding lines are protected with directional overcurrent IEDs

4.1.2.8 Signals

Table 184: DPHLPDOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage

Table continues on next page

Name	Type	Default	Description
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

Table 185: DPHHPDOC Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative phase sequence current
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage
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

Table 186: DPHLPDOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 187: DPHHPDOC Output signals

Name	Type	Description
START	BOOLEAN	Start
OPERATE	BOOLEAN	Operate

4.1.2.9 Settings

Table 188: DPHLPDOC Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	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	0.05...15.00		0.01	1.00	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. 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
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
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
Pol quantity	-2=Pos. seq. volt. 1=Self pol 4=Neg. seq. volt. 5=Cross pol			5=Cross pol	Reference quantity used to determine fault direction

Table 189: DPHLPDOC Non group settings

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
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
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

Table 190: DPHHPDOC Group settings

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	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Operate delay time	40...200000	ms	10	40	Operate delay time
Characteristic angle	-179...180	deg	1	60	Characteristic angle

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
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
Voltage Mem time	0...3000	ms	1	40	Voltage memory time
Pol quantity	-2=Pos. seq. volt. 1=Self pol 4=Neg. seq. volt. 5=Cross pol			5=Cross pol	Reference quantity used to determine fault direction

Table 191: DPHHPDOC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
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

4.1.2.10 Monitored data

Table 192: DPHLPDOC 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 2=backward 3=both		Direction information
DIR_A	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward 3=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 4=test/blocked 5=off		Status

Table 193: DPHHPDOC 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 2=backward 3=both		Direction information

Table continues on next page

Name	Type	Values (Range)	Unit	Description
DIR_A	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase A
DIR_B	Enum	0=unknown 1=forward 2=backward 3=both		Direction phase B
DIR_C	Enum	0=unknown 1=forward 2=backward 3=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

4.1.2.11 Technical data

Table 194: DPHxPDOC Technical data

Characteristic		Value		
Operation accuracy		Depending on the frequency of the current/ voltage measured: f_n ±2 Hz		
	DPHLPDOC	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°		
	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)]		Minimum	Typical	Maximum
	I_{Fault} = 2.0 × set *Start value*	38 ms	43 ms	46 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Table continues on next page				

Characteristic	Value
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)] ±5.0% of the theoretical value or ±40 ms [3)4)]
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

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 to 20
4) Valid for FDPHLPDOC

4.1.2.12 Technical revision history

Table 195: DPHHPDOC Technical revision history

Technical revision	Change
B	Added a new input `NON_DIR`
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

Table 196: DPHLPDOC Technical revision history

Technical revision	Change
B	Added a new input `NON_DIR`
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

4.1.3 Three-phase thermal protection for feeders, cables and distribution transformers T1PTTR

4.1.3.1 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>	49F

4.1.3.2 Function block

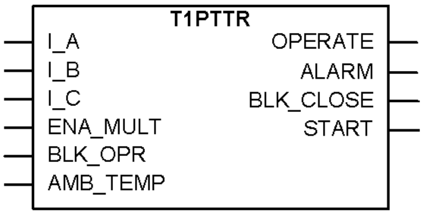


Figure 93: Function block

4.1.3.3 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 thermal overload 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.

4.1.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase thermal protection for feeders, cables and distribution transformers 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 IED. 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*.

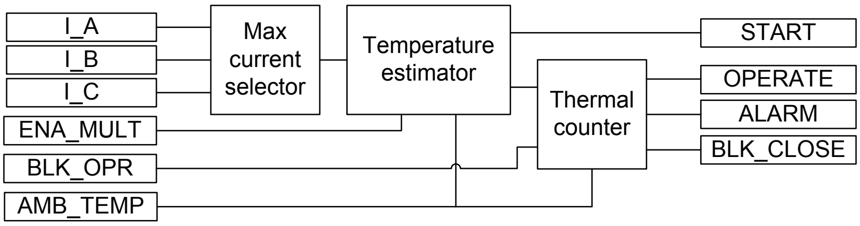


Figure 94: Functional module diagram. I_A, I_B and I_C represent phase currents.

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 2)

I	the largest 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 larger 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 3)

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
τ	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 4)

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 5)

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 IED 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 IED 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.

4.1.3.5 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.

4.1.3.6 Signals

Table 197: T1PTTR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLK_OPR	BOOLEAN	0=False	Block signal for operate outputs
ENA_MULT	BOOLEAN	0=False	Enable Current multiplier
TEMP_AMB	FLOAT32	0	The ambient temperature used in the calculation

Table 198: 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.

4.1.3.7 Settings

Table 199: T1PTTR Group settings

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 multiplier	1...5		1	1	Current multiplier when function is used for parallel lines
Current reference	0.05...4.00	xIn	0.01	1.00	The load current leading to Temperature raise temperature
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
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	20.0...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 200: T1PTTR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Initial temperature	-50.0...100.0	°C	0.1	0.0	Temperature raise above ambient temperature at startup

4.1.3.8 Monitored data

Table 201: 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
T1PTTR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.1.3.9 Technical data

Table 202: 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

1) Overload current > 1.2 × Operate level temperature

4.1.3.10 Technical revision history

Table 203: T1PTTR Technical revision history

Technical revision	Change
C	Removed the *Sensor available* setting parameter
D	Added the AMB_TEMP input

4.2 Earth-fault protection

4.2.1 Non-directional earth-fault protection EFxPTOC

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>	51N-1
Non-directional earth-fault protection - High stage	EFHPTOC	Io>>	51N-2
Non-directional earth-fault protection - Instantaneous stage	EFIPTOC	Io>>>	50N/51N

4.2.1.2 Function block

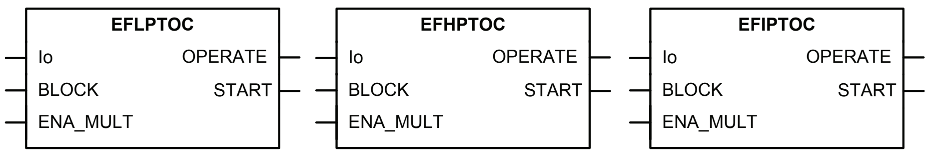


Figure 95: Function block

4.2.1.3 Functionality

The earth-fault 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, if desired.

4.2.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of non-directional earth-fault protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

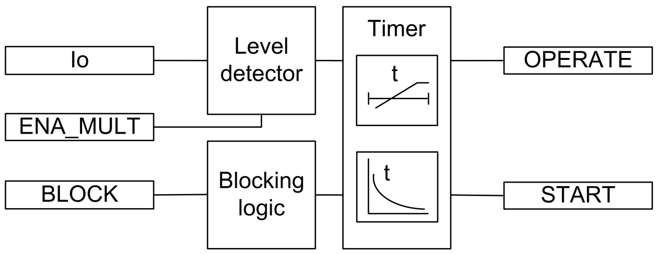


Figure 96: Functional module diagram. Io represents the residual current.

Level detector

The operating quantity can be selected with the setting *Io signal Sel*. The selectable options are "Measured Io" and "Calculated Io". The operating quantity 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 IED 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. 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 the IDMT curves for overcurrent protection section 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 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, 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.

4.2.1.5 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 204: 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 the Measurement modes section in this manual.

4.2.1.6 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 IED 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 205: 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	

Table continues on next page

Operating curve type	EFLPTOC	EFHPTOC
(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 the General function block features section in this manual.

Table 206: 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.

4.2.1.7 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.

4.2.1.8 Signals

Table 207: EFLPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 208: EFHPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 209: EFIPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 210: EFLPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 211: EFHPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 212: EFIPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.1.9 Settings

Table 213: EFLPTOC Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...5.000	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	0.05...15.00		0.01	1.00	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. 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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 214: EFLPTOC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal

Table 215: EFHPTOC Group settings

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	0.05...15.00		0.01	1.00	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. 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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 216: EFHPTOC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal

Table 217: EFIPTOC Group settings

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	40...200000	ms	10	40	Operate delay time

Table 218: EFIPTOC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	1	20	Reset delay time
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal

4.2.1.10 Monitored data

Table 219: 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 4=test/blocked 5=off		Status

Table 220: 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

Table 221: 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

4.2.1.11 Technical data

Table 222: 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)2)]		Minimum	Typical	Maximum
	EFIPTOC: I_{Fault} = 2 × set *Start value* I_{Fault} = 10 × set *Start value*	16 ms 11 ms	19 ms 12 ms	23 ms 14 ms
	EFHPTOC and EFLPTOC: I_{Fault} = 2 × set *Start value*	22 ms	24 ms	25 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 [3)] ±5.0% of the theoretical value or ±40 ms [3)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		

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
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20
4) Valid for FEFLPTOC

4.2.1.12 Technical revision history

Table 223: EFIPTOC Technical revision history

Technical revision	Change
B	The minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Minimum and default values changed to 20 ms for the *Operate delay time* setting Minimum value changed to 1.00 x I_n for the *Start value* setting.
D	Added a setting parameter for the "Measured Io" or "Calculated Io" selection

Table 224: EFHPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Added a setting parameter for the "Measured Io" or "Calculated Io" selection
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

Table 225: EFLPTOC Technical revision history

Technical revision	Change
B	The minimum and default values changed to 40 ms for the *Operate delay time* setting
C	*Start value* step changed to 0.005
D	Added a setting parameter for the "Measured Io" or "Calculated Io" selection
E	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

4.2.2 Directional earth-fault protection DEFxPDEF

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>->	67N-1
Directional earth-fault protection - High stage	DEFHPDEF	Io>>->	67N-2

4.2.2.2 Function block

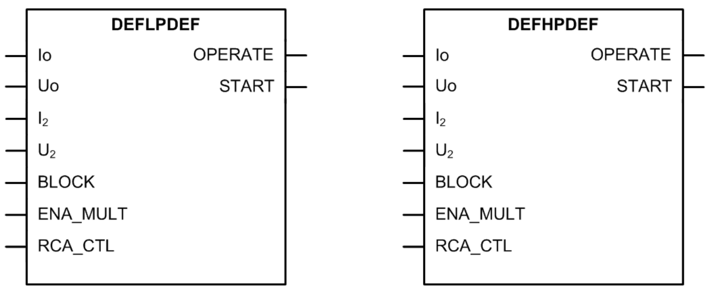


Figure 97: Function block

4.2.2.3 Functionality

The earth-fault 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, if desired.

4.2.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of directional earth-fault protection can be described using a module diagram.

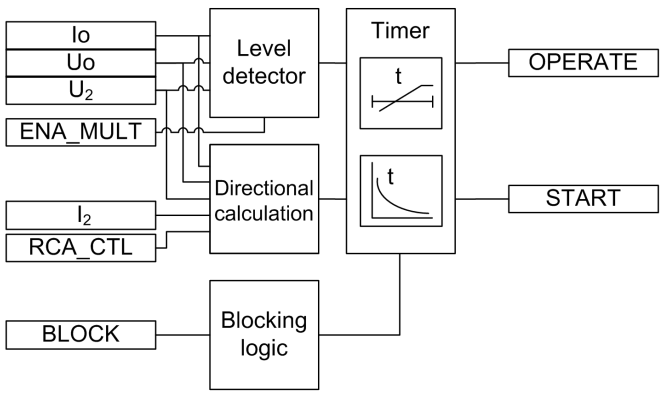


Figure 98: Functional module diagram. Io and Uo represent the residual current and residual voltage. I_2 and U_2 represent the negative sequence components for current and voltage.

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.

The operating quantity (residual current) can be selected with the setting *Io signal Sel*. The options are "Measured Io" and "Calculated Io". If "Measured Io" is selected, the current ratio for Io-channel is given in **Configuration/Analog inputs/ Current (Io,CT)**. If "Calculated Io" is selected, the current ratio is obtained from the phase-current channels given in **Configuration/Analog inputs/Current (3I,CT)**. The polarizing quantity can be selected with the setting *Pol signal Sel*. The options are "Measured Uo", "Calculated Uo" and "Neg. seq. volt". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in **Configuration/Analog inputs/Voltage (Uo,VT)**. If "Calculated Uo" or "Neg. seq. volt" is selected, the voltage ratio is obtained from the phase-voltage channels given in **Configuration/Analog inputs/Voltage (3U,VT)**.

Example 1: Io is measured with cable core CT (100/1 A) and Uo is measured from open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured Io" and "Measured Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in Residual current Io : **Configuration/Analog inputs/Current (Io,CT)**: 100 A : 1 A. The Residual voltage Uo: **Configuration/Analog inputs/Voltage (Uo,VT)**: 11.547 kV : 100 V. The *Residual Current start value* of 1.0 x In corresponds to 1.0 * 100 A = 100 A in the primary. The *Residual Voltage start value* of 1.0 x Un corresponds to 1.0 * 11.547 kV = 11.547 kV in the primary.

Example 2: Both Io and Uo are calculated from the phase quantities. Phase CT-ratio is 100 : 1 A and phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Io" and "Calculated Uo" are selected. The nominal values for residual current and residual voltage are obtained from CT and VT ratios entered in Residual current Io : **Configuration/Analog inputs/Current (3I,CT)**: 100 A : 1 A. The residual voltage Uo: **Configuration/Analog inputs/Voltage (3U,VT)**: 20.000 kV : 100 V. The *Residual Current start value* of 1.0 x In corresponds to 1.0 * 100 A = 100 A in the primary. The *Residual Voltage start value* of 1.0 x Un corresponds to 1.0 * 20.000 kV = 20.000 kV in the primary.

If "Calculated Uo" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual Voltage start value is 0.577 x Un. The calculated Uo requires that all the three phase-to-earth voltages are connected to the IED. Uo cannot be calculated from the phase-to-phase voltages.

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 IED 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 signal Sel* 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 signal Sel* is set to "Measured Uo" or "Calculated Uo", the residual current and residual voltage are used for directional calculation.

If *Pol signal Sel* 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 diagram in the application engineering guide). 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 226: 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 IED 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 the Directional earth-fault characteristics section in this manual.

For definitions of different directional earth-fault characteristics, refer to general function block features information.

The directional calculation module calculates several values which are presented in the monitored data.

Table 227: Monitored data values

Monitored data values	Description
FAULT_DIR	The detected direction of fault during fault situations, that is, when START output is active.
DIRECTION	The momentary operating direction indication output.
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).

Monitored data values are accessible on the LHMI or through tools via communications.

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. 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 the IDMT curves for overcurrent protection section 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 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, 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.

4.2.2.5 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

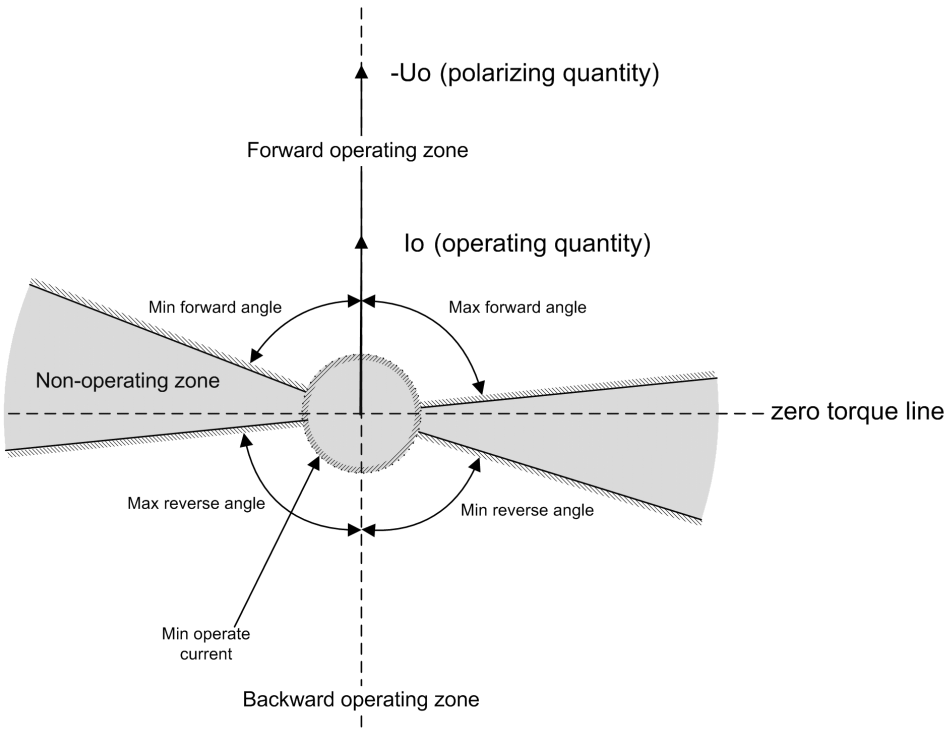


Figure 99: Definition of the relay characteristic angle, RCA=0 degrees in a compensated network

Example 2

The "Phase angle" mode is selected, solidly earthed network (φRCA = +60 deg)

=> *Characteristic angle* = +60 deg

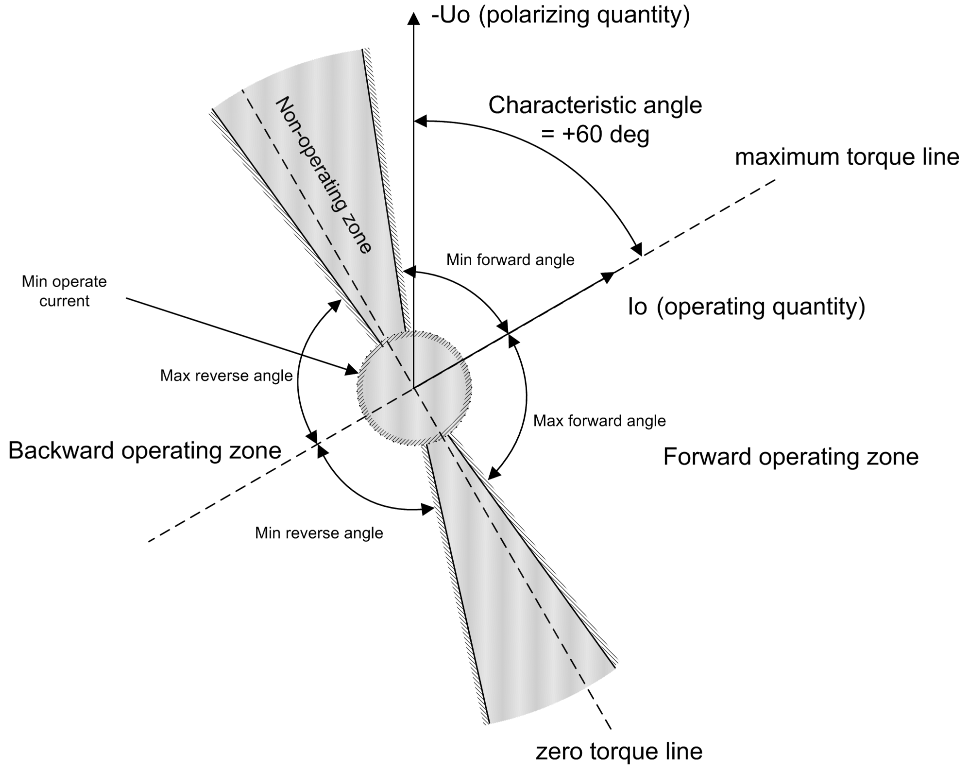


Figure 100: Definition of the relay characteristic angle, RCA=+60 degrees in a solidly earthed network

Example 3

The "Phase angle" mode is selected, isolated network (φRCA = -90 deg)

=> *Characteristic angle* = -90 deg

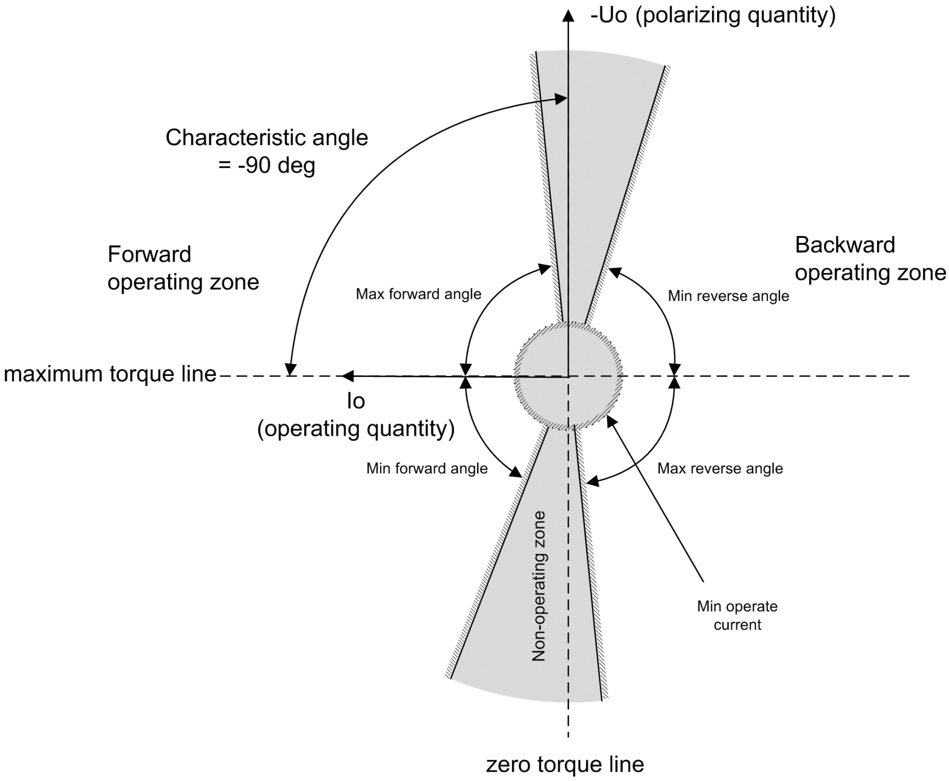


Figure 101: Definition of the relay characteristic angle, RCA=–90 degrees in an isolated network

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 102 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 Directional earth-fault principles.

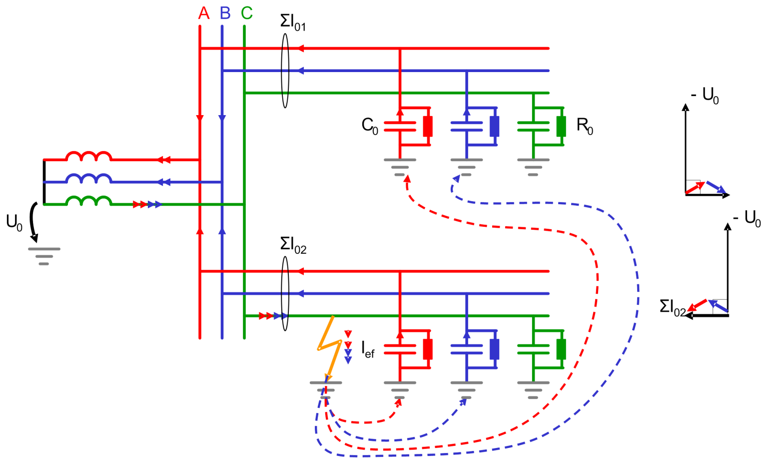


Figure 102: Earth-fault situation in an isolated network

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 IEDs. 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 relay characteristic angle (RCA) should be set to 0 degrees and the operation criteria to "IoCos" or "Phase angle". Figure 103 illustrates a simplified equivalent circuit for a compensated network with an earth fault in phase C.

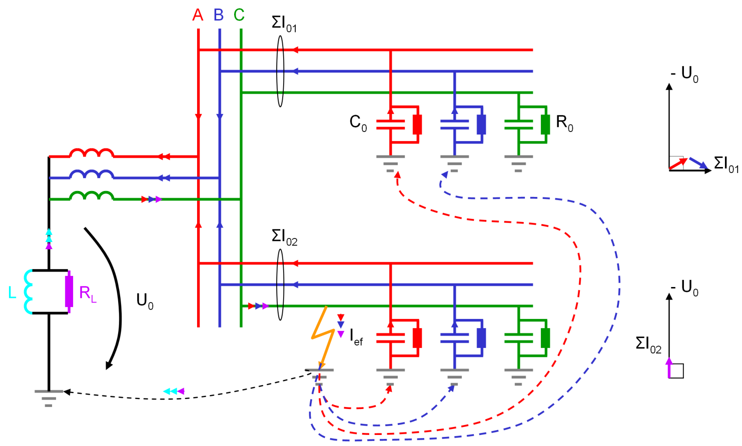


Figure 103: Earth-fault situation in a compensated network

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 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 228 and Table 229.

Table 228: 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 229: 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").

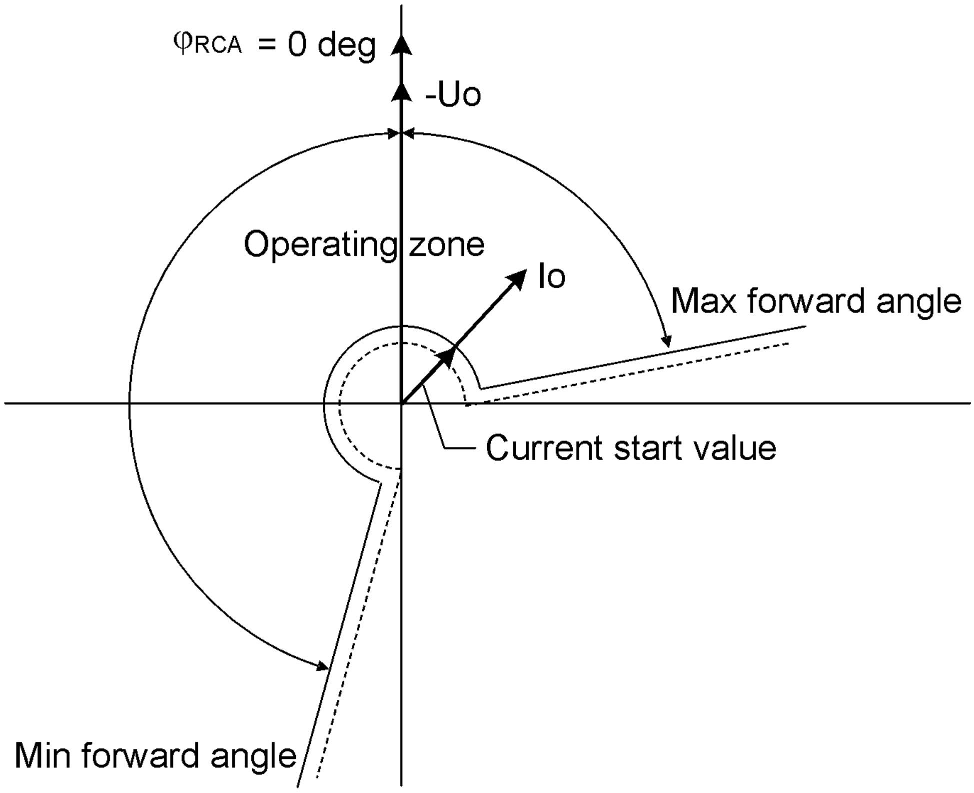


Figure 104: Extended operation area in directional earth-fault protection

4.2.2.6 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 230: 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 the Measurement modes section in this manual.

4.2.2.7 Timer characteristics

DEFxPDEF supports both DT and IDMT characteristics. The user can select the timer characteristics with the *Operating curve type* setting.

The IED 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 231: 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 the General function block features section in this manual.

Table 232: 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 programmable curves

4.2.2.8 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 function indicates with the `DIRECTION` output whether the operating quantity is within the forward or reverse operation sector or within the non-directional sector.

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.

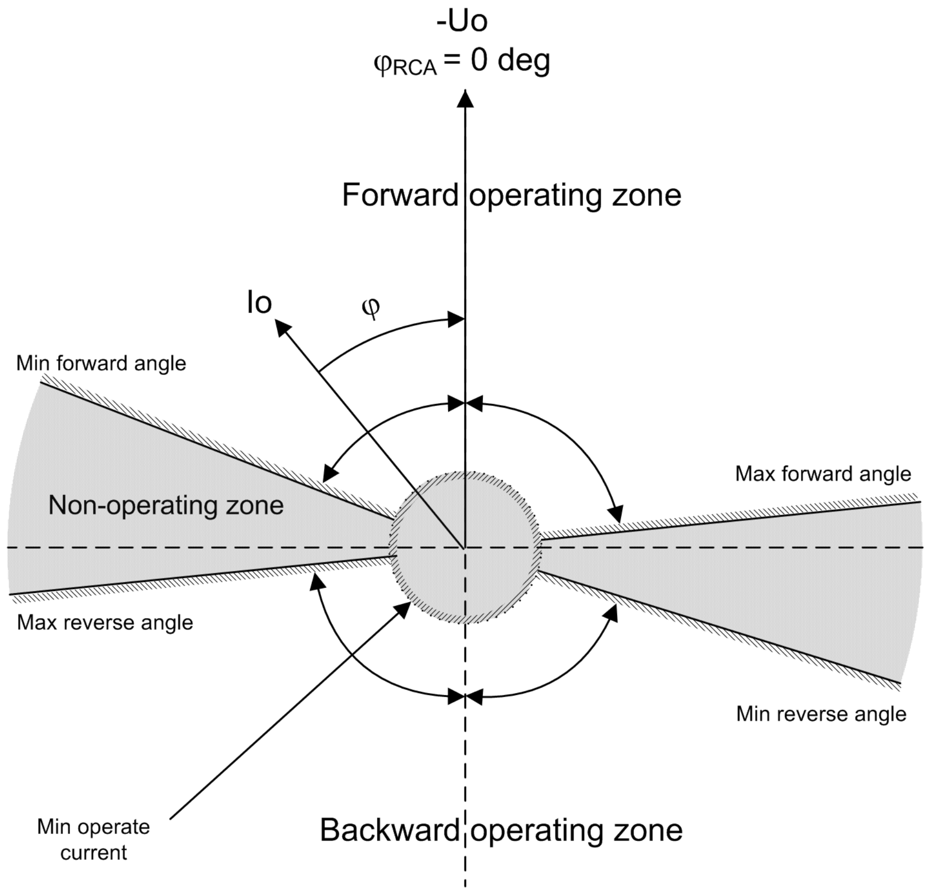


Figure 105: Configurable operating sectors in phase angle characteristic

Table 233: 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 234: Relay characteristic angle control in the IoSin and IoCos operation criteria

Operation mode:	RCA_CTL = "False"	RCA_CTL = "True"
IoSin	Actual operation criterion: Iosin(φ)	Actual operation criterion: Iocos(φ)
IoCos	Actual operation criterion: Iocos(φ)	Actual operation criterion: Iosin(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
```

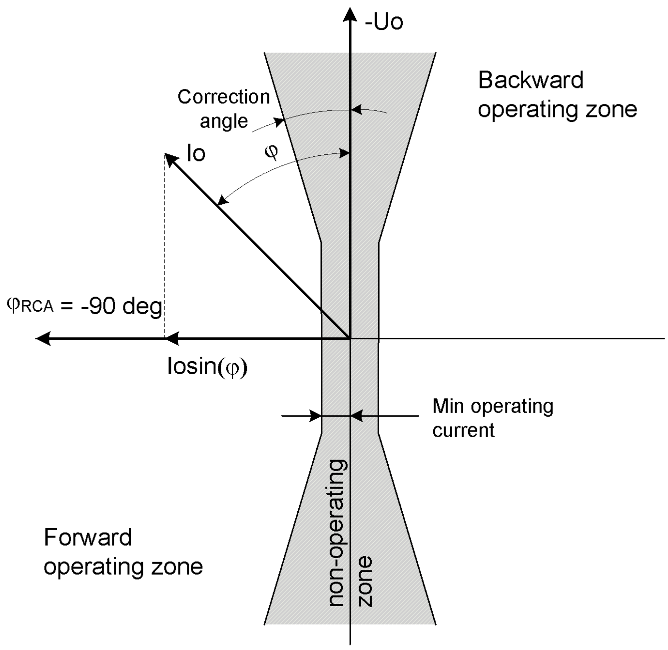


Figure 106: Operating characteristic Iosin(φ) in forward fault

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
```

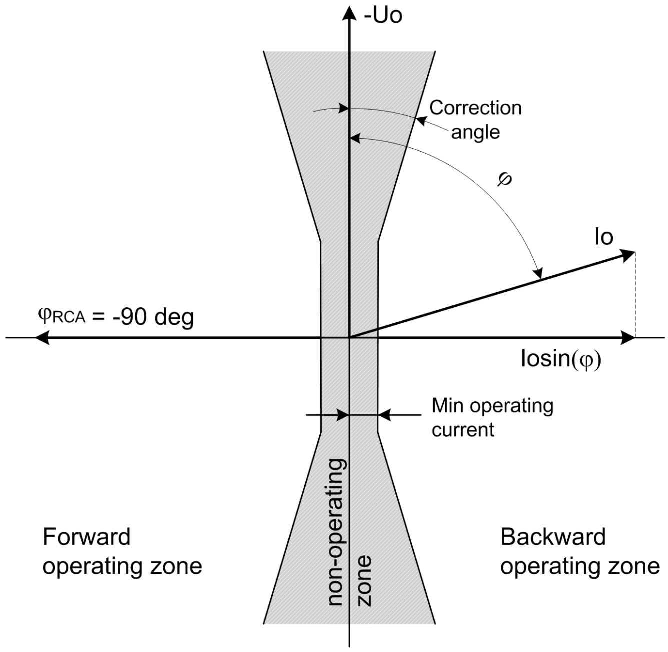


Figure 107: Operating characteristic Iosin(φ) in reverse fault

Example 3.

Iocos(φ) criterion selected, forward-type fault

`=> FAULT_DIR = 1`

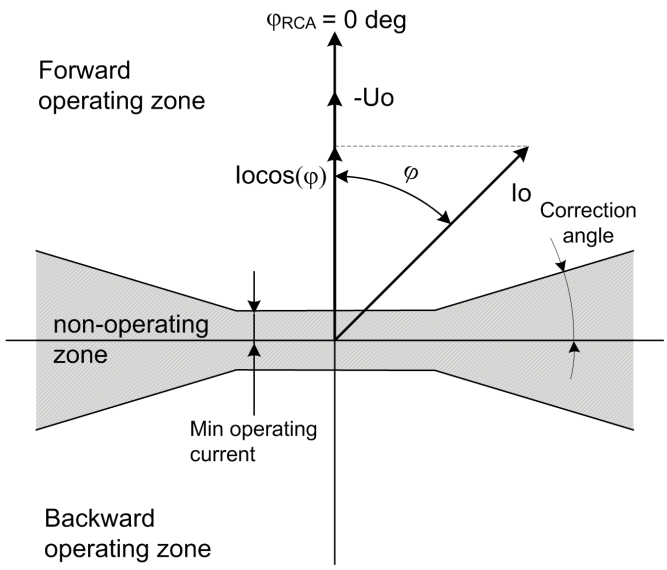


Figure 108: Operating characteristic Iocos(φ) in forward fault

Example 4.

Iocos(φ) criterion selected, reverse-type fault

`=> FAULT_DIR = 2`

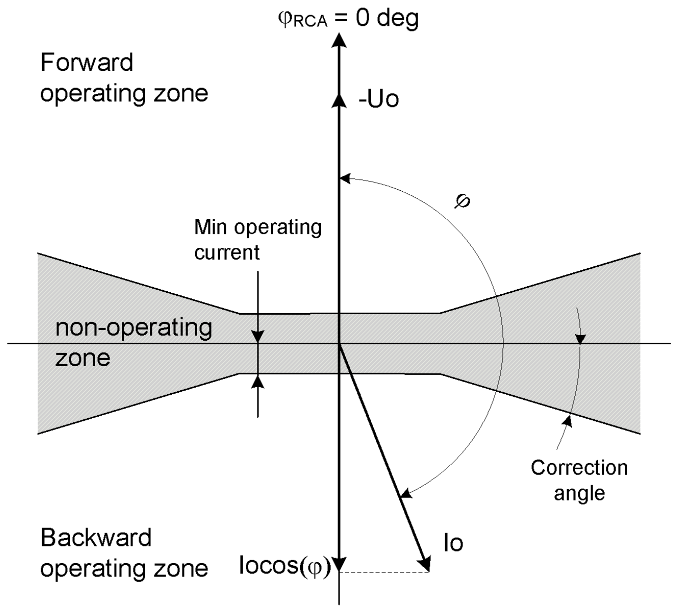


Figure 109: Operating characteristic Iocos(φ) in reverse fault

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.

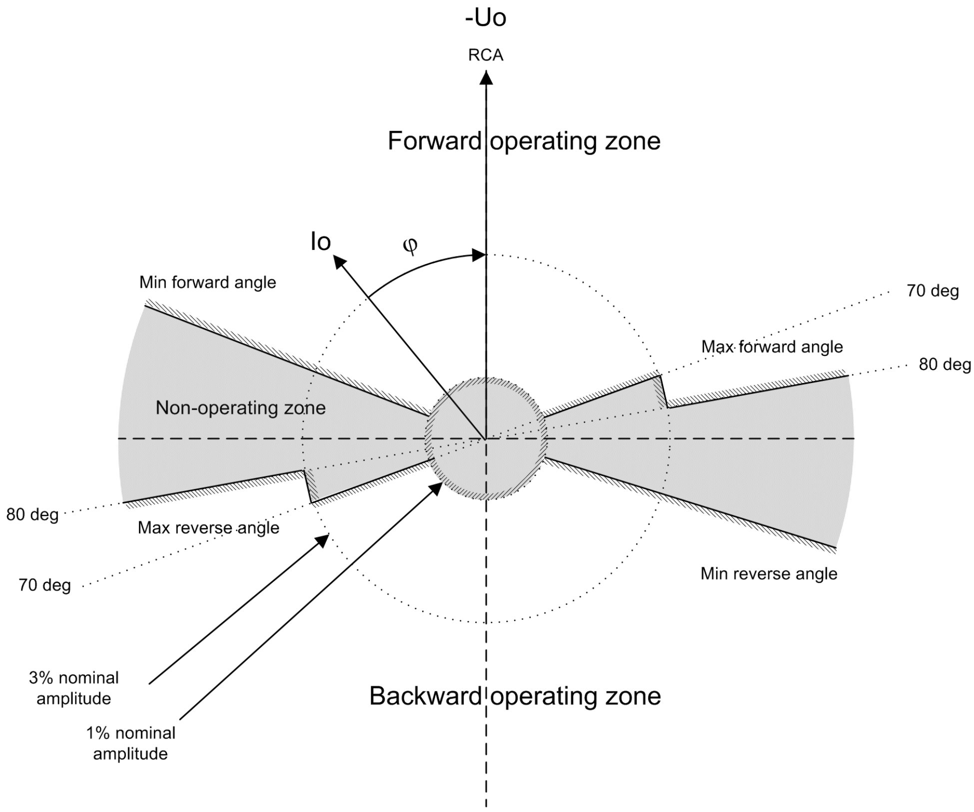


Figure 110: Operating characteristic for phase angle 80

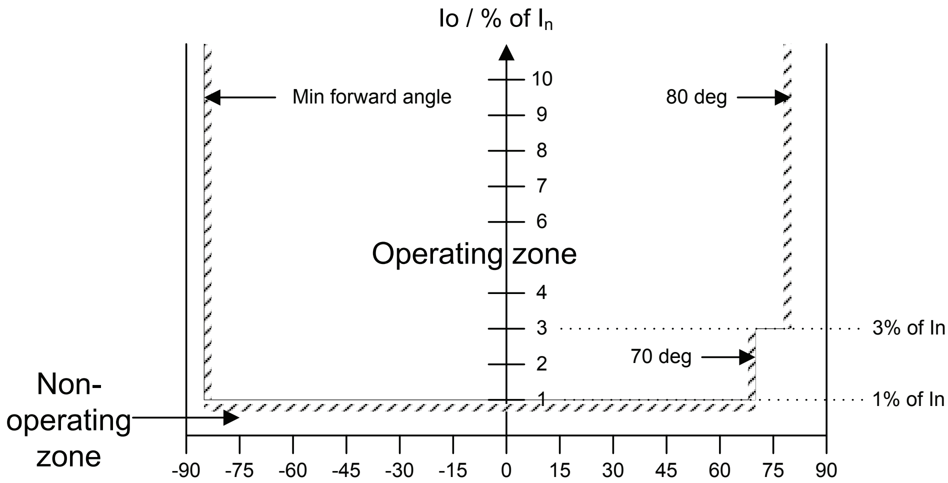


Figure 111: Phase angle 80 amplitude (Directional mode = Forward)

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.

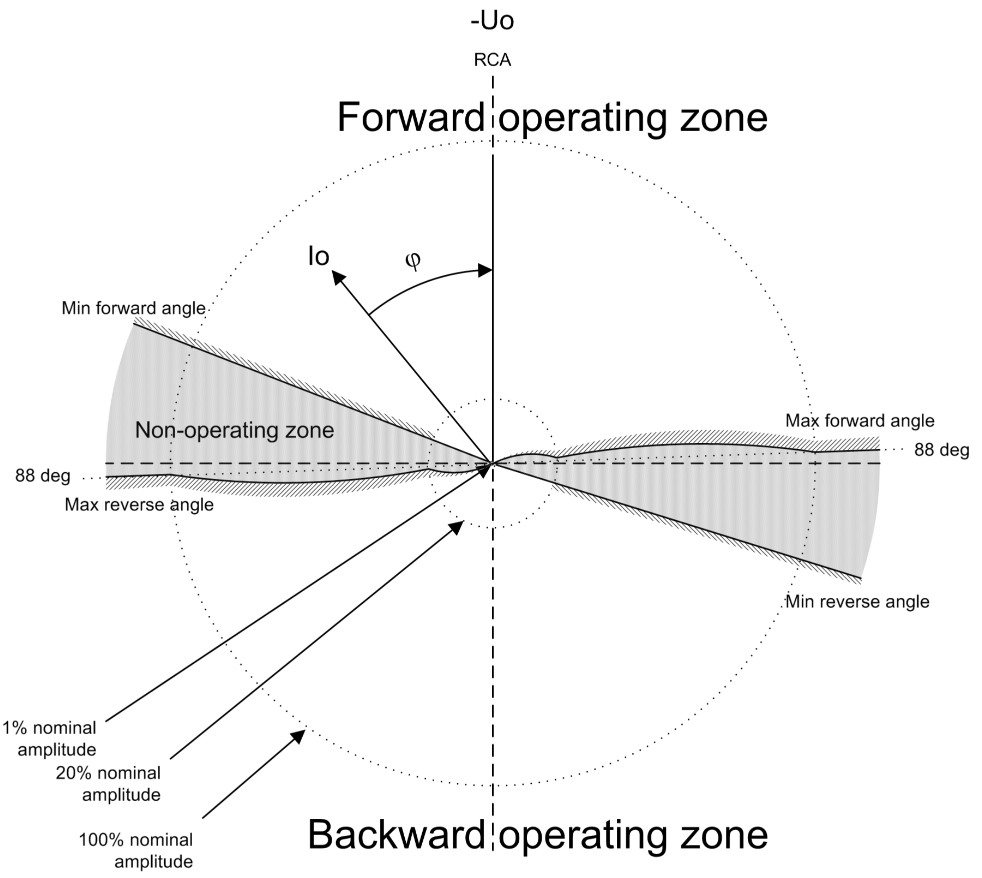


Figure 112: Operating characteristic for phase angle 88

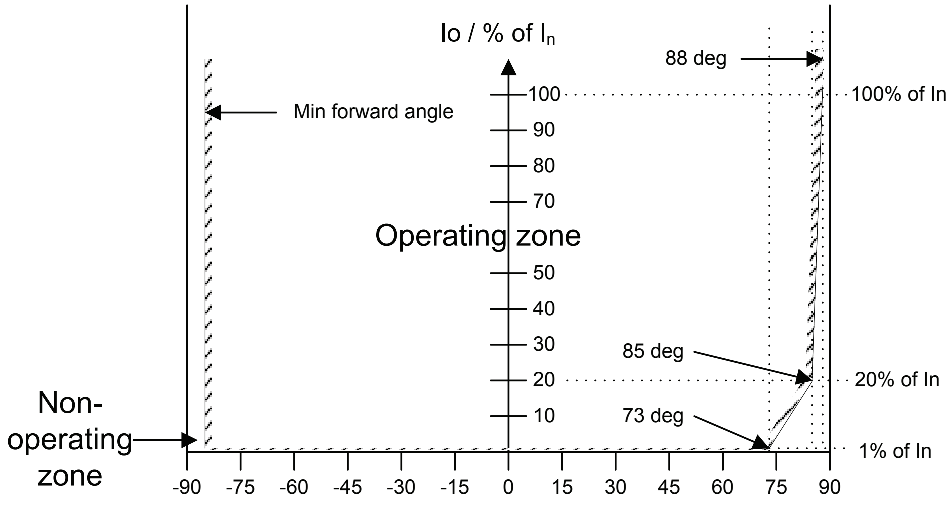


Figure 113: Phase angle 88 amplitude (Directional mode = Forward)

4.2.2.9 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 IED.

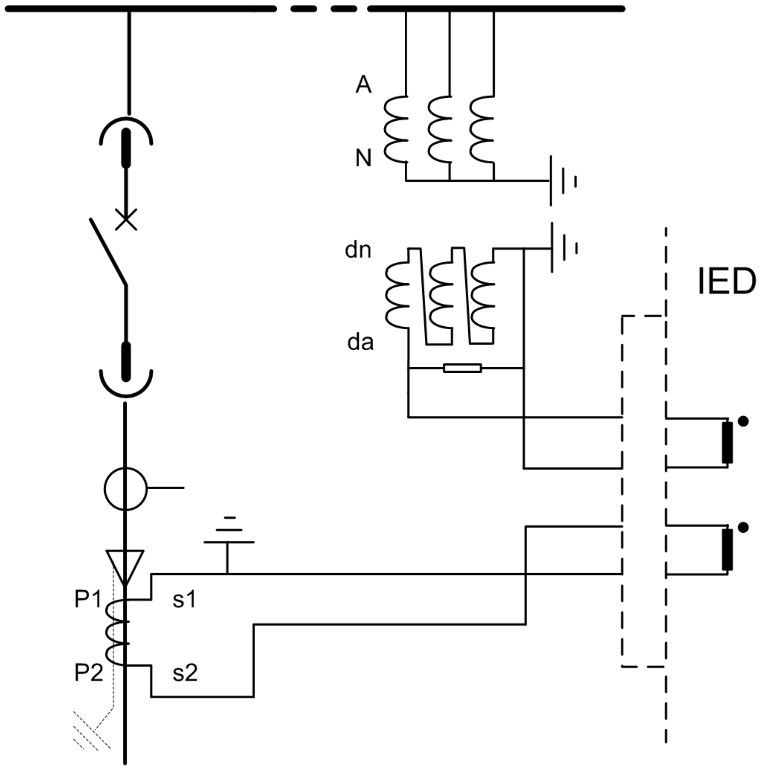


Figure 114: Connection of measuring transformers

4.2.2.10 Signals

Table 235: DEFLPDEF Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	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

Table 236: DEFHPDEF Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	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

Table 237: DEFLPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

Table 238: DEFHPDEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.2.11 Settings

Table 239: DEFLPDEF Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.010...5.000	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	0.05...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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Operate delay time	60...200000	ms	10	60	Operate delay time
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
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 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
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

Table 240: DEFLPDEF Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	1	20	Reset delay time
Minimum operate time	60...60000	ms	1	60	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	0.005...1.000	xIn	0.001	0.005	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Angle correction
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Pol signal Sel	2=Calculated Uo			2=Calculated Uo	Selection for used polarization signal

Table 241: DEFHPDEF Group settings

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	0.05...15.00		0.01	1.00	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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type
Operate delay time	40...200000	ms	10	40	Operate delay time
Operation mode	1=Phase angle 2=IoSin 3=IoCos 4=Phase angle 80 5=Phase angle 88			1=Phase angle	Operation criteria
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
Enable voltage limit	0=False 1=True			1=True	Enable voltage limit

Table 242: DEFHPDEF Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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	0.005...1.000	xIn	0.001	0.005	Minimum operating current
Min operate voltage	0.01...1.00	xUn	0.01	0.01	Minimum operating voltage
Correction angle	0.0...10.0	deg	0.1	0.0	Angle correction

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Pol reversal	0=False 1=True			0=False	Rotate polarizing quantity
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Pol signal Sel	2=Calculated Uo			2=Calculated Uo	Selection for used polarization signal

4.2.2.12 Monitored data

Table 243: DEFLPDEF 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_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		Calculated operating current
DEFLPDEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

Table 244: DEFHPDEF 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_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		Calculated operating current
DEFHPDEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.2.13 Technical data

Table 245: 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 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°

Table continues on next page

Characteristic		Value		
Start time 1)2)		Minimum	Typical	Maximum
	DEFHPDEF I_{Fault} = 2 × set *Start value*	42 ms	44 ms	46 ms
	DEFLPDEF I_{Fault} = 2 × set *Start value*	61 ms	64 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 3) ±5.0% of the theoretical value or ±40 ms 3)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		

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
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 1.5...20
4) Valid for FDEFLPDEF

4.2.2.14 Technical revision history

Table 246: DEFHPDEF Technical revision history

Technical revision	Change
B	Maximum value changed to 180 deg for the *Max forward angle* setting
C	Added a setting parameter for the "Measured Io" or "Calculated Io" selection and setting parameter for the "Measured Uo", "Calculated Uo" or "Neg. seq. volt." selection for polarization. *Operate delay time* and *Minimum operate time* changed from 60 ms to 40 ms. The sector default setting values are changed from 88 degrees to 80 degrees.
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

Table 247: DEFLPDEF Technical revision history

Technical revision	Change
B	Maximum value changed to 180 deg for the *Max forward angle* setting. *Start value* step changed to 0.005
C	Added a setting parameter for the "Measured Io" or "Calculated Io" selection and setting parameter for the "Measured Uo", "Calculated Uo" or "Neg. seq. volt." selection for polarization. The sector default setting values are changed from 88 degrees to 80 degrees.
D	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

4.2.3 Transient/intermittent earth-fault protection INTRPTEF

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	67NIEF

4.2.3.2 Function block

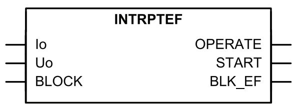


Figure 115: Function block

4.2.3.3 Functionality

The transient/intermittent measuring earth-fault protection 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, if desired.

4.2.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of transient/intermittent earth-fault protection can be described with a module diagram.

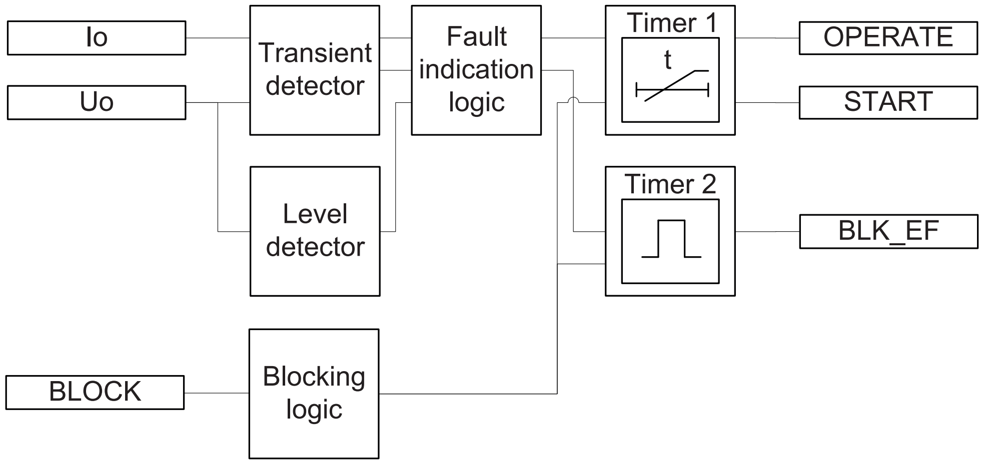


Figure 116: Functional module diagram. Io and Uo stand for residual current and residual voltage

Level detector

The residual voltage can be selected from the *Uo signal Sel* setting. The options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in the global setting **Configuration/Analog inputs/ Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from phase-voltage channels given in the global setting **Configuration/Analog inputs/ Voltage (3U,VT)**.

Example 1: Uo is measured from open-delta connected VTs (20/sqrt(3) kV : 100/ sqrt(3) V : 100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from VT ratios entered in Residual voltage Uo: **Configuration/Analog inputs/Voltage (Uo,VT)**: 11.547 kV :100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 11.547 kV = 11.547 kV in the primary.

Example 2: Uo is calculated from phase quantities. The phase VT-ratio is 20/ sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal values for residual current and residual voltage are obtained from VT ratios entered in Residual voltage Uo: **Configuration/Analog inputs/Voltage (3U,VT)**: 20.000 kV : 100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 20.000 kV = 20.000 kV in the primary.

If "Calculated Uo" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage start value is 0.577 × Un. Calculated Uo requires that all three phase-to-earth voltages are connected to the IED. Uo cannot be calculated from the phase-to-phase voltages.

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*.

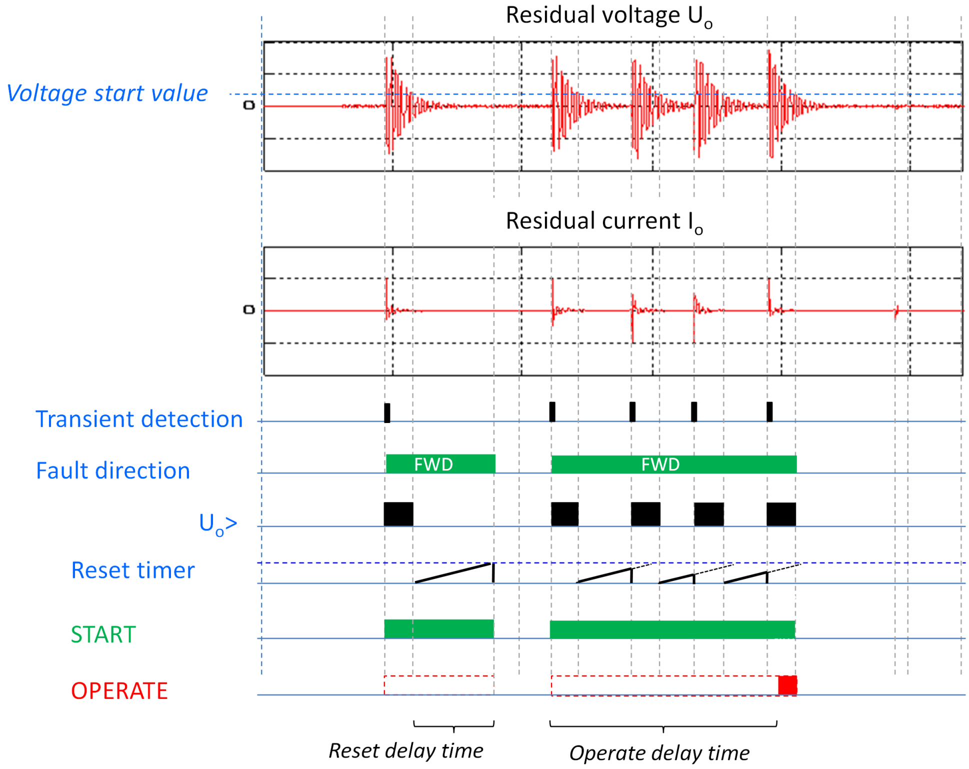


Figure 117: Example of INTRPTEF operation in "Transient EF" mode in the faulty feeder

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

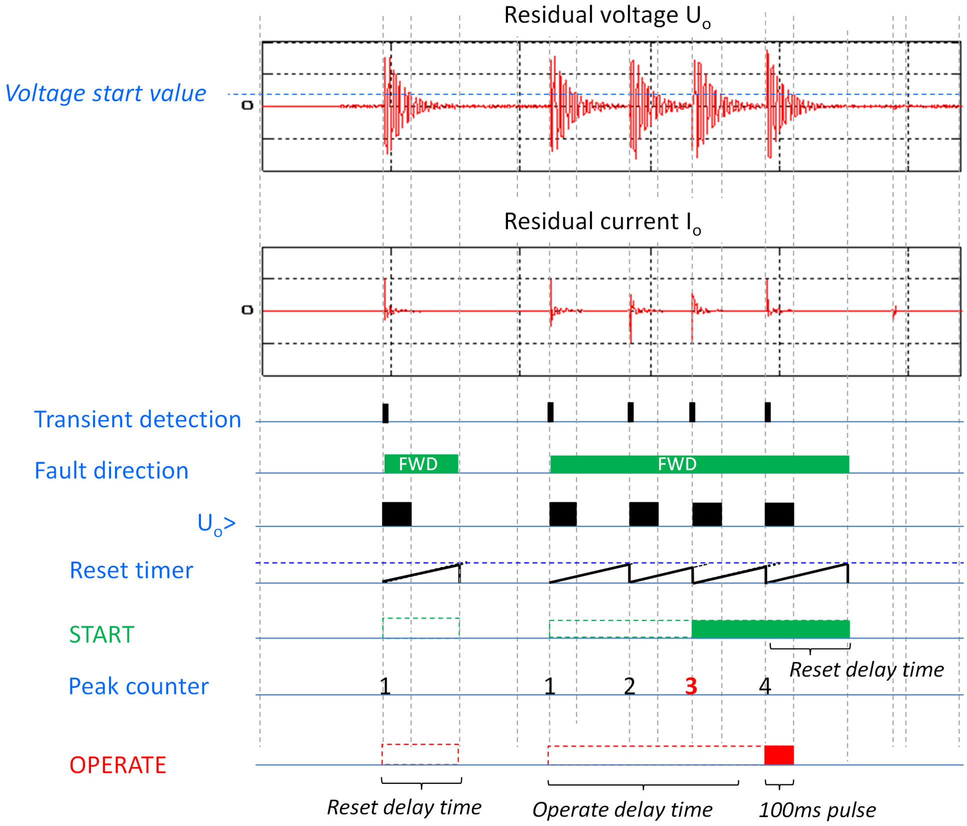


Figure 118: Example of INTRPTEF operation in "Intermittent EF" mode in the faulty feeder, Peak counter limit=3

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 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, the function operates normally but the OPERATE output is not activated.

4.2.3.5 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 119. 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.

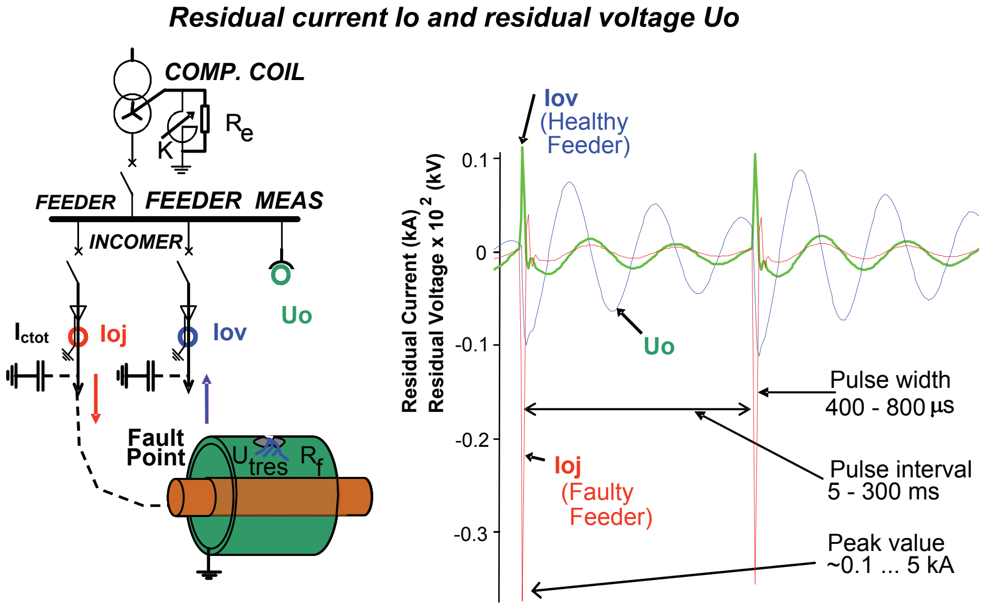


Figure 119: Typical intermittent earth-fault characteristics

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.

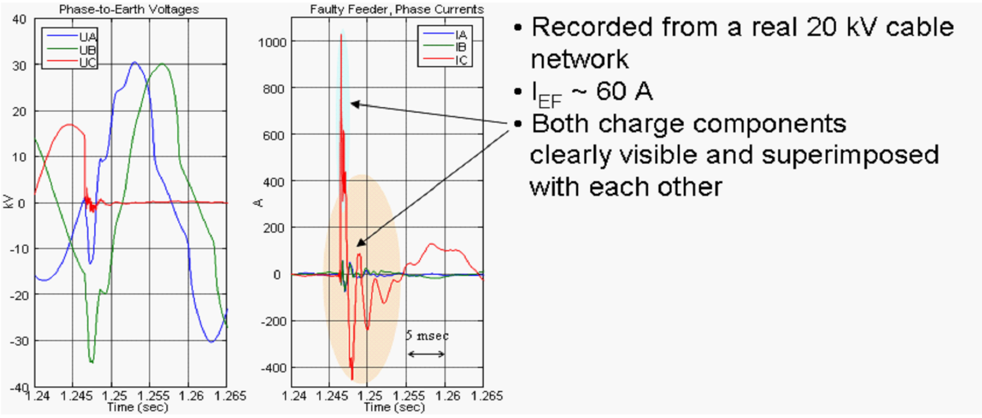


Figure 120: Example of earth-fault transients, including discharge and charge transient components, when a permanent fault occurs in a 20 kV network in phase C

4.2.3.6 Signals

Table 248: INTRPTEF Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 249: INTRPTEF Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start
BLK_EF	BOOLEAN	Block signal for EF to indicate opposite direction peaks

4.2.3.7 Settings

Table 250: INTRPTEF Group settings

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 251: INTRPTEF Non group settings

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
Reset delay time	40...60000	ms	1	500	Reset delay time
Peak counter limit	2...20			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 transient detector
Uo signal Sel	1=Measured Uo 2=Calculated Uo			1=Measured Uo	Selection for used Uo signal

4.2.3.8 Monitored data

Table 252: 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 / operate time
INTRPTEF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

4.2.3.9 Technical data

Table 253: 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 × Uo
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

4.2.3.10 Technical revision history

Table 254: INTRPTEF Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	The *Minimum operate current* setting is added. Correction in IEC61850 mapping: DO BlkEF renamed to InhEF. Minimum value changed from 0.01 to 0.10 (default changed from 0.01 to 0.20) for the *Voltage start value* setting. Minimum value changed from 0 ms to 40 ms for the *Reset delay time* setting.
D	Voltage start value description changed from "Voltage start value for transient EF" to "Voltage start value" since the start value is effective in both operation modes. Added support for calculated Uo. Uo source (measured/calculated) can be selected with "Uo signal Sel". *Voltage start value* setting minimum changed from 0.10 to 0.05.

4.2.4 Admittance-based earth-fault protection EFPADM

4.2.4.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Admittance-based earth-fault protection	EFPADM	Yo>->	21YN

4.2.4.2 Function block

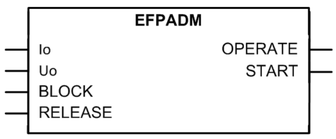


Figure 121: Function block

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:

$$\underline{Y}o = \underline{I}o / -\underline{U}o$$

(Equation 6)

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, if desired.

4.2.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the admittance-based earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

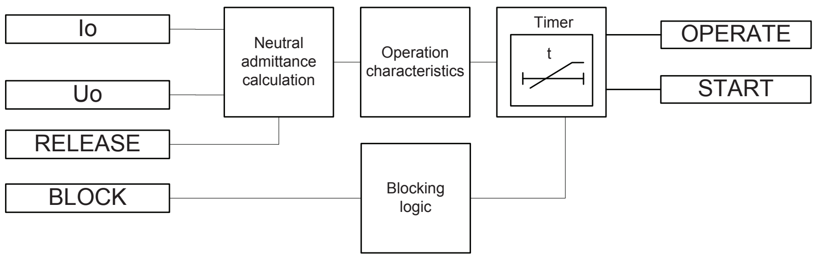


Figure 122: Functional module diagram

Neutral admittance calculation

The residual current can be selected from the *Io signal Sel* setting. The setting options are "Measured Io" and "Calculated Io". If "Measured Io" is selected, the current ratio for Io-channel is given in **Configuration/Analog inputs/Current**

(Io,CT). If "Calculated Io" is selected, the current ratio is obtained from phase-current channels given in **Configuration/Analog inputs/Current (3I,CT)**.

Respectively, the residual voltage can be selected from the *Uo signal Sel* setting. The setting options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in **Configuration/Analog inputs/Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from phase-voltage channels given in **Configuration/Analog inputs/ Voltage (3U,VT)**.

Example 1: Uo is measured from open-delta connected VTs (20/sqrt(3) kV : 100/ sqrt(3) V:100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from the VT ratios entered in *Residual voltage Uo* : **Configuration/Analog inputs/Voltage (Uo,VT)**: 11.547 kV : 100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 11.547 kV = 11.547 kV in the primary.

Example 2: Uo is calculated from phase quantities. The phase VT-ratio is 20/ sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal value for residual voltage is obtained from the VT ratios entered in Residual voltage Uo : **Configuration/Analog inputs/Voltage (3U,VT)** : 20.000kV : 100V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 20.000 kV = 20.000 kV in the primary.

In case, if "Calculated Uo" is selected, the residual voltage nominal value is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage start value is 0.577 × Un. The calculated Uo requires that all three phase-to-earth voltages are connected to the IED. Uo cannot be calculated from the phase-to-phase voltages.

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 7)

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 8)

$\underline{Y}o$	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 9)

$$\approx -j \cdot \frac{I_{eFd}}{U_{ph}}$$

(Equation 10)

$\underline{Y}_{Fdtot}$	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 9 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 123.

The result of Equation 9 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.

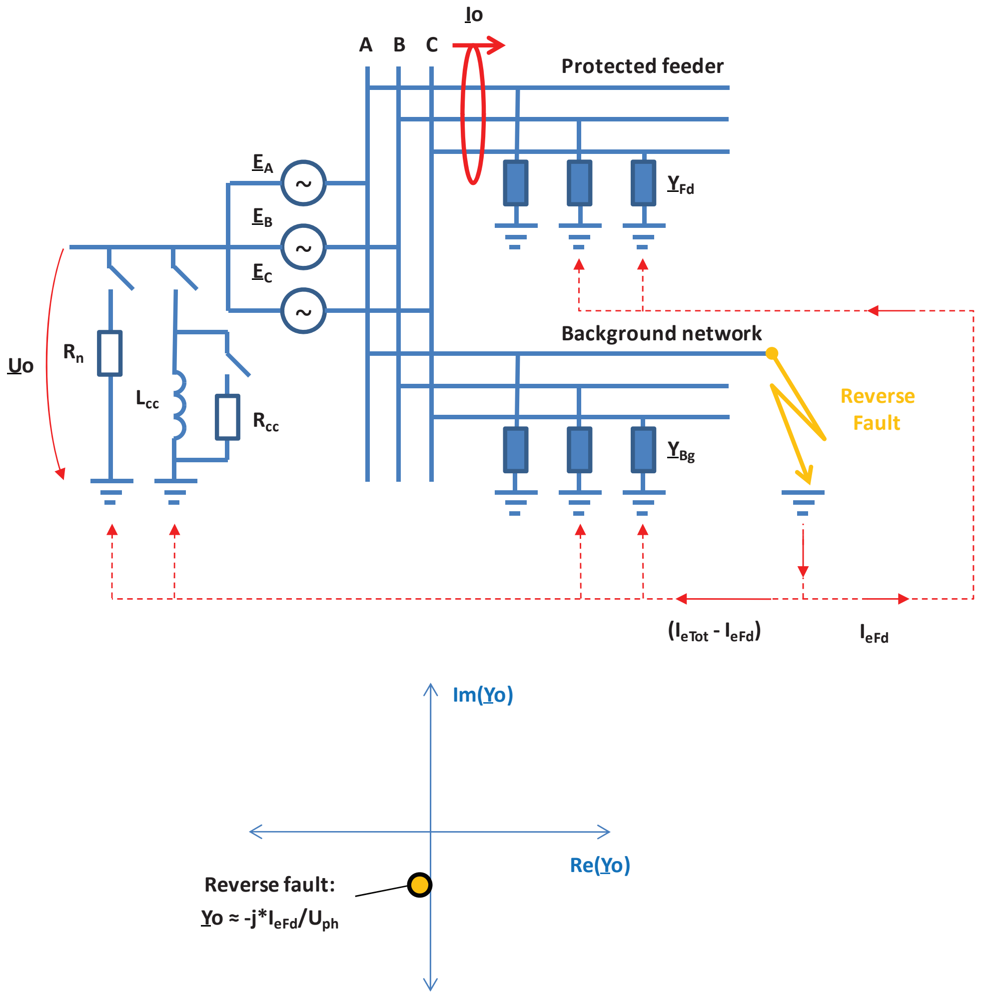


Figure 123: Admittance calculation during a reverse fault

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.

$$\underline{Yo} \approx -j \cdot \frac{I_{eFd}}{U_{ph}} = -j \cdot \frac{10A}{15/\sqrt{3}kV} = -j \cdot 1.15 \text{ milliSiemens}$$

(Equation 11)

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 12)

$$\approx j \cdot \left(\frac{I_{eTot} - I_{eFd}}{U_{ph}} \right)$$

(Equation 13)

Compensated network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC}$$

(Equation 14)

$$\approx \frac{I_{Rcc} + j \cdot \left(I_{eTot} \cdot (1 - K) - I_{eFd} \right)}{U_{ph}}$$

(Equation 15)

High-resistance earthed network:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{Rn}$$

(Equation 16)

$$\approx \frac{I_{Rn} + j \cdot \left(I_{eTot} - I_{eFd} \right)}{U_{ph}}$$

(Equation 17)

$\underline{Y}_{Bgtot}$	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
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 12 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 124.

Equation 14 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 124.

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 16 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 124.

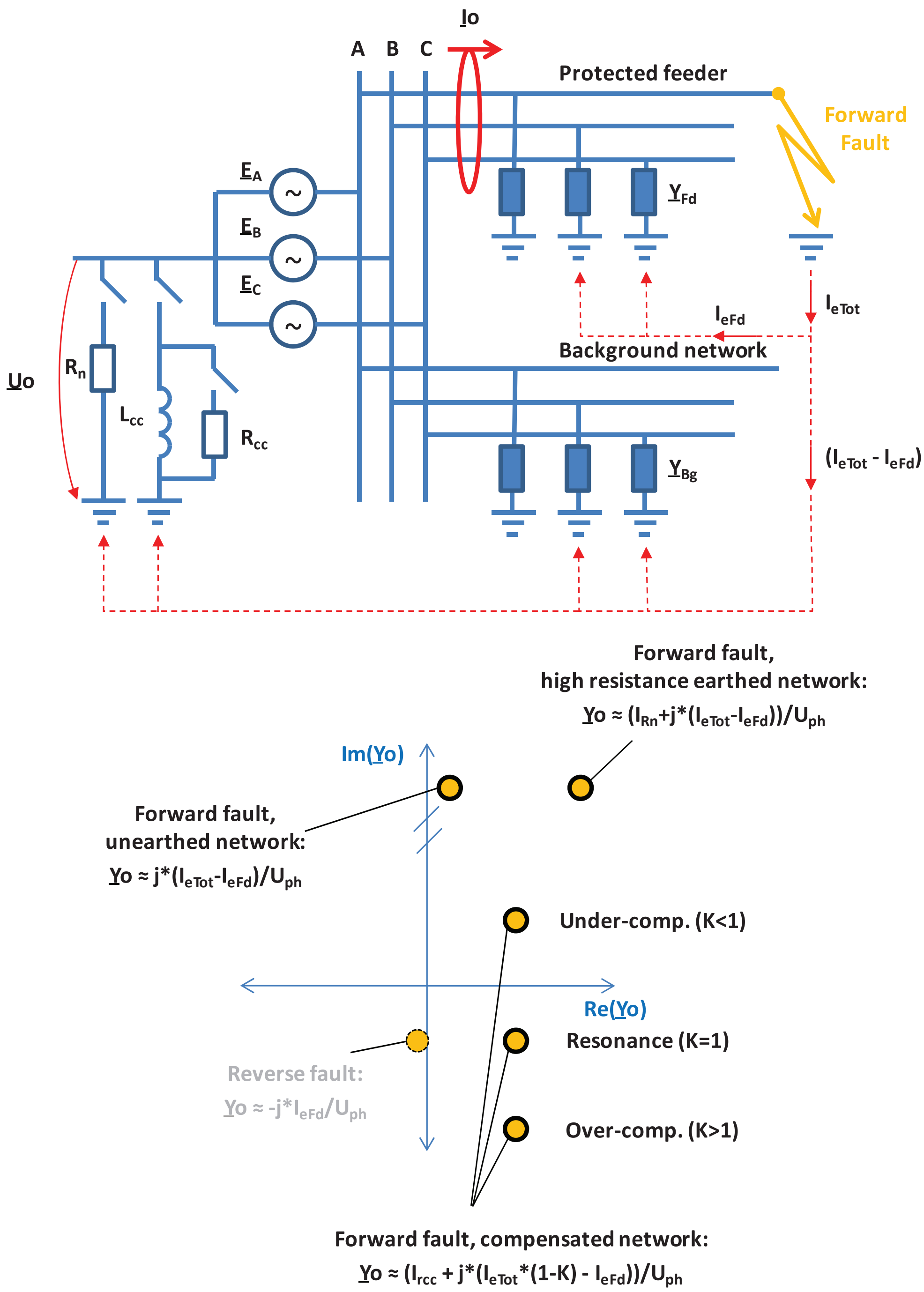


Figure 124: Admittance calculation during a forward fault

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.

$$\underline{Yo} \approx \frac{I_{Rcc} + j \cdot \left(I_{eTot} \cdot (1 - K) - I_{eFd}\right)}{U_{ph}}$$
$$= \frac{15A + j \cdot \left(100A \cdot (1 - 1.1) - 10A\right)}{15kV / \sqrt{3}} \approx (1.73 - j \cdot 2.31) \text{ milliSiemens}$$

(Equation 18)

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 $\underline{Yo}$ 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.

Table 255: Operation criteria

Operation mode	Description
Yo	Admittance criterion
Bo	Susceptance criterion
Go	Conductance criterion
Yo, Go	Admittance criterion combined with the conductance criterion
Yo, Bo	Admittance criterion combined with the susceptance criterion
Go, Bo	Conductance criterion combined with the susceptance criterion
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 125, Figure 126 and Figure 127 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 the chapter 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 19)

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.

$$Y_{pri} = 5.00\ milliSiemens \cdot \frac{100/1A}{11547/100V} = 4.33\ milliSiemens$$

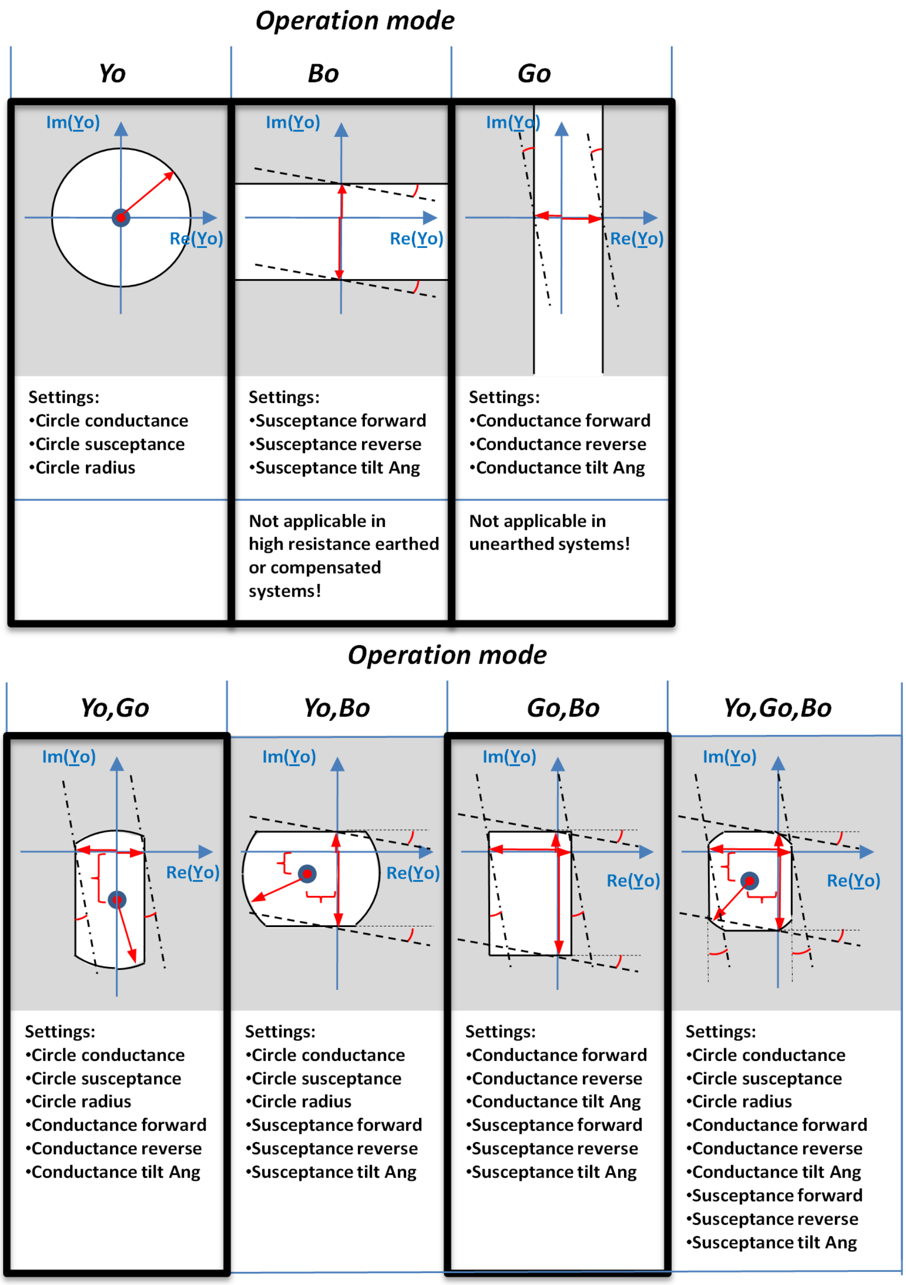


Figure 125: Admittance characteristic with different operation modes when Directional mode = "Non-directional"

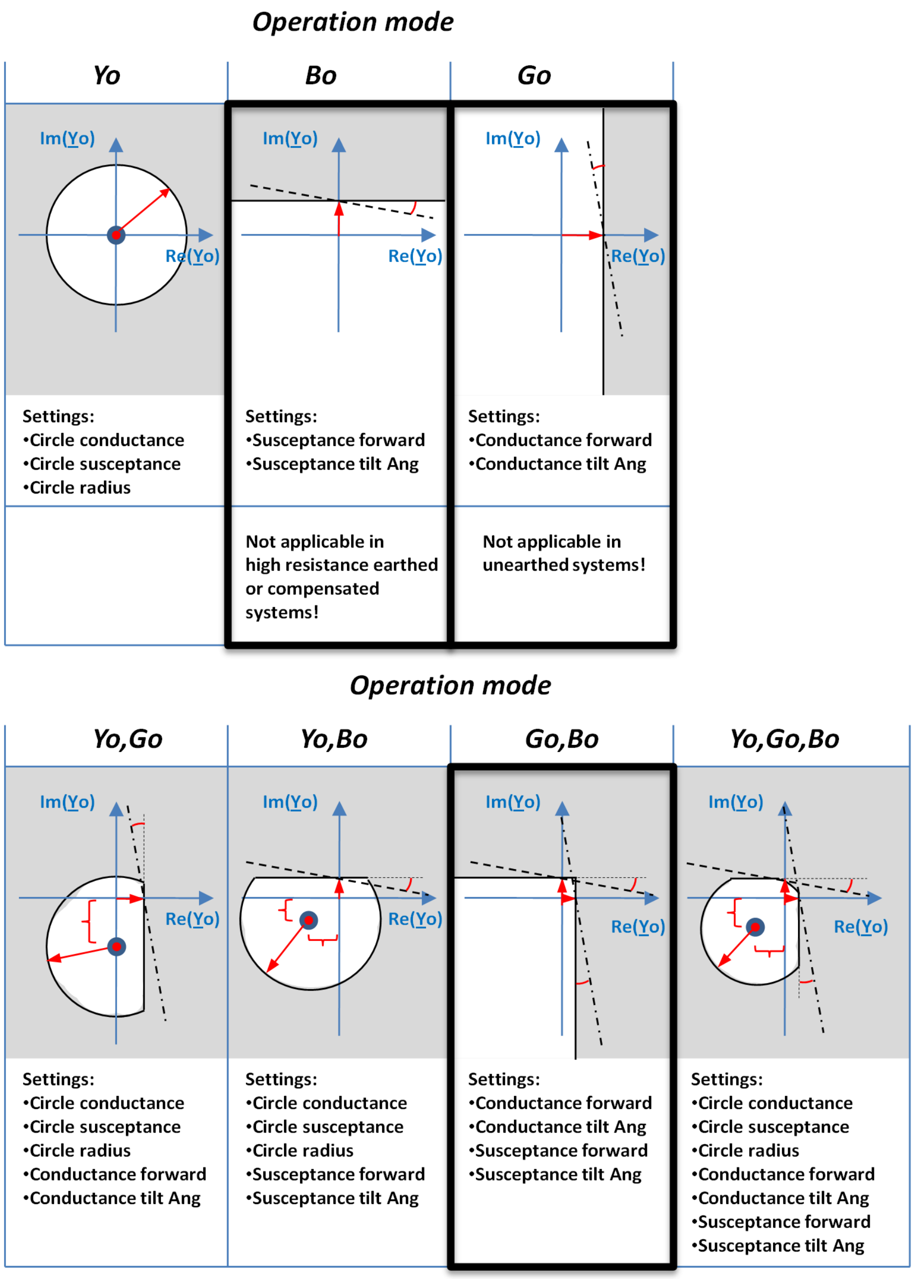


Figure 126: Admittance characteristic with different operation modes when Directional mode = "Forward"

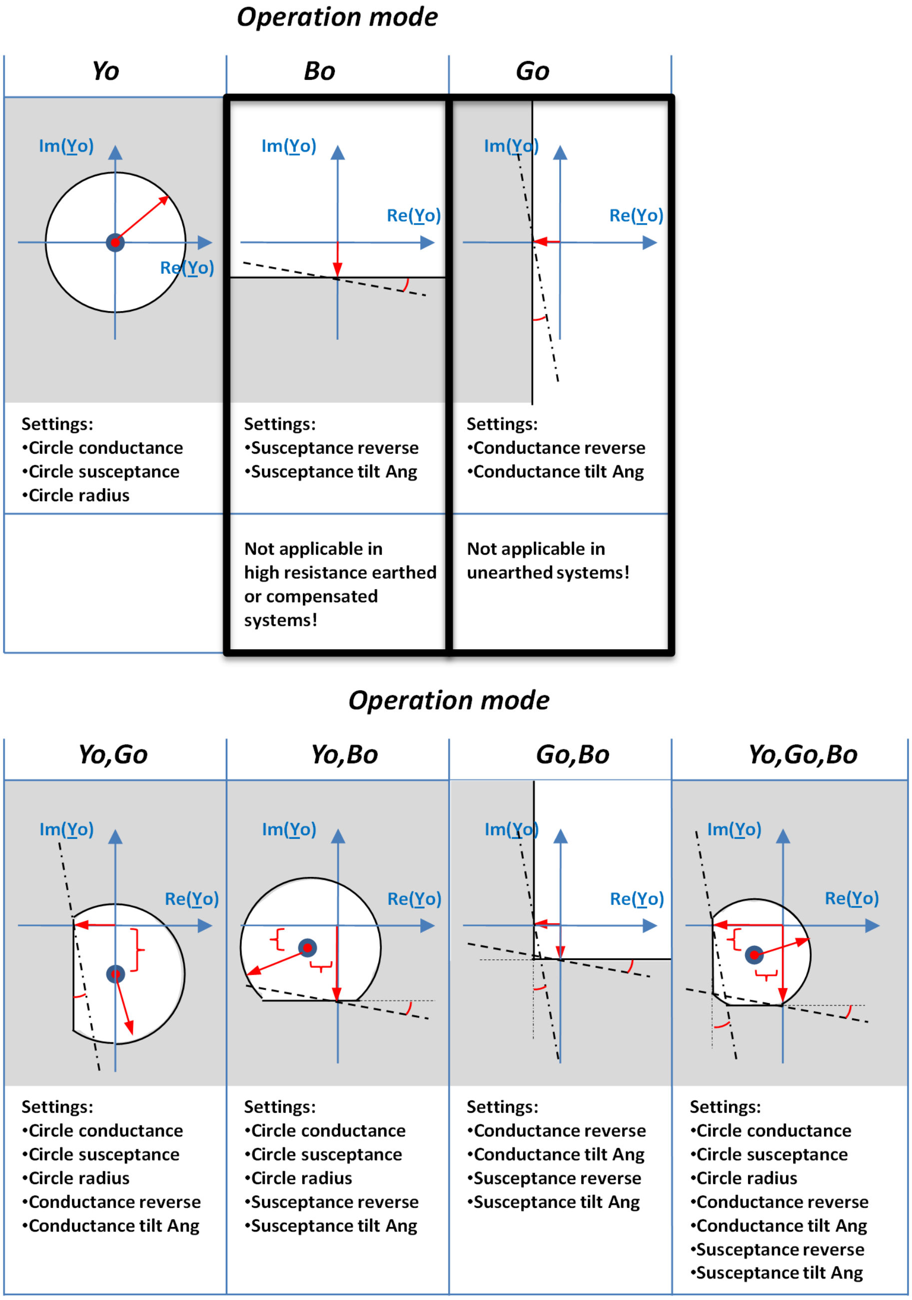


Figure 127: Admittance characteristic with different operation modes when Directional mode = "Reverse"

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 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 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.

4.2.4.5 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 larger 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.

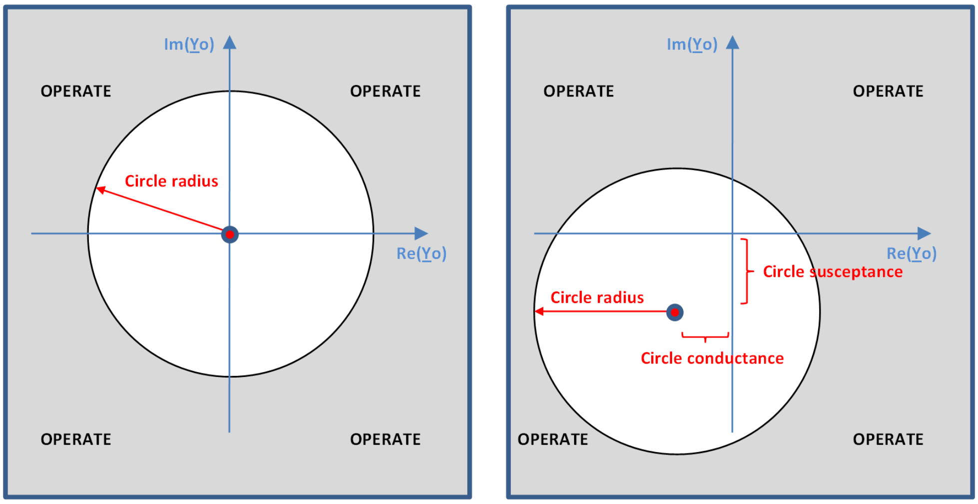


Figure 128: Overadmittance characteristic. Left figure: classical origin-centered admittance circle. Right figure: admittance circle is set off from the origin.

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.

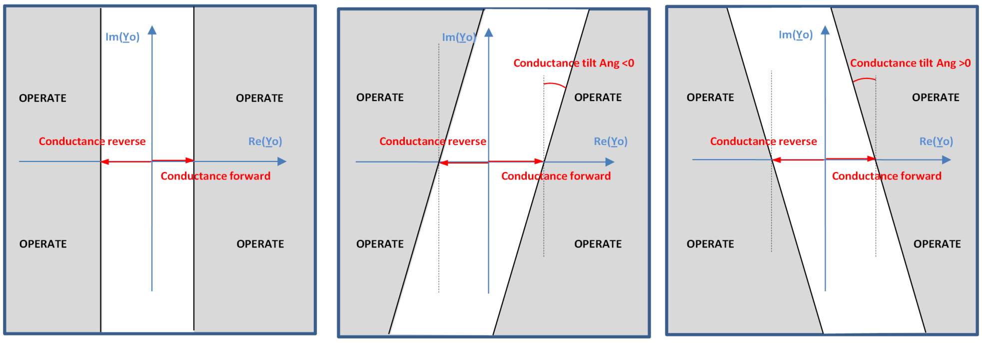


Figure 129: Non-directional overconductance characteristic. Left figure: classical non-directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

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.

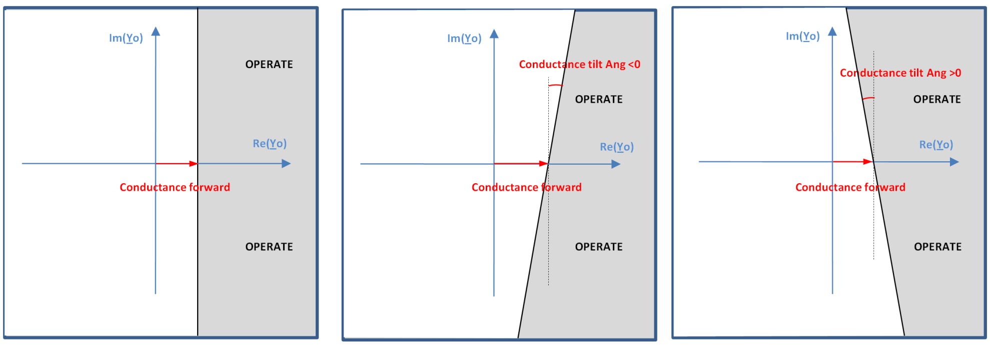


Figure 130: Forward directional overconductance characteristic. Left figure: classical forward directional overconductance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

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.

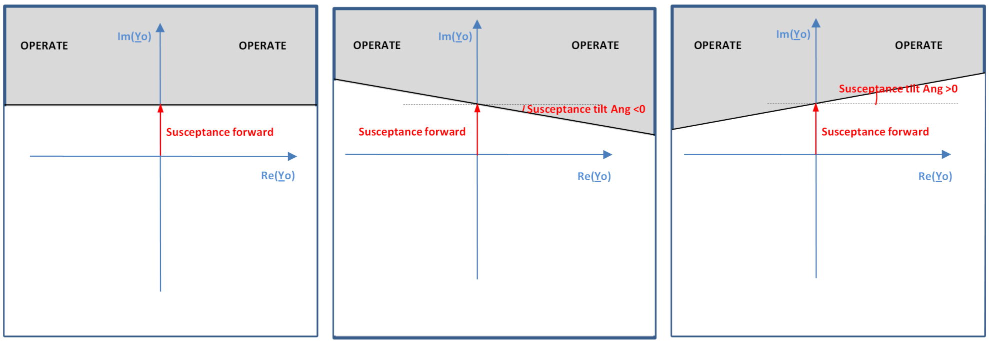


Figure 131: Forward directional oversusceptance characteristic. Left figure: classical forward directional oversusceptance criterion. Middle figure: characteristic is tilted with negative tilt angle. Right figure: characteristic is tilted with positive tilt angle.

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*. If this rule is not followed, a conflict situation is declared in the monitored data CONFLICT.

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.

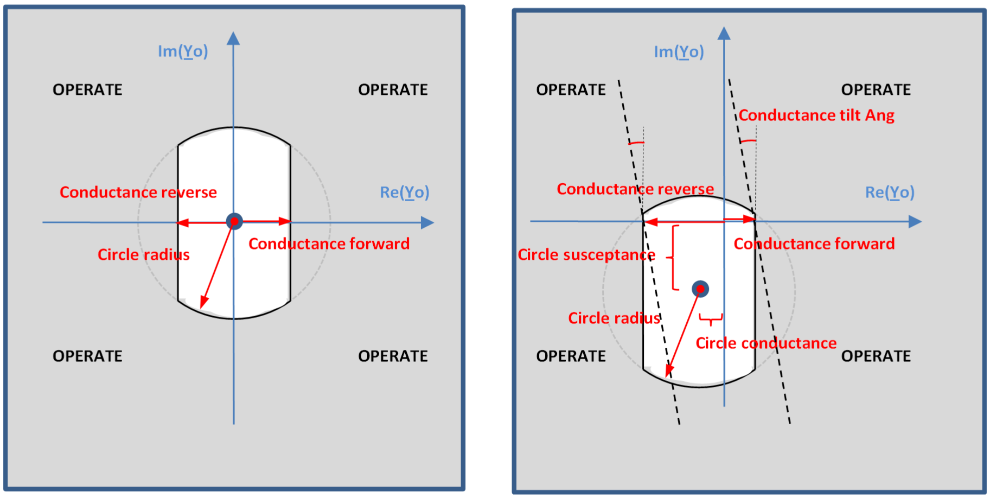


Figure 132: Combined overadmittance and overconductance characteristic. Left figure: classical origin-centered admittance circle combined with two overconductance boundary lines. Right figure: admittance circle is set off from the origin.

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 133.

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 134.

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.

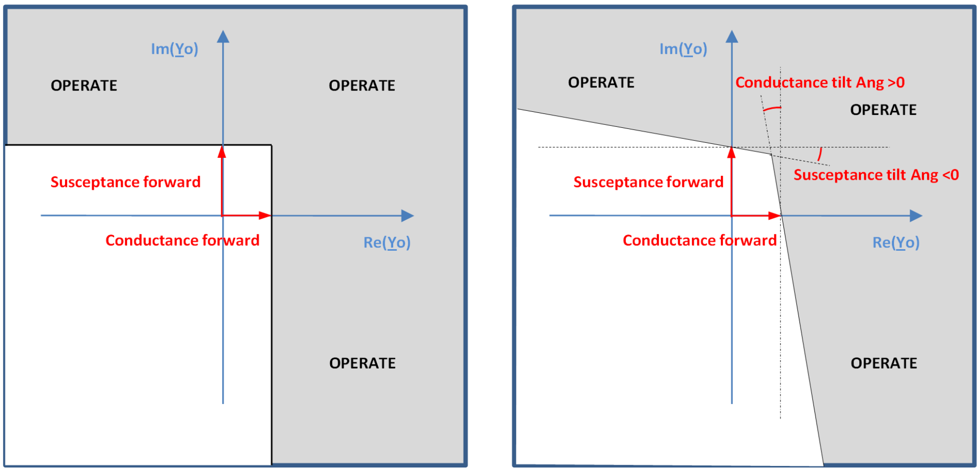


Figure 133: Combined forward directional overconductance and forward directional oversusceptance characteristic. Left figure: the Conductance tilt Ang and Susceptance tilt Ang settings equal zero degrees. Right figure: the setting Conductance tilt Ang > 0 degrees and the setting Susceptance tilt Ang < 0 degrees.

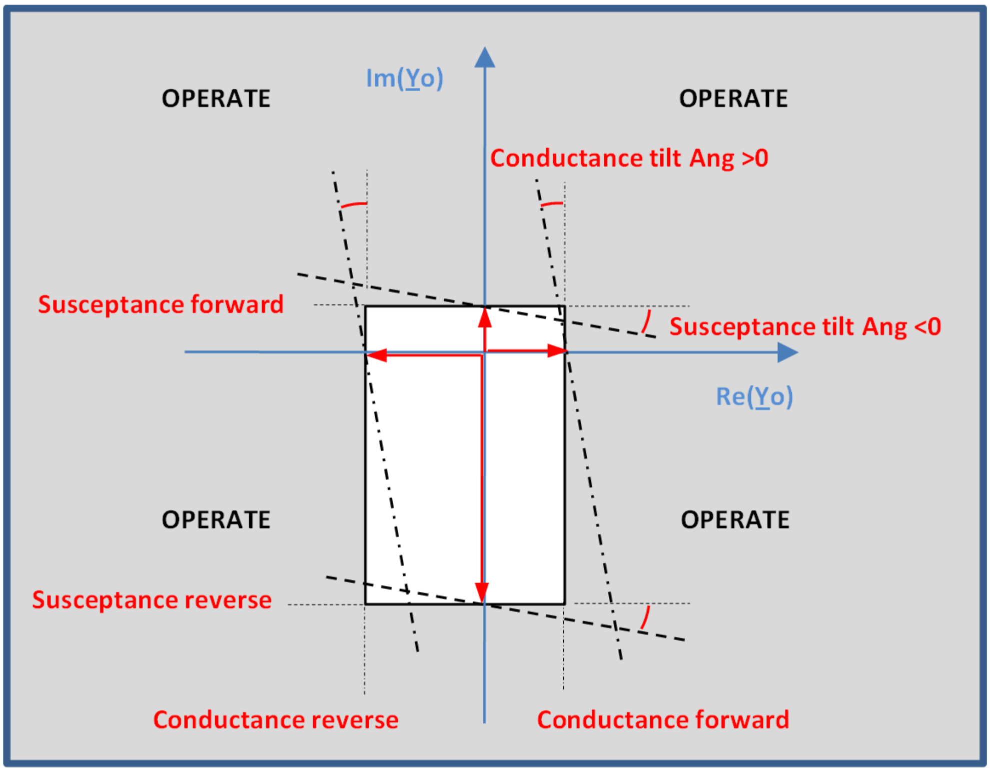


Figure 134: Combined non-directional overconductance and non-directional oversusceptance characteristic

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.

4.2.4.6 Application

Neutral admittance protection 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, 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 neutral admittance 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 neutral admittance 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 135 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.

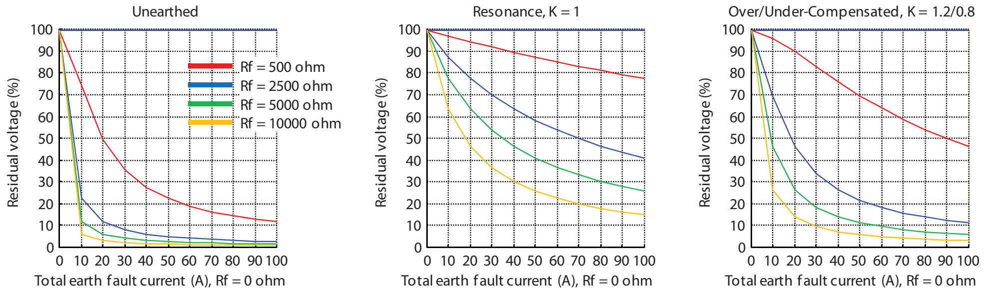


Figure 135: Influence of fault resistance on the residual voltage magnitude in 10 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

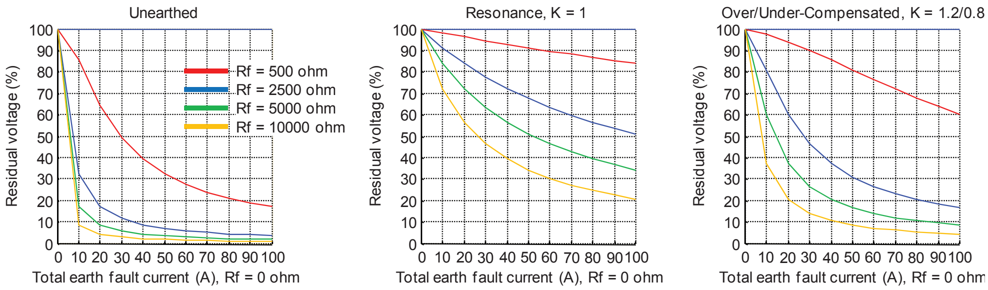


Figure 136: Influence of fault resistance on the residual voltage magnitude in 15 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to be disconnected.

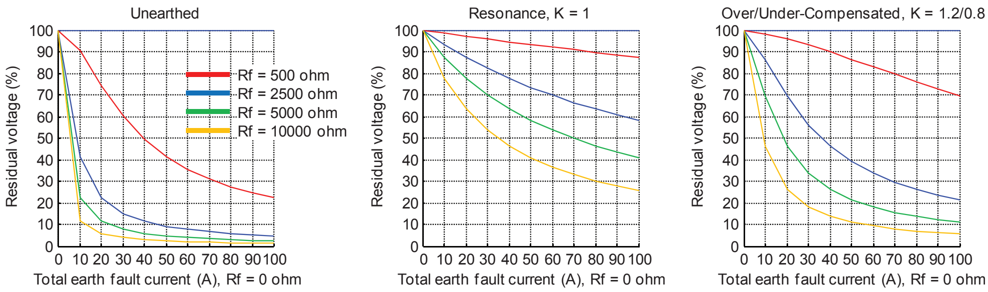


Figure 137: Influence of fault resistance on the residual voltage magnitude in 20 kV unearthed and compensated networks. The leakage resistance is assumed to be 30 times larger than the absolute value of the capacitive reactance of the network. Parallel resistor of the compensation coil is assumed to 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 neutral admittance 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 136, 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.

$$\underline{Y}_{Fdtot} = \frac{10A}{15kV/\sqrt{3}} \approx j \cdot 1.15 \text{ mS}$$

A parallel resistor current of 15 A can be converted into admittance.

$$G_{cc} = \frac{15A}{15kV/\sqrt{3}} \approx 1.73 \text{ mS}$$

According to Equation 9, during an outside fault EFPADM measures the following admittance:

$$\underline{Y}o = -\underline{Y}_{Fdtot} \approx -j \cdot 1.15 \text{ mS}$$

According to Equation 14, during an inside fault EFPADM measures the admittance after the connection of the parallel resistor:

$$\underline{Y}o = \underline{Y}_{Bgtot} + \underline{Y}_{CC} \approx (1.73 + j \cdot B) \text{ mS}$$

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 138. 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 smaller rated value of the parallel resistor, for example, 5 A (at 15 kV), the recommended security margin should be larger, 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

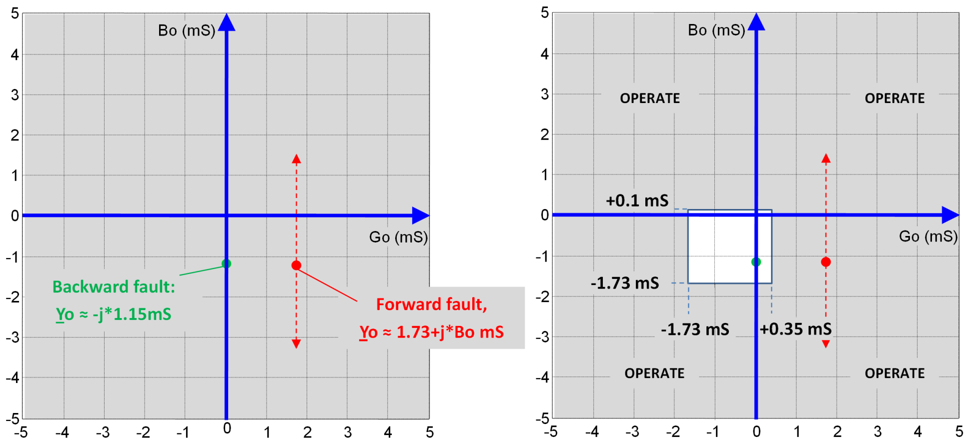


Figure 138: Admittances of the example

4.2.4.7 Signals

Table 256: EFPADM Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RELEASE	BOOLEAN	0=False	External trigger to release neutral admittance protection

Table 257: EFPADM Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.4.8 Settings

Table 258: EFPADM Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Voltage start value	0.05...5.00	xUn	0.01	0.05	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...200000	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
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
Conductance tilt Ang	-30...30	deg	1	0	Tilt angle of conductance boundary line
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
Susceptance tilt Ang	-30...30	deg	1	0	Tilt angle of susceptance boundary line

Table 259: EFPADM Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Uo signal Sel	2=Calculated Uo			2=Calculated Uo	Selection for used Uo signal

4.2.4.9 Monitored data

Table 260: EFPADM 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
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 5=off		Status

4.2.4.10 Technical data

Table 261: 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 $f = n \times f_n$, where n = 2, 3, 4, 5,…		

1) Uo = 1.0 × Un
2) Includes the delay of the signal output contact. Results based on statistical distribution of 1000 measurements.

4.2.5 Harmonic based earth-fault protection HAEFPTOC

4.2.5.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE identification
Harmonics earth-fault protection	HAEFPTOC	Io>HA	51NHA

4.2.5.2 Function block

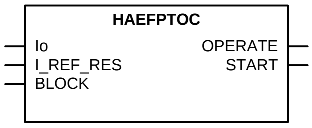


Figure 139: Function block

4.2.5.3 Functionality

The harmonics earth-fault protection 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.

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 IEDs, 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, if desired.

4.2.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the harmonics earth-fault protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

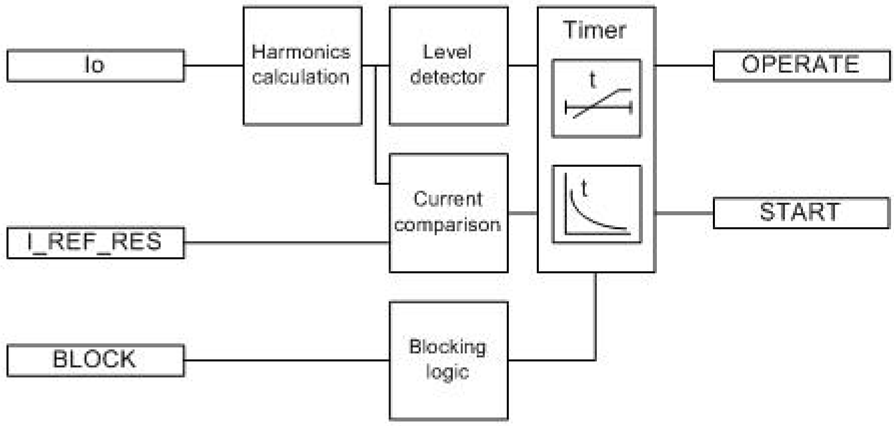


Figure 140: Functional module diagram

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 IEDs on the parallel feeders configured in the protection scheme.

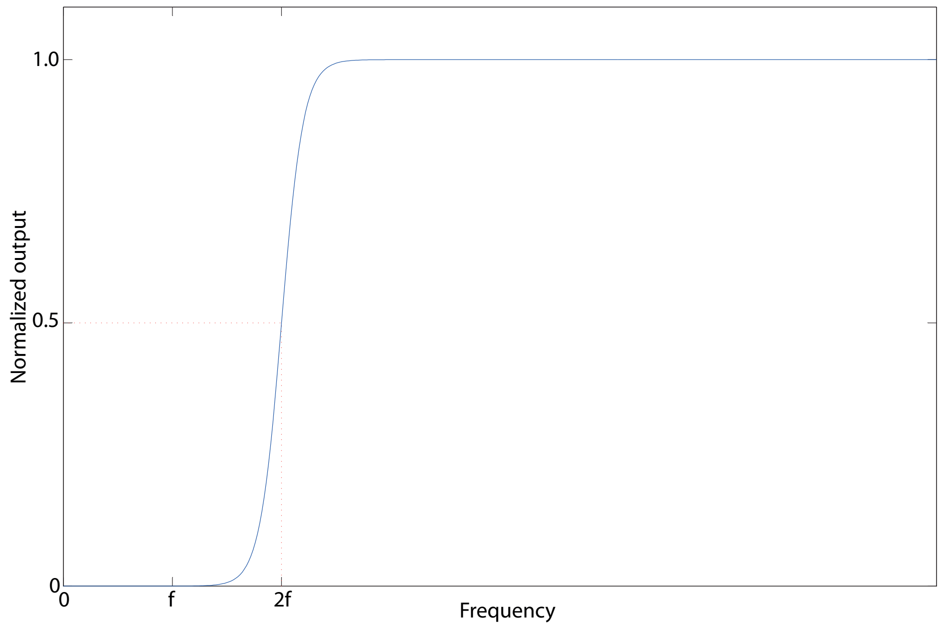


Figure 141: High-pass filter

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 262: Values of the Enable reference use setting

<table>
<tr><th colspan="2">Enable reference use</th><th>Functionality</th></tr>
<tr><td colspan="2">Standalone</td><td>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.</td></tr>
<tr><td rowspan="2">Reference use</td><td>Communication valid</td><td>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.</td></tr>
<tr><td>Communication invalid</td><td>Function operates as in the standalone mode.</td></tr>
</table>

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. 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 the 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 the 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 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, 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.

4.2.5.5 Application

During an earth fault, HAEFPTOC calculates the maximum current for the current feeder. The value is sent over an analog GOOSE to other IEDs 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.

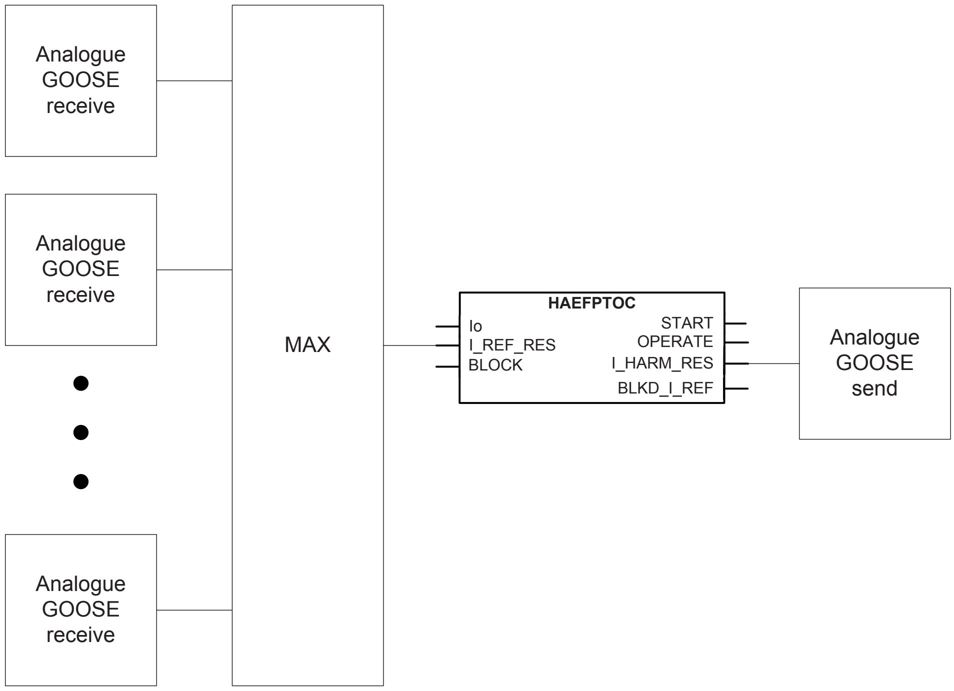


Figure 142: Protection scheme based on the analog GOOSE communication with three analog GOOSE receivers

4.2.5.6 Signals

Table 263: HAEFPTOC Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
I_REF_RES	FLOAT32	0.0	Reference current

Table 264: HAEFPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.5.7 Settings

Table 265: HAEFPTOC Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...5.00	xIn	0.01	0.10	Start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	100...200000	ms	10	600	Operate delay time
Minimum operate time	100...200000	ms	10	500	Minimum operate time for 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
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 266: HAEFPTOC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	10	20	Reset delay time
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

4.2.5.8 Monitored data

Table 267: 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

4.2.5.9 Technical data

Table 268: 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 1)2)	Typically 77 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 IDMT mode 3)	±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

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 measurement.
2) Includes the delay of the signal output contact
3) Maximum *Start value* = 2.5 × I_n, *Start value* multiples in range of 2...20

4.2.6 Wattmetric earth-fault protection WPWDE

4.2.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Wattmetric earth-fault protection	WPWDE	Po>->	32N

4.2.6.2 Function block

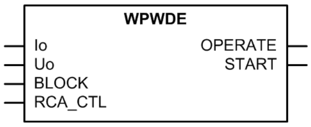


Figure 143: Function block

4.2.6.3 Functionality

The wattmetric 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.

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 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, if desired.

4.2.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the wattmetric earth-fault protection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

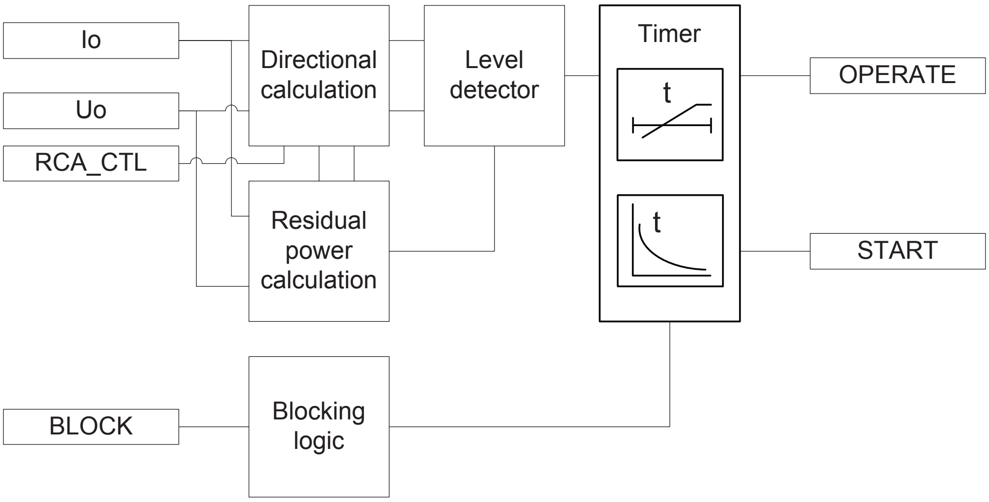


Figure 144: Function module diagram

Directional calculation

The Directional calculation module monitors the angle between the operating quantity (residual current) and polarizing quantity (residual voltage). The operating quantity can be selected with the setting *Io signal Sel*. The selectable options are “Measured Io” and “Calculated Io”. Calculated residual voltage is used for polarizing quantity. 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 and polarizing quantity, and the value (ANGLE) is available in the monitored data view.

The polarizing quantity for a directional earth fault is shifted by 180° and hence it is represented as –Uo in the phasor diagrams.

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°.

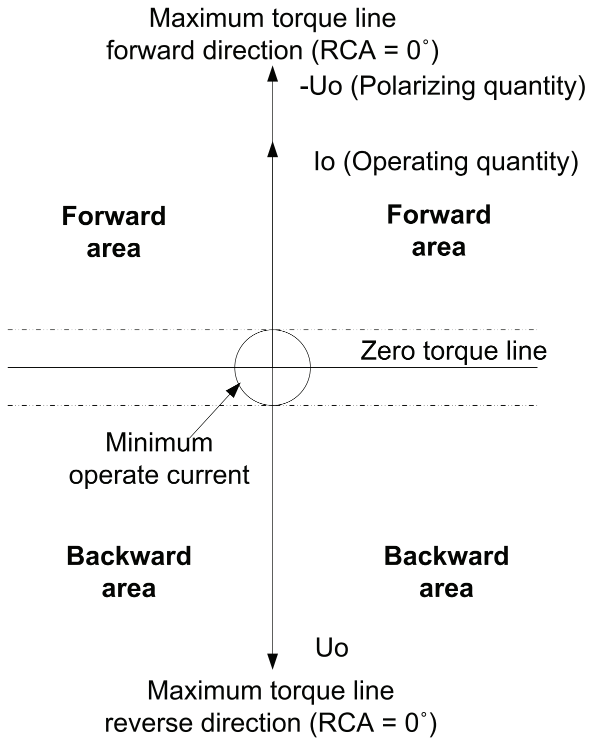


Figure 145: Definition of the relay characteristic angle

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 20)

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.

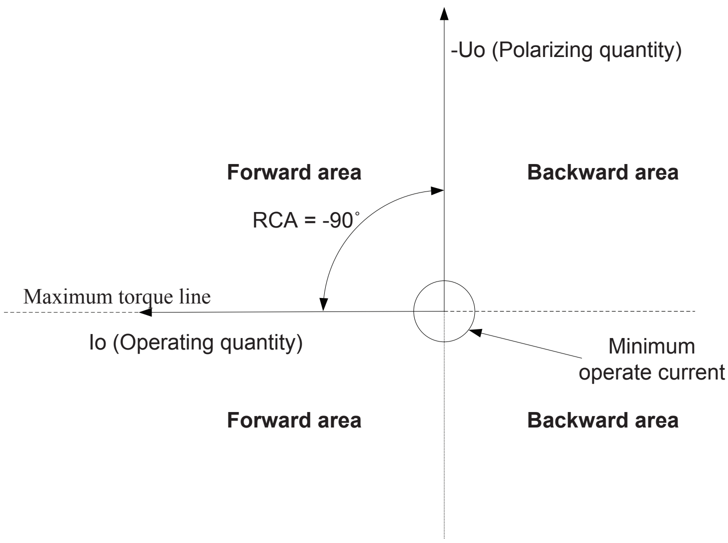


Figure 146: Definition of relay characteristic angle, RCA = -90° in an isolated network

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:

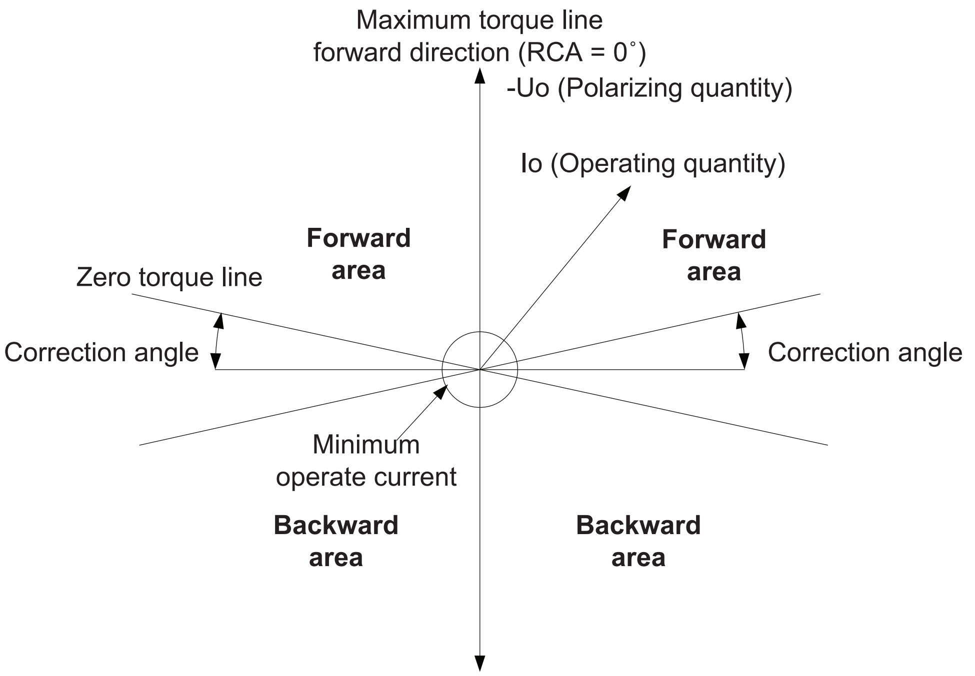


Figure 147: Definition of correction angle

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 IoUoCosφ. 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.

Level detector

Level detector compares the magnitudes of the measured operating quantity, polarizing quantity and calculated residual power to the set *Current start value* , *Voltage start value* and *Power start value* respectively. When all three quantities exceed the limits, Level detector enables the Timer module.

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 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, 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.

4.2.6.5 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 21)

t[s]	operation time in seconds
k	set value of *Time multiplier*
P_{ref}	set value of *Reference power*
P_{cal}	calculated residual power

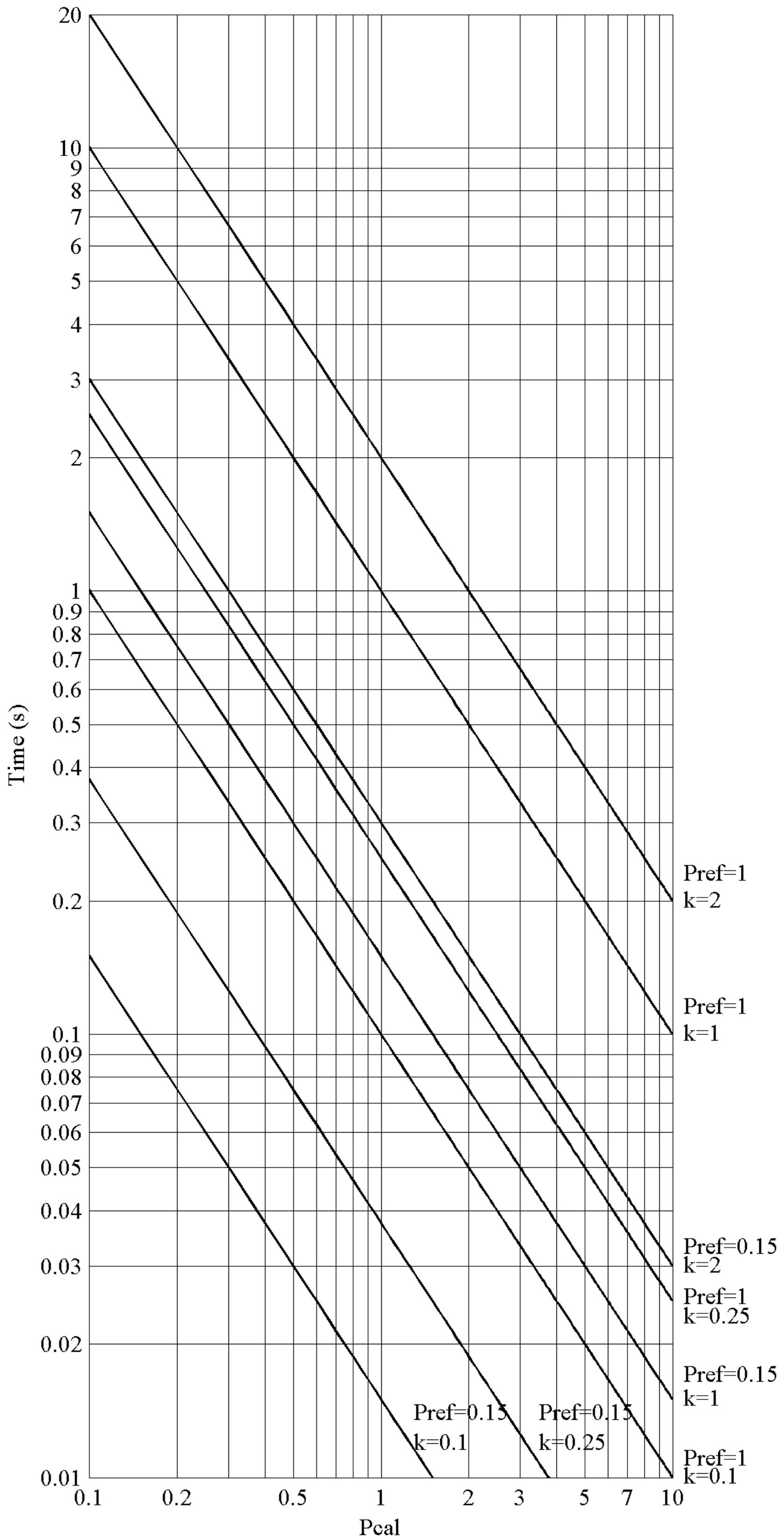

Time (s)
Pcal
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.1
0.2
0.5
1
2
3
5
7
10
Pref=1
k=2
Pref=1
k=1
Pref=0.15
k=2
Pref=1
k=0.25
Pref=0.15
k=1
Pref=0.15
k=0.1
Pref=0.15
k=0.25
Pref=1
k=0.1

Figure 148: Operation time curves for wattmetric IDMT for S_{ref} set at 0.15 xPn

4.2.6.6 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.

4.2.6.7 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).

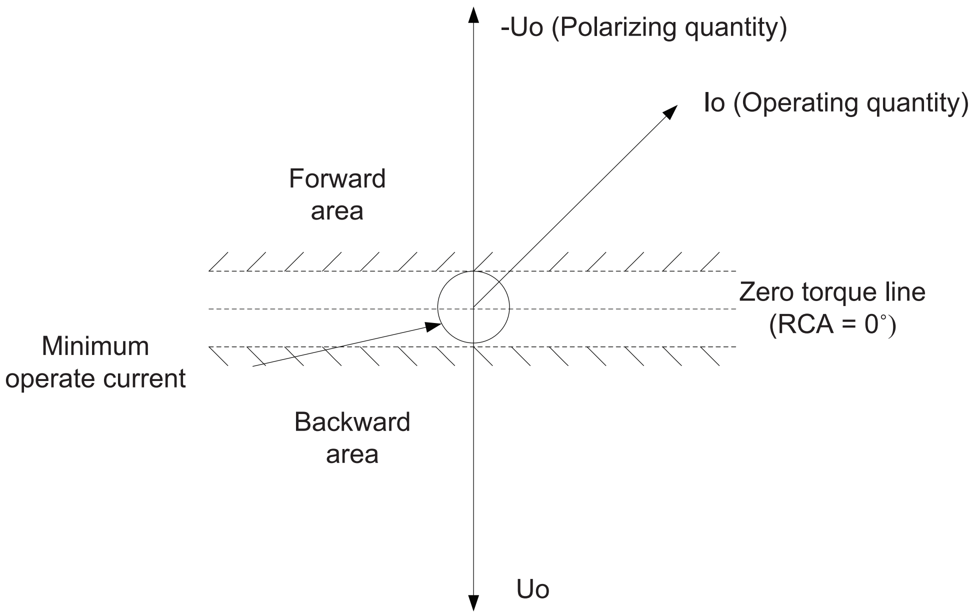


Figure 149: Characteristics of wattmetric protection

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).

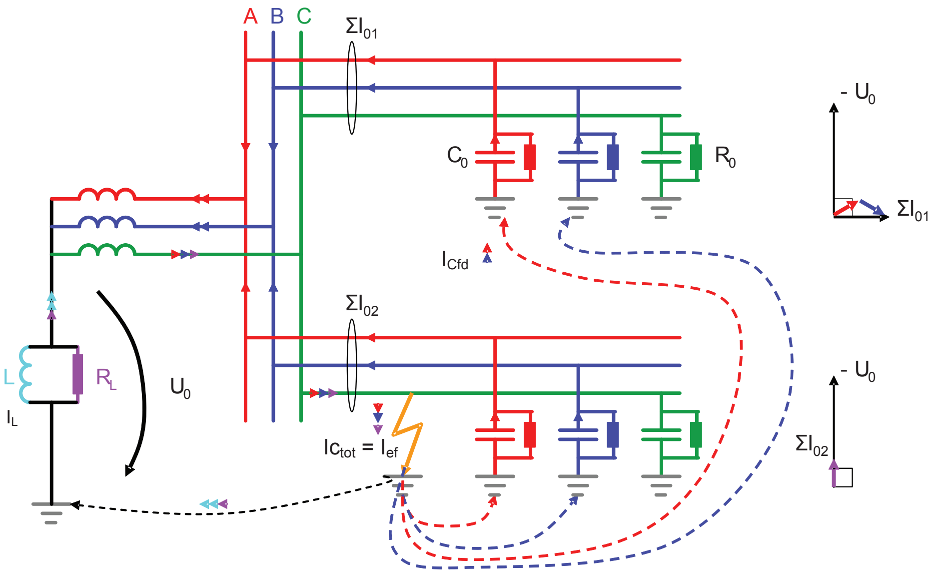


Figure 150: Typical radial compensated network employed with wattmetric protection

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 -90º.

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 0º. 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 0º.

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.

4.2.6.8 Signals

Table 269: WPWDE Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
RCA_CTL	BOOLEAN	0=False	Relay characteristic angle control

Table 270: WPWDE Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.2.6.9 Settings

Table 271: WPWDE Group settings

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 direction
Voltage start value	0.010...1.000	xUn	0.001	0.010	Start value for residual voltage
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Power start value	0.003...1.000	xPn	0.001	0.003	Start value for residual active power
Reference power	0.050...1.000	xPn	0.001	0.150	Reference value of residual power for Wattmetric IDMT curves
Characteristic angle	-179...180	deg	1	-90	Characteristic angle
Time multiplier	0.05...2.00		0.01	1.00	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...200000	ms	10	60	Operate delay time for definite time

Table 272: WPWDE Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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
Io signal Sel	1=Measured Io 2=Calculated Io			1=Measured Io	Selection for used Io signal
Pol signal Sel	2=Calculated Uo			2=Calculated Uo	Selection for used polarization signal

4.2.6.10 Monitored data

Table 273: 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 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

4.2.6.11 Technical data

Table 274: 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	±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,…

1) Io varied during the test. Uo = 1.0 × U_n = phase to earth voltage during earth fault in compensated or un-earthed network. The residual power value before fault = 0.0 pu, f_n = 50 Hz, results based on statistical distribution of 1000 measurement.
2) Includes the delay of the signal output contact.

4.3 Unbalance protection

4.3.1 Negative-sequence overcurrent protection NSPTOC

4.3.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overcurrent protection	NSPTOC	I2>	46

4.3.1.2 Function block

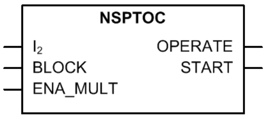


Figure 151: Function block

4.3.1.3 Functionality

The negative-sequence overcurrent protection 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, if desired.

4.3.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the negative-sequence overcurrent protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

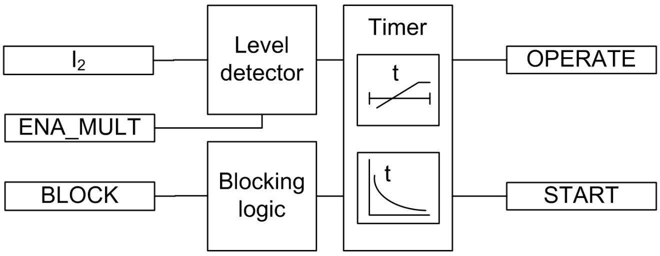


Figure 152: Functional module diagram. I_2 represents negative phase sequence current.

Level detector

The measured negative-sequence current is compared to the set *Start value*. If the measured value exceeds the set *Start value*, the 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 IED 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, 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. 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 the IDMT curves for overcurrent protection section 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 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, 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.

4.3.1.5 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.

4.3.1.6 Signals

Table 275: NSPTOC Input signals

Name	Type	Default	Description
I_2	SIGNAL	0	Negative phase sequence current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
ENA_MULT	BOOLEAN	0=False	Enable signal for current multiplier

Table 276: NSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.1.7 Settings

Table 277: NSPTOC Group settings

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	0.05...15.00		0.01	1.00	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. 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
Type of reset curve	1=Immediate 2=Def time reset 3=Inverse reset			1=Immediate	Selection of reset curve type

Table 278: NSPTOC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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
Curve parameter A	0.0086...120.0000			28.2000	Parameter A for customer programmable curve
Curve parameter B	0.0000...0.7120			0.1217	Parameter B for customer programmable curve
Curve parameter C	0.02...2.00			2.00	Parameter C for customer programmable curve
Curve parameter D	0.46...30.00			29.10	Parameter D for customer programmable curve
Curve parameter E	0.0...1.0			1.0	Parameter E for customer programmable curve

4.3.1.8 Monitored data

Table 279: 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

4.3.1.9 Technical data

Table 280: NSPTOC 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 × set *Start value* I_{Fault} = 10 × set *Start value*	22 ms 14 ms	24 ms 16 ms	25 ms 17 ms
Reset time		Typically 40 ms		
Reset ratio		Typically 0.96		
Retardation time		<35 ms		
Table continues on next page				

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 ±20 ms [3)]
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

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

4.3.1.10 Technical revision history

Table 281: NSPTOC Technical revision history

Technical revision	Change
B	Minimum and default values changed to 40 ms for the *Operate delay time* setting
C	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting

4.3.2 Phase discontinuity protection PDNSPTOC

4.3.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Phase discontinuity protection	PDNSPTOC	I2/I1>	46PD

4.3.2.2 Function block

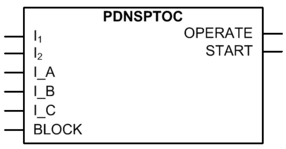


Figure 153: Function block

4.3.2.3 Functionality

The phase discontinuity protection 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, if desired.

4.3.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of phase discontinuity protection can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

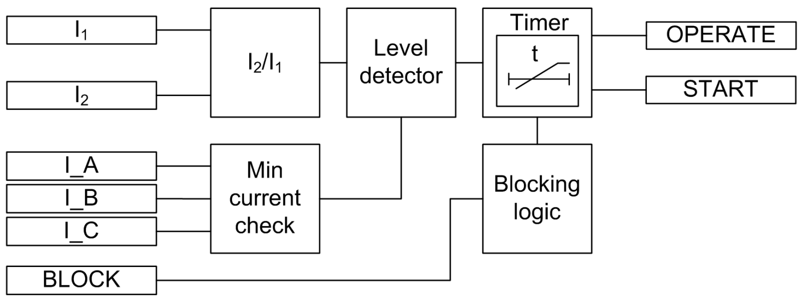


Figure 154: Functional module diagram. I_1 and I_2 represent positive and negative phase sequence currents. I_A, I_B and I_C represent phase currents.

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 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, 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.

4.3.2.5 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 22)

Broken conductor fault situation can occur in phase A in a feeder.

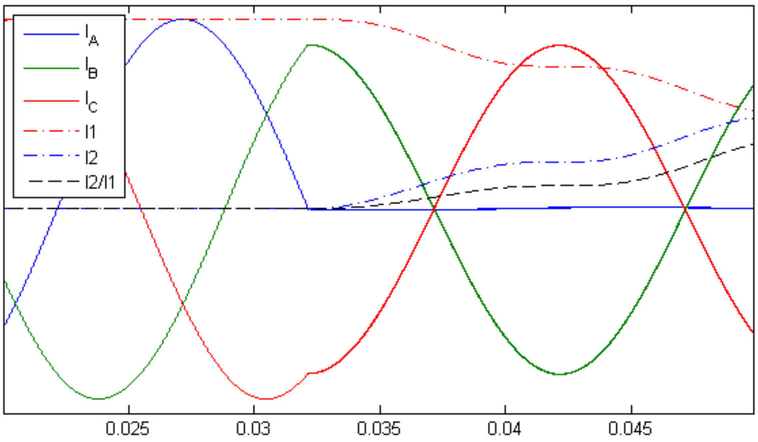


Figure 155: Three-phase current quantities during the broken conductor fault in phase A with the ratio of negative-sequence and positive-sequence currents

4.3.2.6 Signals

Table 282: PDNSPTOC Input signals

Name	Type	Default	Description
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 283: PDNSPTOC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.3.2.7 Settings

Table 284: PDNSPTOC Group settings

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 285: PDNSPTOC Non group settings

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

4.3.2.8 Monitored data

Table 286: 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

4.3.2.9 Technical data

Table 287: 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 × f_n, where n = 2, 3, 4, 5,…

4.4 Voltage protection

4.4.1 Three-phase overvoltage protection PHPTOV

4.4.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase overvoltage protection	PHPTOV	3U>	59

4.4.1.2 Function block

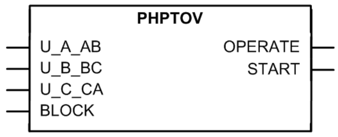


Figure 156: Function block

4.4.1.3 Functionality

The three-phase overvoltage protection 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, if desired.

4.4.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

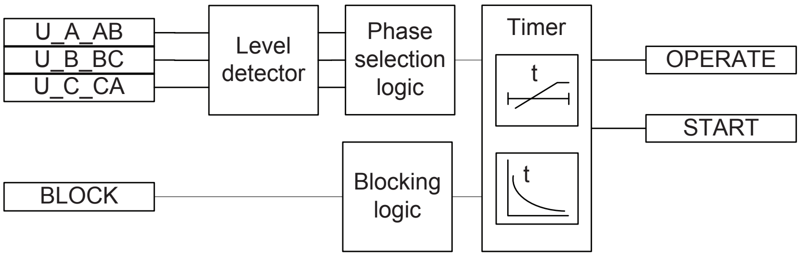


Figure 157: Functional module diagram

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 the IDMT curve saturation of the over voltage protection section 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 the IDMT curves for overvoltage protection section 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* and *Reset delay time* settings.

Table 288: The reset time functionality when the IDMT operate time curve is selected

Type of reset curve	Description of operation
“Immediate”	The operate timer is reset instantaneously when drop-off occurs
“Def time reset”	The operate timer is frozen during drop-off. Operate timer is reset after the set *Reset delay time* is exceeded
“DT Lin decr rst”	The operate timer value linearly decreases during the drop-off situation. The operate timer is reset after the set *Reset delay time* is exceeded

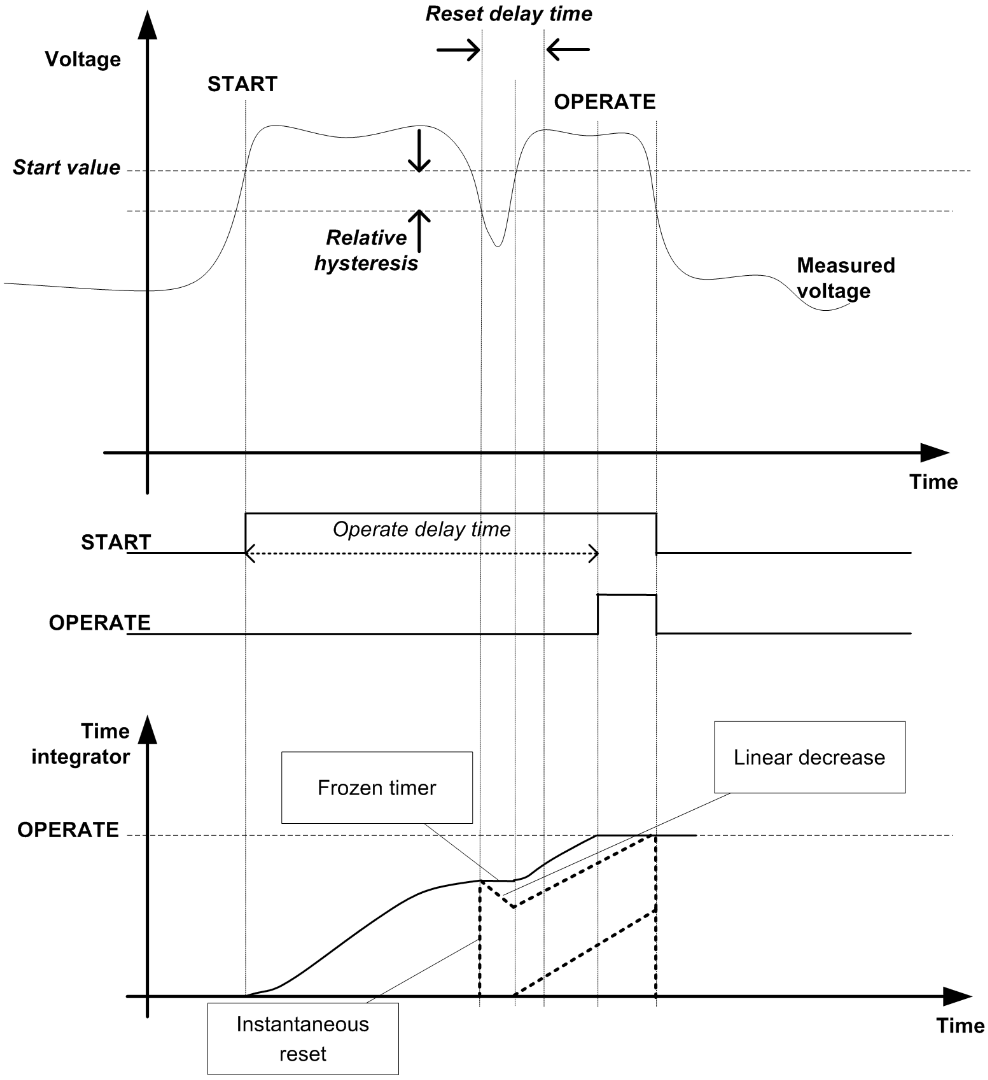


Figure 158: Behavior of different IDMT reset modes. The value for Type of reset curve is "Def time reset". Also other reset modes are presented for the time integrator.

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 the IDMT curves for overvoltage protection section 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 IED 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.

4.4.1.5 Timer characteristics

The operating curve types supported by PHPTOV are:

Table 289: 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

4.4.1.6 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 IED 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.

4.4.1.7 Signals

Table 290: PHPTOV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 291: PHPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.1.8 Settings

Table 292: PHPTOV Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.60	xUn	0.01	1.10	Start value
Time multiplier	0.05...15.00		0.01	1.00	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
Type of reset curve	1=Immediate 2=Def time reset -1=DT Lin decr rst			1=Immediate	Selection of reset curve type

Table 293: PHPTOV Non group settings

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
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 parameter A	0.005...200.000			1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00			1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0			0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000			0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000			1.000	Parameter E for customer programmable curve
Curve Sat Relative	0.0...3.0		0.1	2.0	Tuning parameter to avoid curve discontinuities
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.4.1.9 Monitored data

Table 294: 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

4.4.1.10 Technical data

Table 295: 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)]		Minimum	Typical	Maximum
	U_{Fault} = 1.1 × set *Start value*	22 ms	24 ms	26 ms
Reset time		Typically 40 ms		
Reset ratio		Depends of 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,…		

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

4.4.1.11 Technical revision history

Table 296: PHPTOV Technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

4.4.2 Three-phase undervoltage protection PHPTUV

4.4.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase undervoltage protection	PHPTUV	3U<	27

4.4.2.2 Function block

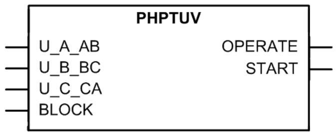


Figure 159: Function block

4.4.2.3 Functionality

The three-phase undervoltage protection 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 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, if desired.

4.4.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the three-phase undervoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

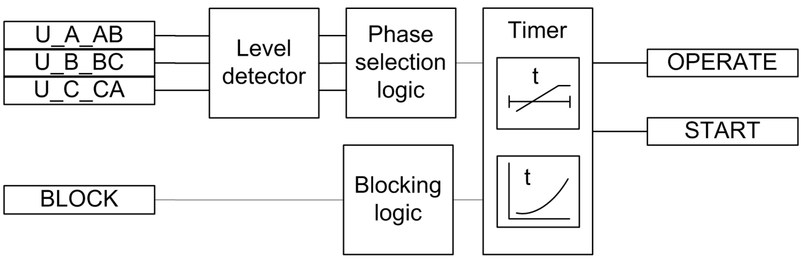


Figure 160: Functional module diagram

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 the IDMT curves for under voltage protection section 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 the IDMT curves for under voltage protection section 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* and *Reset delay time* settings.

Table 297: The reset time functionality when the IDMT operate time curve is selected

Type of reset curve	Description of operation
“Immediate”	The operate timer is reset instantaneously when drop-off occurs
“Def time reset”	The operate timer is frozen during drop-off. Operate timer is reset after the set *Reset delay time* is exceeded
“DT Lin decr rst”	The operate timer value linearly decreases during the drop-off situation. The operate timer is reset after the set *Reset delay time* is exceeded

Example

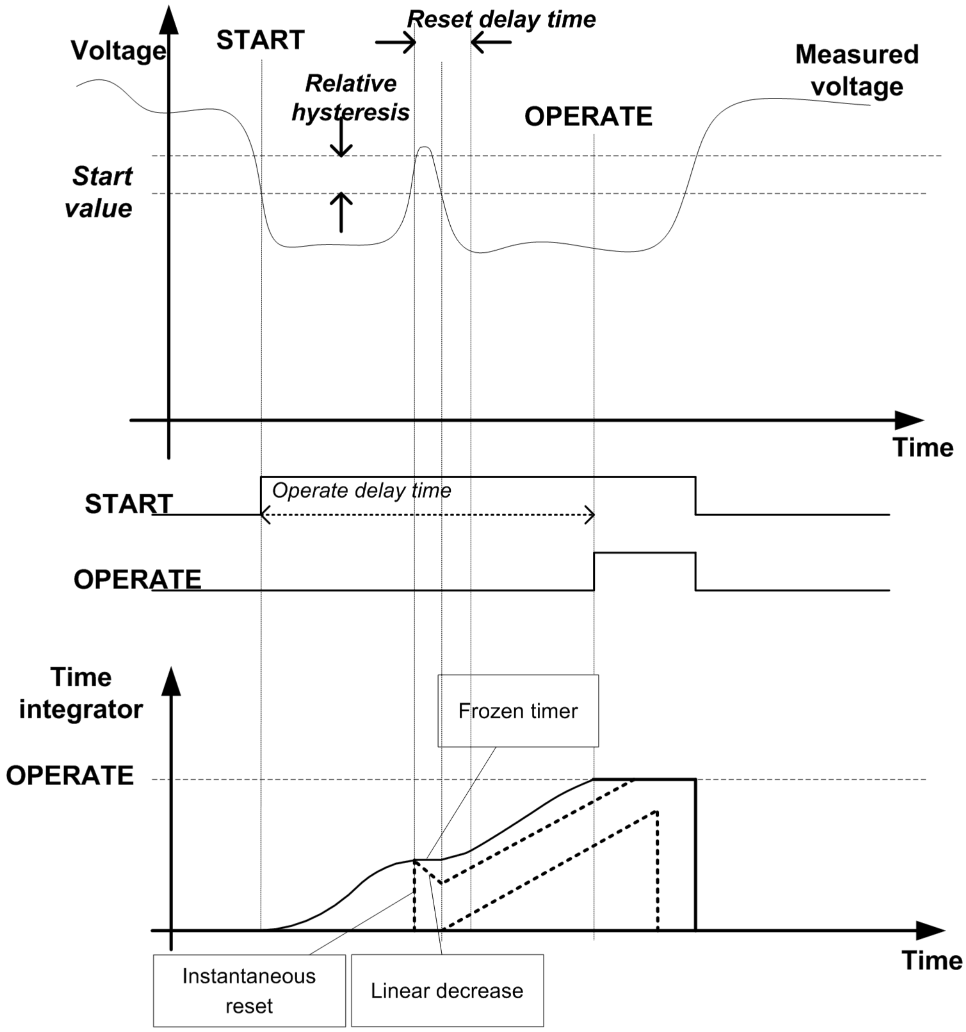


Figure 161: Behavior of different IDMT reset modes. The value for Type of reset curve is "Def time reset". Also other reset modes are presented for the time integrator.

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 the IDMT curves for overcurrent protection section 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 IED 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.

4.4.2.5 Timer characteristics

The operating curve types supported by PHPTUV are:

Table 298: 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

4.4.2.6 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.

4.4.2.7 Signals

Table 299: PHPTUV Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 300: PHPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.2.8 Settings

Table 301: PHPTUV Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Start value	0.05...1.20	xUn	0.01	0.90	Start value
Time multiplier	0.05...15.00		0.01	1.00	Time multiplier in IEC/ANSI IDMT curves
Operate delay time	60...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
Type of reset curve	1=Immediate 2=Def time reset -1=DT Lin decr rst			1=Immediate	Selection of reset curve type

Table 302: PHPTUV Non group settings

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
Minimum operate time	60...60000	ms	1	60	Minimum operate time for IDMT curves
Reset delay time	0...60000	ms	1	20	Reset delay time
Curve parameter A	0.005...200.000			1.000	Parameter A for customer programmable curve
Curve parameter B	0.50...100.00			1.00	Parameter B for customer programmable curve
Curve parameter C	0.0...1.0			0.0	Parameter C for customer programmable curve
Curve parameter D	0.000...60.000			0.000	Parameter D for customer programmable curve
Curve parameter E	0.000...3.000			1.000	Parameter E for customer programmable curve
Curve Sat Relative	0.0...3.0		0.1	2.0	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
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for operation

4.4.2.9 Monitored data

Table 303: 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

4.4.2.10 Technical data

Table 304: 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[1)2)]		Minimum	Typical	Maximum
	U_{Fault} = 0.9 × set *Start value*	62 ms	64 ms	66 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,…		

1) *Start value* = 1.0 × U_n, Voltage before fault = 1.1 × U_n, f_n = 50 Hz, undervoltage 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) Minimum *Start value* = 0.50, *Start value* multiples in range of 0.90...0.20

4.4.2.11 Technical revision history

Table 305: PHPTUV Technical revision history

Technical revision	Change
B	Step value changed from 0.05 to 0.01 for the *Time multiplier* setting.

4.4.3 Residual overvoltage protection ROVPTOV

4.4.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual overvoltage protection	ROVPTOV	Uo>	59G

4.4.3.2 Function block

Figure 162: Function block

4.4.3.3 Functionality

The residual overvoltage protection 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, if desired.

4.4.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of residual overvoltage protection can be described by using a module diagram.

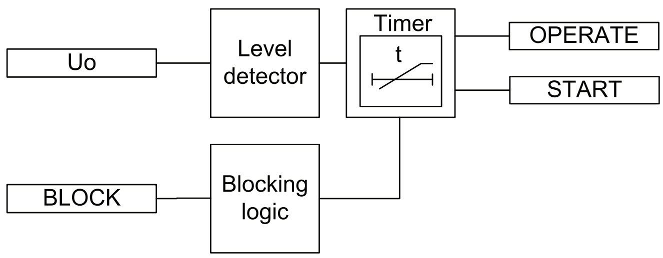


Figure 163: Functional module diagram. Uo represents the residual voltage.

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. The residual voltage can be selected with the *Uo signal Sel* setting. The options are "Measured Uo" and "Calculated Uo". If "Measured Uo" is selected, the voltage ratio for Uo-channel is given in the global setting **Configuration/Analog inputs/Voltage (Uo,VT)**. If "Calculated Uo" is selected, the voltage ratio is obtained from phase-voltage channels given in the global setting **Configuration/Analog inputs/Voltage (3U,VT)**.

Example 1: Uo is measured from the open-delta connected VTs (20/sqrt(3) kV : 100/sqrt(3) V : 100/3 V). In this case, "Measured Uo" is selected. The nominal values for residual voltage is obtained from the VT ratios entered in Residual voltage Uo: **Configuration/Analog inputs/Voltage (Uo,VT)**: 11.547 kV:100 V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 11.547 kV = 11.547 kV in the primary.

Example 2: Uo is calculated from the phase quantities. The phase VT-ratio is 20/sqrt(3) kV : 100/sqrt(3) V. In this case, "Calculated Uo" is selected. The nominal value for residual voltage is obtained from the VT ratios entered in Residual voltage Uo: **Configuration/Analog inputs/Voltage (3U,VT)**: 20.000kV : 100V. The residual voltage start value of 1.0 × Un corresponds to 1.0 × 20.000 kV = 20.000 kV in the primary.

If "Calculated Uo" is selected, the nominal value of residual voltage is always phase-to-phase voltage. Thus, the valid maximum setting for residual voltage *Start value* is 0.577 × Un. The calculated Uo requires that all three phase-to-earth voltages are connected to the IED. Uo cannot be calculated from the phase-to-phase voltages.

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 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, 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.

4.4.3.5 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.

4.4.3.6 Signals

Table 306: ROVPTOV Input signals

Name	Type	Default	Description
Uo	SIGNAL	0	Residual voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 307: ROVPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.3.7 Settings

Table 308: ROVPTOV Group settings

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 309: ROVPTOV Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	1	20	Reset delay time
Uo signal Sel	2=Calculated Uo			2=Calculated Uo	Selection for used Uo signal

4.4.3.8 Monitored data

Table 310: 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

4.4.3.9 Technical data

Table 311: 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)]		Minimum	Typical	Maximum
	U_{Fault} = 1.1 × set *Start value*	55 ms	56 ms	58 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

4.4.3.10 Technical revision history

Table 312: ROVPTOV Technical revision history

Technical revision	Change
B	Added a setting parameter for the "Measured Uo" or "Calculated Uo" selection

4.4.4 Negative-sequence overvoltage protection NSPTOV

4.4.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Negative-sequence overvoltage protection	NSPTOV	U2>	47O-

4.4.4.2 Function block

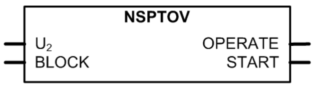


Figure 164: Function block

4.4.4.3 Functionality

The negative-sequence overvoltage protection 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, if desired.

4.4.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the negative-sequence overvoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

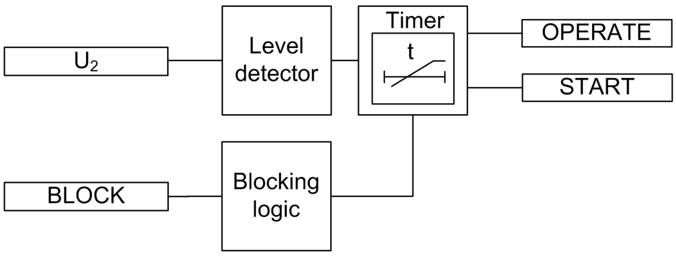


Figure 165: Functional module diagram. U_2 is used for representing negative phase sequence voltage.

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 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, 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.

4.4.4.5 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.

4.4.4.6 Signals

Table 313: NSPTOV Input signals

Name	Type	Default	Description
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 314: NSPTOV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.4.7 Settings

Table 315: NSPTOV Group settings

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 316: NSPTOV Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	1	20	Reset delay time

4.4.4.8 Monitored data

Table 317: 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

4.4.4.9 Technical data

Table 318: NSPTOV 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[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,…		

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

4.4.4.10 Technical revision history

Table 319: NSPTOV Technical revision history

Technical revision	Change
B	Internal change

4.4.5 Positive-sequence undervoltage protection PSPTUV

4.4.5.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Positive-sequence undervoltage protection	PSPTUV	U1<	47U+

4.4.5.2 Function block

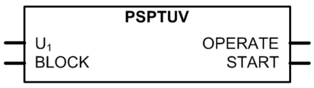


Figure 166: Function block

4.4.5.3 Functionality

The positive-sequence undervoltage protection 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, if desired.

4.4.5.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the positive-sequence undervoltage protection can be described using a module diagram. All the modules in the diagram are explained in the next sections.

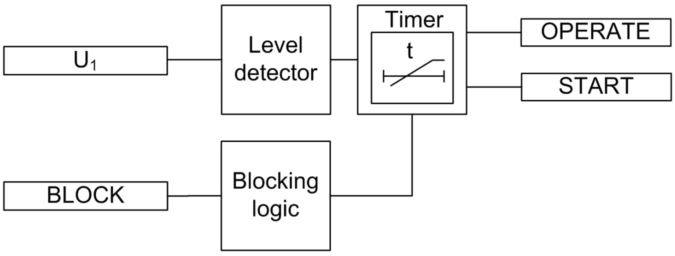


Figure 167: Functional module diagram. U_1 is used for representing positive phase sequence voltage.

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.

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 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, 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.

4.4.5.5 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.

4.4.5.6 Signals

Table 320: PSPTUV Input signals

Name	Type	Default	Description
U_1	SIGNAL	0	Positive phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 321: PSPTUV Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.4.5.7 Settings

Table 322: PSPTUV Group settings

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
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 323: PSPTUV Non group settings

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

4.4.5.8 Monitored data

Table 324: 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

4.4.5.9 Technical data

Table 325: 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* U_{Fault} = 0.9 × set *Start value*	51 ms 43 ms	53 ms 45 ms	54 ms 46ms
Reset time		Typically 40 ms		
Reset ratio		Depends of 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,…		

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

4.4.5.10 Technical revision history

Table 326: PSPTUV Technical revision history

Technical revision	Change
B	-

4.5 Frequency protection

4.5.1 Frequency protection FRPFRQ

4.5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency protection	FRPFRQ	f>/f<, df/dt	81O/81U, 81R

4.5.1.2 Function block

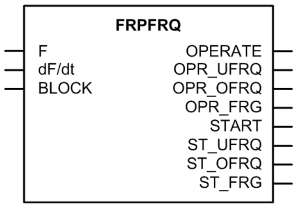


Figure 168: Function block

4.5.1.3 Functionality

The frequency protection 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, if desired.

4.5.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the frequency protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

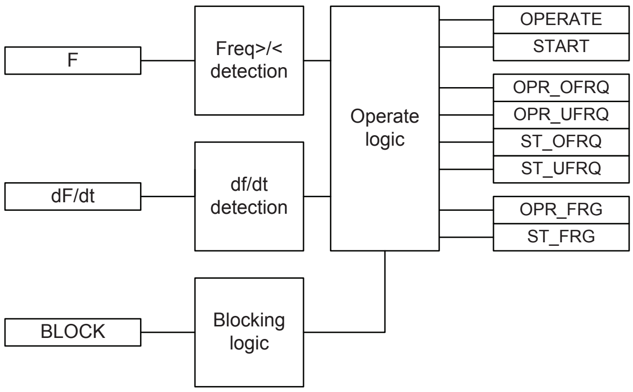


Figure 169: Functional module diagram

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 IED does not accept the set value "0.00" 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 327: *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. 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.

Table continues on next page

Operation mode	Description
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.

Table continues on next page

Operation mode	Description
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.
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.
Table continues on 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. 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 328: 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 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, 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.

4.5.1.5 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.

4.5.1.6 Signals

Table 329: FRPFRQ Input signals

Name	Type	Default	Description
F	SIGNAL	0	Measured frequency
dF/dt	SIGNAL	0	Rate of change of frequency
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 330: 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

4.5.1.7 Settings

Table 331: FRPFRQ Group settings

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>	0.900...1.200	xFn	0.001	1.050	Frequency start value overfrequency
Start value Freq<	0.800...1.100	xFn	0.001	0.950	Frequency start value underfrequency
Start value df/dt	-0.200...0.200	xFn /s	0.005	0.010	Frequency start value rate of change
Operate Tm Freq	80...200000	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 332: FRPFRQ Non group settings

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

4.5.1.8 Monitored data

Table 333: 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

4.5.1.9 Technical data

Table 334: FRPFRQ Technical data

Characteristic		Value
Operation accuracy	f>/f<	±10 mHz
	df/dt	±100 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
	df/dt	<120 ms
Reset time		<150 ms
Operate time accuracy		±1.0% of the set value or ±30 ms

4.5.2 Load shedding and restoration LSHDPFRQ

4.5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Load shedding and restoration	LSHDPFRQ	UFLS/R	81LSH

4.5.2.2 Function block

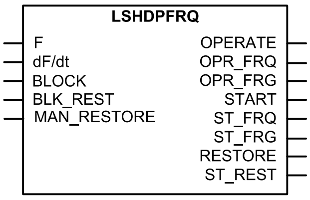


Figure 170: Function block

4.5.2.3 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.

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, if desired.

4.5.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the load shedding and restoration function can be described using a module diagram. All the modules are explained in the next sections.

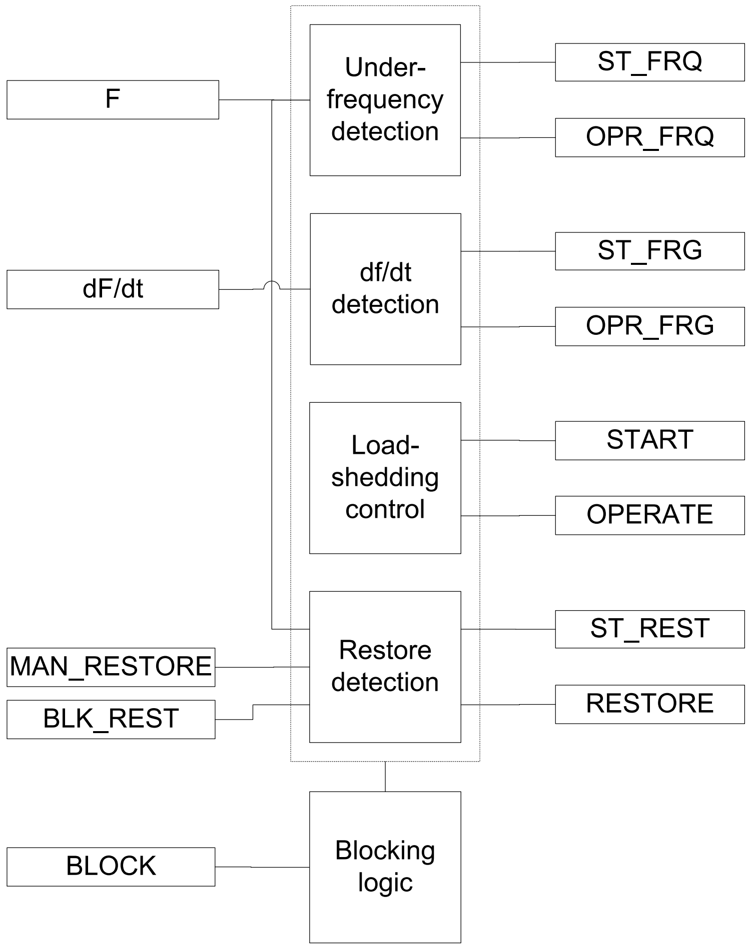


Figure 171: Functional module diagram

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.

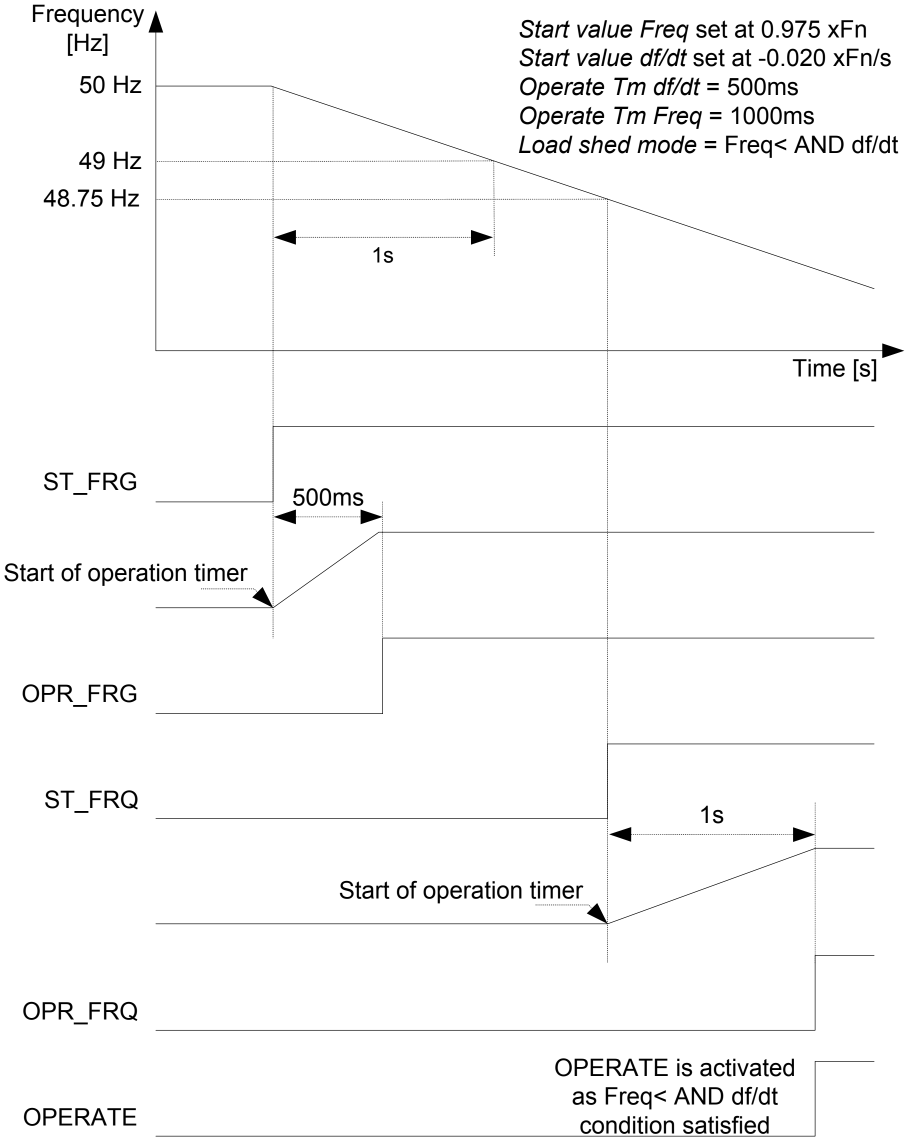


Figure 172: Load-shedding operation in the “Freq< AND df/dt>” mode when both Freq< and df/dt conditions are satisfied (Rated frequency=50 Hz)

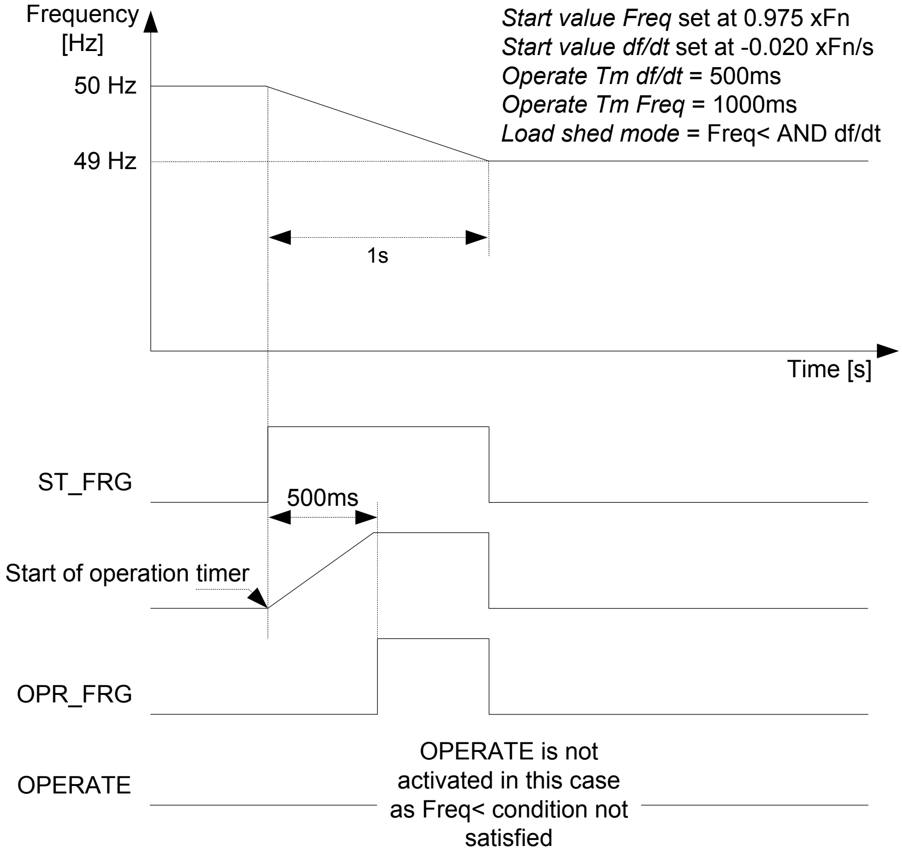


Figure 173: Load-shedding operation in the “Freq< AND df/dt>” mode when only the df/dt condition is satisfied (Rated frequency=50 Hz)

Restore detection

If after the activation of the `OPERATE` input the frequency recovers to a level above the *Restore start Val* setting, the `RESTORE` signal output is activated. The `RESTORE` output remains active for a 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 frequency 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 IED 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.

4.5.2.5 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.

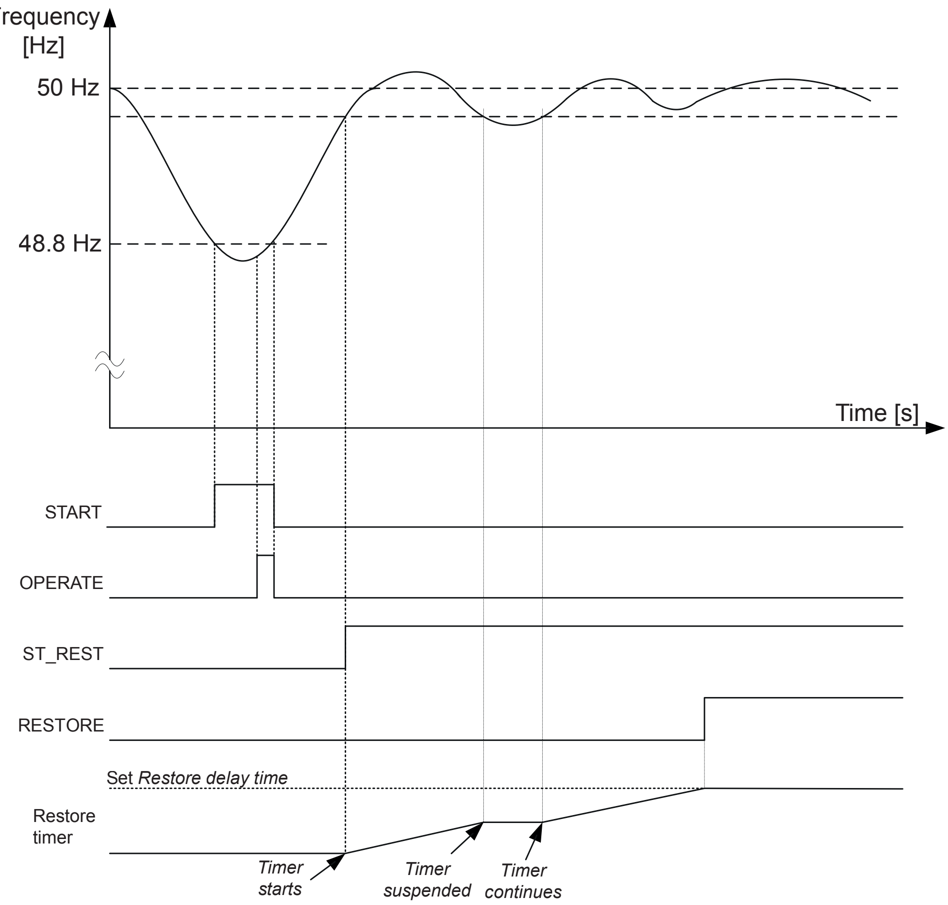


Figure 174: Operation of the load-shedding function

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 335: 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 (49.2 Hz)	30000 ms
3	0.968 · Fn (49.2 Hz)	15000 ms
4	0.958 · Fn (49.2 Hz)	5000ms
5	0.950 · Fn (49.2 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 large 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 336: 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 (-0.25 Hz/s)	2000 ms
3	-0.015 · Fn /s (-0.25 Hz/s)	1000 ms
4	-0.020 · Fn /s (-0.25 Hz/s)	500 ms
5	-0.025 · Fn /s (-0.25 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 337: Setting for a five-step restoring operation

Load-shedding steps	Restoring 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
4	0.990 · Fn (49.5 Hz)	50000 ms
5	0.990 · Fn (49.5 Hz)	10000 ms

4.5.2.6 Signals

Table 338: LSHDPFRQ Input signals

Name	Type	Default	Description
F	SIGNAL	0	Measured frequency
dF/dt	SIGNAL	0	Rate of change of frequency
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

Table 339: 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

4.5.2.7 Settings

Table 340: LSHDPFRQ Group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Load shed mode	1=Freq< 6=Freq< OR df/dt 8=Freq< AND df/dt			1=Freq<	Set the operation mode for load shedding function
Restore mode	1=Disabled 2=Auto 3=Manual			1=Disabled	Mode of operation of restore functionality
Start value Freq	0.800...1.200	xFn	0.001	0.975	Frequency setting/start value
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Start value df/dt	-0.200...-0.005	xFn /s	0.005	-0.010	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	0.800...1.200	xFn	0.001	0.998	Restore frequency setting value
Restore delay time	80...200000	ms	10	300	Time delay to restore

Table 341: LSHDPFRQ Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	1	50	Time delay after which the definite timers will reset

4.5.2.8 Monitored data

Table 342: 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

4.5.2.9 Technical data

Table 343: LSHDPFRQ Technical data

Characteristic		Value
Operation accuracy	f<	±10 mHz
	df/dt	±100 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<	<80 ms
	df/dt	<120 ms
Reset time		<150 ms
Operate time accuracy		±1.0% of the set value or ±30 ms

4.6 Multipurpose protection MAPGAPC

4.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Multipurpose protection	MAPGAPC	MAP	MAP

4.6.2 Function block

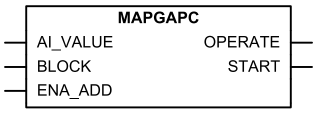


Figure 175: Function block

4.6.3 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, if desired.

4.6.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the multipurpose protection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

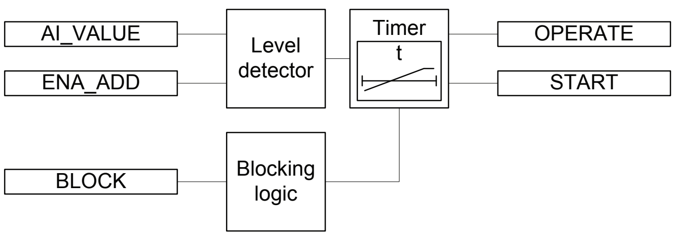


Figure 176: Functional module diagram

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 344: 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 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, 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.

4.6.5 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.

4.6.6 Signals

Table 345: 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

Table 346: MAPGAPC Output signals

Name	Type	Description
OPERATE	BOOLEAN	Operate
START	BOOLEAN	Start

4.6.7 Settings

Table 347: MAPGAPC Group settings

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 348: MAPGAPC Non group settings

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
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

4.6.8 Monitored data

Table 349: 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

4.6.9 Technical data

Table 350: MAPGAPC Technical data

Characteristic	Value
Operation accuracy	±1.0% of the set value or ±20 ms

Section 5 Protection related functions

5.1 Three-phase inrush detector INRPHAR

5.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Three-phase inrush detector	INRPHAR	3I2f>	68

5.1.2 Function block

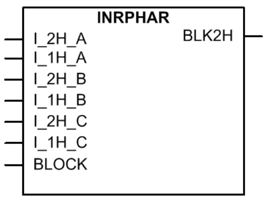


Figure 177: Function block

5.1.3 Functionality

The transformer inrush detection INRPHAR is used to coordinate 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 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of an inrush current detection function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

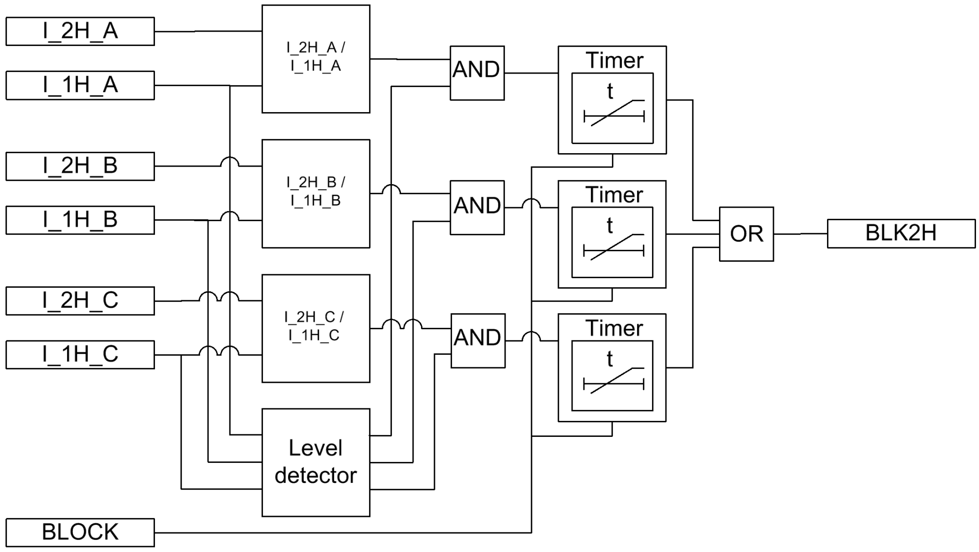


Figure 178: Functional module diagram. I_1H and I_2H represent fundamental and second harmonic values of phase currents.

I_2H/I_1H

This module calculates the ratio of the second harmonic (I_2H) and fundamental frequency (I_1H) 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 five percent of the nominal current.

Timer

Once activated, the timer runs until the set *Operate delay time* value. The time characteristic is according to DT. When the operation timer has reached the *Operate delay time* value, the `BLK2H` output is activated. After the timer has elapsed and the inrush situation still exists, the `BLK2H` signal remains active until the I_2H/I_1H ratio drops below the value set for the ratio in all phases, 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.

It is recommended to use the second harmonic and the waveform based inrush blocking from the TR2PTDF function if available.

5.1.5 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 second harmonic component over the fundamental component exceeds the set value.

Other applications of this function include the detection of inrush in lines connected to a transformer.

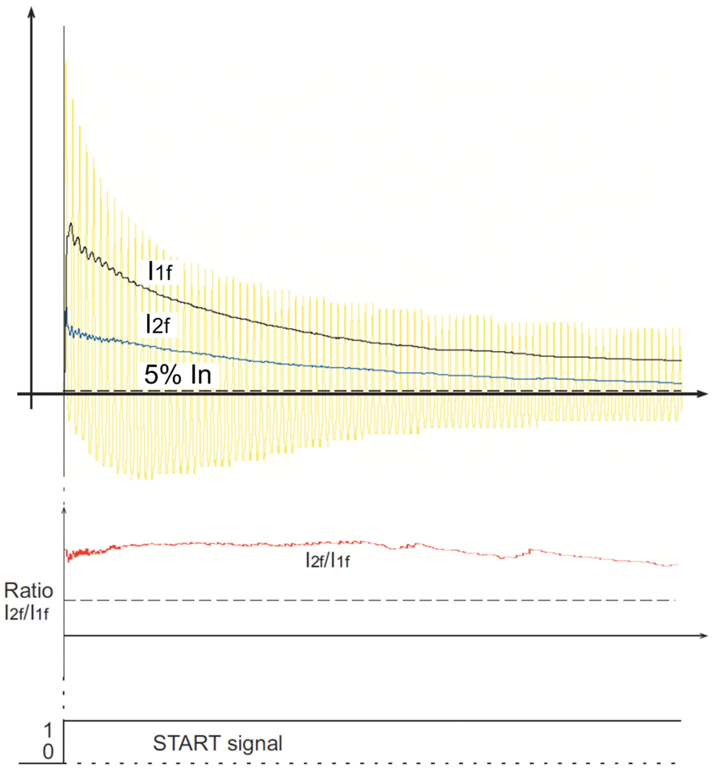


Figure 179: Inrush current in transformer

It is recommended to use the second harmonic and the waveform based inrush blocking from the transformer differential protection function TR2PTDF if available.

5.1.6 Signals

Table 351: INRPHAR Input signals

Name	Type	Default	Description
I_2H_A	SIGNAL	0	Second harmonic phase A current
I_1H_A	SIGNAL	0	Fundamental frequency phase A current
I_2H_B	SIGNAL	0	Second harmonic phase B current
I_1H_B	SIGNAL	0	Fundamental frequency phase B current
I_2H_C	SIGNAL	0	Second harmonic phase C current
I_1H_C	SIGNAL	0	Fundamental frequency phase C current
BLOCK	BOOLEAN	0=False	Block input status

Table 352: INRPHAR Output signals

Name	Type	Description
BLK2H	BOOLEAN	Second harmonic based block

5.1.7 Settings

Table 353: INRPHAR Group settings

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 354: INRPHAR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Reset delay time	0...60000	ms	1	20	Reset delay time

5.1.8 Monitored data

Table 355: INRPHAR Monitored data

Name	Type	Values (Range)	Unit	Description
INRPHAR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.1.9 Technical data

Table 356: INRPHAR Technical data

Characteristic	Value
Operation accuracy	At the frequency f = f_n
	Current measurement: ±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 Master trip TRPPTRC

5.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Master trip	TRPPTRC	Master Trip	94/86

5.2.2 Function block

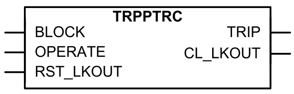


Figure 180: Function block

5.2.3 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.

5.2.4 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 the tripping logic function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

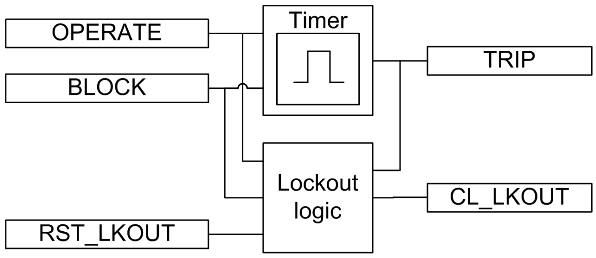


Figure 181: Functional module diagram

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 IED, or from external protection functions via one or more of the IED's binary inputs. The function has a single trip output TRIP for connecting the function to one or more of the IED's binary outputs, and also to other functions within the IED 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 357: 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 clearing is possible.
Lockout	`TRIP` is locked and can be cleared only locally via menu or the `RST_LKOUT` input.

5.2.5 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 IED, for example when starting the breaker failure protection.

TRPPTRC is used for simple three-phase tripping applications.

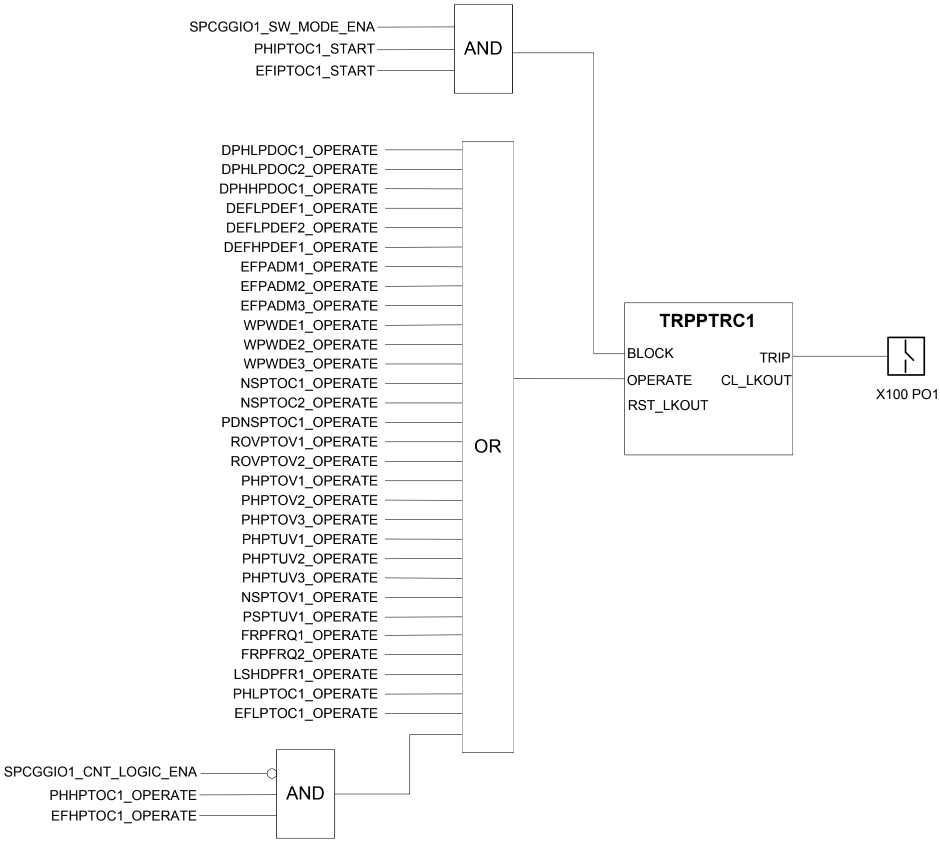


Figure 182: Typical TRPPTRC connection

5.2.6 Signals

Table 358: 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

Table 359: TRPPTRC Output signals

Name	Type	Description
TRIP	BOOLEAN	General trip output signal
CL_LKOUT	BOOLEAN	Circuit breaker lockout output (set until reset)

5.2.7 Settings

Table 360: TRPPTRC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Trip pulse time	20...60000	ms	1	150	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

5.2.8 Monitored data

Table 361: TRPPTRC Monitored data

Name	Type	Values (Range)	Unit	Description
TRPPTRC	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

5.2.9 Technical revision history

Table 362: TRPPTRC Technical revision history

Technical revision	Change
B	-
C	-

5.3 Fault locator SCEFRFLO

5.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fault locator function	SCEFRFLO	FLOC	21FL

5.3.2 Function block

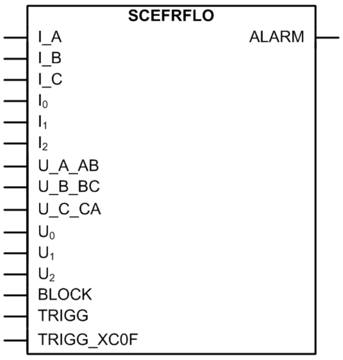


Figure 183: Function block

5.3.3 Functionality

The fault locator function SCEFRFLO provides impedance-based fault location. It is designed for radially operated distribution systems. It is applicable for locating 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. Under certain limitations, SCEFRFLO can also be applied for an earth-fault location in unearthed distribution networks.

The fault distance calculation is based on locally measured fundamental frequency current and voltage phasors. The full operation of SCEFRFLO requires that all phase currents and phase-to-earth voltages are measured.

The fault distance estimate is obtained when SCEFRFLO is externally or internally triggered.

5.3.4 Operation principle

The fault distance calculation is done in two steps. First, the fault type is determined with the inbuilt 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.

As a fundamental operation criterion, the phase current and voltage magnitudes must exceed the threshold values of 2% xIn and 3% xUn, respectively.

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 as shown in Figure 184.

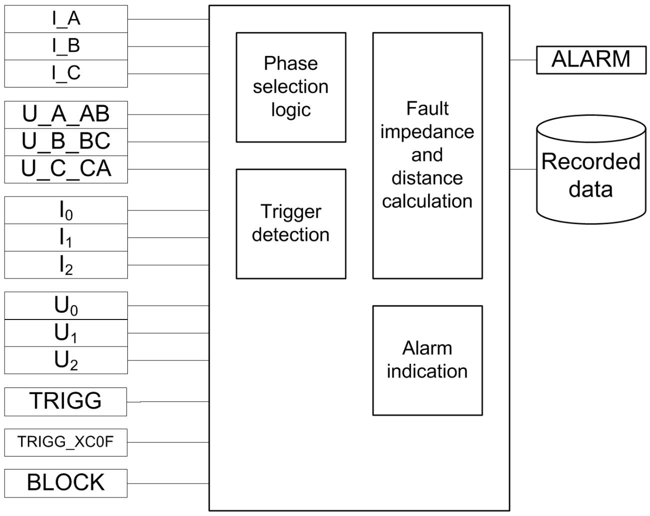


Figure 184: Functional module diagram

5.3.4.1 Phase Selection Logic

Identification of the faulty phases is provided by the built-in Phase Selection Logic based on combined impedance and current criterion. Phase selection logic is virtually setting-free and has only one parameter, *Z Max phase load*, for discriminating a large 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 23)

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 363.

Table 363: 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 individual earth faults. When the faults are located at the same feeder, the corresponding phase-to-phase loop (either “AB Fault” or “BC Fault” or “CA Fault”) is used for calculation. When the faults are located at different feeders, the phase-to-earth loop (either “AG Fault” or “BG Fault” or “CG Fault”) corresponding to the faulty phase at the protected feeder is used for calculation.

5.3.4.2 Fault impedance and distance calculation

As soon as a fault condition is recognized by the phase selection logic, the fault distance calculation is started with one of the seven impedance-measuring elements, that is, the fault loops. SCEFRFLO employs 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 364: The calculated impedance values available in the recorded data

Impedance value	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.
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.

These impedance values can be utilized as such or they can be further processed in system level fault location applications, such as distribution management system (DMS).

Fault loops "AG Fault" or "BG Fault" or "CG Fault"

Fault loops "AG Fault", "BG Fault" or "CG Fault" are used for single-phase-to-earth faults. When the individual earth faults are located at different feeders, they are also applied in the case of two-phase-to-earth fault. In this case, the phase-to-earth loop (either "AG Fault" or "BG Fault" or "CG Fault") corresponding to the faulty phase at the protected feeder, is used for calculation. Figure 185 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 24)

$$Flt\ loop\ resistance = R_1 + R_N + R_{fault}$$

(Equation 25)

$$Flt\ loop\ reactance = X_1 + X_N$$

(Equation 26)

$$Flt\ phase\ reactance = X_1$$

(Equation 27)

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 earth return path resistance (= (R0 – R1)/3) from the substation to the fault location
X_N	Estimated earth return path reactance (= (X0 – X1)/3) from the substation to the fault location
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.

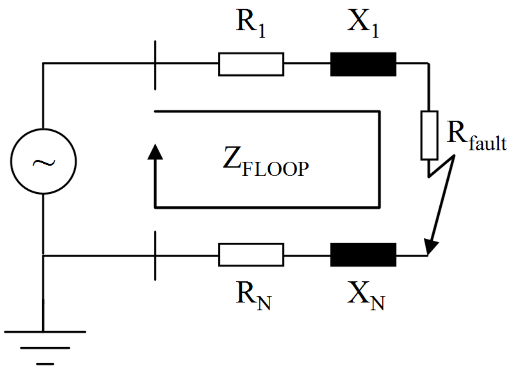


Figure 185: Fault loop impedance for phase-to-earth fault loops "AG Fault", "BG Fault" or "CG Fault"

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 IED location.

The "Load compensation" algorithm utilizes 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 186, 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 186.

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* parameter is the distance at which a single load tap corresponding to the total load of the feeder would result in a voltage drop equal to U_{drop}(real). The dashed curve shows the voltage drop profile in this case.

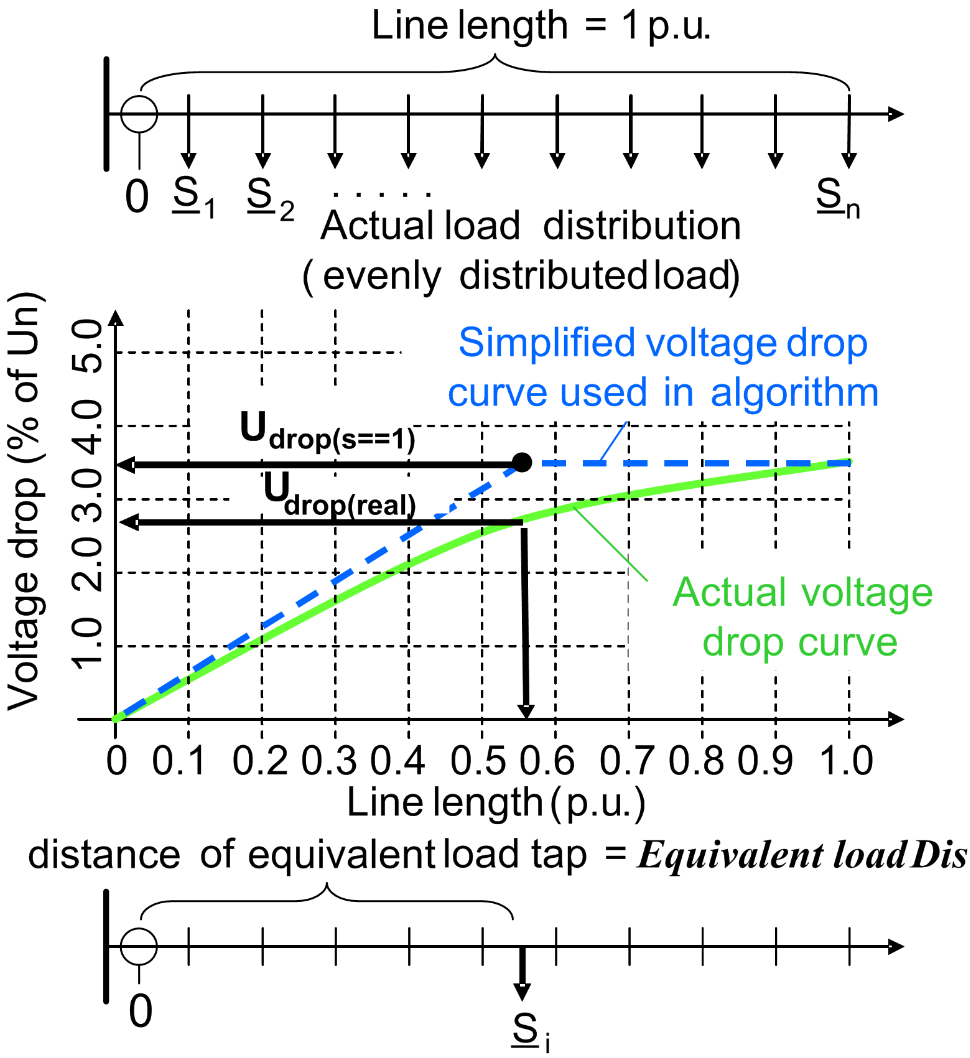


Figure 186: Description of the equivalent load distance

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.

Another method to calculate *Equivalent load Dis* is based on load flow and voltage drop calculations, which are typically taken from a network calculation program. This method uses a certain equation.

$$Equivalent\ load\ Dis = \frac{U_{d(real)}}{U_{d(tap,d=1)}}$$

(Equation 28)

$U_{d(real)}$	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 186). 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 ($R_{fault} = 0\ \Omega$) 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 zero-sequence “Io based” or negative-sequence “I2 based” current based algorithm is used. 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.

Under 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 29 is valid.

$$Flt\ to\ Lod\ Cur\ ratio = \frac{\left|I_{ef(Rfault=0)}\right|}{\left|I_{Load}\right|}$$

(Equation 29)

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 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 and the resistance should not be too high, the maximum is a few hundred ohms. Also low value of Flt to Lod Cur ratio causes inaccuracy and affects the quality of fault distance estimate. Considered inaccuracies affecting the calculated fault distance estimate are reported in the recorded result quality indicator value Flt Dist quality in Table 365.

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 187 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 30)

$$Flt\ loop\ resistance = R_1 + \frac{R_{fault}}{2}$$

(Equation 31)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 32)

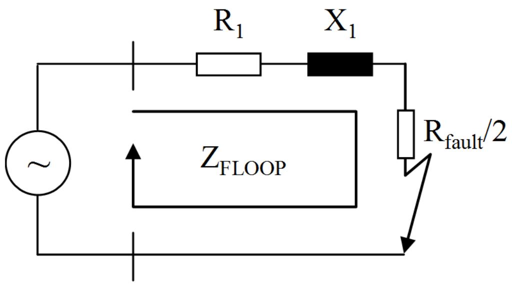


Figure 187: Fault loop impedance for phase-to-phase fault loops (either “AB Fault”, “BC Fault” or “CA Fault”)

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*. The load compensation should be disabled only if the ratio between the fault current and load current is large 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* = “TRUE”. However, 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 188 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 33)

$$Flt\ loop\ resistance = R_1 + R_{fault}$$

(Equation 34)

$$Flt\ loop\ reactance = Flt\ phase\ reactance = X_1$$

(Equation 35)

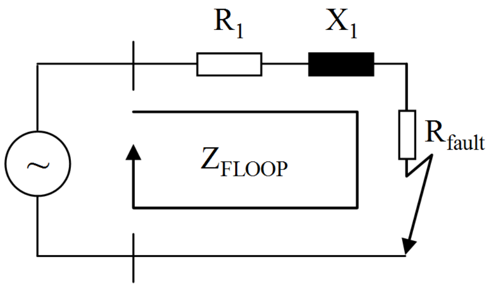


Figure 188: Fault loop impedance for a three-phase fault loop (“ABC Fault”)

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 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*. The load compensation should be disabled only if the ratio between the fault current and load current is large 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* = “TRUE”. However, 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 189. In case of earth faults, the estimated fault point resistance includes the total fault point resistance between the faulted 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 as per phase value, for example, the arc resistance per phase.

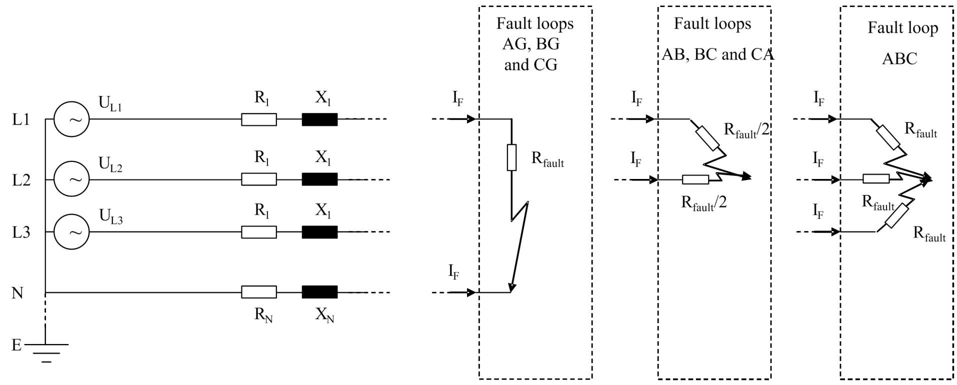


Figure 189: Definition of a physical fault point resistance in different fault loops

Steady-state asymmetry and load compensation

In reality, 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 utilize the delta-quantities which mitigate the effects of the steady-state asymmetry.

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 large or when the fault distance estimate for 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 36)

x_{fault}	Corresponds to the signal value during fault
$x_{pre\text{-}fault}$	Corresponds to the 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. In case Flt Dist quality equals 1, the result is not affected by error sources. This results in good quality for fault distance estimate. If factors affecting negatively to fault distance estimation are detected, the Flt Dist quality is according to Table 365. In this case estimated fault distance, Flt distance value is given in HMI in parenthesis.

Table 365: 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} 1)
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)

1) Total loop reactance according to settings

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 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 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. Even these can be omitted in the short circuit loops, if the setting *Enable simple model* equals "TRUE".

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 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.

$$X_1 \approx \omega_n \times 10^{-4} \left(2 \times \ln \frac{a_{en}}{r} + 0.5 \right) [\Omega / km]$$

(Equation 37)

ω_n	$2 \times \pi \times f_n$, where f_n = fundamental frequency [Hz]
a_{en}	$\sqrt[3]{(a_{12} \times a_{23} \times a_{31})}$ the geometric average of phase distances [m]
a_{xy}	distance [m] between phases x and y
r	radius [m] for single conductor

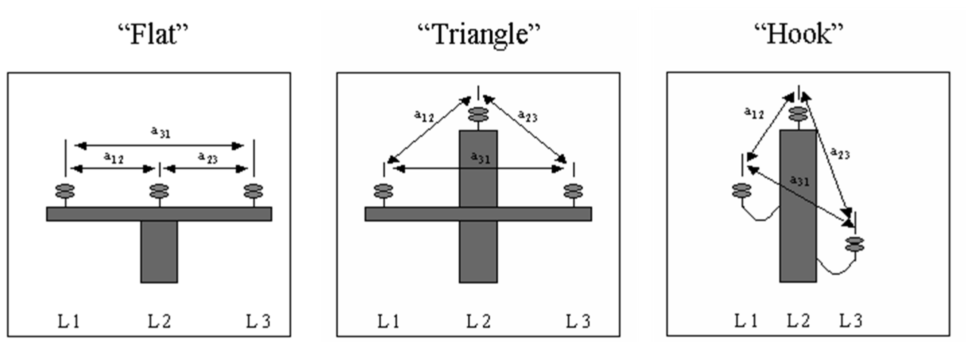


Figure 190: Typical distribution line tower configurations

Example values of positive-sequence impedances for typical medium voltage overhead-lines are given in the following tables.

Table 366: Positive-sequence impedance values for typical 11 kV conductors, “Flat” tower configuration assumed

Name	R1 [Ω/km]	X1 [Ω/km]
ACSR 50 SQ.mm	0.532	0.373
ACSR 500 SQ.mm	0.0725	0.270

Table 367: Positive-sequence impedance values for typical 10/20 kV conductors, “Flat” tower configuration assumed

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
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 368: Positive-sequence impedance values for typical 33 kV conductors, “Flat” tower configuration assumed

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 38)

$$R_0\,[60Hz] \approx R1 + 0.17765\,[\Omega / km]$$

(Equation 39)

$$X_0 \approx 2 \times \omega_n \times 10^{-4} \left(3 \times \ln \frac{w}{r_{en}} + 0.25 \right) [\Omega / km]$$

(Equation 40)

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]
r_{en}	$\sqrt[3]{r\sqrt[3]{a_{12}^2 \times a_{23}^2 \times a_{31}^2}}$
	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*.

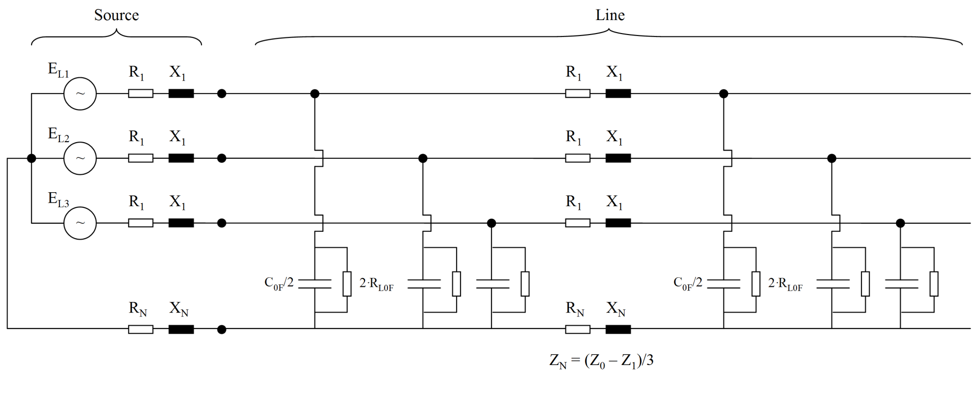


Figure 191: Equivalent diagram of the protected feeder. R_{L0F} = Ph leakage Ris.

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.

$$Ph\ capacitive\ React = \frac{1}{(\omega_n \times C_{0F})}$$

(Equation 41)

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.

$$Ph\ capacitive\ React = \frac{\sqrt{3} \times U_{xy}}{I_{ef}}$$

(Equation 42)

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 and thus, if the switching state of the protected feeder changes, the value should be updated.

Figure 192 shows an example configuration, which enables the measurement of setting *Ph capacitive React*.

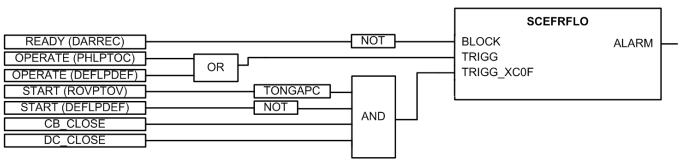


Figure 192: An example configuration, which enables the measurement of setting Ph capacitive React

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 IED with three line sections with independent impedance settings. This improves the accuracy of physical fault distance conversion done in the IED, 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.

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.

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.

Impedance model with three line sections is enabled by setting *Line Len section A*, *Line Len section B* and *Line Len section C* all 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 in the conversion of fault loop reactance into physical fault distance is demonstrated in example shown in Figure 193 with 10 kilometer 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 193.

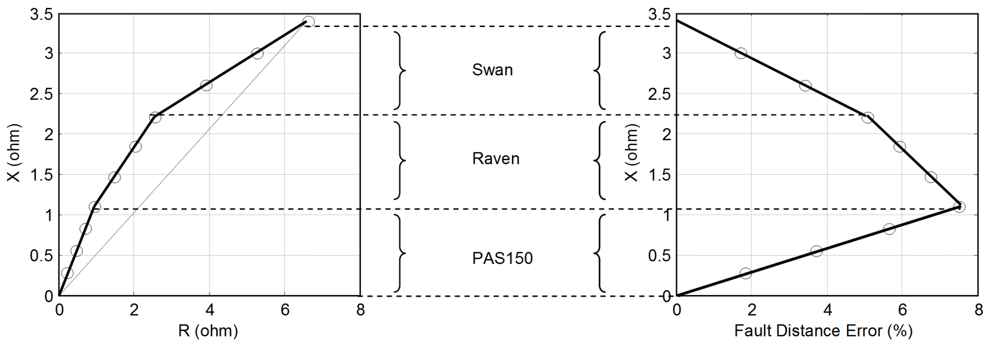


Figure 193: Example impedance diagram of an electrically non-homogeneous feeder (left), and the resulting error in fault distance if the measured fault loop reactance is converted into physical fault distance by using only one line section parameters (right).

In Figure 193 the feeder is modelled either with one or three line sections with parameters given in Table 369.

Table 369: 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	10000 pu	4000 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	3000 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	3000 pu

Figure 193 illustrates the conversion error from 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 194). The actual fault location must be identified using additional information, for example, short circuit current indicators placed on tapping points.

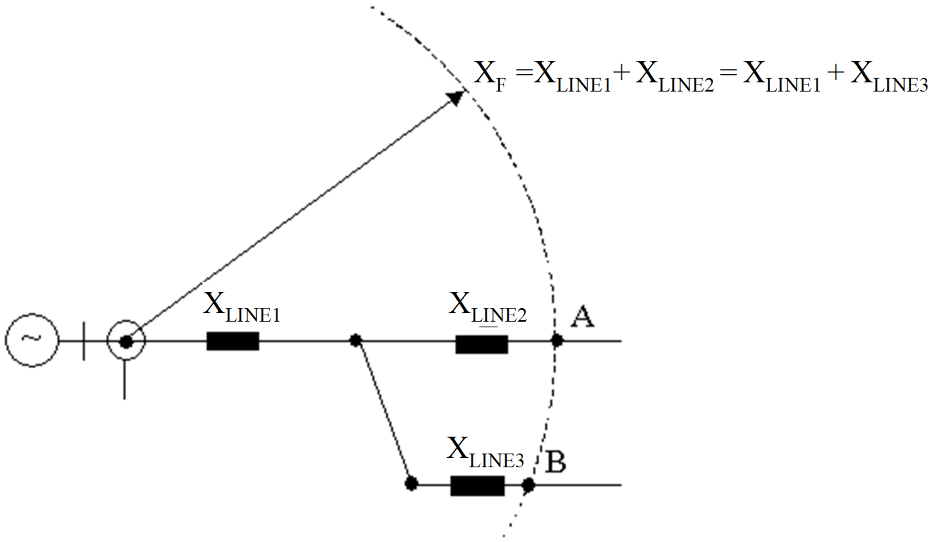


Figure 194: Fault on a distribution line with spurs

5.3.4.3 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 fault distance value recording moment. The fault distance estimate, Flt distance, together with the timestamp 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` 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 is timed suitably to provide sufficient distance estimation calculation time before tripping of the feeder circuit breaker.
- In case of internal triggering, the `TRIGG` 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. In case stabilization criterion has not been fulfilled, the fault distance estimate is given just before the phase currents are interrupted. The phase selection logic is a non-directional function, and thus 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 195 illustrates typical behaviour 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.

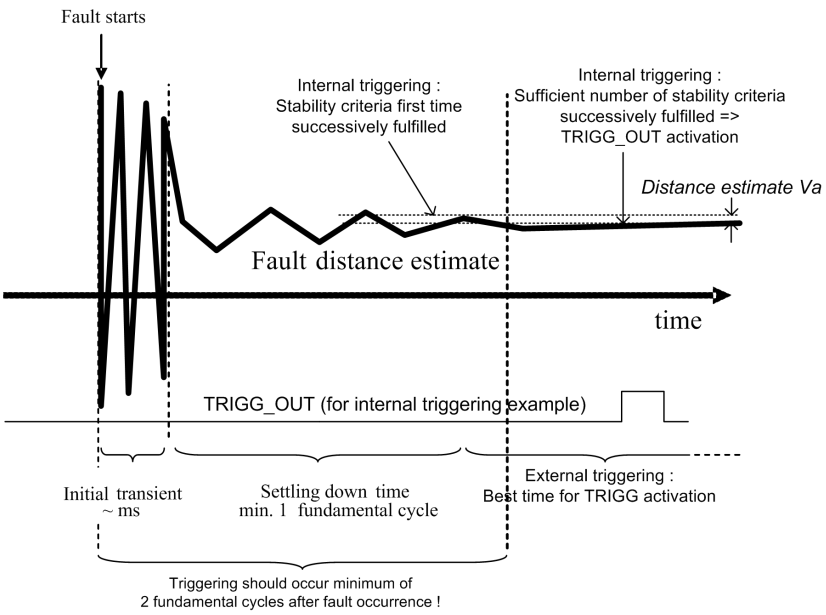


Figure 195: The behavior of fault distance estimate in time

5.3.4.4 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.

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.

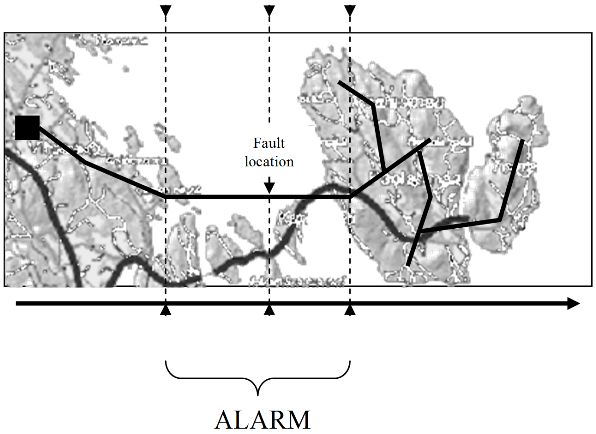


Figure 196: An example of the ALARM output use

5.3.4.5 Recorded data

All the information required for a later fault analysis is recorded to SCEFRFLO recorded data. In the IED, 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. The cross reference table shows which of the recorded data values are available as continuous monitoring values during a fault.

Table 370: 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

5.3.4.6 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".

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” or “CA Fault” or “ABC Fault”) can be measured accurately. In this case, the earth-fault loops (fault loops either “AG Fault”, “BG Fault” or “CG Fault”) cannot provide correct fault distance estimates and the triggering of the function in case of earth fault is automatically disabled.

5.3.5 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. Under certain limitations, SCEFRFLO can also be applied for earth-fault location in unearthed distribution networks.

Configuration example

A typical configuration example for SCEFRFLO triggering is illustrated in Figure 192 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 inverted `READY` signal 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 suggested 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, for earth faults, when *EF algorithm Sel* is set to "Load compensation" or "Load modelling".

5.3.6 Signals

Table 371: SCEFRFLO Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
Io	SIGNAL	0	Residual current
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
Uo	SIGNAL	0	Residual voltage
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode
TRIGG	BOOLEAN	0=False	Distance calculation triggering signal
TRIGG_XC0F	BOOLEAN	0=False	XC0F calculation triggering signal

Table 372: SCEFRFLO Output signals

Name	Type	Description
ALARM	BOOLEAN	Fault location alarm signal

5.3.7 Settings

Table 373: SCEFRFLO Group settings

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
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
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Equivalent load Dis	0.00...1.00		0.01	0.50	Equivalent load distance when EF algorithm equals to load modelling
R1 line section A	0.000...1000.000	ohm / pu	0.001	1.000	Positive sequence line resistance, line section A
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
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 374: SCEFRFLO Non group settings

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
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

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
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
Distance estimate Va	0.001...0.300		0.001	0.015	Allowed variation of short circuit distance estimate

5.3.8 Monitored data

Table 375: SCEFRFLO Monitored data

Name	Type	Values (Range)	Unit	Description
RF	FLOAT32	0.0...1000000.0	ohm	Fault point resistance in primary ohms
FAULT_LOOP	Enum	0=No fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC 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	0.0...1000000.0	ohm	Fault loop resistance in primary ohms
XFLOOP	FLOAT32	0.0...1000000.0	ohm	Fault loop reactance in primary ohms
XFPHASE	FLOAT32	0.0...1000000.0	ohm	Fault phase 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	0.0...1000000.0	ohm	Estimated PhE capacitive reactance of line
SCEFRFLO	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status
Triggering time	Timestamp			Estimate triggering time
Flt loop	Enum	0=No fault 1=AG Fault 2=BG Fault 3=CG Fault 4=AB Fault 5=BC Fault 6=CA Fault 7=ABC Fault		Fault loop

Table continues on next page

Name	Type	Values (Range)	Unit	Description
Flt distance	FLOAT32	0.00...3000.00	pu	Fault distance
Flt Dist quality	INT32	0...511		Fault distance quality
Flt loop resistance	FLOAT32	0.0...1000000.0	ohm	Fault loop resistance
Flt loop reactance	FLOAT32	0.0...1000000.0	ohm	Fault loop reactance
Flt phase reactance	FLOAT32	0.0...1000000.0	ohm	Fault phase reactance
Flt point resistance	FLOAT32	0.0...1000000.0	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	0.0...1000000.0	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	xIn	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	xIn	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	xIn	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
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

Table continues on next page

Name	Type	Values (Range)	Unit	Description
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	xIn	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	xIn	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	xIn	Fault voltage phase C, magnitude
V Flt Phs C angle	FLOAT32	-180.00...180.00	deg	Fault voltage phase C, angle

5.3.9 Technical data

Table 376: 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

Section 6 Supervision functions

6.1 Trip circuit supervision TCSSCBR

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

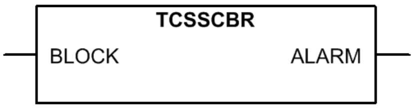


Figure 197: Function block

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 IED 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 trip circuit supervision can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

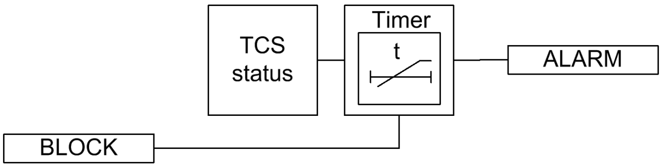


Figure 198: Functional module diagram

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 199 shows an application of the trip circuit supervision function use. The best solution is to connect an external R_{ext} shunt resistor in parallel with the circuit breaker internal contact. Although the circuit breaker internal 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 resistance remains small, that is, it does not harm or overload the circuit breaker's trip coil.

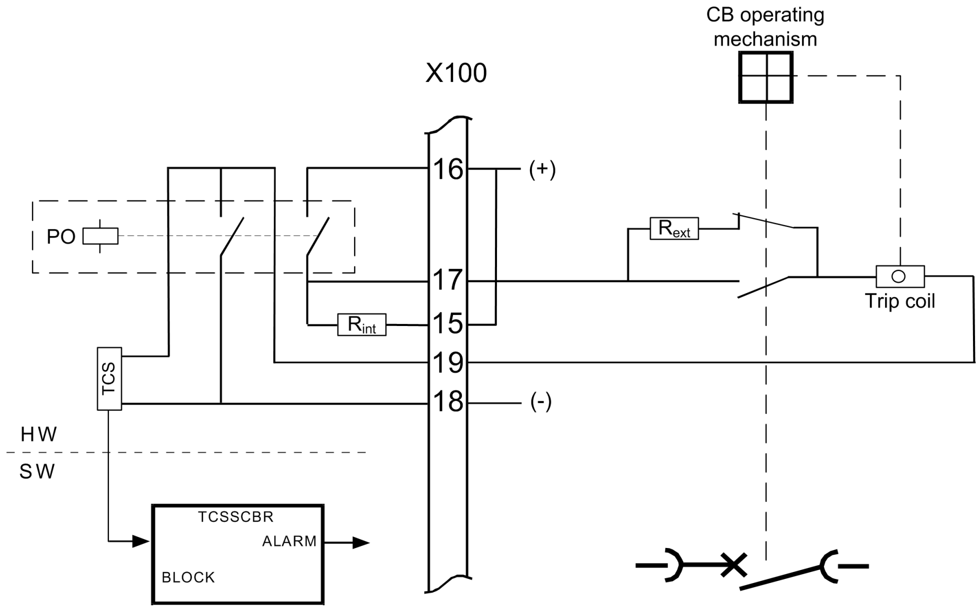


Figure 199: Operating principle of the trip-circuit supervision with an external resistor. The TCSSCBR blocking switch is not required since the external resistor is used.

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 would be to block the supervision function whenever the circuit breaker is open.

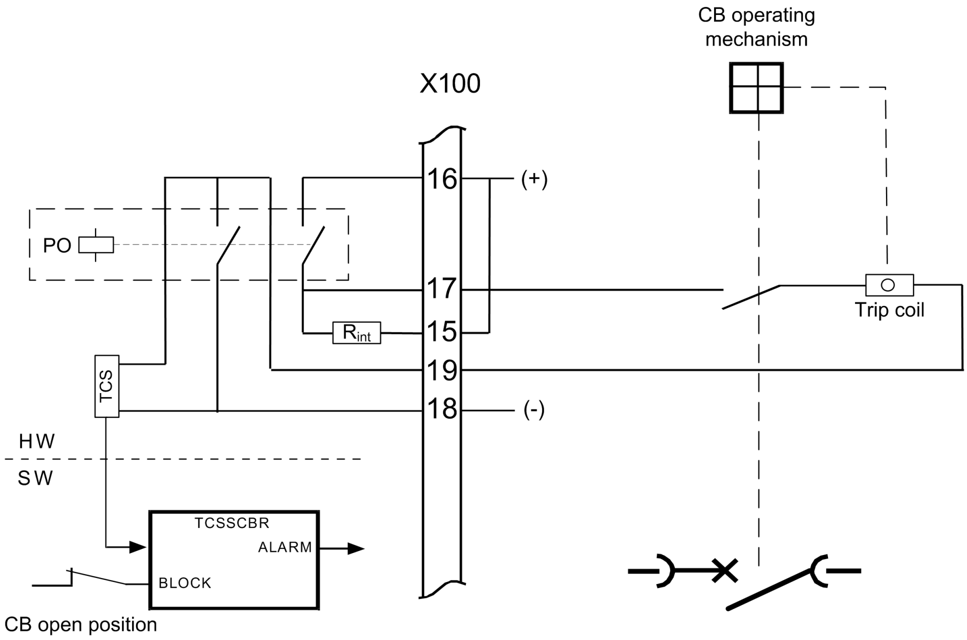


Figure 200: Operating principle of the trip-circuit supervision without an external resistor. The circuit breaker open indication is set to block TCSSCBR when the circuit breaker is open.

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.

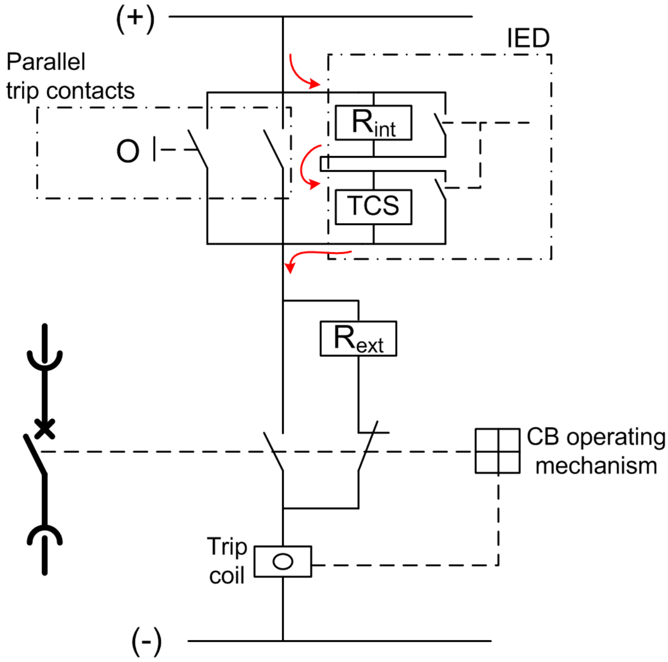


Figure 201: Constant test current flow in parallel trip contacts and trip circuit supervision

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.

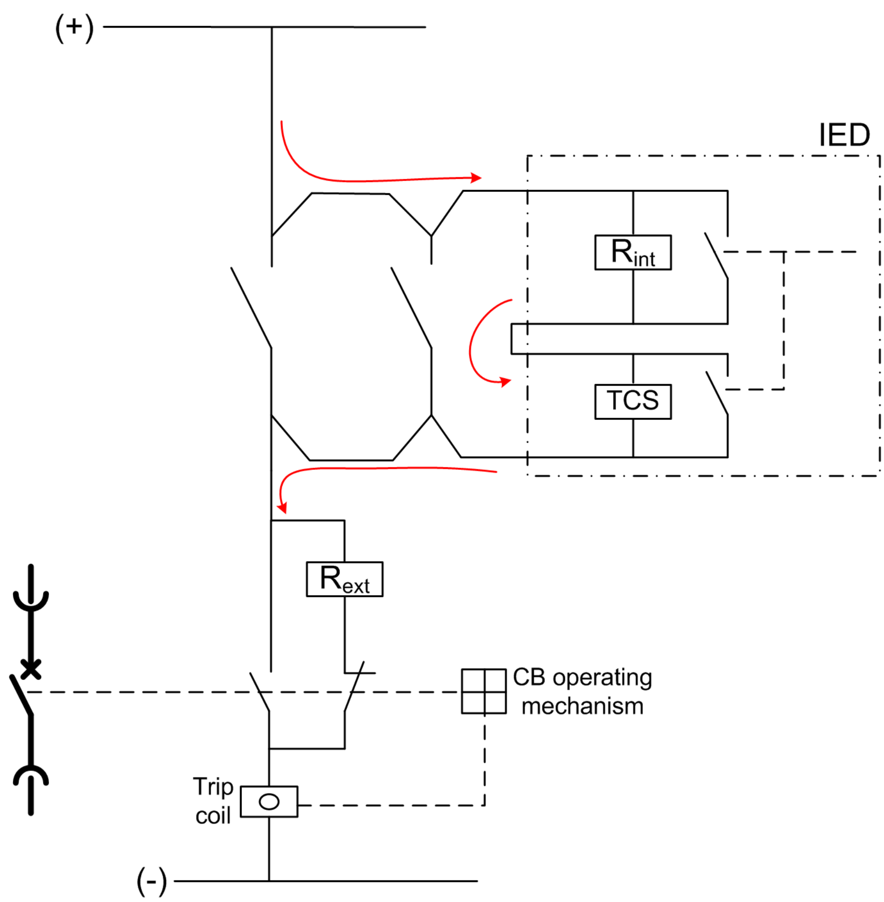


Figure 202: Improved connection for parallel trip contacts where the test current flows through all wires and joints

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 IED 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 IED 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 IED 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 IED trip contact and the circuit breaker coil. This way the breaking capacity question is solved, but the TCS circuit in the protection IED 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:

$$U_C - (R_{ext} + R_{int} + R_s) \times I_c \geq 20V \quad AC / DC$$

(Equation 43)

U_c	Operating voltage over the supervised trip circuit
I_c	Measuring current through the trip circuit, appr. 1.5 mA (0.99...1.72 mA)
R_{ext}	external shunt resistance
R_{int}	internal shunt resistance, 1 kΩ
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 377: Values recommended for the external resistor R_{ext}

Operating voltage U_c	Shunt resistor R_{ext}
48 V DC	1.2 kΩ, 5 W
60 V DC	5.6 kΩ, 5 W
110 V DC	22 kΩ, 5 W
220 V DC	33 kΩ, 5 W

Due to the requirement that the voltage over the TCS contact must be 20V or higher, the correct operation is not guaranteed with auxiliary operating voltages lower than 48V DC because of the voltage drop in R_{int},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 (<48V DC) auxiliary circuit operating voltages, it is recommended to use the circuit breaker position to block unintentional operation of TCS. The use of the position indication is described earlier in this chapter.

Using power output contacts without trip circuit supervision

If TCS is not used but the contact information of corresponding power outputs are required, the internal resistor can be by-passed. The output can then be utilized as a normal power output. When bypassing the internal resistor, the wiring between the terminals of the corresponding output X100:16-15(PO3) or X100:21-20(PO4) can be disconnected. The internal resistor is required if the complete TCS circuit is used.

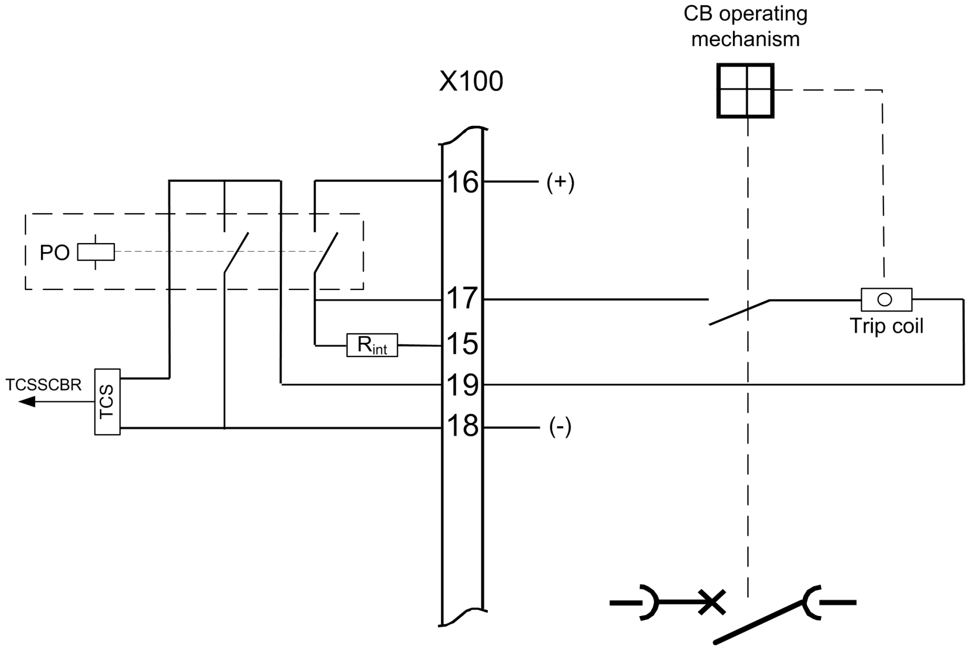


Figure 203: Connection of a power output in a case when TCS is not used and the internal resistor is disconnected

Incorrect connections and use of trip circuit supervision

Although the TCS circuit 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 IED. In addition to the weak breaking capacity, the internal resistor is not dimensioned to withstand current without a TCS circuit. As a result, this kind of incorrect connection causes immediate burning of the internal resistor when the circuit breaker is in the close position and the voltage is applied to the trip circuit. The following picture shows incorrect usage of a TCS circuit when only one of the contacts is used.

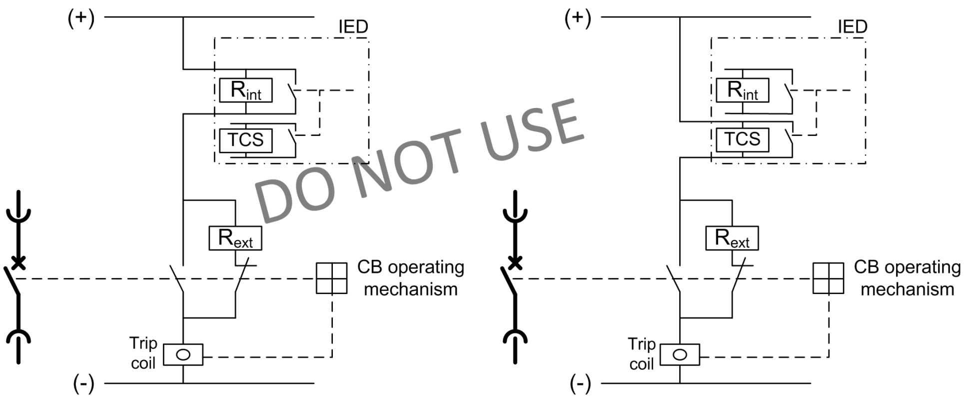


Figure 204: Incorrect connection of trip-circuit supervision

A connection of three protection IEDs with a double pole trip circuit is shown in the following figure. Only the IED R3 has an internal TCS circuit. In order to test the operation of the IED R2, but not to trip the circuit breaker, the upper trip contact of the IED R2 is disconnected, as shown in the figure, while the lower contact is still connected. When the IED R2 operates, the coil current starts to flow through the internal resistor of the IED R3 and the resistor burns immediately. As proven with the previous examples, both trip contacts must operate together. Attention should also be paid for correct usage of the trip-circuit supervision while, for example, testing the IED.

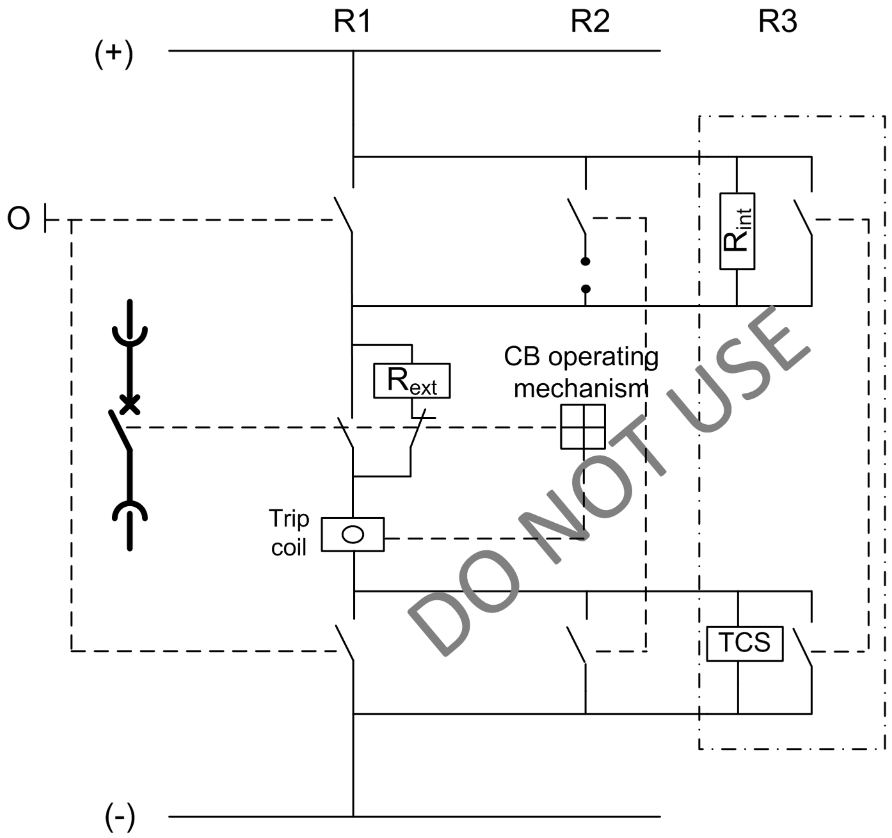


Figure 205: Incorrect testing of IEDs

6.1.6 Signals

Table 378: TCSSCBR Input signals

Name	Type	Default	Description
BLOCK	BOOLEAN	0=False	Block input status

Table 379: TCSSCBR Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm output

6.1.7 Settings

Table 380: TCSSCBR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Operate delay time	20...300000	ms	1	3000	Operate delay time
Reset delay time	20...60000	ms	1	1000	Reset delay time

6.1.8 Monitored data

Table 381: 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 Fuse failure supervision SEQRFUF

6.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Fuse failure supervision	SEQRFUF	FUSEF	60

6.2.2 Function block

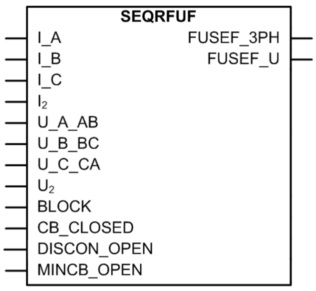


Figure 206: Function block

6.2.3 Functionality

The fuse failure supervision function SEQRFUF 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 IED to avoid misoperations of the voltage protection functions.

SEQRFUF 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.

6.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the fuse failure supervision function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

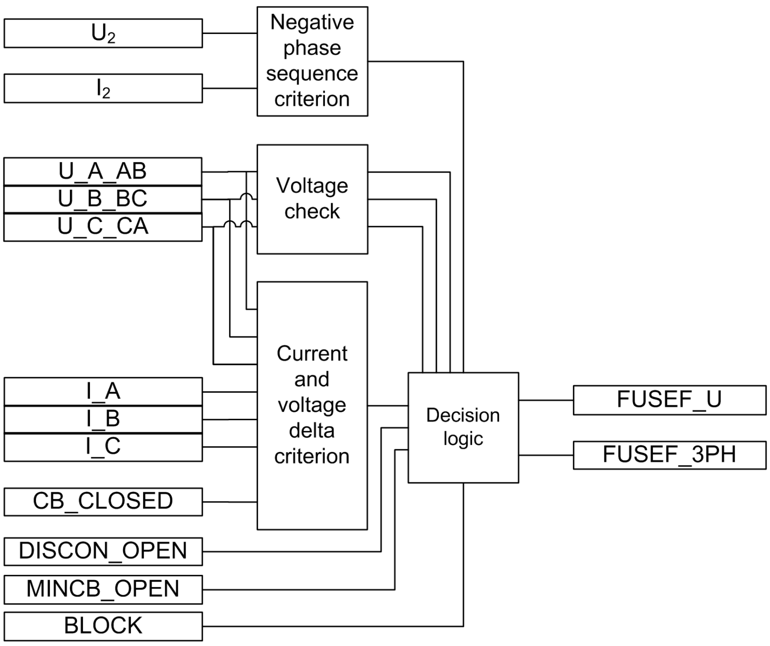


Figure 207: Functional module diagram

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 SEQRFUF 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

The fuse failure detection outputs FUSEF_U and FUSEF_3PH are controlled according to the detection criteria or external signals.

Table 382: 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.
	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.

Table continues on next page

Fuse failure detection criterion	Conditions and function response
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 an IED 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 an IED 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.

6.2.5 Application

Some protection functions operate on the basis of the measured voltage value in the IED 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 IED.

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.

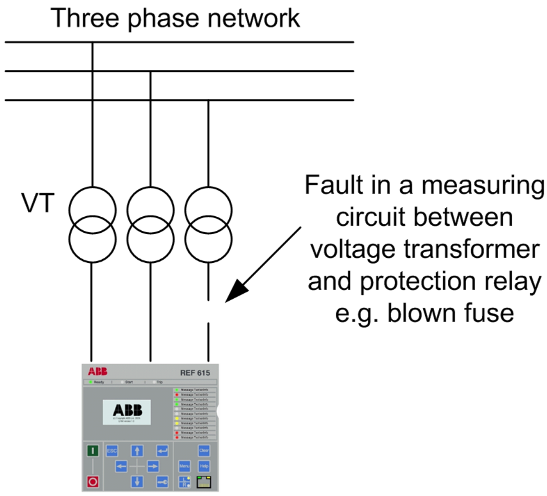


Figure 208: Fault in a circuit from the voltage transformer to the IED

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, SEQRFUF has two outputs for this purpose.

6.2.6 Signals

Table 383: SEQRFUF Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
I_2	SIGNAL	0	Negative sequence current
U_A_AB	SIGNAL	0	Phase A voltage
U_B_BC	SIGNAL	0	Phase B voltage
U_C_CA	SIGNAL	0	Phase C voltage
U_2	SIGNAL	0	Negative phase sequence voltage
BLOCK	BOOLEAN	0=False	Block of function
Table continues on 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 disconnector is open
MINCB_OPEN	BOOLEAN	0=False	Active when external MCB opens protected voltage circuit

Table 384: SEQRFUF Output signals

Name	Type	Description
FUSEF_3PH	BOOLEAN	Three-phase start of function
FUSEF_U	BOOLEAN	General start of function

6.2.7 Settings

Table 385: SEQRFUF Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Neg Seq current Lev	0.03...0.20	xIn	0.01	0.03	Operate level of neg seq undercurrent element
Neg Seq voltage Lev	0.03...0.20	xUn	0.01	0.10	Operate level of neg seq overvoltage element
Current change rate	0.01...0.50	xIn	0.01	0.15	Operate level of change in phase current
Voltage change rate	0.50...0.90	xUn	0.01	0.60	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 delta	0.01...1.00	xUn	0.01	0.70	Minimum operate level of phase voltage for delta calculation
Min Op current delta	0.01...1.00	xIn	0.01	0.10	Minimum operate level of phase current for delta calculation
Seal in voltage	0.01...1.00	xUn	0.01	0.70	Operate level of seal-in phase voltage
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

6.2.8 Monitored data

Table 386: SEQRFUF Monitored data

Name	Type	Values (Range)	Unit	Description
SEQRFUF	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.2.9 Technical data

Table 387: SEQRFUF 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

6.3 Operation time counter MDSOPT

6.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Runtime counter for machines and devices	MDSOPT	OPTS	OPTM

6.3.2 Function block

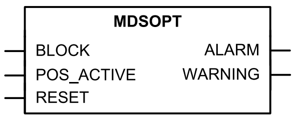


Figure 209: Function block

6.3.3 Functionality

The generic runtime counter 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.

6.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the generic runtime counter for machines and devices can be described using a module diagram. All the modules in the diagram are explained in the next sections.

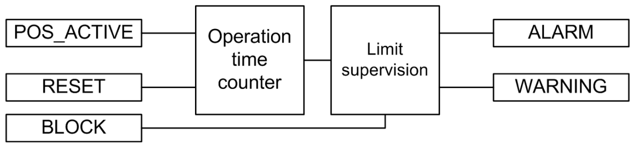


Figure 210: Functional module diagram

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.

6.3.5 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.

6.3.6 Signals

Table 388: 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

Table 389: MDSOPT Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm accumulated operation time exceeds Alarm value
WARNING	BOOLEAN	Warning accumulated operation time exceeds Warning value

6.3.7 Settings

Table 390: MDSOPT Non group settings

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
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 3=Timed Warn Alm			1=Immediate	Operating time mode for warning and alarm

6.3.8 Monitored data

Table 391: 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

6.3.9 Technical data

Table 392: MDSOPT Technical data

Description	Value
Motor run-time measurement accuracy[1)]	±0.5%

1) Of the reading, for a stand-alone relay, without time synchronization.

6.3.10 Technical revision history

Table 393: MDSOPT Technical revision history

Technical revision	Change
B	Internal improvement.
C	Internal improvement.

6.4 Voltage presence PHSVPR

6.4.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage presence	PHSVPR	PHSVPR	PHSVPR

6.4.2 Function block

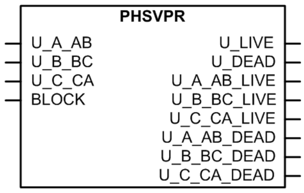


Figure 211: Function block

6.4.3 Functionality

The function block PHSVPR supervises the voltage presence status. The function can be used for indicating voltage presence status of a load break switch or a circuit breaker.

6.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are “On” and “Off”.

The operation of the function can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

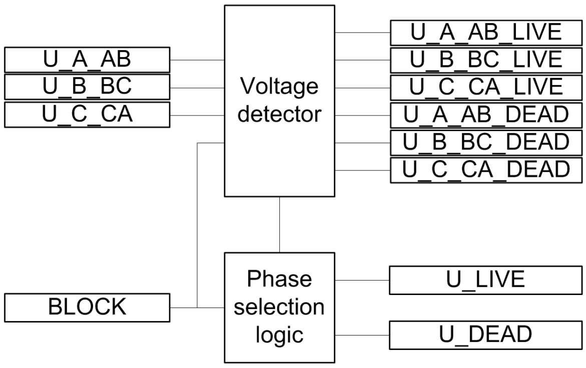


Figure 212: Functional module diagram

Voltage detector

This module supervises voltage presence status value of a load switch or a circuit breaker. The *Voltage selection* setting is used for selecting the phase-to-earth or phase-to-phase voltages for voltage detection, and the *Phase supervision* setting defines which phase or phases are monitored. The measured voltages are compared with threshold settings.

If the measured voltage is larger than the limit value set by *V live value* setting and high voltage lasts longer than the time set by *V live time* setting, the voltage presence is interpreted as live. The corresponding phase specific output indicating live situation is activated. Phase status is also reported to the phase selection logic module.

Once the voltage is lower than setting *V live value*, corresponding phase specific output is deactivated and voltage live timer is reset.

If the measured voltage is lower than setting *V dead value* and low voltage situation lasts longer than the time set by *V dead time* setting, the voltage presence is interpreted as dead. The corresponding phase specific output indicating dead situation is activated. Phase status is also reported to the phase selection logic module.

Once the voltage is larger than setting *V dead value*, the corresponding phase specific output is deactivated and voltage dead timer is reset.

The *Relative hysteresis* setting can be used for preventing unnecessary oscillations if the input signal varies slightly above or below the threshold 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 activation of the `BLOCK` input deactivates all outputs and resets internal timers.

Phase selection logic

General output `U_LIVE` is activated when setting *Num of phases* matches the number of phases where voltage is set above high level setting. `U_LIVE` output is deactivated immediately after voltage live condition is no longer met.

General output U_DEAD is activated when setting *Num of phases* matches the number of phases where voltage is below the set low level setting. U_DEAD output is deactivated immediately after voltage dead condition is no longer met.

The activation of the BLOCK input deactivates all outputs.

6.4.5 Application

Voltage presence indication PHSVPR can be used to detect which one of the MV feeders is energized for feeding the MV/LV transformer. This can reduce the needed time to restore the power after a fault occurs in the distribution network and power needs to be manually re-routed.

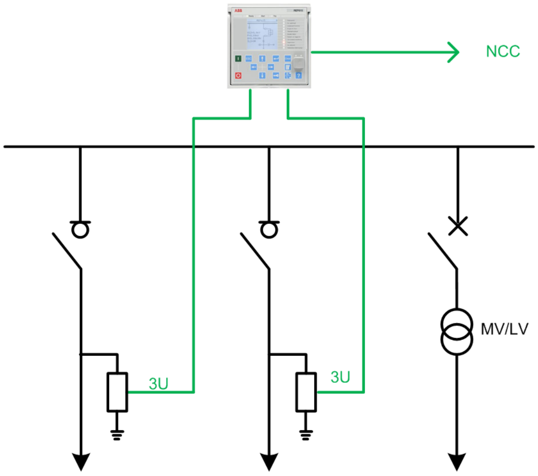


Figure 213: Detect live line to feed MV/LV transformer

PHSVPR can be used in addition to the other indications to detect if it is safe to start working on the line (for example service work).

Never use PHSVPR as the only indication to check if the line is dead.

If the IED is used for the fault indication purposes only, then there might be need to confirm the upstream breaker tripping. PHSVPR can be used for this purpose together with protection and generic counter functions.

6.4.6 Signals

Table 394: PHSVPR Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 395: PHSVPR Output signals

Name	Type	Description
U_LIVE	BOOLEAN	Indicate low voltage presence
U_A_AB_LIVE	BOOLEAN	Indicate high phase to earth voltage A or phase to phase voltage AB
U_B_BC_LIVE	BOOLEAN	Indicate high phase to earth voltage B or phase to phase voltage BC
U_C_CA_LIVE	BOOLEAN	Indicate high phase to earth voltage C or phase to phase voltage CA
U_DEAD	BOOLEAN	Indicate low voltage presence
U_A_AB_DEAD	BOOLEAN	Indicate low phase to earth voltage A or phase to phase voltage AB
U_B_BC_DEAD	BOOLEAN	Indicate low phase to earth voltage B or phase to phase voltage BC
U_C_CA_DEAD	BOOLEAN	Indicate low phase to earth voltage C or phase to phase voltage CA

6.4.7 Settings

Table 396: PHSVPR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Voltage selection	1=phase-to-earth 2=phase-to-phase			2=phase-to-phase	Parameter to select phase or phase-to-phase voltages
Phase supervision	1=A + AB 2=B + BC 3=A&B + AB&BC 4=C + CA 5=A&C + AB&CA 6=B&C + BC&CA 7=A&B&C + AB&BC&CA			4=C + CA	Monitored voltage phase
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
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 for voltage supervision
V live value	0.2...1.0	xUn	0.1	0.5	Limit value for high voltage
V live time	40...10000	ms	1	100	Duration time for high voltage
V dead value	0.1...0.8	xUn	0.1	0.2	Limit value for low voltage
V dead time	40...10000	ms	1	100	Duration time for low voltage
Relative hysteresis	1.0...5.0	%	0.1	4.0	Relative hysteresis for voltage supervision

6.4.8 Monitored data

Table 397: PHSVPR Monitored data

Name	Type	Values (Range)	Unit	Description
PHSVPR	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

6.4.9 Technical data

Table 398: PHSVPR 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
Operation time accuracy	±1.0% of the set value or ±20 ms

Section 7 Condition monitoring functions

7.1 Circuit breaker condition monitoring SSCBR

7.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Circuit breaker condition monitoring	SSCBR	CBCM	CBCM

7.1.2 Function block

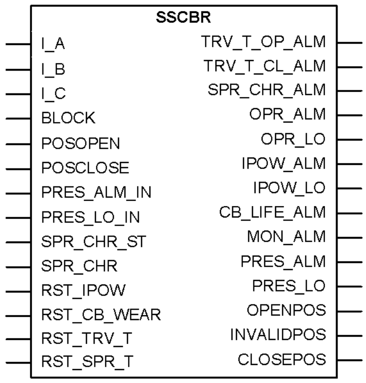


Figure 214: Function block

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 $I^y t$ values. Alarms are generated when the calculated values exceed the threshold settings.

The function contains a blocking functionality. It is possible to block the function outputs, if desired.

7.1.4 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 the functions can be described with a module diagram. All the modules in the diagram are explained in the next sections.

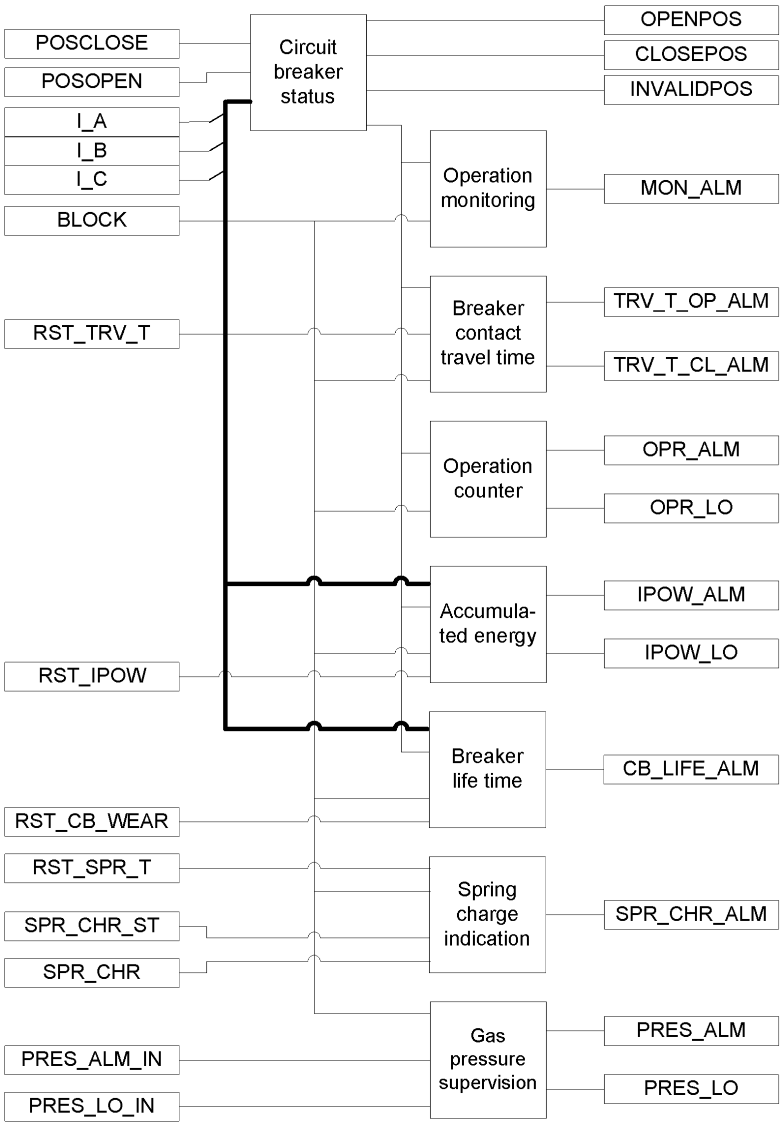


Figure 215: Functional module diagram

7.1.4.1 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.

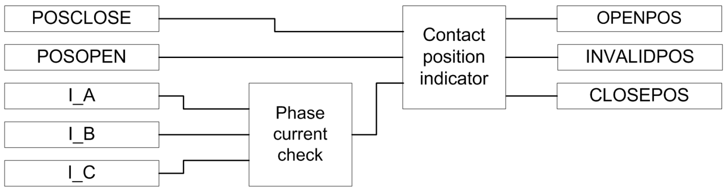


Figure 216: Functional module diagram for monitoring circuit breaker status

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 `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.

7.1.4.2 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.

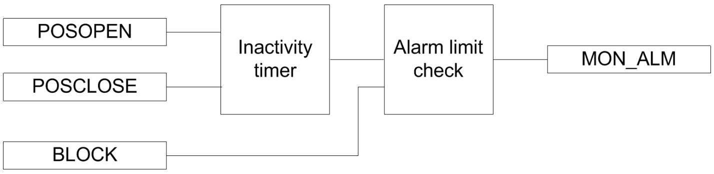


Figure 217: Functional module diagram for calculating inactive days and alarm for circuit breaker operation monitoring

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.

7.1.4.3 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.

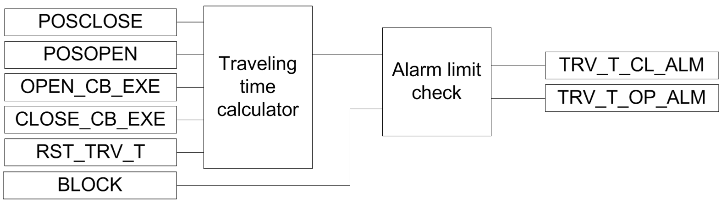


Figure 218: Functional module diagram for breaker contact travel time

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.

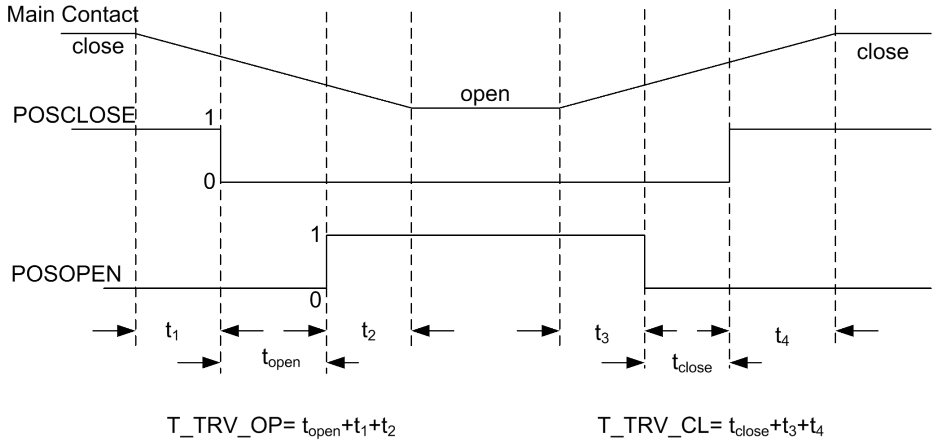


Figure 219: Travel time calculation when Travel time Clc mode is “From Pos to Pos”

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.

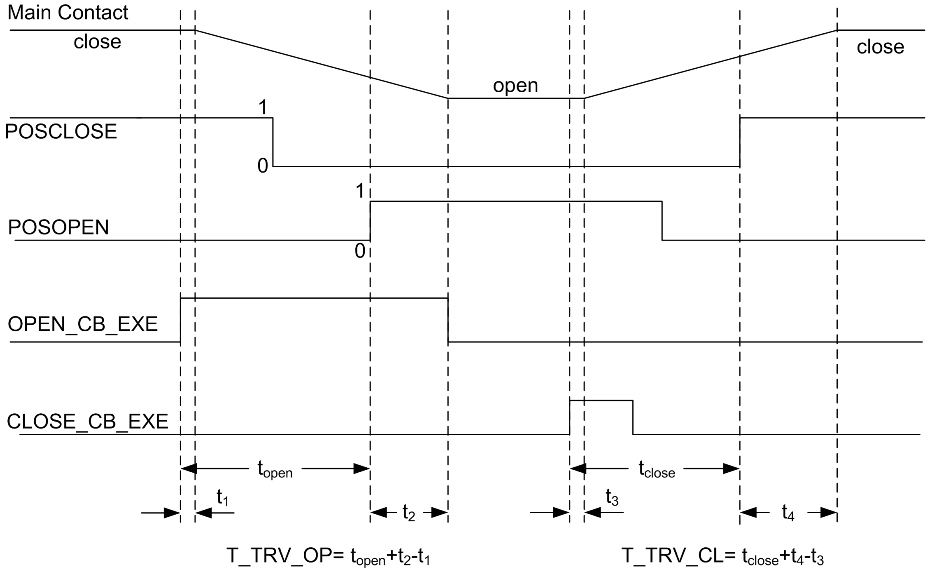


Figure 220: Travel time calculation when Travel time Clc mode is "From Cmd to Pos"

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.

7.1.4.4 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.

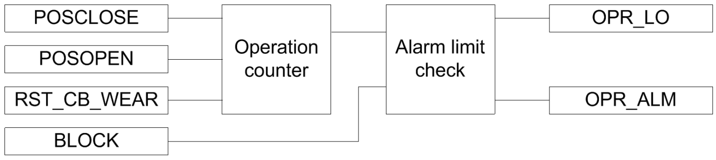


Figure 221: Functional module diagram for counting circuit breaker operations

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.

7.1.4.5 Accumulation of I^yt

Accumulation of the I^yt 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.

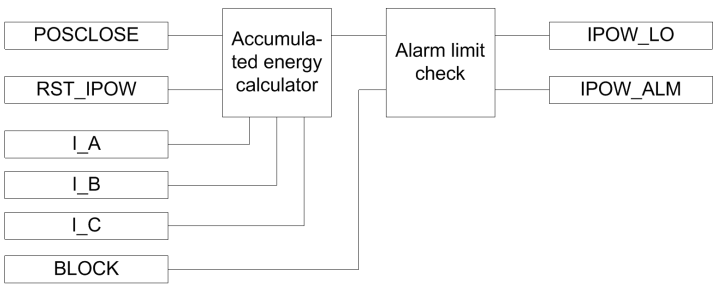


Figure 222: Functional module diagram for calculating accumulative energy and alarm

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.

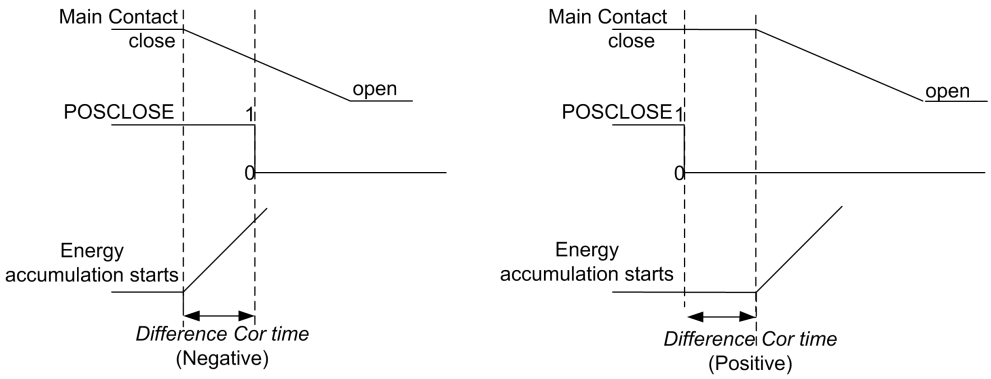


Figure 223: Significance of the Difference Cor time setting

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.

7.1.4.6 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.

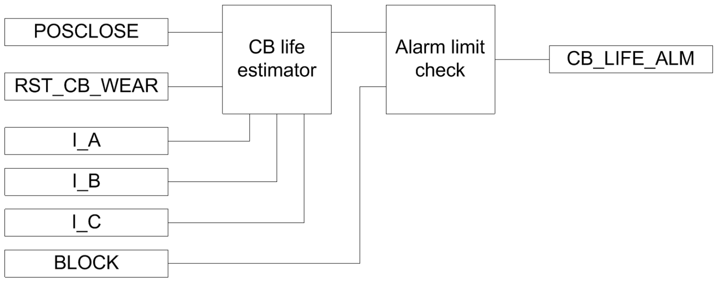


Figure 224: Functional module diagram for estimating the life of the circuit breaker

Circuit breaker life estimator

The circuit breaker life estimator module calculates the remaining life of the circuit breaker. If the tripping current is less 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 more than the rated fault current set with the *Rated fault current* setting, the possible operations are zero. The remaining life of the tripping current in between these two values is calculated based on the trip curve given by the manufacturer. 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, respectively.

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.

7.1.4.7 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.

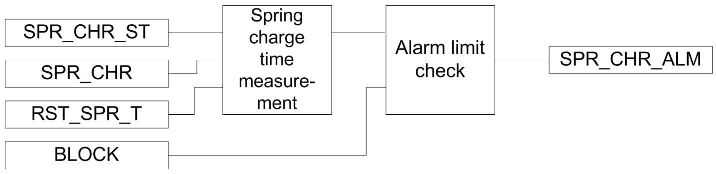


Figure 225: Functional module diagram for circuit breaker spring-charged indication and alarm

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.

7.1.4.8 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.

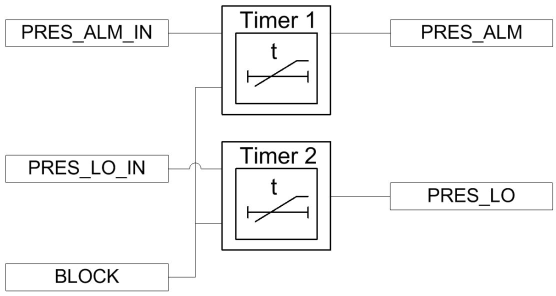


Figure 226: Functional module diagram for circuit breaker gas pressure alarm

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.

7.1.5 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

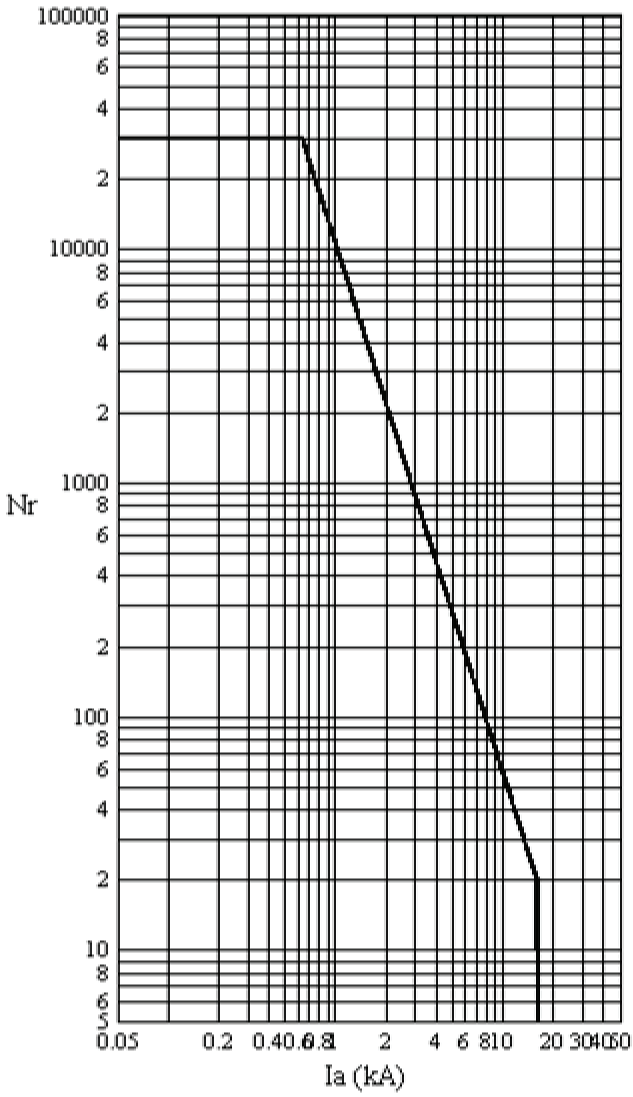


Figure 227: Trip Curves for a typical 12 kV, 630 A, 16 kA vacuum interrupter

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 of Directional Coef

The directional coefficient is calculated according to the formula:

$$Directional\,Coef = \frac{\log\left(\frac{B}{A}\right)}{\log\left(\frac{I_f}{I_r}\right)} = -2.2609$$

(Equation 44)

I_r	Rated operating current = 630 A
I_f	Rated fault current = 16 kA
A	Op number rated = 30000
B	Op number fault = 20

Calculation for estimating the remaining life

Figure 227 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.

7.1.6 Signals

Table 399: SSCBR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
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

Table continues on next page

Name	Type	Default	Description
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

Table 400: 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

7.1.7 Settings

Table 401: SSCBR Non group settings

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	1	40	Alarm level setting for open travel time in ms
Close alarm time	0...200	ms	1	40	Alarm level Setting for close travel time in ms
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Opening time Cor	0...100	ms	1	10	Correction factor for open travel time in ms
Closing time Cor	0...100	ms	1	10	Correction factor for CB close travel time in ms
Spring charge time	0...60000	ms	10	1000	Setting of alarm for spring charging time of CB in ms
Counter initial Val	0...9999		1	0	The operation numbers counter initialization value
Alarm Op number	0...9999		1	200	Alarm limit for number of operations
Lockout Op number	0...9999		1	300	Lock out limit for number of operations
Current exponent	0.00...2.00		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
Ini Acc currents Pwr	0.00...20000.00		0.01	0.00	Initial value for accumulation energy (Iyt)
Directional Coef	-3.00...-0.50		0.01	-1.50	Directional coefficient for CB life calculation
Initial CB Rmn life	0...9999		1	5000	Initial value for the CB remaining life
Rated Op current	100.00...5000.00	A	0.01	1000.00	Rated operating current of the breaker
Rated fault current	500.00...75000.00	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
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
Inactive Alm days	0...9999		1	2000	Alarm limit value of the inactive days counter
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

7.1.8 Monitored data

Table 402: 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	-9999...9999		CB Remaining life phase A
CB_LIFE_B	INT32	-9999...9999		CB Remaining life phase B
CB_LIFE_C	INT32	-9999...9999		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

7.1.9 Technical data

Table 403: SSCBR Technical data

Characteristic	Value
Current measuring accuracy	±1.5% or ±0.002 x I_n (at currents in the range of 0.1…10 x I_n) ±5.0% (at currents in the range of 10…40 x I_n)
Operate time accuracy	±1.0% of the set value or ±20 ms
Travelling time measurement	+10 ms / -0 ms

7.1.10 Technical revision history

Table 404: SSCBR Technical revision history

Technical revision	Change
B	Added the possibility to reset spring charge time and breaker travel times
C	Removed the DIFTRVTOPALM and DIFTRVTCLALM outputs and the corresponding *Open Dif alarm time* and *Close Dif alarm time* setting parameters
D	The *Operation cycle* setting parameter renamed to *Initial CB Rmn life*. The IPOW_A (_B, _C) range changed.

Section 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 also available in VMMXU.

The residual current measurement function RESCMMXU is used for monitoring and metering the residual current 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 three-phase power and energy measurement PEMMXU is used for monitoring and metering 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 and remotely to a network control center with communication.

If the measured data 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**.

If the *Demand interval* setting is set to "15 minutes", for example, the demand values are updated every quarter of an hour. The demand time interval is synchronized to the real-time clock of the IED. 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 IED, 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.

Value reporting

The measurement functions are capable of reporting new values for network control center (SCADA system) based on the following 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.

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 405: 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)
Residual current measurement (RESCMMXU)	1% of nominal (In)
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.

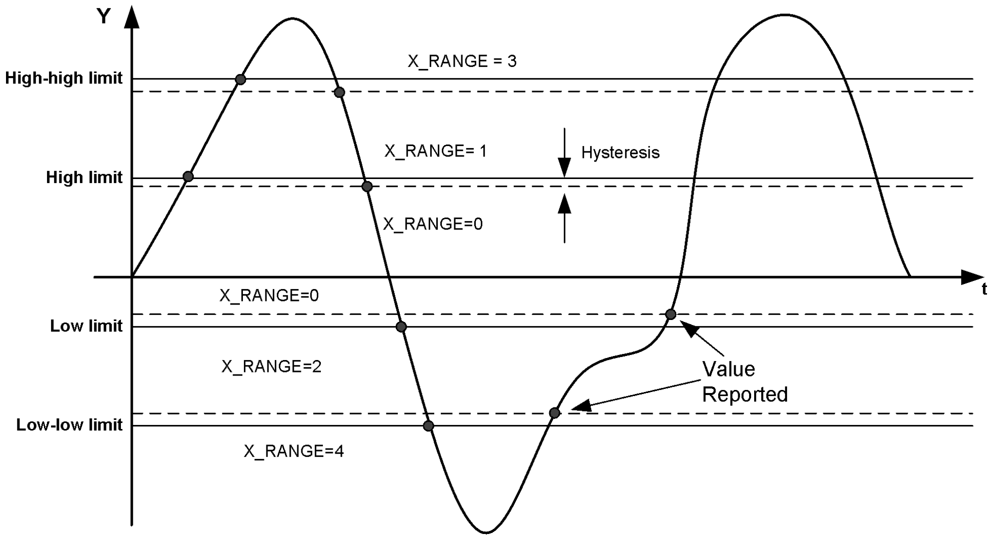


Figure 228: Presentation of operating limits

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 406: 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*
Residual current measurement (RESCMMXU)	High limit	*A high limit res*
	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*

Table continues on next page

Function	Settings for limit value supervision	
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.

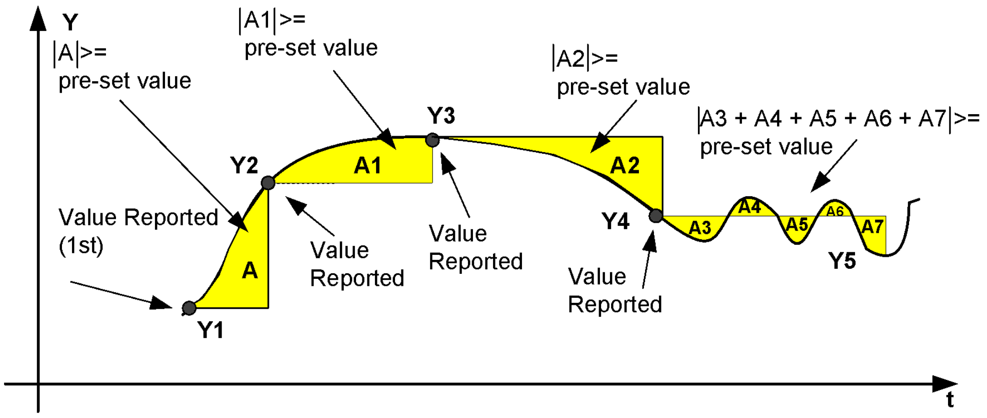


Figure 229: Integral deadband supervision

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 45)

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 407: Parameters for deadband calculation

Function	Settings	Maximum/minimum (=range)
Three-phase current measurement (CMMXU)	*A deadband*	*40 / 0 (=40xIn)*
Three-phase voltage measurement (VMMXU)	*V Deadband*	*4 / 0 (=4xUn)*
Residual current measurement (RESCMMXU)	*A deadband res*	*40 / 0 (=40xIn)*
Frequency measurement (FMMXU)	*F deadband*	*75 / 35 (=40Hz)*
Phase sequence current measurement (CSMSQI)	*Ps Seq A deadband, Ng Seq A deadband, Zro A deadband*	*40 / 0 (=40xIn)*
Phase sequence voltage measurement (VSMSQI)	*Ps Seq V deadband, Ng Seq V deadband, Zro V deadband*	*4/0 (=4xUn)*
Three-phase power and energy measurement (PEMMXU)	-	

In the three-phase power and energy measurement function PEMMXU, the deadband supervision is done separately for apparent power S, with the preset value of fixed 10 percent of the Sn, and the power factor PF, with the preset values fixed at 0.10. The power measurement-related values P, Q, S and PF are reported simultaneously when either one of the S or PF values exceed the preset limit.. All the power measurement-related values P, Q, S and PF are reported simultaneously when either one of the S or PF values exceeds the preset limit.

Power and energy calculation

The three-phase power is calculated from the phase-to-earth voltages and phase-to-earth currents. The power measurement function is capable of calculating a complex power based on the fundamental frequency component phasors (DFT).

$$\overline{S} = (\overline{U}_A \cdot \overline{I}^*_A + \overline{U}_B \cdot \overline{I}^*_B + \overline{U}_C \cdot \overline{I}^*_C)$$

(Equation 46)

Once the complex apparent power is calculated, P, Q, S and PF are calculated with the equations:

$$P = \mathrm{Re}(\overline{S})$$

(Equation 47)

$$Q = \mathrm{Im}(\overline{S})$$

(Equation 48)

$$S = \left|\overline{S}\right| = \sqrt{P^2 + Q^2}$$

(Equation 49)

$$Cos\varphi = \frac{P}{S}$$

(Equation 50)

Depending on the unit multiplier selected with *Power unit Mult*, the calculated power values are presented in units of kVA/kW/kVAr or in units of MVA/MW/MVAr.

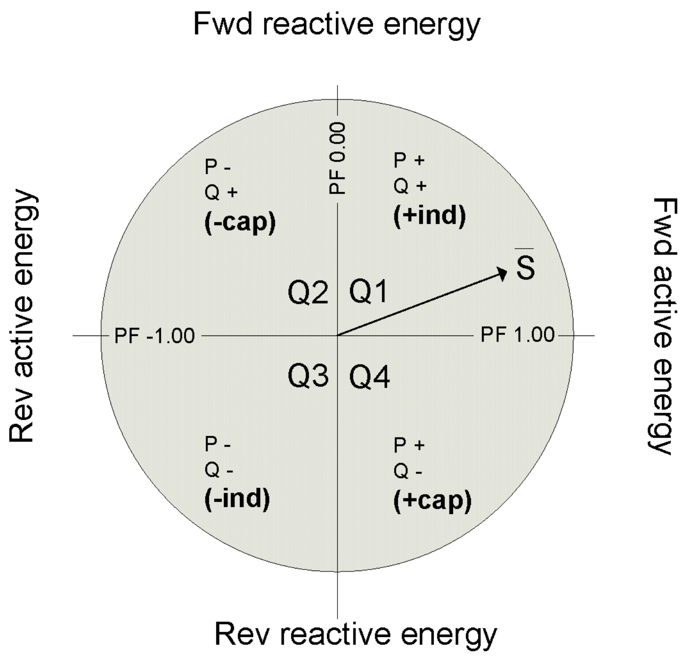


Figure 230: Complex power and power quadrants

Table 408: 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 WArh Initial* and ER_RV_ACM to *Reverse WArh 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 General function block features 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 IEDs 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 IED analog measurement chain can be verified during normal service by a periodic comparison of the measured value from the IED 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 in keeping the communication load in minimum and yet measurement values are reported frequently enough.

8.1.4 Three-phase current measurement CMMXU

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	3I

8.1.4.2 Function block

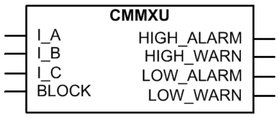


Figure 231: Function block

8.1.4.3 Signals

Table 409: CMMXU Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 410: 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

8.1.4.4 Settings

Table 411: CMMXU Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
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
A high high limit	0.00...40.00	xIn		1.40	High alarm current limit
A high limit	0.00...40.00	xIn		1.20	High warning current limit
A low limit	0.00...40.00	xIn		0.00	Low warning current limit
A low low limit	0.00...40.00	xIn		0.00	Low alarm current limit
A deadband	100...100000			2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.4.5 Monitored data

Table 412: CMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
IL1-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase A
IL2-A	FLOAT32	0.00...40.00	xIn	Measured current amplitude phase B
IL3-A	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
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	xIn	xIn	IL1 Amplitude, magnitude of reported value
I_DMD_A	FLOAT32	xIn	xIn	Demand value of IL1 current
I_RANGE_A	INT32	0...4		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
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
I_DB_B	FLOAT32	xIn	xIn	IL2 Amplitude, magnitude of reported value
I_DMD_B	FLOAT32	xIn	xIn	Demand value of IL2 current
I_RANGE_B	INT32	0...4		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	xIn	xIn	IL3 Amplitude, magnitude of reported value
I_DMD_C	FLOAT32	xIn	xIn	Demand value of IL3 current
I_RANGE_C	INT32	0...4		IL3 Amplitude range

8.1.4.6 Technical data

Table 413: 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

8.1.4.7 Technical revision history

Table 414: CMMXU Technical revision history

Technical revision	Change
B	Menu changes

8.1.5 Three-phase voltage measurement VMMXU

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	3U

8.1.5.2 Function block

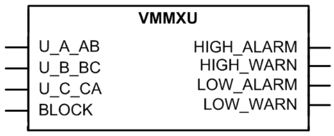


Figure 232: Function block

8.1.5.3 Signals

Table 415: VMMXU Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase to earth voltage A or phase to phase voltage AB
U_B_BC	SIGNAL	0	Phase to earth voltage B or phase to phase voltage BC
U_C_CA	SIGNAL	0	Phase to earth voltage C or phase to phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 416: 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

8.1.5.4 Settings

Table 417: VMMXU Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
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		1.40	High alarm voltage limit
V high limit	0.00...4.00	xUn		1.20	High warning voltage limit
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
V low limit	0.00...4.00	xUn		0.00	Low warning voltage limit
V low low limit	0.00...4.00	xUn		0.00	Low alarm voltage limit
V deadband	100...100000			10000	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.5.5 Monitored data

Table 418: VMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
U12-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase AB
U23-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase BC
U31-kV	FLOAT32	0.00...4.00	xUn	Measured phase to phase voltage amplitude phase CA
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 reported value
U_DMD_AB	FLOAT32	0.00...4.00	xUn	Demand value of U12 voltage
U_RANGE_AB	INT32	0...4		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 reported value
U_DMD_BC	FLOAT32	0.00...4.00	xUn	Demand value of U23 voltage
U_RANGE_BC	INT32	0...4		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 reported value
U_DMD_CA	FLOAT32	0.00...4.00	xUn	Demand value of U31 voltage

Table continues on next page

Name	Type	Values (Range)	Unit	Description
U_RANGE_CA	INT32	0...4		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

8.1.5.6 Technical data

Table 419: 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 Residual current measurement RESCMMXU

8.1.6.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Residual current measurement	RESCMMXU	Io	Io

8.1.6.2 Function block

Figure 233: Function block

8.1.6.3 Signals

Table 420: RESCMMXU Input signals

Name	Type	Default	Description
Io	SIGNAL	0	Residual current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 421: RESCMMXU Output signals

Name	Type	Description
HIGH_ALARM	BOOLEAN	High alarm
HIGH_WARN	BOOLEAN	High warning

8.1.6.4 Settings

Table 422: RESCMMXU Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Measurement mode	1=RMS 2=DFT			2=DFT	Selects used measurement mode
A Hi high limit res	0.00...40.00	xIn		0.20	High alarm current limit
A high limit res	0.00...40.00	xIn		0.05	High warning current limit
A deadband res	100...100000			2500	Deadband configuration value for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.6.5 Monitored data

Table 423: RESCMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
Io-A	FLOAT32	0.00...40.00	xIn	Measured residual current
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

8.1.6.6 Technical data

Table 424: 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

8.1.6.7 Technical revision history

Table 425: RESCMMXU Technical revision history

Technical revision	Change
B	-

8.1.7 Frequency measurement FMMXU

8.1.7.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Frequency measurement	FMMXU1	F	F

8.1.7.2 Function block

Figure 234: Function block

8.1.7.3 Signals

Table 426: FMMXU Input signals

Name	Type	Default	Description
F	SIGNAL	—	Measured system frequency

8.1.7.4 Settings

Table 427: FMMXU Non group settings

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		60.00	High alarm frequency limit
F high limit	35.00...75.00	Hz		55.00	High warning frequency limit
F low limit	35.00...75.00	Hz		45.00	Low warning frequency limit
F low low limit	35.00...75.00	Hz		40.00	Low alarm frequency limit
F deadband	100...100000			1000	Deadband configuration value for integral calculation (percentage of difference between min and max as 0,001 % s)

8.1.7.5 Monitored data

Table 428: FMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
f-Hz	FLOAT32	35.00...75.00	Hz	Measured frequency

8.1.7.6 Technical data

Table 429: FMMXU Technical data

Characteristic	Value
Operation accuracy	±10 mHz (in measurement range 35...75 Hz)

8.1.8 Sequence current measurement CSMSQI

8.1.8.1 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

8.1.8.2 Function block

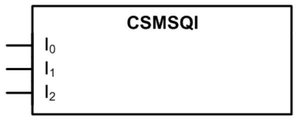


Figure 235: Function block

8.1.8.3 Signals

Table 430: CSMSQI Input signals

Name	Type	Default	Description
I_0	SIGNAL	0	Zero sequence current
I_1	SIGNAL	0	Positive sequence current
I_2	SIGNAL	0	Negative sequence current

8.1.8.4 Settings

Table 431: CSMSQI Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Ps Seq A Hi high Lim	0.00...40.00	xIn		1.40	High alarm current limit for positive sequence current
Ps Seq A high limit	0.00...40.00	xIn		1.20	High warning current limit for positive sequence current
Ps Seq A low limit	0.00...40.00	xIn		0.00	Low warning current limit for positive sequence current
Ps Seq A low low Lim	0.00...40.00	xIn		0.00	Low alarm current limit for positive sequence current
Ps Seq A deadband	100...100000			2500	Deadband configuration value for positive sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Ng Seq A Hi high Lim	0.00...40.00	xIn		0.20	High alarm current limit for negative sequence current
Ng Seq A High limit	0.00...40.00	xIn		0.05	High warning current limit for negative sequence current
Ng Seq A low limit	0.00...40.00	xIn		0.00	Low warning current limit for negative sequence current
Ng Seq A low low Lim	0.00...40.00	xIn		0.00	Low alarm current limit for negative sequence current
Ng Seq A deadband	100...100000			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		0.20	High alarm current limit for zero sequence current
Zro A High limit	0.00...40.00	xIn		0.05	High warning current limit for zero sequence current
Zro A low limit	0.00...40.00	xIn		0.00	Low warning current limit for zero sequence current
Zro A low low Lim	0.00...40.00	xIn		0.00	Low alarm current limit for zero sequence current
Zro A deadband	100...100000			2500	Deadband configuration value for zero sequence current for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.8.5 Monitored data

Table 432: CSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
NgSeq-A	FLOAT32	0.00...40.00	xIn	Measured negative sequence current
PsSeq-A	FLOAT32	0.00...40.00	xIn	Measured positive sequence current
ZroSeq-A	FLOAT32	0.00...40.00	xIn	Measured zero sequence current

8.1.8.6 Technical data

Table 433: 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,…

8.1.9 Sequence voltage measurement VSMSQI

8.1.9.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Sequence voltage measurement	VSMSQI	U1, U2, U0	U1, U2, U0

8.1.9.2 Function block

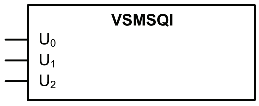


Figure 236: Function block

8.1.9.3 Signals

Table 434: VSMSQI Input signals

Name	Type	Default	Description
U_0	SIGNAL	0	Zero sequence voltage
U_1	SIGNAL	0	Positive phase sequence voltage
U_2	SIGNAL	0	Negative phase sequence voltage

8.1.9.4 Settings

Table 435: VSMSQI Non group settings

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		1.40	High alarm voltage limit for positive sequence voltage
Ps Seq V high limit	0.00...4.00	xUn		1.20	High warning voltage limit for positive sequence voltage
Ps Seq V low limit	0.00...4.00	xUn		0.00	Low warning voltage limit for positive sequence voltage
Ps Seq V low low Lim	0.00...4.00	xUn		0.00	Low alarm voltage limit for positive sequence voltage
Ps Seq V deadband	100...100000			10000	Deadband configuration value for positive sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Ng Seq V Hi high Lim	0.00...4.00	xUn		0.20	High alarm voltage limit for negative sequence voltage
Ng Seq V High limit	0.00...4.00	xUn		0.05	High warning voltage limit for negative sequence voltage
Ng Seq V low limit	0.00...4.00	xUn		0.00	Low warning voltage limit for negative sequence voltage
Ng Seq V low low Lim	0.00...4.00	xUn		0.00	Low alarm voltage limit for negative sequence voltage
Ng Seq V deadband	100...100000			10000	Deadband configuration value for negative sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)
Zro V Hi high Lim	0.00...4.00	xUn		0.20	High alarm voltage limit for zero sequence voltage
Zro V High limit	0.00...4.00	xUn		0.05	High warning voltage limit for zero sequence voltage
Zro V low limit	0.00...4.00	xUn		0.00	Low warning voltage limit for zero sequence voltage
Zro V low low Lim	0.00...4.00	xUn		0.00	Low alarm voltage limit for zero sequence voltage
Zro V deadband	100...100000			10000	Deadband configuration value for zero sequence voltage for integral calculation. (percentage of difference between min and max as 0,001 % s)

8.1.9.5 Monitored data

Table 436: VSMSQI Monitored data

Name	Type	Values (Range)	Unit	Description
NgSeq-kV	FLOAT32	0.00...4.00	xUn	Measured negative sequence voltage
PsSeq-kV	FLOAT32	0.00...4.00	xUn	Measured positive sequence voltage
ZroSeq-kV	FLOAT32	0.00...4.00	xUn	Measured zero sequence voltage

8.1.9.6 Technical data

Table 437: 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,…

8.1.10 Three-phase power and energy measurement PEMMXU

8.1.10.1 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

8.1.10.2 Function block

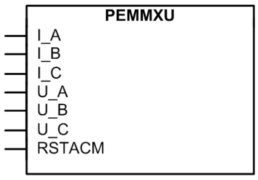


Figure 237: Function block

8.1.10.3 Signals

Table 438: PEMMXU Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current
I_B	SIGNAL	0	Phase B current
I_C	SIGNAL	0	Phase C current
U_A	SIGNAL	0	Phase A voltage
U_B	SIGNAL	0	Phase B voltage
U_C	SIGNAL	0	Phase C voltage
RSTACM	BOOLEAN	0=False	Reset of accumulated energy reading

8.1.10.4 Settings

Table 439: PEMMXU Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Power unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the power related values
Energy unit Mult	3=Kilo 6=Mega			3=Kilo	Unit multiplier for presentation of the energy related values
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
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
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

8.1.10.5 Monitored data

Table 440: PEMMXU Monitored data

Name	Type	Values (Range)	Unit	Description
S-kVA	FLOAT32	-999999.9...999999.9	kVA	Total Apparent Power
P-kW	FLOAT32	-999999.9...999999.9	kW	Total Active Power
Q-kVAr	FLOAT32	-999999.9...999999.9	kVAr	Total Reactive Power
PF	FLOAT32	-1.00...1.00		Average Power factor
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
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

8.1.10.6 Technical data

Table 441: PEMMXU Technical data

Characteristic	Value
Operation accuracy	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 Active power and energy in range |PF| > 0.71 Reactive power and energy in range |PF| < 0.71
	±1.5% for power (S, P and Q) ±0.015 for power factor ±1.5% for energy
Suppression of harmonics	DFT: -50 dB at f = n × f_n, where n = 2, 3, 4, 5,…

8.2 Disturbance recorder

8.2.1 Functionality

The relay is provided with a disturbance recorder with up to 12 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.

The analog channels can be set to 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 non-volatile memory and can be uploaded for subsequent fault analysis.

8.2.1.1 Recorded analog inputs

The user can map any analog signal type of the IED to each analog channel of the disturbance recorder by setting the *Channel selection* parameter of the corresponding analog channel. In addition, the user can enable or disable each analog channel of the disturbance recorder by setting the *Operation* parameter of the corresponding analog channel to "on" or "off".

All analog channels of the disturbance recorder that are enabled and have a valid signal type mapped are included in the recording.

8.2.1.2 Triggering alternatives

The recording can be triggered by any or several of the following alternatives:

- Triggering according to the state change of any or several of the binary channels of the disturbance recorder. The user can set the level sensitivity 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 events through state changes of the *Recording started*, *Recording made* and *Recording stored* status parameters. The *Recording stored* parameter indicates that the recording has been stored to the non-volatile 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

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, if preferred, 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.

Manual triggering

The recorder can be triggered manually via the LHMI or via communication by setting the *Trig recording* parameter to TRUE.

Periodic triggering

Periodic triggering means that the recorder automatically makes a recording at certain time intervals. The user can adjust the interval 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 user should first set the *Periodic trig time* parameter to zero and then to the new value. The user can monitor the time remaining to the next triggering with the `Time to trigger` monitored data which counts downwards.

8.2.1.3 Length of recordings

The user can define the length of a recording 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 amount of recordings that fit into the available recording memory. The user can see this information with the `Rem. amount of rec` monitored data. The fixed memory size allocated for 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 user can view the number of recordings currently in memory with the `Number of recordings` monitored data. The currently 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.

8.2.1.4 Sampling frequencies

The sampling frequency of the disturbance recorder analog channels depends on the set rated frequency. One fundamental cycle always contains the amount 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 442: Sampling frequencies of the disturbance recorder analog channels

Storage rate (samples per fundamental cycle)	Recording length	Sampling frequency of analog channels, when the rated frequency is 50 Hz	Sampling frequency of binary channels, when the rated frequency is 50 Hz	Sampling frequency of analog channels, when the rated frequency is 60 Hz	Sampling frequency of binary channels, when the rated frequency is 60 Hz
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

8.2.1.5 Uploading of recordings

The IED stores COMTRADE files to the `C:\COMTRADE\` folder. The files can be uploaded with the PCM tool 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.

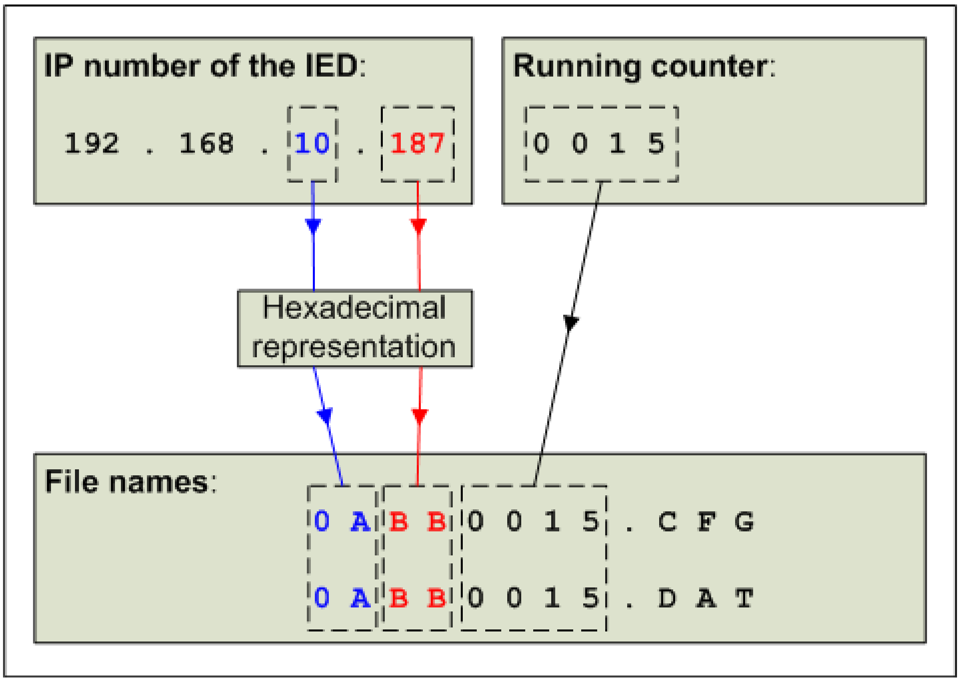


Figure 238: Disturbance recorder file naming

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 IED'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.

8.2.1.6 Deletion of recordings

There are several ways to delete disturbance recordings. The recordings can be deleted individually or all at once.

Individual disturbance recordings can be deleted with the PCM tool or any appropriate computer software, which can access the IED's `C:\COMTRADE` folder. The disturbance recording is not removed from the IED memory until both of the corresponding COMTRADE files, .CFG and .DAT, are deleted. The user may have to delete both of the files types separately, depending on the software used.

Deleting all disturbance recordings at once is done either with the PCM tool 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.

8.2.1.7 Storage mode

The disturbance recorder can capture data in two modes: waveform and trend mode. The user can set the storage mode 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*.

8.2.1.8 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 user can adjust the percentage of the data duration preceding the triggering, that is, the so-called pre-trigger time, with the *Pre-trg length* parameter. The duration of the data following the triggering, that is, the so-called 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.

8.2.1.9 Operation modes

Disturbance recorder has two operation modes: saturation and overwrite mode. The user can change the operation mode of the disturbance recorder 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

When the operation mode is "Overwrite" and 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 more 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 the saturation and the overwrite mode until the previous recording is completed. On the other hand, 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 were pre-trigger samples lacking.

8.2.1.10 Exclusion mode

Exclusion mode is on, when the value set with 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 only applies 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 user can monitor the remaining exclusion time with the *Exclusion time rem* parameter of the corresponding analog or binary channel. The *Exclusion time rem* parameter counts downwards.

8.2.2 Configuration

The user can configure the disturbance recorder with the PCM600 tool or any tool supporting the IEC 61850 standard.

The user can enable or disable the disturbance recorder with the *Operation* parameter under the **Configuration/Disturbance recorder/General** menu.

One analog signal type of the IED can be mapped to each of the analog channels of the disturbance recorder. The mapping is done with the *Channel selection* parameter of the corresponding analog channel. The name of the analog channel is user-configurable. The user can modify it by writing the new name to the *Channel id text* parameter of the corresponding analog channel.

Any external or internal digital signal of the IED 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 IED. The connection is made with dynamic mapping to the binary channel of the disturbance recorder using, for example, SMT 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 user can configure the name of the binary channel and modify it by writing the new name to the *Channel id text* parameter of the corresponding binary channel.

Note that 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 a binary channel of the disturbance recorder, the user can set the *Operation* parameter of the corresponding binary channel to the values "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 *Recording started* parameter can be used to control the indication LEDs of the IED. The output of the *Recording started* parameter is TRUE due to the triggering of the disturbance recorder, until all the data for the corresponding recording is recorded.

The IP number of the IED and the content of the *Bay name* parameter are both included in the COMTRADE configuration file for identification purposes.

8.2.3 Application

The disturbance recorder is used for post-fault analysis and for verifying the correct operation of protection IEDs 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 IED converts the recordings to the COMTRADE format.

COMTRADE is the general standard format used in 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.

8.2.4 Settings

Table 443: Non-group general settings for disturbance recorder

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
Operation mode	1=Saturation 2=Overwrite		1	1	Operation mode of the recorder

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
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 444: Non-group analog channel settings for disturbance recorder

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off		1	1=on	Analog channel is enabled or disabled
Channel selection	0=Disabled, 1=Io 2=IL1 3=IL2 4=IL3 10=U1 11=U2 12=U3 14=U1B 15=U2B 16=U3B 17=CIo 18=SI1[1)] 19=SI2[1)] 20=SU0 21=SU1[1)] 22=SU2[1)] 26=SUoB 27=SU1B[1)] 28=SU2B[1)]		0	0=Disabled	Select the signal to be recorded by this channel. Applicable values for this parameter are product variant dependent. Every product variant includes only the values that are applicable to that particular variant
Channel id text	0 to 64 characters, alphanumeric			DR analog channel X	Identification text for the analog channel used in the COMTRADE format

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
High trigger level	0.00...60.00	pu	0.01	10.00	High trigger level for the analog channel
Low trigger level	0.00...2.00	pu	0.01	0.00	Low trigger level for the analog channel
Storage mode	0=Waveform 1=Trend / cycle		1	0	Storage mode for the analog channel

1) Recordable values are available only in trend mode. In waveform mode, samples for this signal type are constant zeroes. However, these signal types can be used to trigger the recorder on limit violations of the corresponding analog channel.

Table 445: Non-group binary channel settings for disturbance recorder

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off		1	5=off	Binary channel is enabled or disabled
Level trigger mode	1=Positive or Rising 2=Negative or Falling 3=Both 4=Level trigger off		1	1=Rising	Level trigger mode for the binary channel
Storage mode	0=Waveform 1=Trend / cycle		1	0	Storage mode for the binary channel
Channel id text	0 to 64 characters, alphanumeric			DR binary channel X	Identification text for the analog channel used in the COMTRADE format

Table 446: Control data for disturbance recorder

Parameter	Values (Range)	Unit	Step	Default	Description
Trig recording	0=Cancel 1=Trig				Trigger the disturbance recording
Clear recordings	0=Cancel 1=Clear				Clear all recordings currently in memory

8.2.5 Monitored data

Table 447: Monitored data for disturbance recorder

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 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

8.2.6 Technical revision history

Table 448: RDRE Technical revision history

Technical revision	Change
B	ChNum changed to EChNum (RADR's). RADR9...12 added (Analog channel 9 -12). RBDR33...64 added (Binary channel 33 - 64).
C	Enum update for *Channel selection* parameters (DR.RADRx.EChNum.setVal) Std. enum changes to Clear and Manual Trig
D	Symbols in the *Channel selection* setting are updated

Section 9 Control functions

9.1 Circuit breaker control CBXCBR and Disconnector control DCXSWI

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	I<->O CB
Disconnector control	DCXSWI	I<->O DCC	I<->O DCC

9.1.2 Function block

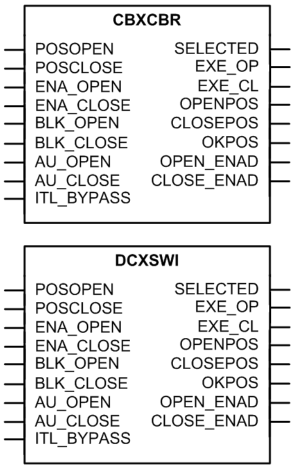


Figure 239: Function block

9.1.3 Functionality

The CBXCBR and DCXSWI are intended for circuit breaker and disconnector 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 and disconnector 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 information. 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 449: Status indication

Status (POSITION)	POSOPEN/OPENPOS	POSCLOSE/ CLOSEPOS	OKPOS
1=Open	1=True	0=False	1=True
2=Closed	0=False	1=True	1=True
3=Faulty/Bad (11)	1=True	1=True	0=False
0=Intermediate (00)	0=False	0=False	0=False

Blocking

CBXCBR and DCXSWI have a blocking functionality to prevent human errors that can cause injuries to the operator and damages to the system components.

The basic principle for all blocking signals is that they affect the commands of other clients: the operator place and protection and autoreclosing functions, for example. There are two blocking principles.

- Enabling the opening command: the function is used to block the operation of the opening command. Note that this block signal also affects the OPEN input of immediate command.
- Enabling the closing command: the function is used to block the operation of the closing command. Note that this block signal also affects the CLOSE input of immediate command.

The ITL_BYPASS input is used if the interlocking functionality needs to be bypassed. When INT_BYPASS is TRUE, the apparatus control is made possible by discarding the ENA_OPEN and ENA_CLOSE input states. However, the BLK_OPEN and BLK_CLOSE input signals are not bypassed with the interlocking bypass functionality since they always have the higher priority.

Opening and closing operations

The corresponding 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. If the control command is executed against the blocking or if the enabling of the corresponding command is not valid, CBXCBR and DCXSWI generate an error message.

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 when the object state shows that the apparatus has entered the correct state. 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.

The *Pulse length* setting does not affect the length of the trip pulse.

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.

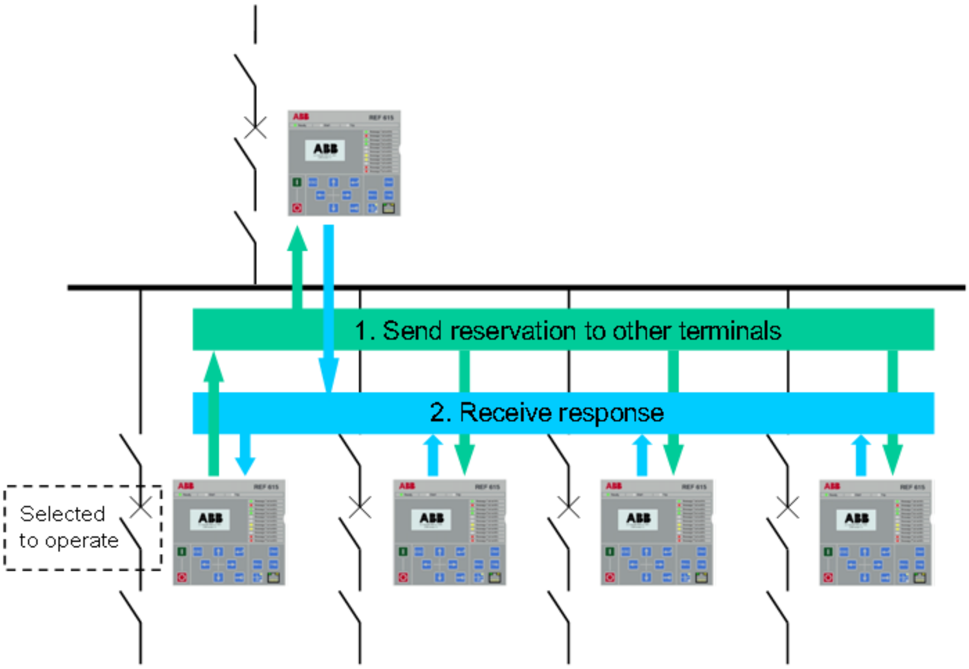


Figure 240: Control procedure in the SBO method

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 and DCXSWI. 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 the substation level can be applied using the IEC61850 GOOSE messages between feeders.

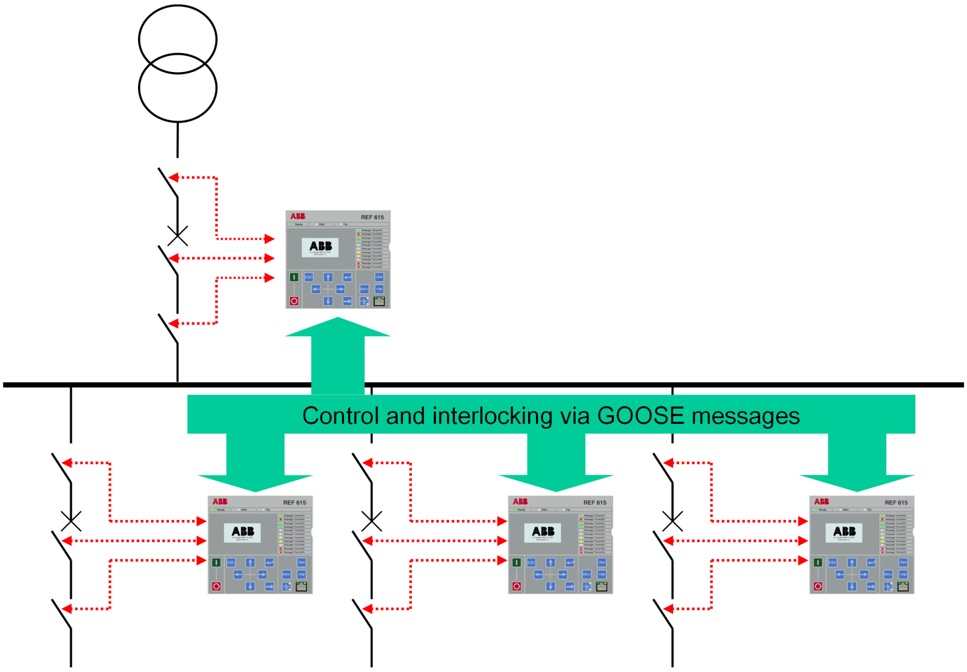


Figure 241: Status indication-based interlocking via the GOOSE messaging

9.1.6 Signals

Table 450: CBXCBR Input signals

Name	Type	Default	Description
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
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE
AU_OPEN	BOOLEAN	0=False	Input signal used to open the breaker[1)]
AU_CLOSE	BOOLEAN	0=False	Input signal used to close the breaker[1)]
POSOPEN	BOOLEAN	0=False	Signal for open position of apparatus from I/O[1)]
POSCLOSE	BOOLEAN	0=False	Signal for closed position of apparatus from I/O[1)]

1) Not available for monitoring

Table 451: DCXSWI Input signals

Name	Type	Default	Description
POSOPEN	BOOLEAN	1=True	Apparatus open position
POSCLOSE	BOOLEAN	1=True	Apparatus closed position
ENA_OPEN	BOOLEAN	0=False	Enables opening

Table continues on next page

Name	Type	Default	Description
ENA_CLOSE	BOOLEAN	0=False	Enables closing
BLK_OPEN	BOOLEAN	0=False	Blocks opening
BLK_CLOSE	BOOLEAN	0=False	Blocks closing
AU_OPEN	BOOLEAN	0=False	Executes the command for open direction
AU_CLOSE	BOOLEAN	0=False	Executes the command for close direction
ITL_BYPASS	BOOLEAN	0=False	Discards ENA_OPEN and ENA_CLOSE interlocking when TRUE

Table 452: 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
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

Table 453: 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

9.1.7 Settings

Table 454: CBXCBR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	60000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Operation counter	0...10000			0	Breaker operation cycles

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Adaptive pulse	0=False 1=True			1=True	Stop in right position
Event delay	0...10000	ms	1	100	Event delay of the intermediate position
Operation timeout	10...60000	ms		500	Timeout for negative termination

Table 455: DCXSWI Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation mode on/off
Select timeout	10000...300000	ms	10000	60000	Select timeout in ms
Pulse length	10...60000	ms	1	100	Open and close pulse length
Operation counter	0...10000			0	Breaker operation cycles
Control model	0=status-only 1=direct-with-normal-security 4=sbo-with-enhanced-security			4=sbo-with-enhanced-security	Select control model
Adaptive pulse	0=False 1=True			1=True	Stop in right position
Event delay	0...60000	ms	1	10000	Event delay of the intermediate position
Operation timeout	10...60000	ms		30000	Timeout for negative termination

9.1.8 Monitored data

Table 456: CBXCBR Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

Table 457: DCXSWI 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

Table 458: CBXCBR Technical revision history

Technical revision	Change
B	Interlocking bypass input (ITL_BYPASS) and opening enabled (OPEN_ENAD)/closing enabled (CLOSE_ENAD) outputs added. ITL_BYPASS bypasses the ENA_OPEN and ENA_CLOSE states.

9.2 Earthing switch indication ESSXSWI

9.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Earthing switch indication	ESSXSWI	I<->O ES	I<->O ES

9.2.2 Function block

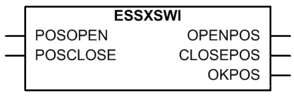


Figure 242: Function block

9.2.3 Functionality

The function ESSXSWI indicates remotely and locally the open, close and undefined states of the earthing switch. The functionality of both is identical, but each one is allocated for a specific purpose visible in the function names.

The functions are designed according to the IEC 61850-7-4 standard with the logical node XSWI.

9.2.4 Operation principle

Status indication and validity check

The object state is defined by the two digital inputs POSOPEN and POSCLOSE. 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 459: Status indication

State	OPEN	CLOSE
Open	ON	OFF
Close	OFF	ON
Bad/Faulty 11	ON	ON
Intermediate 00	OFF	OFF

9.2.5 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 the ESSXSWI function covers remote and local status indication of, for example, air-break switches and earthing switches, which represent the lowest level of power switching devices without short-circuit breaking capability.

9.2.6 Signals

Table 460: ESSXSWI Input signals

Name	Type	Default	Description
OPENPOS	BOOLEAN	0=False	Apparatus open position[1)]
CLOSEPOS	BOOLEAN	0=False	Apparatus closed position[1)]

1) Not available for monitoring

Table 461: ESSXSWI Output signals

Name	Type	Description
OPENPOS	BOOLEAN	Apparatus open position
CLOSEPOS	BOOLEAN	Apparatus closed position
OKPOS	BOOLEAN	Apparatus position is ok

9.2.7 Settings

Table 462: ESSXSWI Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Event delay	0...60000	ms	1	30000	Event delay of the intermediate position

9.2.8 Monitored data

Table 463: ESSXSWI Monitored data

Name	Type	Values (Range)	Unit	Description
POSITION	Dbpos	0=intermediate 1=open 2=closed 3=faulty		Apparatus position indication

9.3 Synchronism and energizing check SECRSYN

9.3.1 Identification

Functional description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Synchronism and energizing check	SECRSYN	SYNC	25

9.3.2 Function block

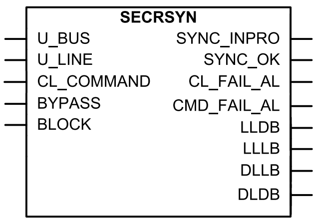


Figure 243: Function block

9.3.3 Functionality

The synchrocheck 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 if desired.

9.3.4 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 the synchronism and energizing check functionality can be described using a module diagram. All the modules in the diagram are explained in the next sections.

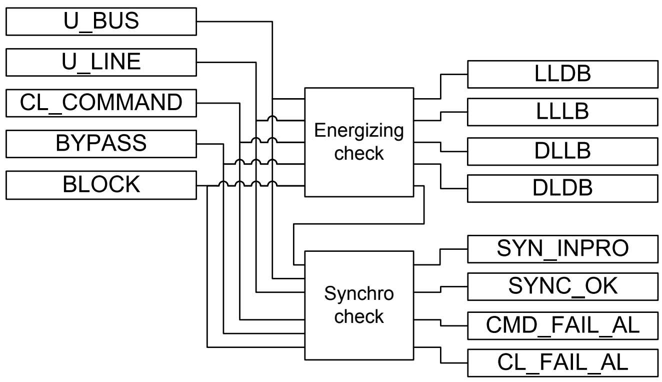


Figure 244: Functional module diagram

The 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.

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 464: 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*.

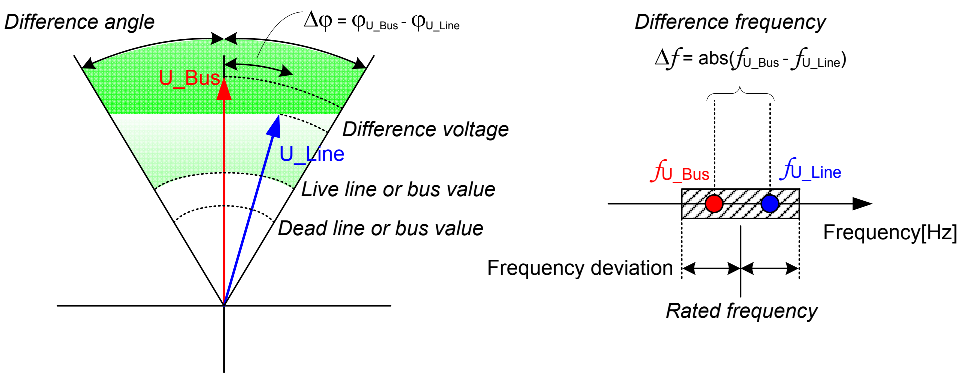


Figure 245: Conditions to be fulfilled when detecting synchronism between systems

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.

$$Closing\ angle = \left| (\angle U_{Bus} - \angle U_{Line})° + ((f_{Bus} - f_{line}) \times (T_{CB} + T_{PL}) \times 360°) \right|$$

(Equation 51)

$\angle U_{Bus}$	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 IED output contacts defined with the *Closing time of CB* setting parameter value

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. The mode is used for situations where Synchro check only gives the permission to the control block that executes the CB closing.

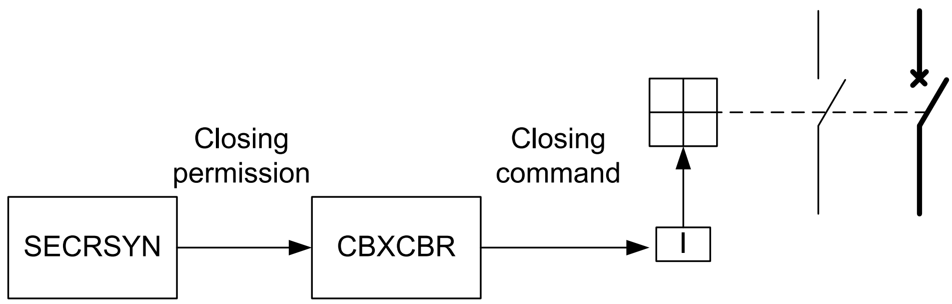


Figure 246: A simplified block diagram of the Synchro check function in the continuous mode operation

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, besides the normal closing conditions, is needed for delivering the closing signal. In the command control mode operation, the Synchro check function itself closes the breaker via the SYNC_OK output when the conditions are fulfilled. In this case, the control function block delivers the command signal to close the Synchro check function for the releasing of a closing-signal pulse to the circuit breaker. If the closing conditions are fulfilled during a permitted check time set with *Maximum Syn time*, the Synchro check function delivers a closing signal to the circuit breaker after the command signal is delivered for closing.

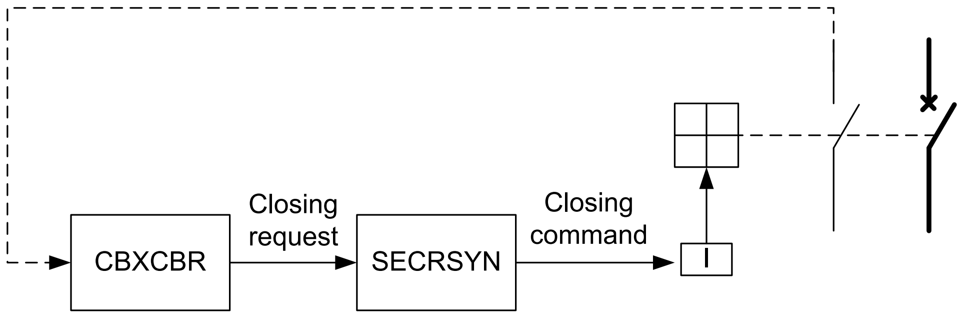


Figure 247: A simplified block diagram of SECRSYN in the command mode operation

The closing signal is delivered only once for each activated external closing command signal. The pulse length of the delivered closing is set with the *Close pulse* setting.

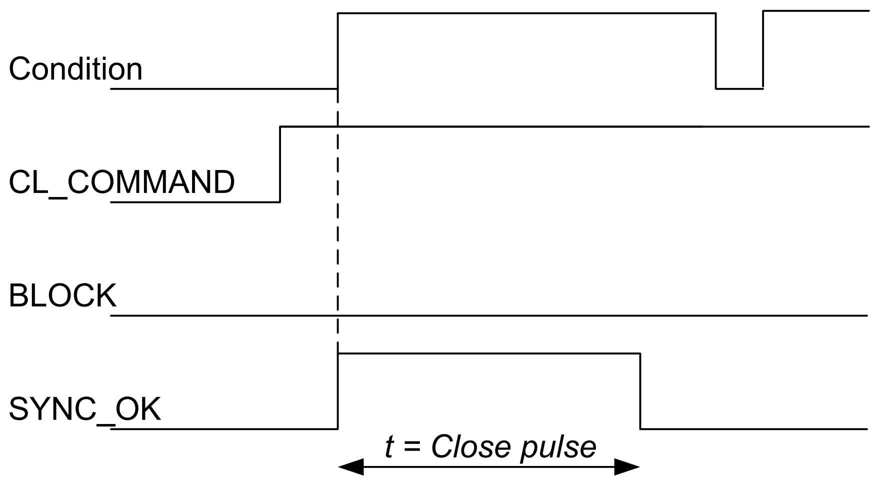


Figure 248: Determination of the pulse length of the closing signal

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.

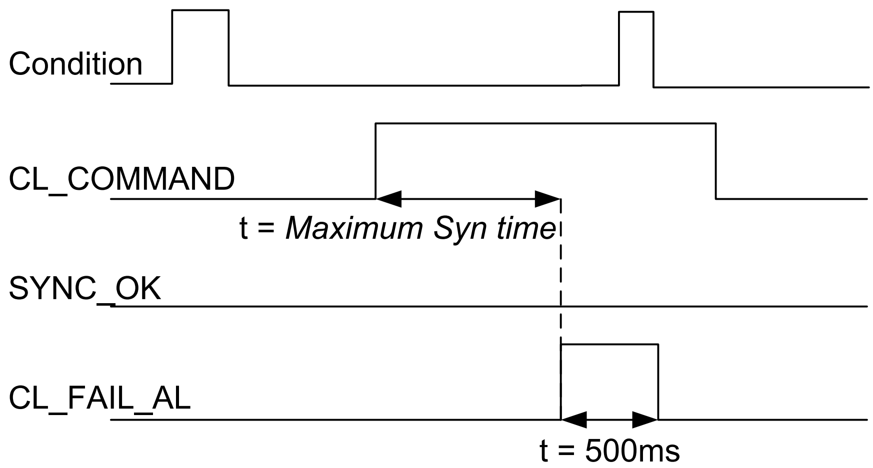


Figure 249: Determination of the checking time for closing

The control module 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.

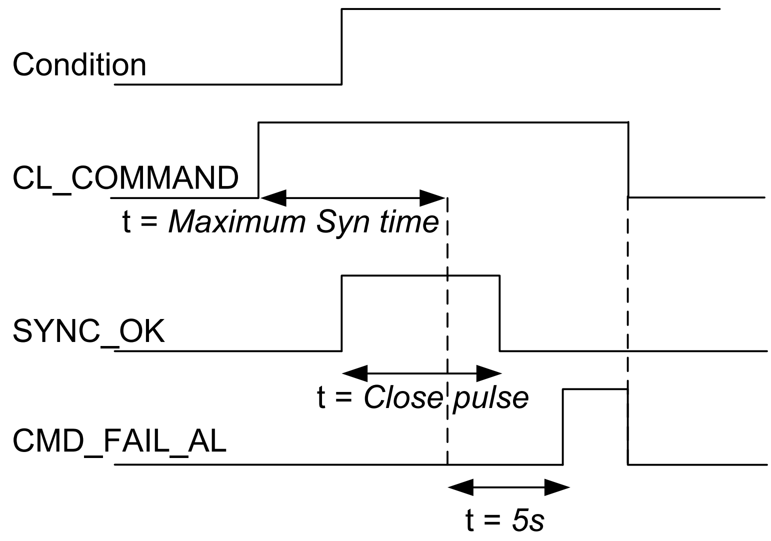


Figure 250: Determination of the alarm limit for a still-active command signal

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 closing pulse 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 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.

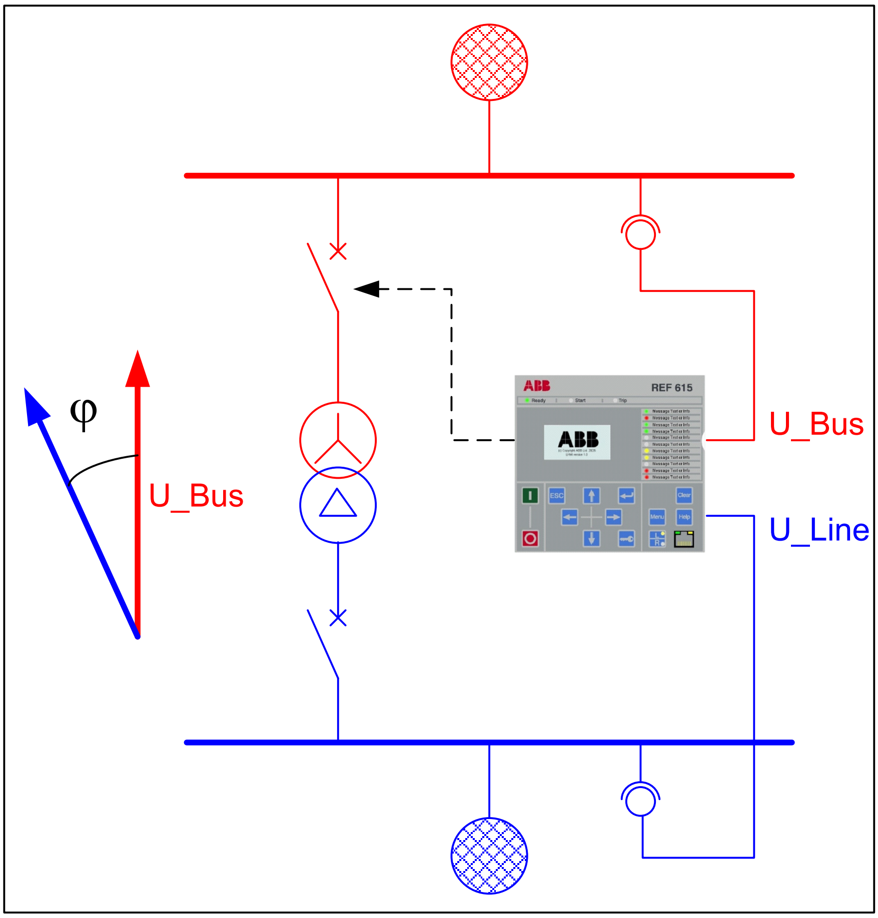


Figure 251: Angle difference when power transformer is in sychrocheck zone

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.

9.3.5 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 IED 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 IED 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.

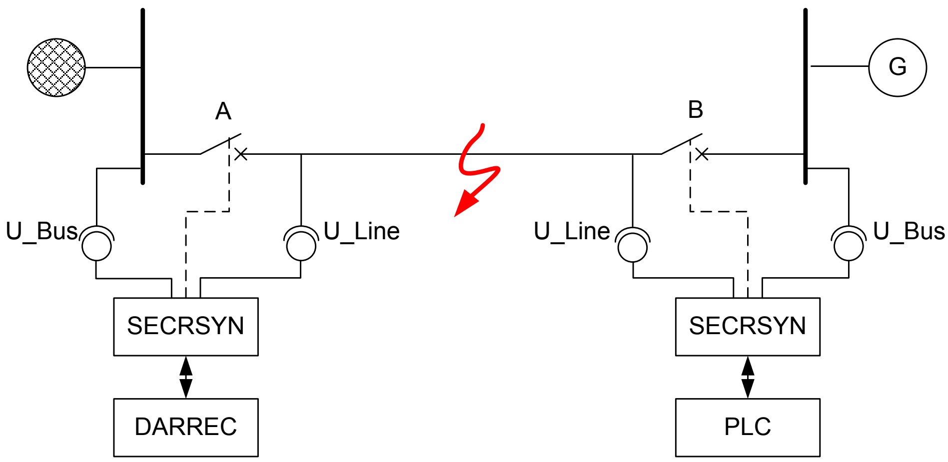


Figure 252: Synchrocheck function SECRSYN checking energizing conditions and synchronism

Connections

A special attention is paid to the connection of the IED. Furthermore it is checked that the primary side wiring is correct.

A faulty wiring of the voltage inputs of the IED 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 IED 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 IED 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 IED 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 253 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.

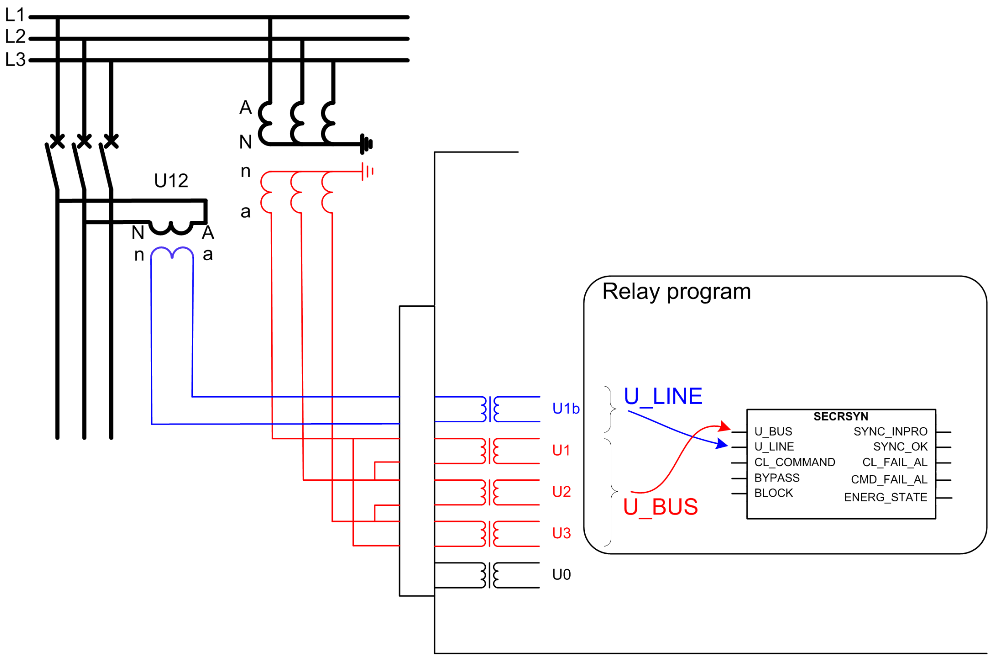


Figure 253: Connection of voltages for the IED and signals used in synchrocheck

9.3.6 Signals

Table 465: SECRSYN Input signals

Name	Type	Default	Description
U_BUS	SIGNAL	0	Busbar voltage
U_LINE	SIGNAL	0	Line voltage
CL_COMMAND	BOOLEAN	0=False	External closing request
BYPASS	BOOLEAN	0=False	Request to bypass synchronism check and voltage check
BLOCK	BOOLEAN	0=False	Blocking signal of the synchro check and voltage check function

Table 466: 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

9.3.7 Settings

Table 467: SECRSYN Group settings

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 7=Not Both Live			1=Both Dead	Energizing check mode
Difference voltage	0.01...0.50	xUn	0.01	0.05	Maximum voltage difference limit
Difference frequency	0.001...0.100	xFn	0.001	0.001	Maximum frequency difference limit
Difference angle	5...90	deg	1	5	Maximum angle difference limit

Table 468: SECRSYN Non group settings

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			2=Synchronous	Synchro check operation mode
Control mode	1=Continuous 2=Command			1=Continuous	Selection of synchro check command or Continuous control 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	0.5	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
Close pulse	200...60000	ms	10	200	Breaker closing pulse duration
Max energizing V	0.50...1.15	xUn	0.01	1.05	Maximum voltage for energizing
Phase shift	-180...180	deg	1	180	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

9.3.8 Monitored data

Table 469: 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	0.00...1.00	xUn	Calculated voltage amplitude difference
FR_DIFF_MEAS	FLOAT32	0.000...0.100	xFn	Calculated voltage frequency difference
PH_DIFF_MEAS	FLOAT32	0.00...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

9.3.9 Technical data

Table 470: 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

9.4 Autoreclosing DARREC

9.4.1 Identification

Function description	IEC 61850 logical node name	IEC 60617 identification	ANSI/IEEE C37.2 device number
Autoreclosing	DARREC	O-->I	79

9.4.2 Function block

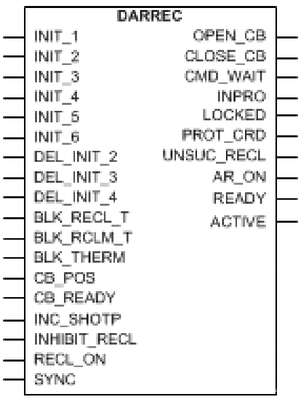


Figure 254: Function block

9.4.3 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 auto-reclose function AR can be used with any circuit breaker suitable for auto-reclosing. The function provides five programmable auto-reclose shots which can perform one to five successive auto-reclosings of desired type and duration, for instance one high-speed and one delayed auto-reclosing.

When the reclosing is initiated with starting of the protection function, the auto-reclose 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.

9.4.3.1 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 471: 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).

9.4.3.2 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.

9.4.3.3 Master and slave scheme

With the cooperation between the AR units in the same IED or between IEDs, 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.

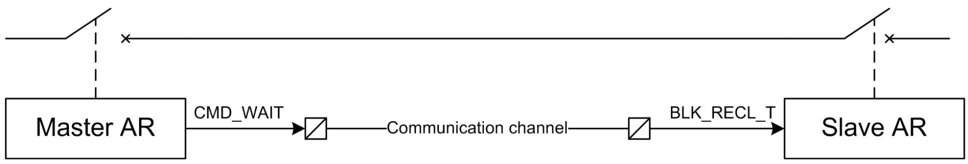


Figure 255: Master and slave scheme

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 auto-reclose shot.

If the terminal priority of the AR unit is set to "none", the AR unit skips all these actions.

9.4.3.4 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 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.

9.4.4 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 the autoreclosing function can be described using a module diagram. All the modules in the diagram are explained in the next sections.

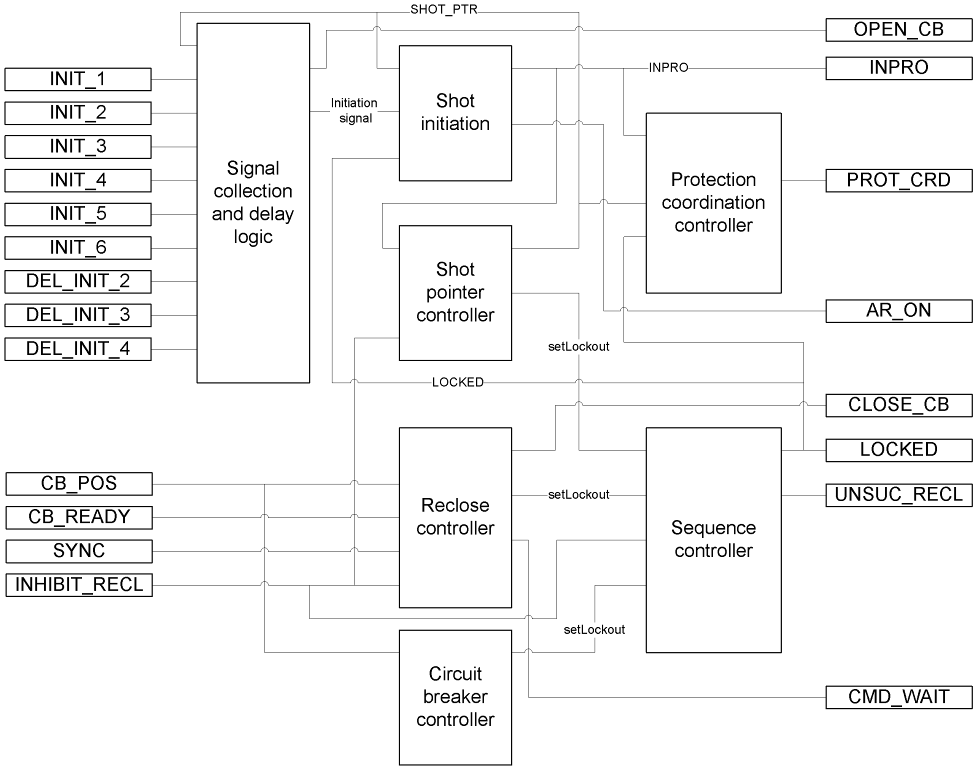


Figure 256: Functional module diagram

9.4.4.1 Signal collection and delay logic

When the protection trips, the initiation of auto-reclose 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.

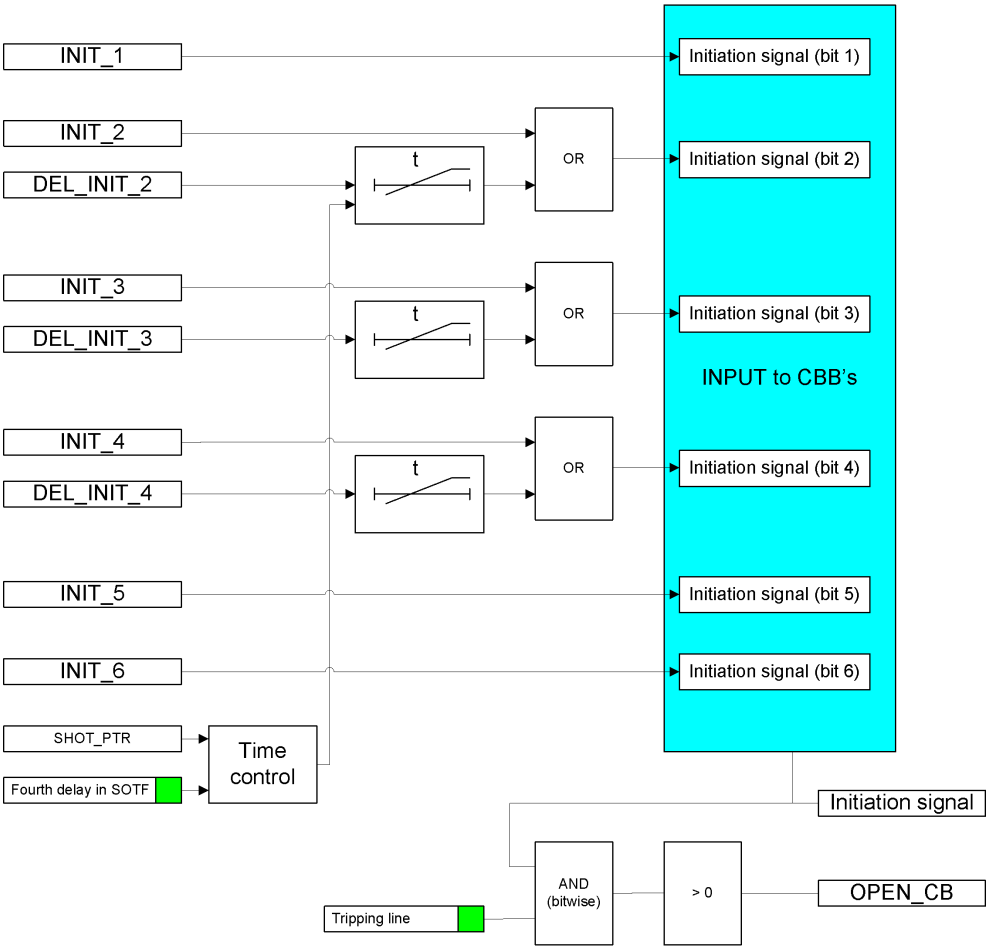


Figure 257: Schematic diagram of delayed initiation input signals

In total, the AR function contains six separate initiation lines used for the initiation or blocking of the auto-reclose 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.

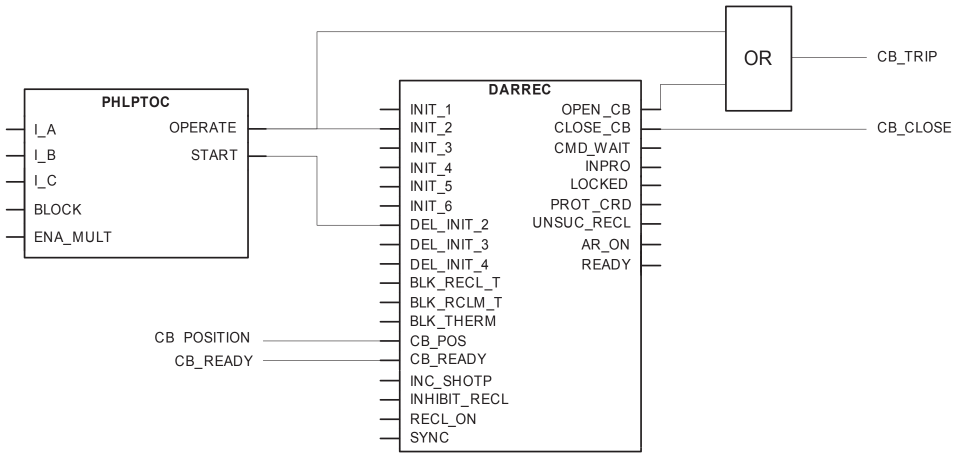


Figure 258: Autoreclosing configuration example

Delayed `DEL_INIT_2...4` signals are used only when the auto-reclose shot is initiated with the start signal of a protection stage. After a start delay, the AR function opens the circuit breaker and an auto-reclose 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 auto-reclose 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 auto-reclose situation is where one auto-reclose 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 auto-reclose sequence is successful: the reclaim time elapses and no new sequence is started.

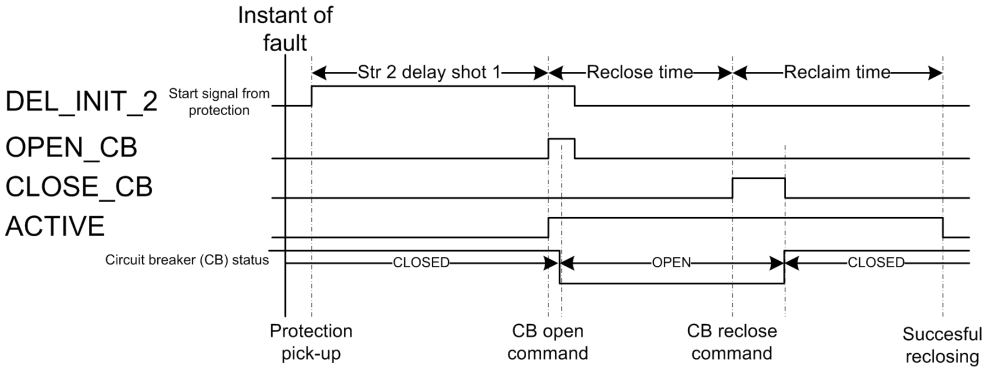


Figure 259: Signal scheme of autoreclose operation initiated with protection start signal

The auto-reclose shot is initiated with a start signal of the protection function after the start delay time has elapsed. The auto-reclose starts when the *Str 2 delay shot 1* setting elapses.

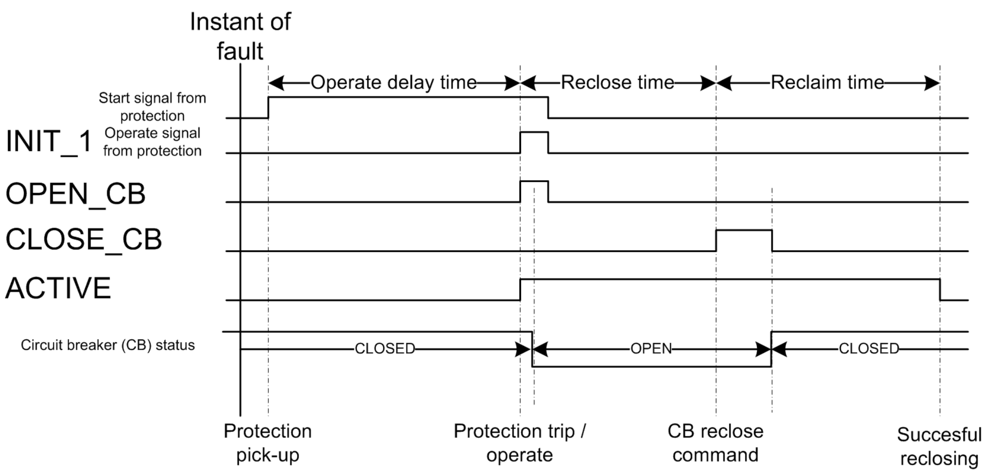


Figure 260: Signal scheme of autoreclose operation initiated with protection operate signal

The auto-reclose shot is initiated with a trip signal of the protection function. The auto-reclose starts when the protection operate delay time elapses.

Normally, all trip and start signals are used to initiate an auto-reclose 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.

9.4.4.2 Shot initiation

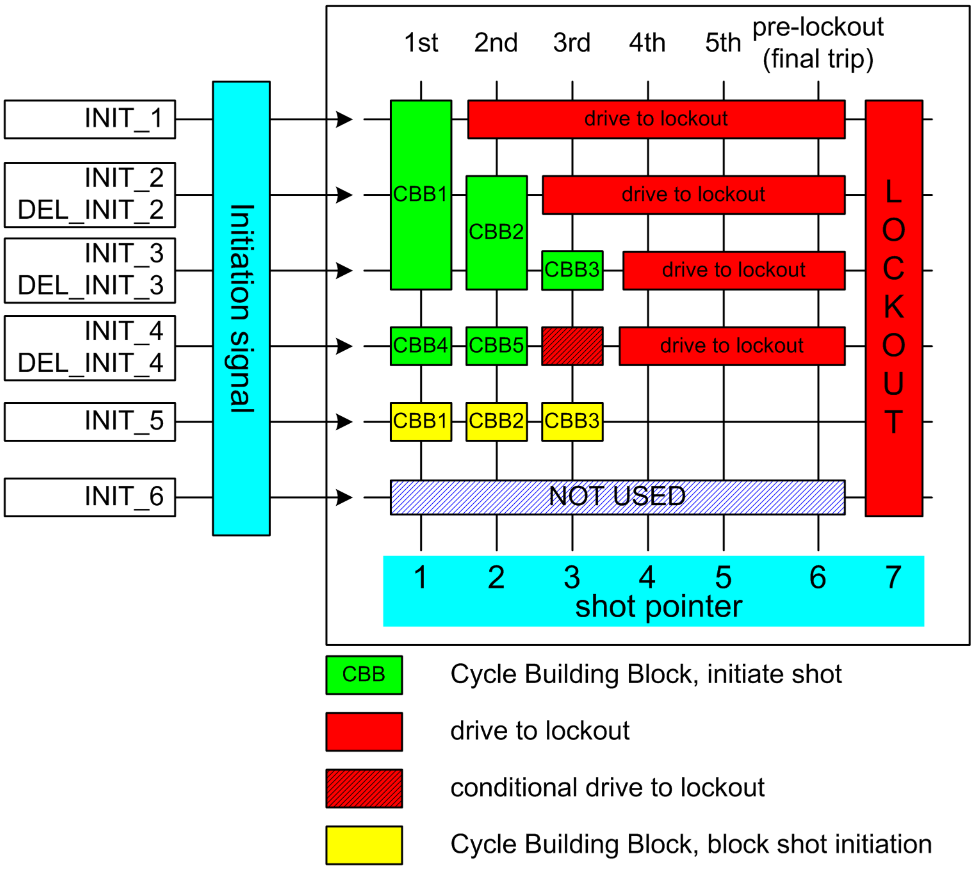


Figure 261: Example of an auto-reclose program with a reclose scheme matrix

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.

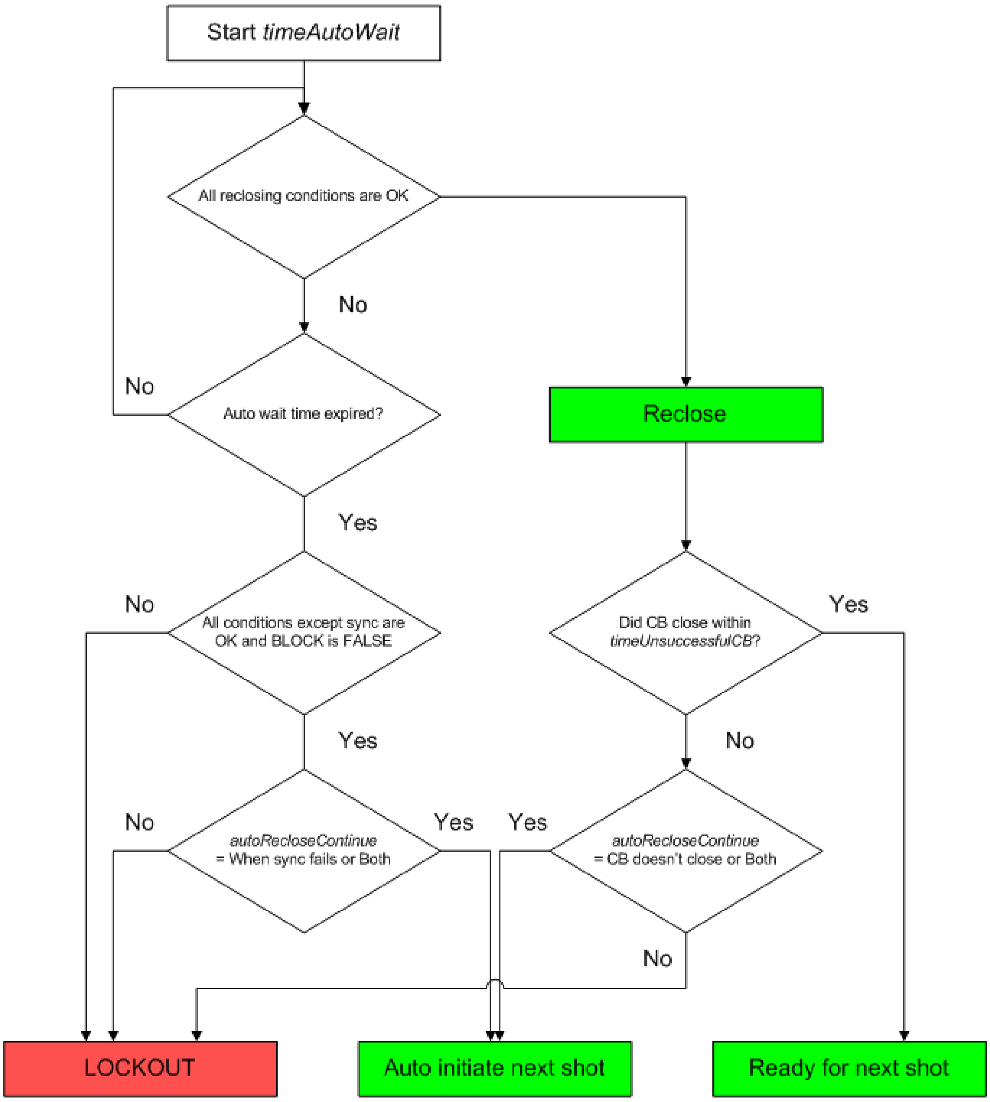


Figure 262: Logic diagram of auto-initiation sequence detection

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.

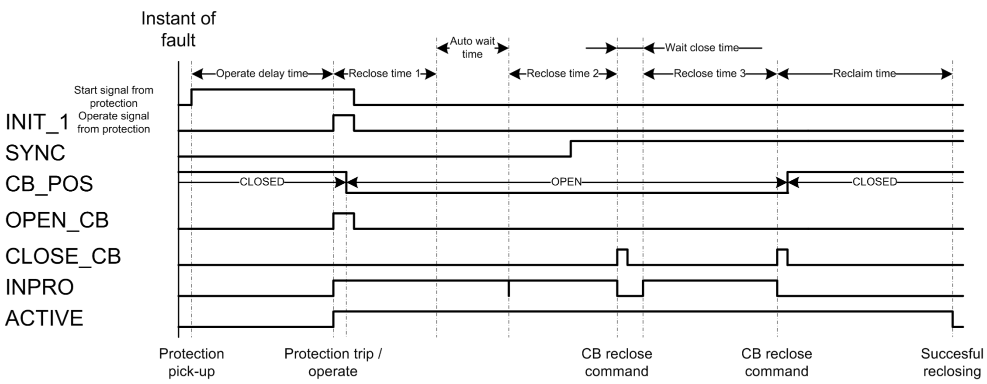


Figure 263: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

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.

9.4.4.3 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.

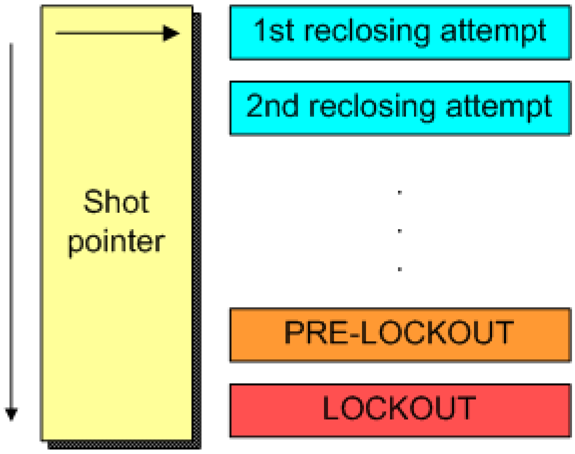


Figure 264: Shot pointer function

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.

9.4.4.4 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 auto-reclose 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.

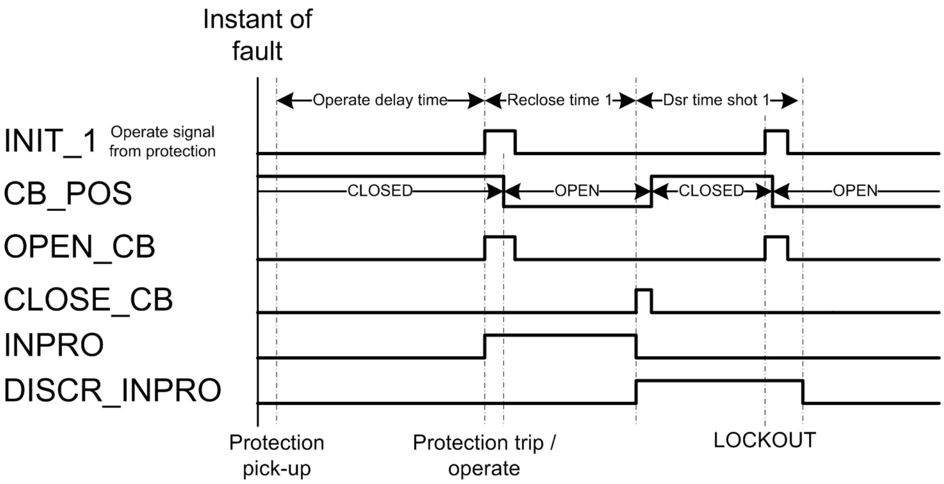


Figure 265: Initiation during discrimination time - AR function goes to lockout

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.

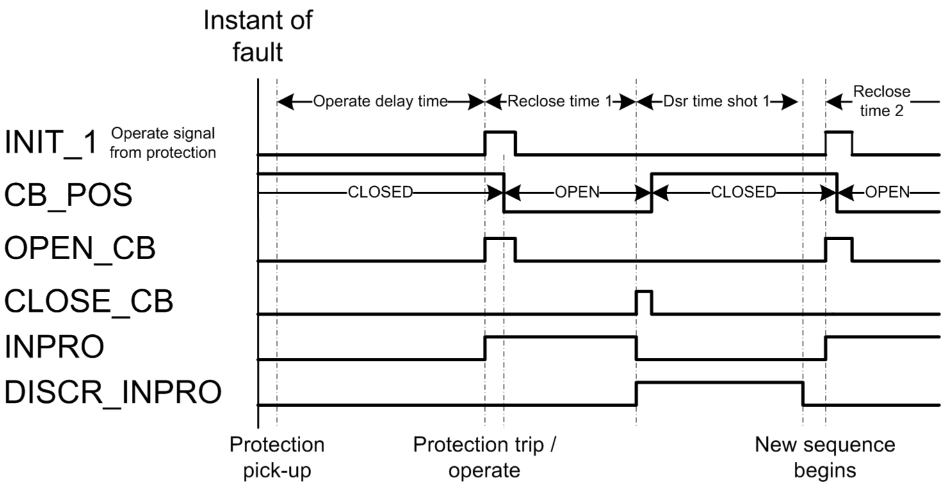


Figure 266: Initiation after elapsed discrimination time - new shot begins

9.4.4.5 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 *RsRec* 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 *RsRec* 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.

9.4.4.6 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

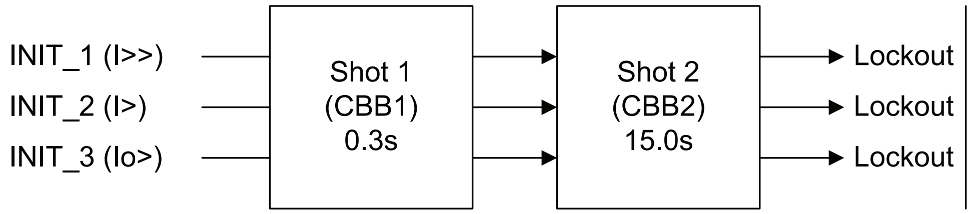


Figure 267: Configuration example of using the `PROT_CRD` *output for protection blocking*

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.

9.4.4.7 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 auto-reclose function is driven to lockout or, if allowed, an auto-initiation is activated.

The main motivation for auto-reclosing 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 auto-reclose 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 auto-reclose 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 auto-reclose 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 auto-reclose function in cases where the fault causes repetitive auto-reclose sequences during a short period of time. For instance, if a tree causes a short circuit and, as a result, there are auto-reclose 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.

9.4.5 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 *RsCnt* parameter. The same functionality can also be found in the clear menu (DARREC1 counters).

9.4.6 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, auto-reclose 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 472: Important definitions related to auto-reclosing

auto-reclose shot	an operation where after a preset time the breaker is closed from the breaker tripping caused by protection
auto-reclose 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 auto-reclose operations. Since no auto-reclosing follows, the circuit breaker remains open. This is called final trip or definite trip.

9.4.6.1 Shot initiation

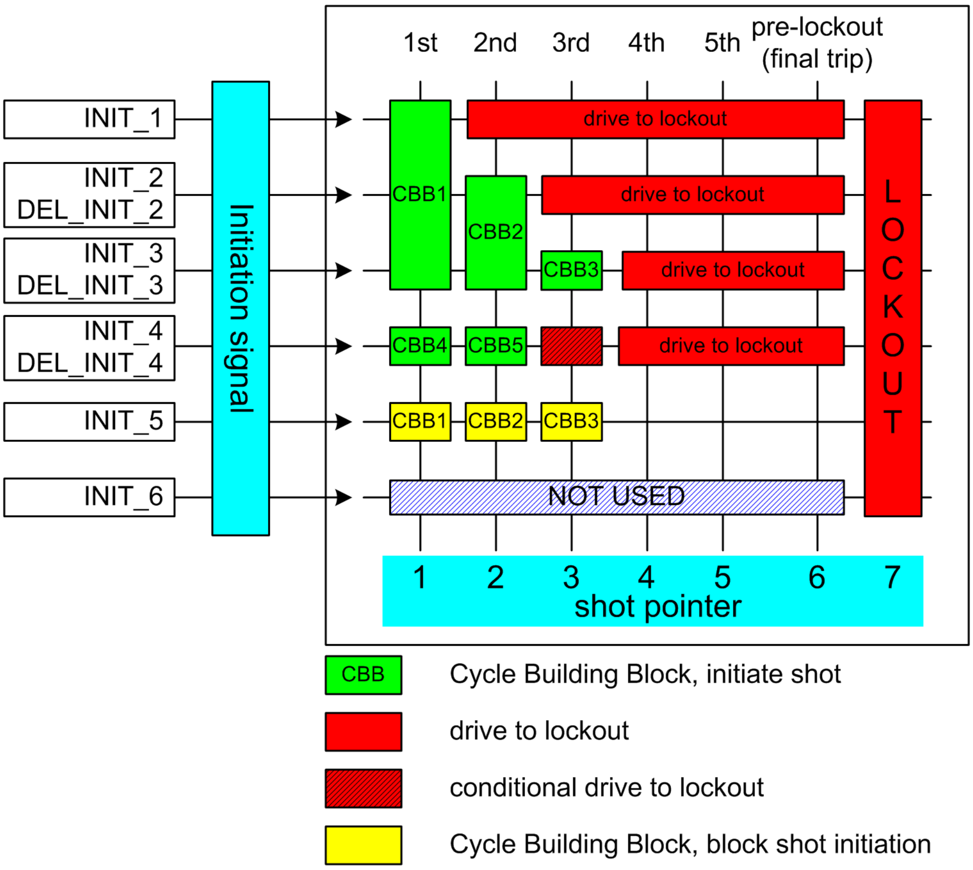


Figure 268: Example of an auto-reclose program with a reclose scheme matrix

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.

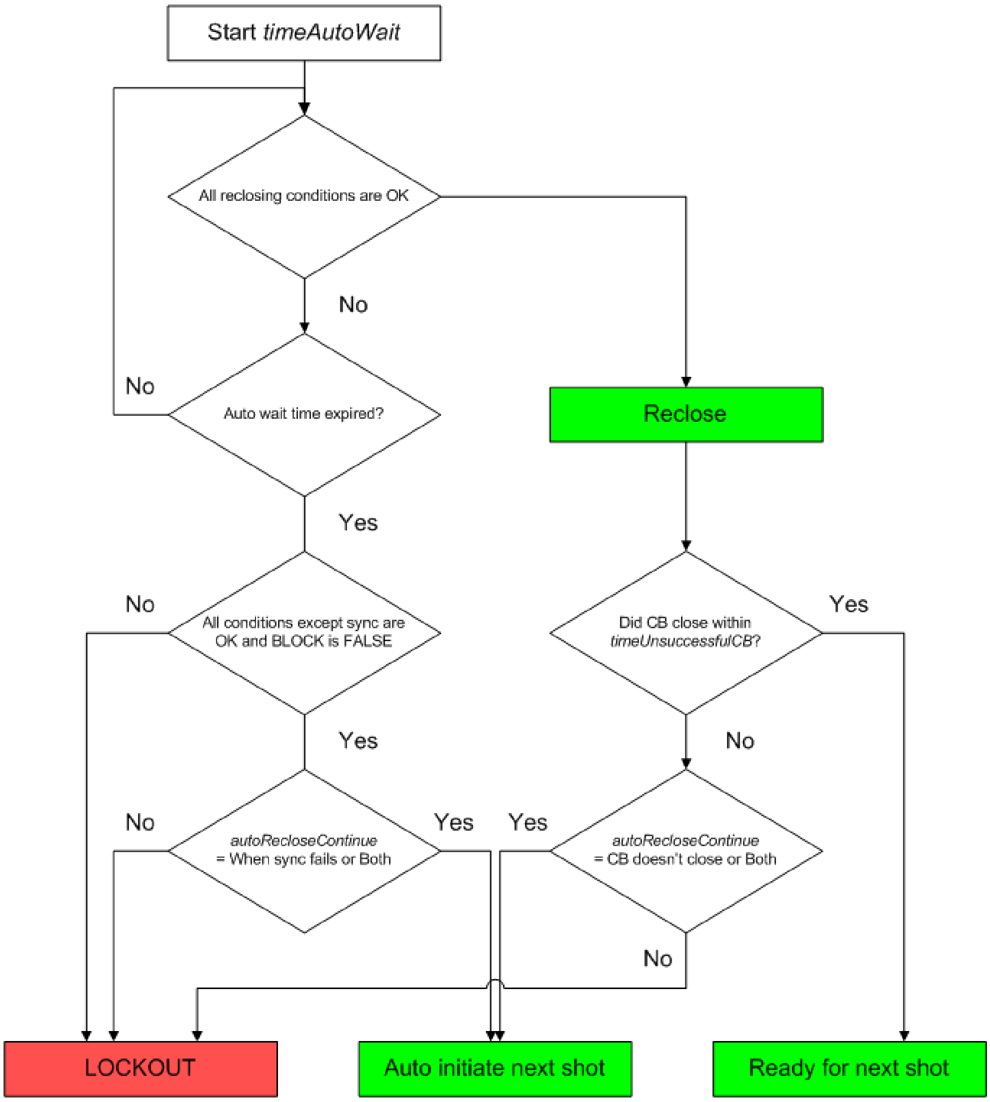


Figure 269: Logic diagram of auto-initiation sequence detection

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.

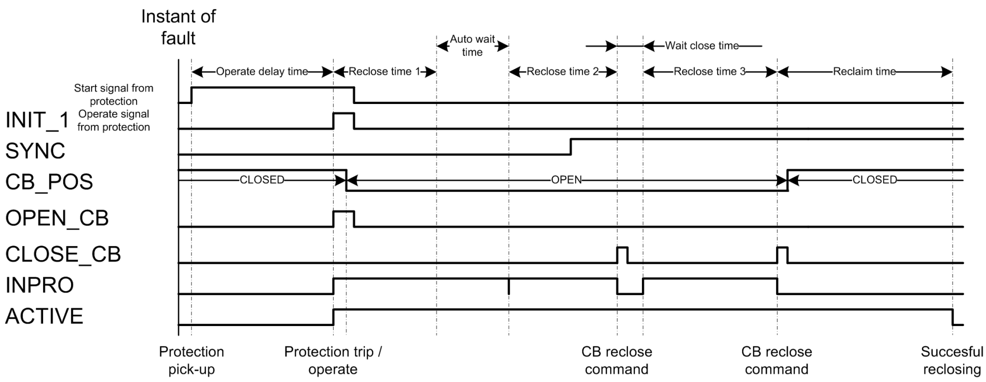


Figure 270: Example of an auto-initiation sequence with synchronization failure in the first shot and circuit breaker closing failure in the second shot

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.

9.4.6.2 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.

9.4.6.3 Configuration examples

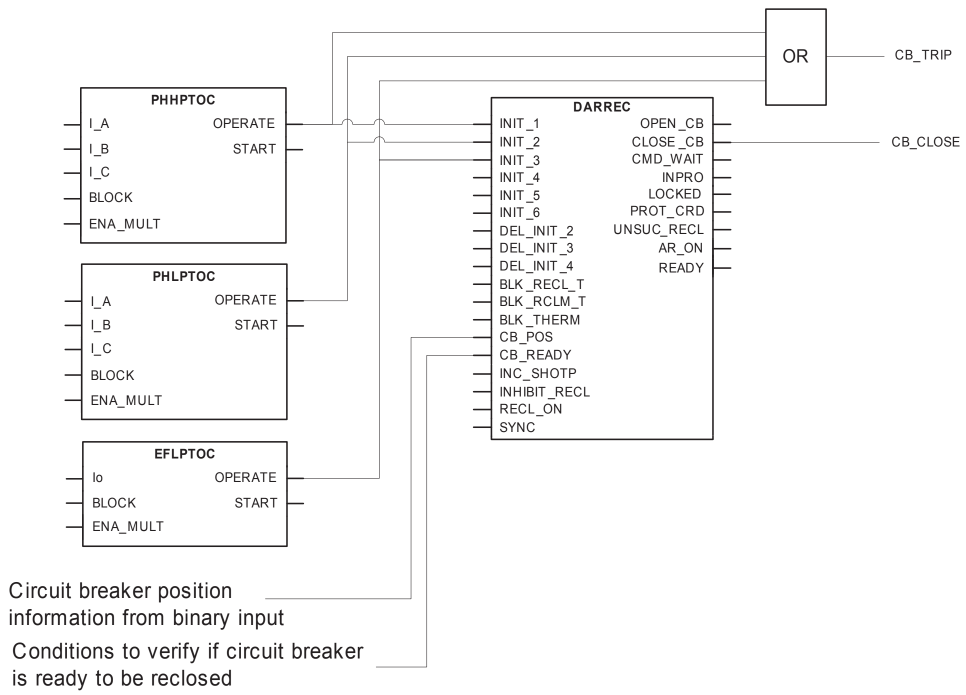


Figure 271: Example connection between protection and autoreclosing functions in IED configuration

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.

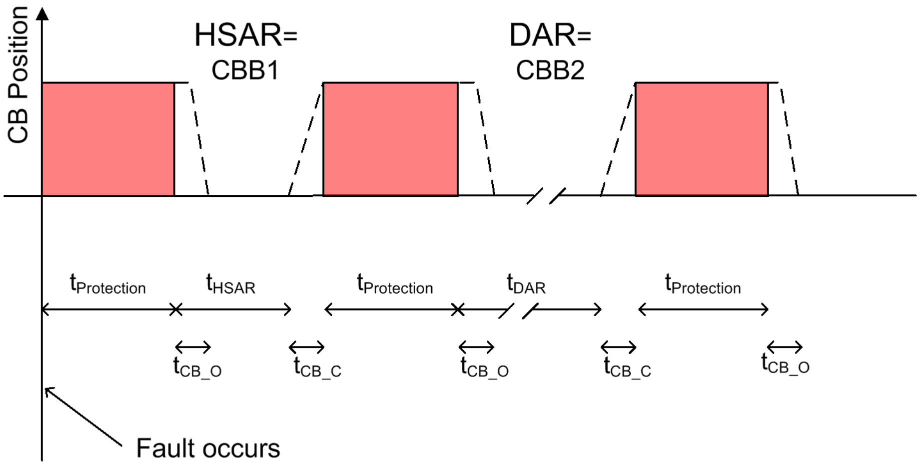


Figure 272: Autoreclosing sequence with two shots

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 473 as follows:

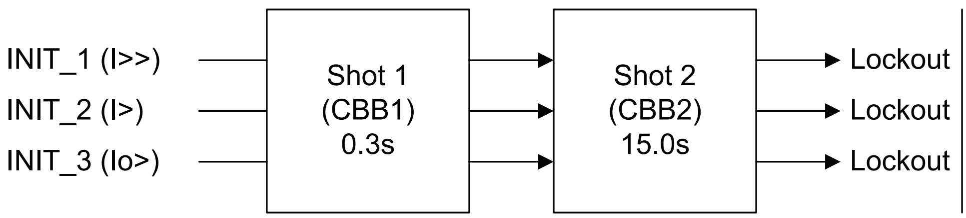


Figure 273: Two shots with three initiation lines

Table 473: 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.

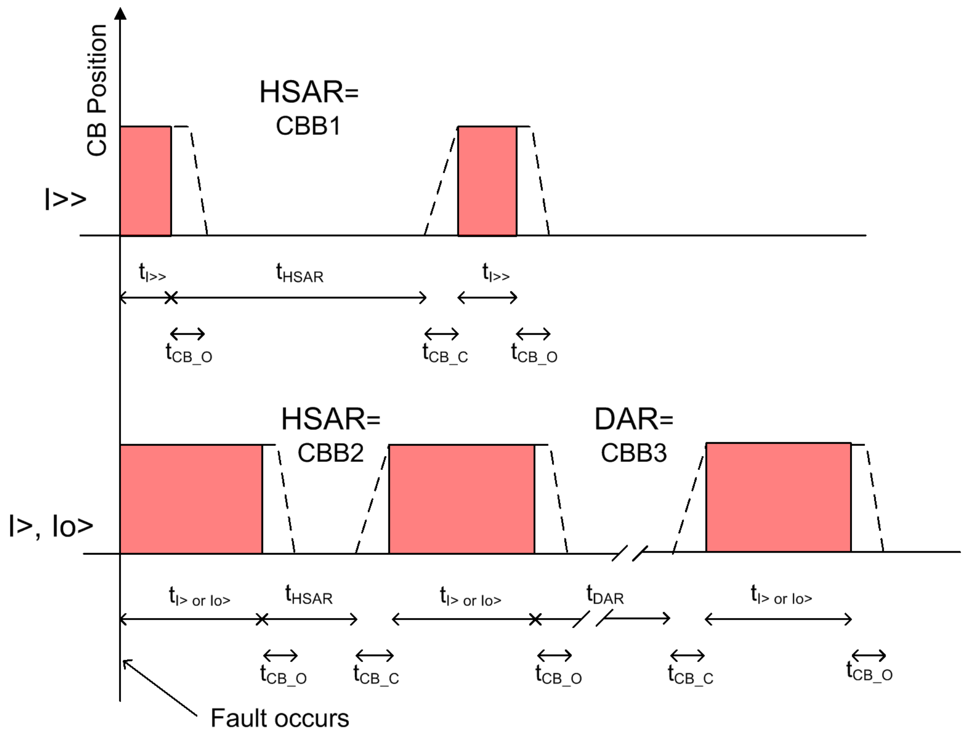


Figure 274: Autoreclosing sequence with two shots with different shot settings according to initiation signal

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.

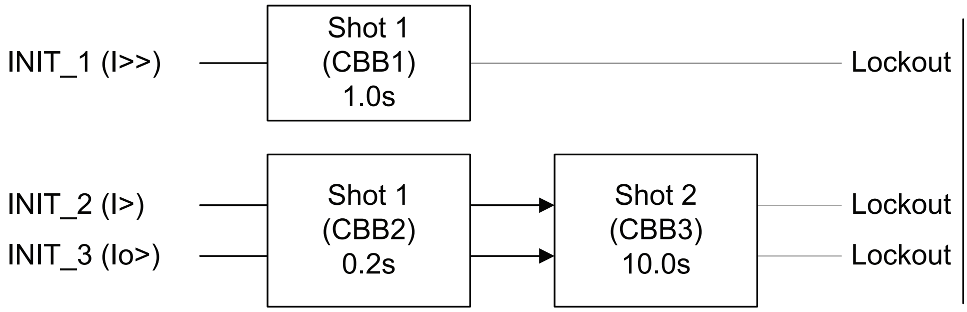


Figure 275: Three shots with three initiation lines

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 474: 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

9.4.6.4 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.

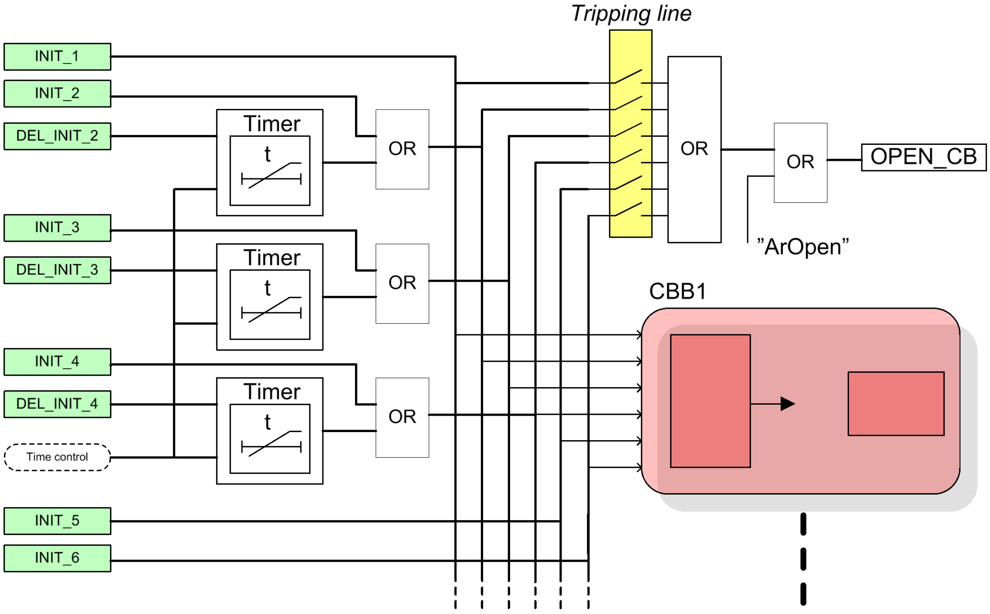


Figure 276: Simplified logic diagram of initiation lines

Each delayed initiation line has four different time settings:

Table 475: 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.

9.4.6.5 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.

9.4.6.6 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.

9.4.7 Signals

Table 476: 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
RECL_ON	BOOLEAN	0=False	Level sensitive signal for allowing (high) / not allowing (low) reclosing
SYNC	BOOLEAN	0=False	Synchronizing check fulfilled

Table 477: 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 between the AR and the protection
UNSUC_RECL	BOOLEAN	Indicates an unsuccessful reclosing sequence
AR_ON	BOOLEAN	Autoreclosing allowed
READY	BOOLEAN	Indicates that the AR is ready for a new sequence
ACTIVE	BOOLEAN	Reclosing sequence is in progress

9.4.8 Settings

Table 478: DARREC Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off/On
Reclosing operation	1=Off 2=External Ctl 3=On			1=Off	Reclosing operation (Off, External Ctl / On)
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 haltDeadTime release
Max trip time	100...10000	ms	100	10000	Maximum wait time for deactivation of protection signals
Close pulse time	10...10000	ms	10	200	CB close pulse time
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
Reclaim time	100...1800000	ms	100	10000	Reclaim time
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
Terminal priority	1=None 2=Low (follower) 3=High (master)			1=None	Terminal priority
Table continues on next page					

Parameter	Values (Range)	Unit	Step	Default	Description
Synchronisation set	0...127			0	Selection for synchronizing requirement for 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	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
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			0	Tripping line, defines INIT inputs which cause OPEN_CB activation
Control line	0...63			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
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			0	Initiation lines for CBB1
Init signals CBB2	0...63			0	Initiation lines for CBB2
Init signals CBB3	0...63			0	Initiation lines for CBB3
Init signals CBB4	0...63			0	Initiation lines for CBB4
Init signals CBB5	0...63			0	Initiation lines for CBB5
Init signals CBB6	0...63			0	Initiation lines for CBB6
Init signals CBB7	0...63			0	Initiation lines for CBB7
Blk signals CBB1	0...63			0	Blocking lines for CBB1
Blk signals CBB2	0...63			0	Blocking lines for CBB2
Blk signals CBB3	0...63			0	Blocking lines for CBB3
Blk signals CBB4	0...63			0	Blocking lines for CBB4
Blk signals CBB5	0...63			0	Blocking lines for CBB5
Blk signals CBB6	0...63			0	Blocking lines for CBB6

Table continues on next page

Parameter	Values (Range)	Unit	Step	Default	Description
Blk signals CBB7	0...63			0	Blocking lines for CBB7
Shot number CBB1	0...5			0	Shot number for CBB1
Shot number CBB2	0...5			0	Shot number for CBB2
Shot number CBB3	0...5			0	Shot number for CBB3
Shot number CBB4	0...5			0	Shot number for CBB4
Shot number CBB5	0...5			0	Shot number for CBB5
Shot number CBB6	0...5			0	Shot number for CBB6
Shot number CBB7	0...5			0	Shot number 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
Frq Op counter limit	0...250			0	Frequent operation counter lockout limit
Frq Op counter time	1...250	min		1	Frequent operation counter time
Frq Op recovery time	1...250	min		1	Frequent operation counter recovery time
Auto init	0...63			0	Defines INIT lines that are activated at auto initiation

9.4.9 Monitored data

Table 479: DARREC Monitored data

Name	Type	Values (Range)	Unit	Description
DISA_COUNT	BOOLEAN	0=False 1=True		Signal for counter disabling
FRQ_OPR_CNT	INT32	0...2147483647		Frequent operation counter
FRQ_OPR_AL	BOOLEAN	0=False 1=True		Frequent operation counter alarm
STATUS	Enum	-2=Unsuccessful -1=Not defined 1=Ready 2=In progress 3=Successful		AR status signal for IEC61850
ACTIVE	BOOLEAN	0=False 1=True		Reclosing sequence is in progress
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
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	0...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

9.4.10 Technical data

Table 480: DARREC Technical data

Characteristic	Value
Operate time accuracy	±1.0% of the set value or ±20 ms

9.4.11 Technical revision history

Table 481: Technical revision history

Technical revision	Change
B	The `PROT_DISA` output removed and removed the related settings
C	The default value of the *CB closed Pos status* setting changed from "True" to "False"

9.5 Automatic transfer switch ATSABTC

9.5.1 Identification

Description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Automatic transfer switch	ATSABTC	ATSABTC	ATSABTC

9.5.2 Function block

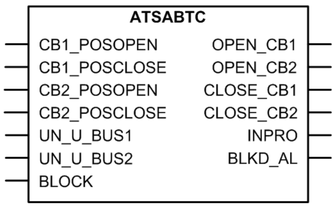


Figure 277: Function block

9.5.3 Functionality

The automatic transfer switch function ATSABTC acts as a back-up in case of interruption in the active supply path. In the application, voltages are measured on bus 1 and bus 2, while the currents are measured on the common busbar. An undervoltage on the active bus automatically switches over to the other healthy bus. Automatic reconnection to the preferred bus is established when the voltage on the preferred bus has reached a normal level. The preferred main bus can be selected from the settings. The automatic operation can be selected on/off from a virtual button on the SLD.

Automatic operation ongoing is signalled outside to output `INPRO`. If the automatic operations are blocked an alarm is activated on the LED panel.

9.5.4 Operation principle

The *Operation* setting is used to enable or disable the function. "On" enables the function and "Off" disables the function.

The operation of ATSABTC can be described by using a module diagram. All the modules in the diagram are explained in the next sections.

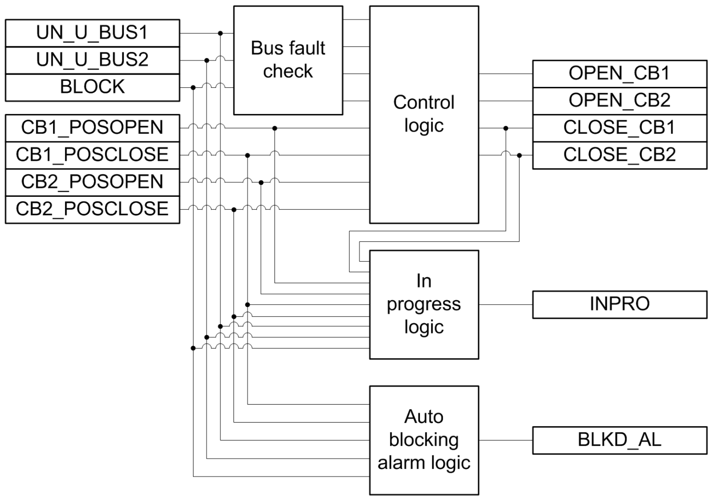


Figure 278: Functional module diagram

All inputs and outputs for the ATSABTC function block are binary signals. Voltage presence indication at each bus is connected to inputs `UN_U_BUS1` and `UN_U_BUS2`, where a binary TRUE represents under-voltage on bus. Fault on the busbar (earth fault or overcurrent) is connected to the input `BLOCK`.

Bus fault check

Under-voltage on respective bus is detected with `UN_U_BUS1` and `UN_U_BUS2`. Input `BLOCK` also indicates common bus fault, but furthermore blocks the automatic operation in the control logic modules.

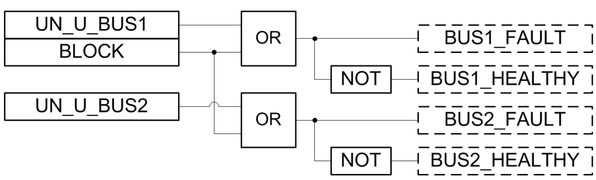


Figure 279: Sub module diagram for Bus fault check

Control logic

Depending on the *Main bus priority* setting, the control logic reads the states of the circuit breakers and performs automatic transfers depending on bus voltage presence and blocking conditions. In control logic sub module diagrams, all the open/close situations in automatic mode are illustrated.

CB1 control logic

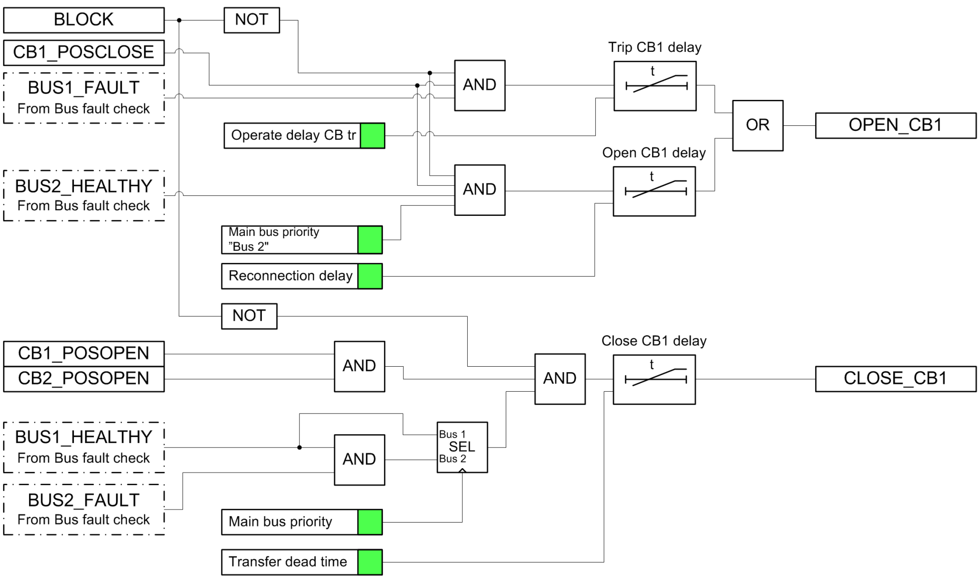


Figure 280: Sub module diagram for CB1 control logic

Operation of the output signals is described in the table.

Table 482: Operating conditions for output signals of CB1

Output signal	Operation description	Operation type
OPEN_CB1	If bus 1 is faulty and the CB1 position is closed, OPEN_CB1 is activated after *CB1 Trip delay* has expired.	Protection
	Setting *Main bus priority* = “bus 2”. If CB1 position is closed and bus 2 is healthy, OPEN_CB1 is activated after *Open CB1 delay* has expired.	Automatic reconnection
CLOSE_CB1	Setting *Main bus priority* = “bus 1”. If both CB1 and CB2 are open, and bus 1 is healthy, CLOSE_CB1 is activated after *Close CB1 delay* has expired. Operation is independent of the state on bus 2.	Automatic reconnection
	Setting *Main bus priority* = “bus 2”. If both CB1 and CB2 are open, bus 2 is faulty and bus 1 is healthy, CLOSE_CB1 is activated after *Close CB1 delay* has expired.	Automatic transfer

Activation of BLOCK input deactivates the outputs and resets the timers.

CB2 control logic

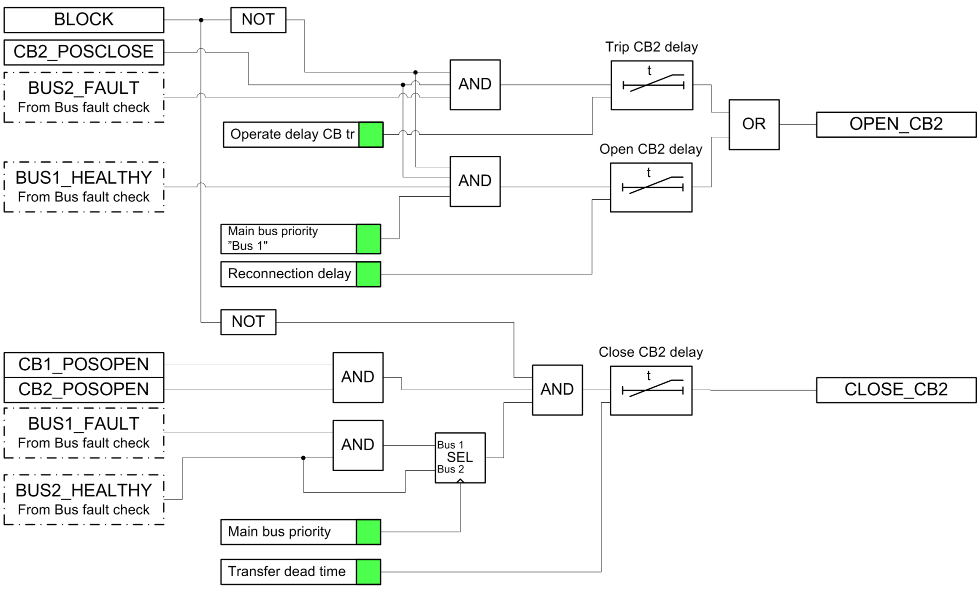


Figure 281: Sub module diagram for CB2 control logic

Operation of the output signals is described in the table.

Table 483: Operating conditions for output signals of CB2

Output signal	Operation description	Operation type
OPEN_CB2	If bus 2 is faulty and the CB2 position is closed, OPEN_CB2 is activated after *CB2 Trip delay* has expired.	Protection
	Setting *Main bus priority* = "bus 1". If CB2 position is closed and bus 1 is healthy, OPEN_CB2 is activated after *Open CB2 delay* has expired.	Automatic reconnection
CLOSE_CB2	Setting *Main bus priority* = "bus 2". If both CB1 and CB2 are open, and bus 2 is healthy, CLOSE_CB2 is activated after Close CB2 delay has expired. Operation is independent of the state on bus 1.	Automatic reconnection
	Setting *Main bus priority* = "bus 1". If both CB1 and CB2 are open, bus 1 is faulty and bus 2 is healthy, CLOSE_CB2 is activated after *Close CB2 delay* has expired.	Automatic transfer

Activation of BLOCK input deactivates the outputs and resets the timers.

In progress logic

Automatic operation ongoing is signalled outside to output INPRO. The INPRO output is set TRUE if an undervoltage is detected on the active bus or if an auto reconnection is initialized. INPRO is reset when an auto transfer or an auto reconnection is completed or if the fault is cleared during the waiting time.

Auto blocking alarm logic

Blocking alarm for auto switching is signalled outside to output BLKD_AL. Blocking alarm is TRUE for various reasons.

- BLOCK input is active
- CB1 is closed and under-voltage detected on bus 2
- CB2 is closed and under-voltage detected on bus 1
- Undervoltage detected on both bus 1 and bus 2

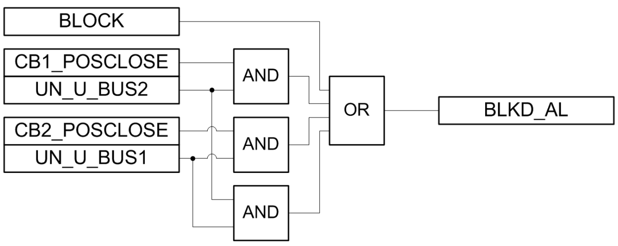


Figure 282: Sub module diagram for auto blocking alarm logic

9.5.5 Application

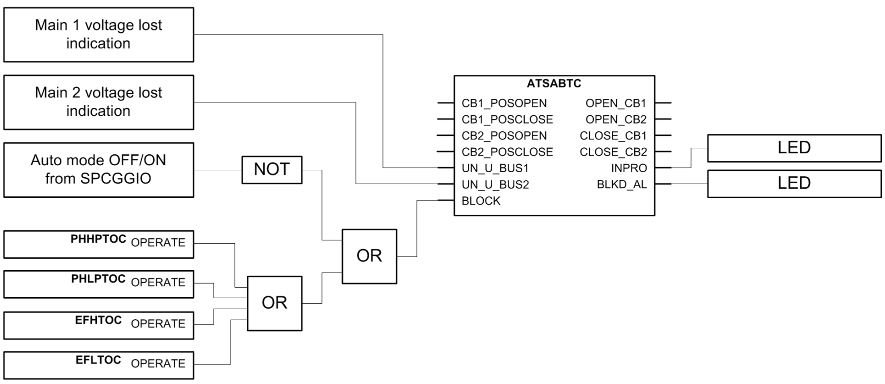


Figure 283: Application configuration example

A recommended application configuration example is described in Figure 9.5.4. Undervoltage detection on bus 1 and undervoltage detection on bus 2 are connected directly to the UN_U_BUS1 and UN_U_BUS2. The undervoltage indication at each bus can be detected from for example functions PHPTUV, VMMXU or PHSVPR. Load fault detections on busbar, such as overcurrent and earth-fault functions are connected as grouped protection input to BLOCK. *Auto mode OFF/ON* is connected to input BLOCK.

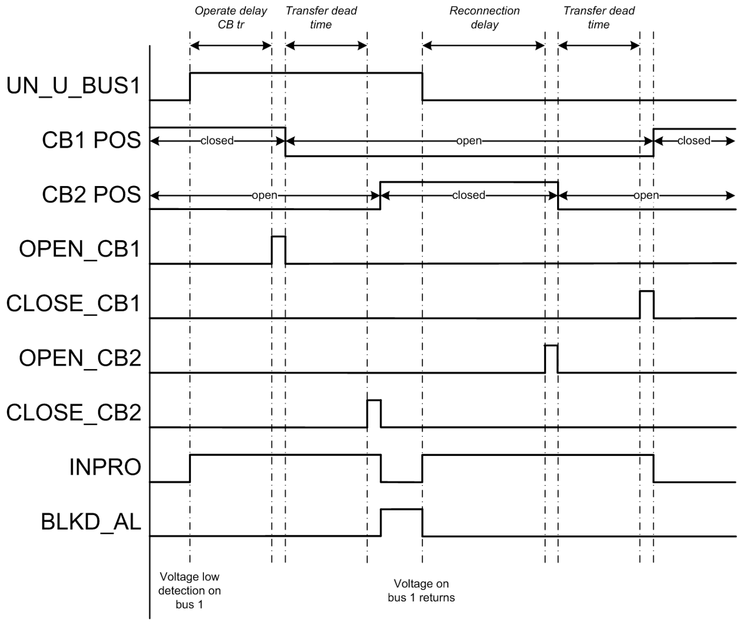


Figure 284: Signal scheme illustrating an automatic transfer switch and an automatic reconnection operation caused by a temporary under-voltage on the preferred bus 1 (all other excluded inputs are FALSE during the sequence)

9.5.6 Signals

Table 484: ATSABTC1 Input signals

Name	Type	Default	Description
CB1_POSOPEN	BOOLEAN	0=False	Circuit breaker open status for bus 1
CB1_POSCLOSE	BOOLEAN	0=False	Circuit breaker close status for bus 1
CB2_POSOPEN	BOOLEAN	0=False	Circuit breaker open status for bus 2
CB2_POSCLOSE	BOOLEAN	0=False	Circuit breaker close status for bus 2
UN_U_BUS1	BOOLEAN	0=False	Undervoltage on bus 1
UN_U_BUS2	BOOLEAN	0=False	Undervoltage on bus 2
BLOCK	BOOLEAN	0=False	Blocking of function

Table 485: ATSABTC1 Output signals

Name	Type	Description
OPEN_CB1	BOOLEAN	Circuit breaker open command for bus 1
CLOSE_CB1	BOOLEAN	Circuit breaker close command for bus 1
OPEN_CB2	BOOLEAN	Circuit breaker open command for bus 2
CLOSE_CB2	BOOLEAN	Circuit breaker close command for bus 2
INPRO	BOOLEAN	Automatic operation in progress
BLKD_AL	BOOLEAN	Automatic transfer switch blocked alarm

9.5.7 Settings

Table 486: ATSABTC1 Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Main bus priority	1=Bus 1 2=Bus 2			1=Bus 1	Main bus priority (1 or 2)
Operate delay CB tr	0...120000	ms	10	200	Circuit breaker trip delay
Transfer dead time	0...120000	ms	10	100	Transfer dead time for closing of circuit breaker
Reconnection delay	0...300000	ms	10	60000	Delay for opening of non prioritized CB

9.5.8 Monitored data

Table 487: ATSABTC1 Monitored data

Name	Type	Values (Range)	Unit	Description
ATSABTC1	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

9.5.9 Technical data

Table 488: ATSABTC Technical data

Characteristic	Value
Operation time accuracy	±1.0% of the set value or ±20 ms

Section 10 Power quality measurement functions

10.1 Current total demand distortion monitoring CMHAI

10.1.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Current total demand distortion monitoring	CMHAI	PQM3I	PQM3I

10.1.2 Function block

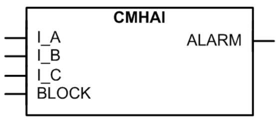


Figure 285: Function block

10.1.3 Functionality

The distortion monitoring function CMHAI is used for monitoring the current total demand distortion TDD.

10.1.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the current distortion monitoring function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

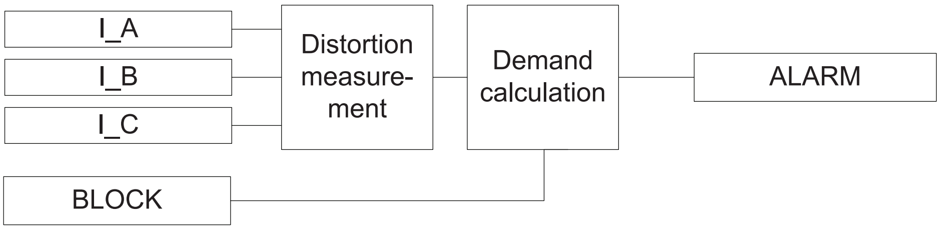


Figure 286: Functional module diagram

Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total demand distortion TDD is calculated from the measured harmonic components with the formula

$$TDD = \frac{\sqrt{\sum_{k=2}^{N} I_k^2}}{I_{max\_demand}}$$

(Equation 52)

I_k	k^{th} harmonic component
I_{max_demand}	The maximum demand current measured by CMMXU

If CMMXU is not available in the configuration or the measured maximum demand current is less than the *Initial Dmd current* setting, *Initial Dmd current* is used for I_{max_demand}.

Demand calculation

The demand value for TDD is calculated separately for each phase. If any of the calculated total demand distortion values is above the set alarm limit *TDD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

10.1.5 Application

In standards, the power quality is defined through the characteristics of the supply voltage. Transients, short-duration and long-duration voltage variations, unbalance and waveform distortions are the key characteristics describing power quality. Power quality is, however, a customer-driven issue. It could be said that any power problem concerning voltage or current that results in a failure or misoperation of customer equipment is a power quality problem.

Harmonic distortion in a power system is caused by nonlinear devices. Electronic power converter loads constitute the most important class of nonlinear loads in a power system. The switch mode power supplies in a number of single-phase electronic equipment, such as personal computers, printers and copiers, have a very high third-harmonic content in the current. Three-phase electronic power converters, that is, dc/ac drives, however, do not generate third-harmonic currents. Still, they can be significant sources of harmonics.

Power quality monitoring is an essential service that utilities can provide for their industrial and key customers. Not only can a monitoring system provide information about system disturbances and their possible causes, it can also detect problem conditions throughout the system before they cause customer complaints, equipment malfunctions and even equipment damage or failure. Power quality problems are not limited to the utility side of the system. In fact, the majority of power quality problems are localized within customer facilities. Thus, power quality monitoring is not only an effective customer service strategy but also a way to protect a utility's reputation for quality power and service.

CMHAI provides a method for monitoring the power quality by means of the current waveform distortion. CMHAI provides a short-term 3-second average and a long-term demand for TDD.

10.1.6 Signals

Table 489: CMHAI Input signals

Name	Type	Default	Description
I_A	Signal	0	Phase A current
I_B	Signal	0	Phase B current
I_C	Signal	0	Phase C current
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 490: CMHAI Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal for TDD

10.1.7 Settings

Table 491: CMHAI Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Demand interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes 6=180 minutes			2=10 minutes	Time interval for demand calculation
Demand window	1=Sliding 2=Non-sliding			1=Sliding	Demand calculation window type
TDD alarm limit	1.0...100.0	%	0.1	50.0	TDD alarm limit
Initial Dmd current	0.10...1.00	xIn	0.01	1.00	Initial demand current

10.1.8 Monitored data

Table 492: CMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
Max demand TDD IL1	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase A
Max demand TDD IL2	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase B
Max demand TDD IL3	FLOAT32	0.00...500.00	%	Maximum demand TDD for phase C
Time max dmd TDD IL1	Timestamp			Time of maximum demand TDD phase A
Time max dmd TDD IL2	Timestamp			Time of maximum demand TDD phase B
Time max dmd TDD IL3	Timestamp			Time of maximum demand TDD phase C
3SMHTDD_A	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase A
DMD_TDD_A	FLOAT32	0.00...500.00	%	Demand value for TDD for phase A
3SMHTDD_B	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase B
DMD_TDD_B	FLOAT32	0.00...500.00	%	Demand value for TDD for phase B
3SMHTDD_C	FLOAT32	0.00...500.00	%	3 second mean value of TDD for phase C
DMD_TDD_C	FLOAT32	0.00...500.00	%	Demand value for TDD for phase C

10.2 Voltage total harmonic distortion monitoring VMHAI

10.2.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage total harmonic distortion monitoring	VMHAI	PQM3U	PQM3V

10.2.2 Function block

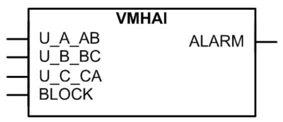


Figure 287: Function block

10.2.3 Functionality

The distortion monitoring function VMHAI is used for monitoring the voltage total harmonic distortion THD.

10.2.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the voltage distortion monitoring function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

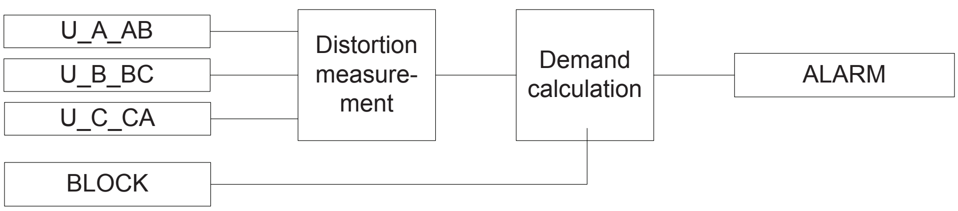


Figure 288: Functional module diagram

Distortion measurement

The distortion measurement module measures harmonics up to the 11th harmonic. The total harmonic distortion THD for voltage is calculated from the measured harmonic components with the formula

$$THD = \frac{\sqrt{\sum_{k=2}^{N} U_k^2}}{U_1}$$

(Equation 53)

U_k k[th] harmonic component

U_1 the voltage fundamental component amplitude

Demand calculation

The demand value for THD is calculated separately for each phase. If any of the calculated demand THD values is above the set alarm limit *THD alarm limit*, the ALARM output is activated.

The demand calculation window is set with the *Demand interval* setting. It has seven window lengths from "1 minute" to "180 minutes". The window type can be set with the *Demand window* setting. The available options are "Sliding" and "Non-sliding".

The activation of the BLOCK input blocks the ALARM output.

10.2.5 Application

VMHAI provides a method for monitoring the power quality by means of the voltage waveform distortion. VMHAI provides a short-term three-second average and long-term demand for THD.

10.2.6 Signals

Table 493: VMHAI Input signals

Name	Type	Default	Description
U_A_AB	SIGNAL	0	Phase-to-earth voltage A or phase-to-phase voltage AB
U_B_BC	SIGNAL	0	Phase-to-earth voltage B or phase-to-phase voltage BC
U_C_CA	SIGNAL	0	Phase-to-earth voltage C or phase-to-phase voltage CA
BLOCK	BOOLEAN	0=False	Block signal for all binary outputs

Table 494: VMHAI Output signals

Name	Type	Description
ALARM	BOOLEAN	Alarm signal for THD

10.2.7 Settings

Table 495: VMHAI Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
Demand interval	0=1 minute 1=5 minutes 2=10 minutes 3=15 minutes 4=30 minutes 5=60 minutes 6=180 minutes			2=10 minutes	Time interval for demand calculation
Demand window	1=Sliding 2=Non-sliding			1=Sliding	Demand calculation window type
THD alarm limit	1.0...100.0	%	0.1	50.0	THD alarm limit

10.2.8 Monitored data

Table 496: VMHAI Monitored data

Name	Type	Values (Range)	Unit	Description
Max demand THD UL1	FLOAT32	0.00...500.00	%	Maximum demand THD for phase A
Max demand THD UL2	FLOAT32	0.00...500.00	%	Maximum demand THD for phase B
Max demand THD UL3	FLOAT32	0.00...500.00	%	Maximum demand THD for phase C
Time max dmd THD UL1	Timestamp			Time of maximum demand THD phase A
Time max dmd THD UL2	Timestamp			Time of maximum demand THD phase B
Time max dmd THD UL3	Timestamp			Time of maximum demand THD phase C
3SMHTHD_A	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase A
DMD_THD_A	FLOAT32	0.00...500.00	%	Demand value for THD for phase A
3SMHTHD_B	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase B
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
DMD_THD_B	FLOAT32	0.00...500.00	%	Demand value for THD for phase B
3SMHTHD_C	FLOAT32	0.00...500.00	%	3 second mean value of THD for phase C
DMD_THD_C	FLOAT32	0.00...500.00	%	Demand value for THD for phase C

10.3 Voltage variation PHQVVR

10.3.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage variation detection function	PHQVVR	PQMU	PQMV

10.3.2 Function block

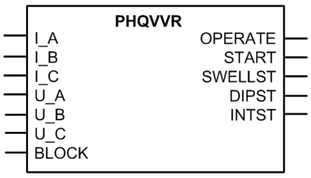


Figure 289: Function block

10.3.3 Functionality

The voltage variation measurement 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, if desired.

10.3.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the voltage variation detection function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

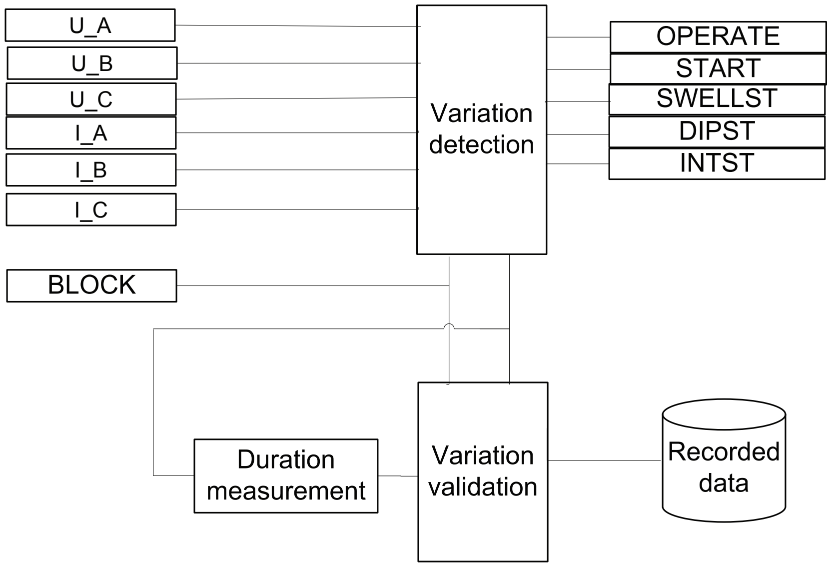


Figure 290: Functional module diagram

10.3.4.1 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.

10.3.4.2 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.

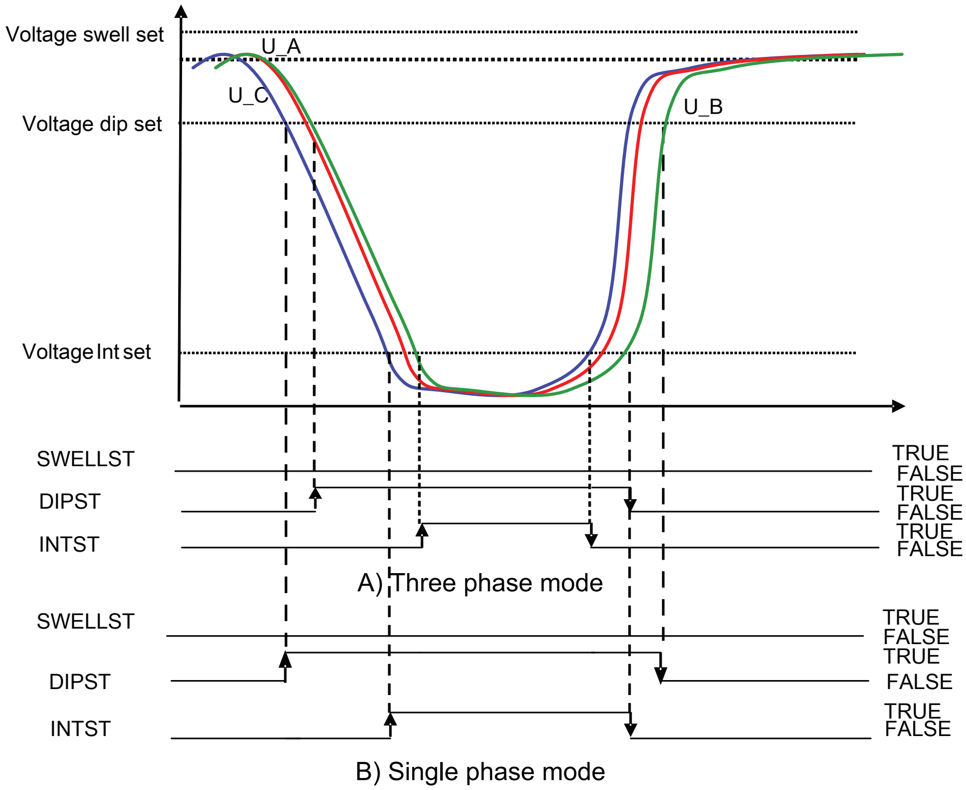


Figure 291: Detection of three-phase voltage interruption

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.

10.3.4.3 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 292 shows voltage dip operational regions. In Figure 291, 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.

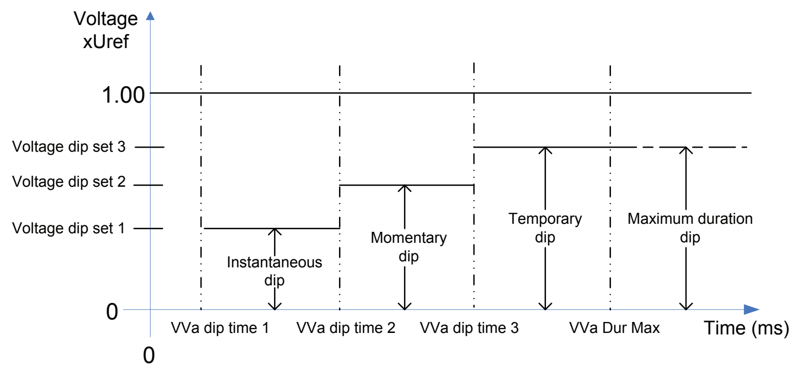


Figure 292: Voltage dip operational regions

In Figure 293, 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.

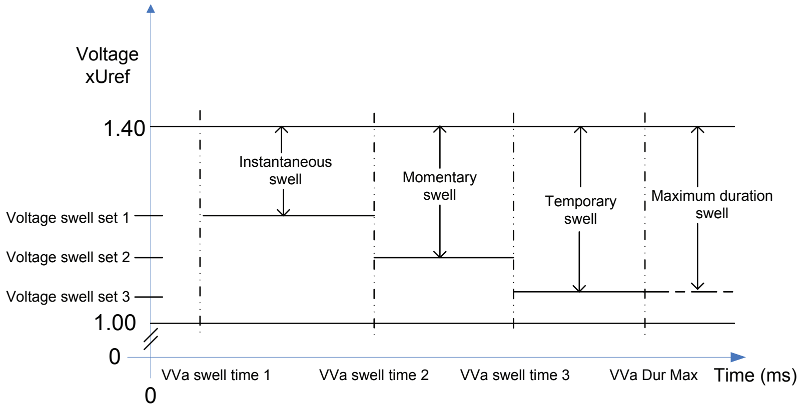


Figure 293: Voltage swell operational regions

For interruption, as shown in Figure 294, 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.

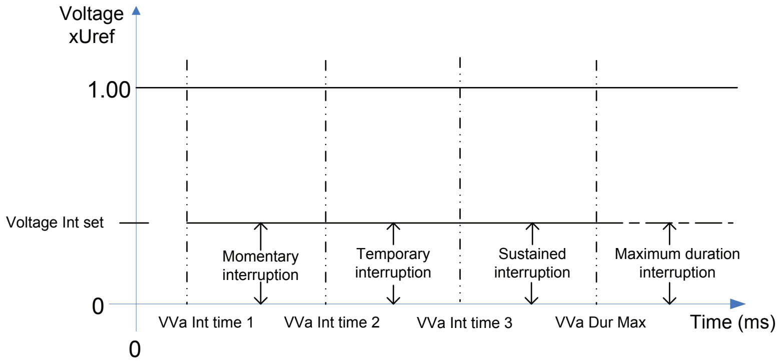


Figure 294: Interruption operating regions

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.

10.3.4.4 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 295. 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.

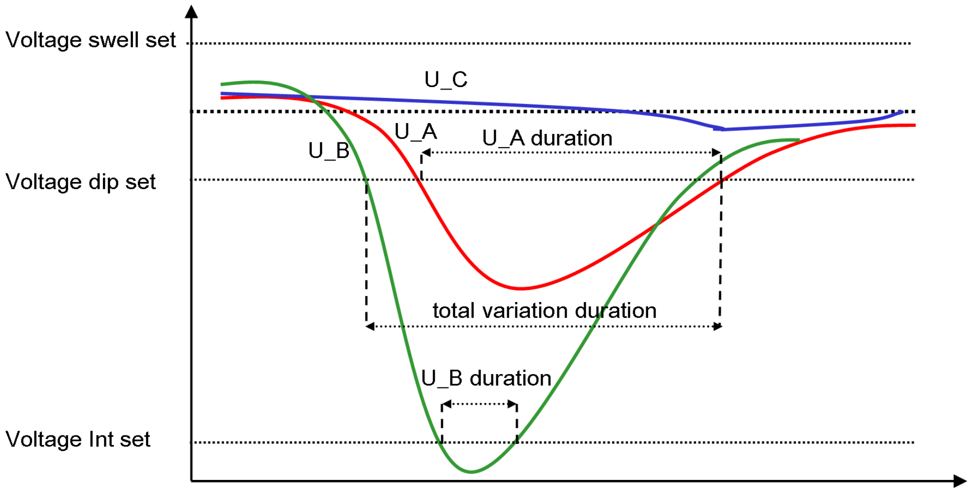


Figure 295: Single-phase interruption for the Phase mode value "Single Phase"

10.3.4.5 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 291. 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 Figure 295, 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 296. 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.

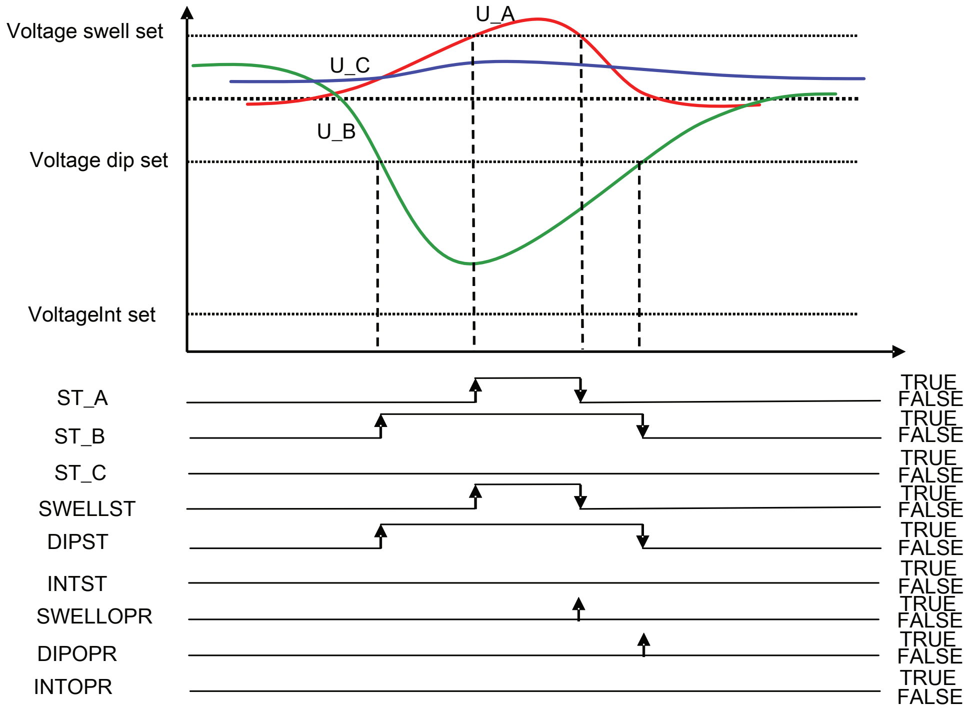


Figure 296: Concurrent dip and swell when Phase mode is "Single Phase"

In Figure 297, 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 297 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 296 and Figure 297 it is assumed that variation durations are sufficient for detections to take place.

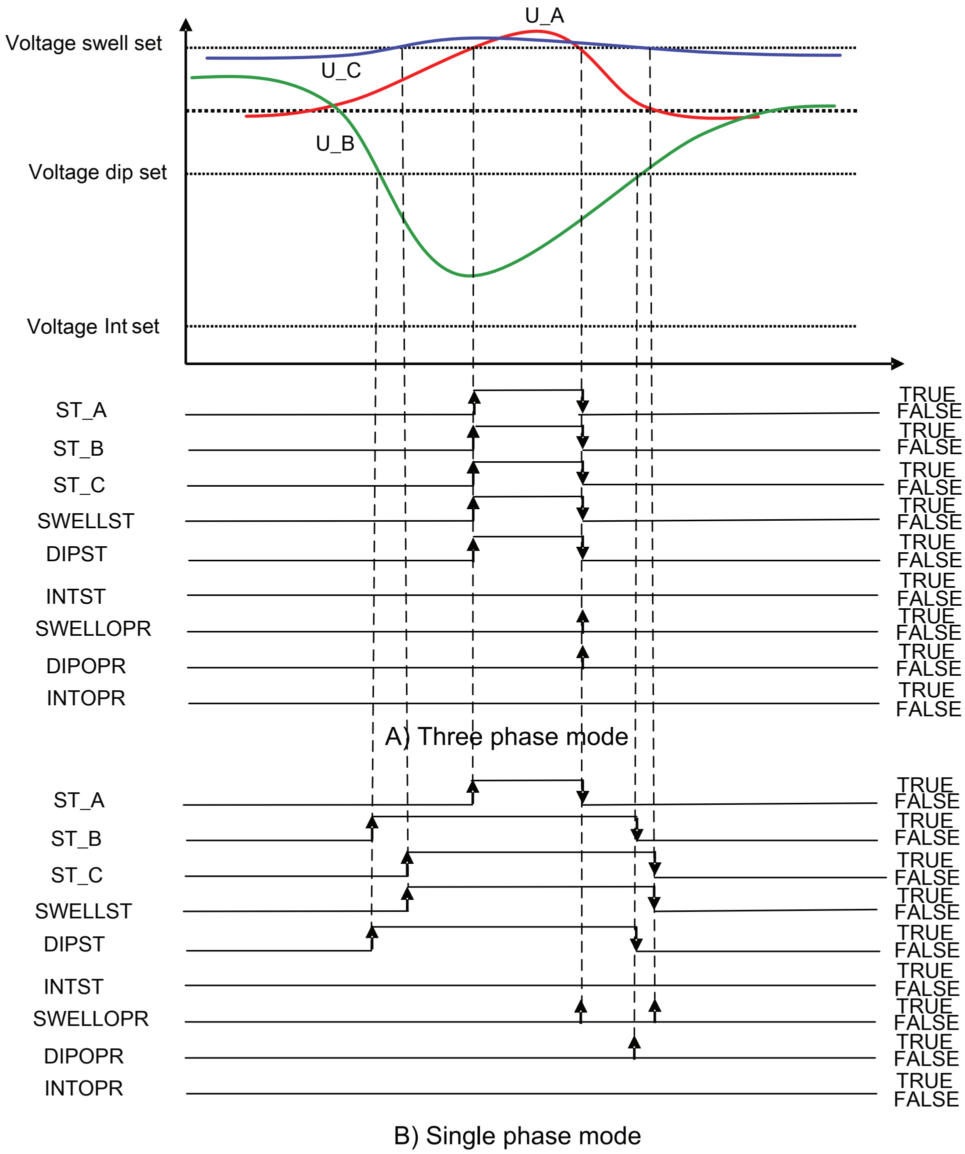


Figure 297: Concurrent dip and two-phase swell

10.3.5 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 298. 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 magnitude-tracked. 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 497. 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 298 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 298. 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.

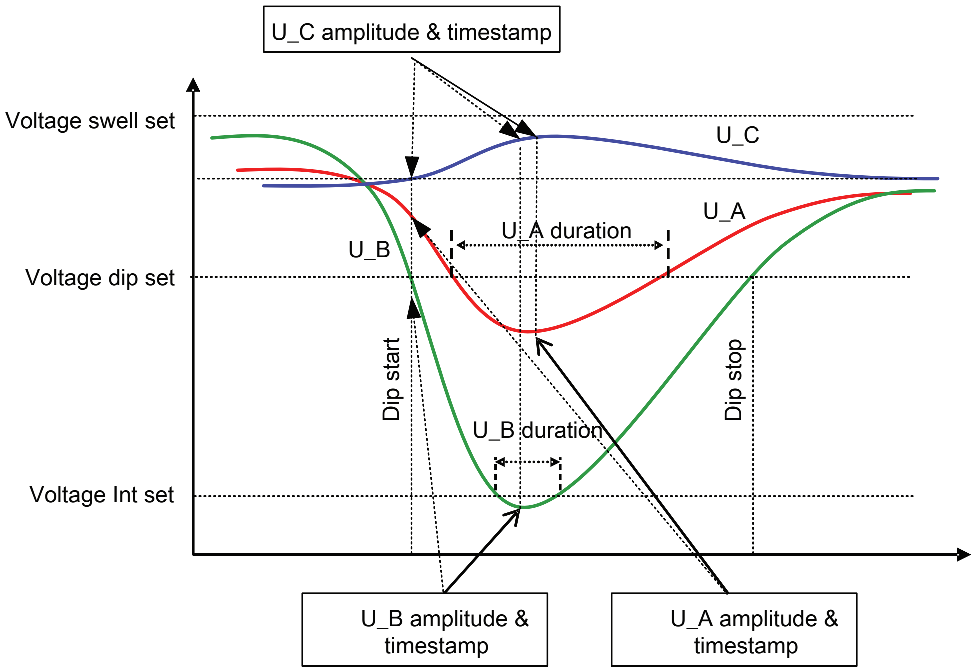


Figure 298: Valid recorded voltage interruption and two dips

Table 497: 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 498: 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

10.3.6 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.

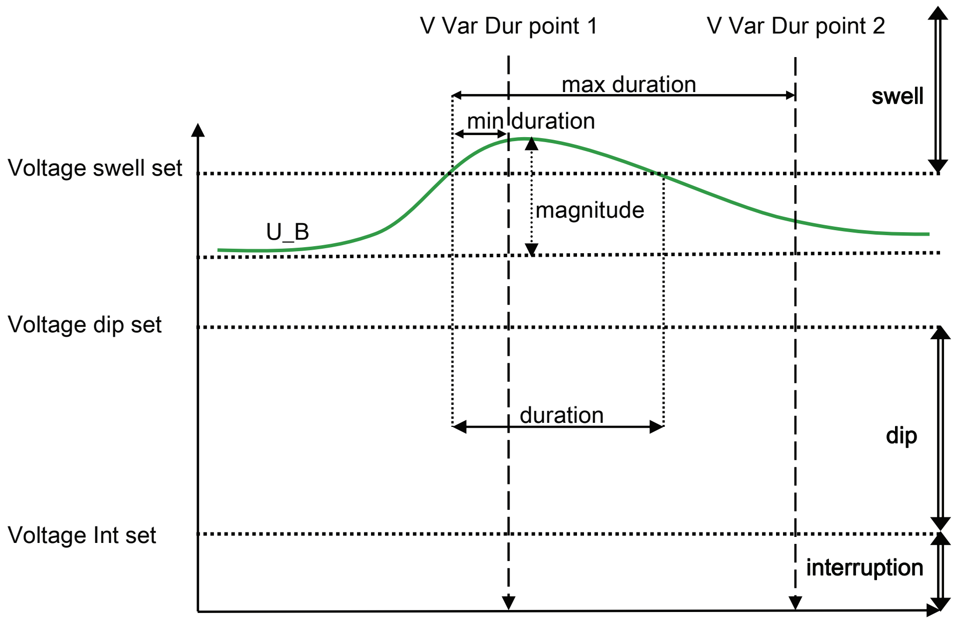


Figure 299: Duration and voltage magnitude limits for swell, dip and interruption measurement

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.

10.3.7 Signals

Table 499: PHQVVR Input signals

Name	Type	Default	Description
I_A	SIGNAL	0	Phase A current magnitude
I_B	SIGNAL	0	Phase B current magnitude
I_C	SIGNAL	0	Phase C current magnitude
U_A	SIGNAL	0	Phase-to-earth voltage A
U_B	SIGNAL	0	Phase-to-earth voltage B
U_C	SIGNAL	0	Phase-to-earth voltage C
BLOCK	BOOLEAN	0=False	Block signal for activating the blocking mode

Table 500: 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

10.3.8 Settings

Table 501: PHQVVR Group settings

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
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 502: PHQVVR Non group settings

Parameter	Values (Range)	Unit	Step	Default	Description
Operation	1=on 5=off			1=on	Operation Off / On
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			2=Single Phase	Three/Single phase mode
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

10.3.9 Monitored data

Table 503: 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 next page

Name	Type	Values (Range)	Unit	Description
Variation Ph A	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUn	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	xUn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Table continues on next page				

Name	Type	Values (Range)	Unit	Description
Variation Ph C	FLOAT32	0.00...5.00	xUn	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	xUn	Variation magnitude Phase A
Var Ph A rec time	Timestamp			Variation magnitude Phase A time stamp
Variation Ph B	FLOAT32	0.00...5.00	xUn	Variation magnitude Phase B
Var Ph B rec time	Timestamp			Variation magnitude Phase B time stamp
Variation Ph C	FLOAT32	0.00...5.00	xUn	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

Table continues on next page

Name	Type	Values (Range)	Unit	Description
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

10.3.10 Technical data

Table 504: PHQVVR Technical data

Characteristic	Value
Operation accuracy	±1.5% of the set value or ±0.2% of reference voltage
Reset ratio	Typical: 0.96 (Swell), 1.04 (Dip, Interruption)

10.4 Voltage unbalance VSQVUB

10.4.1 Identification

Function description	IEC 61850 identification	IEC 60617 identification	ANSI/IEEE C37.2 device number
Voltage unbalance power quality	VSQVUB	VSQVUB	PQMUBV

10.4.2 Function block

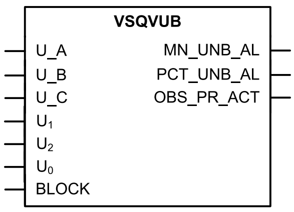


Figure 300: Function block

10.4.3 Functionality

The voltage unbalance power quality 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 or 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 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, if desired.

10.4.4 Operation principle

The function can be enabled and disabled with the *Operation* setting. The corresponding parameter values are "On" and "Off".

The operation of the voltage unbalance power quality function can be described with a module diagram. All the modules in the diagram are explained in the next sections.

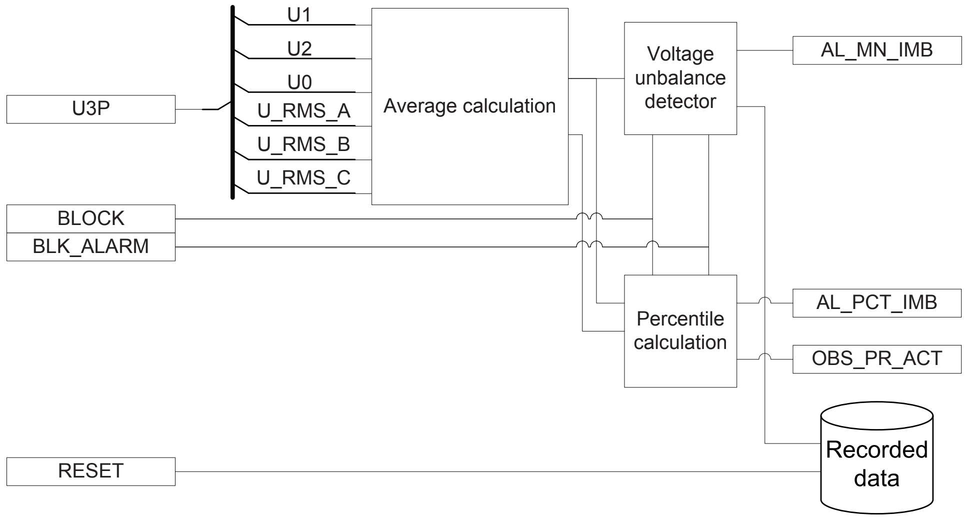


Figure 301: Functional module diagram

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`.

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.

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.

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.

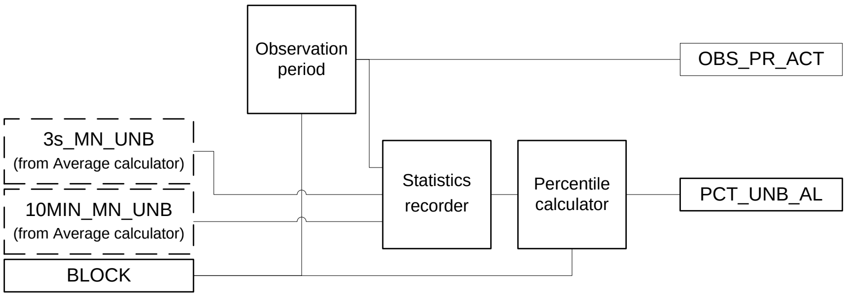


Figure 302: Percentile calculation

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. When the trigger mode is selected "Single", it is the single triggering mode, when the trigger mode is selected "Periodic", it is the periodic triggering mode and when the trigger mode is selected "Continuous", it is the continuous triggering mode.

In the single triggering mode, only one period of observation time is activated. In the periodic triggering mode, the time gap between the two trigger signals is seven days. In the continuous triggering mode, 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.

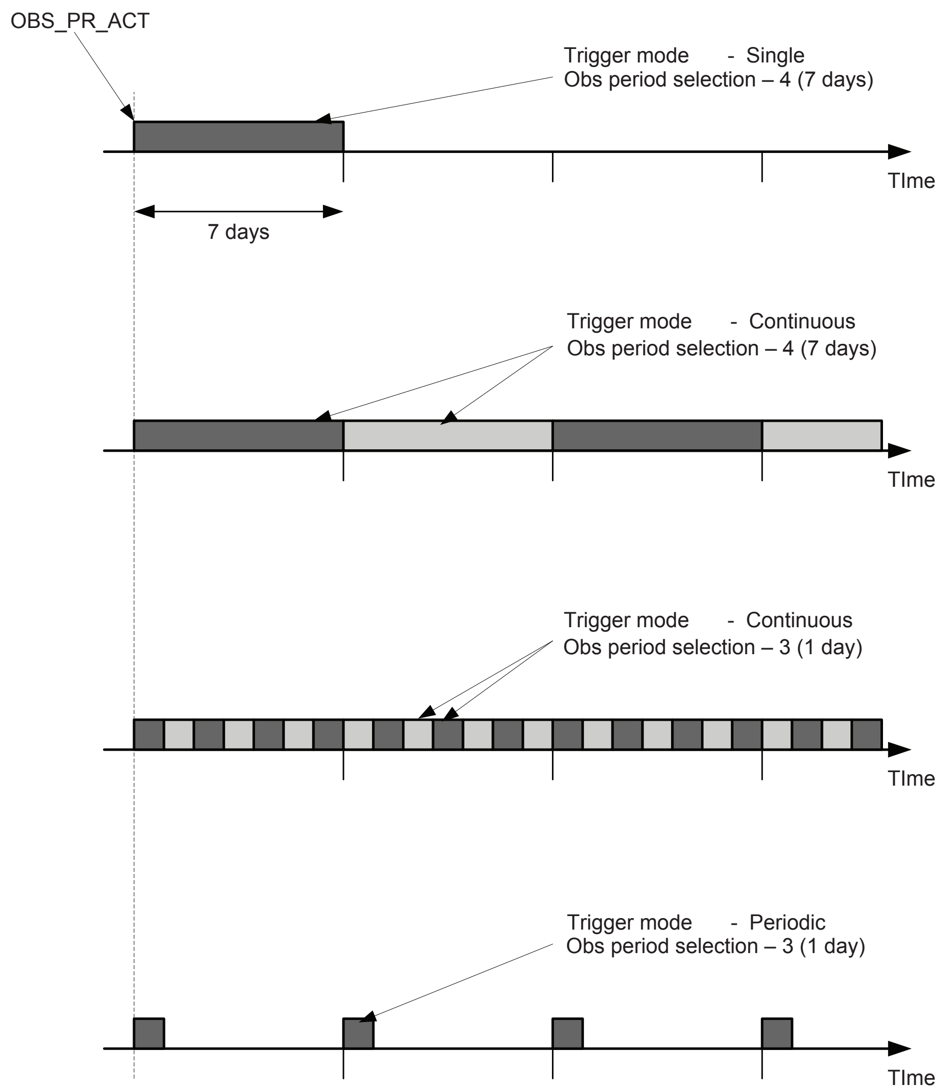


Figure 303: Periods for statistics recorder with different trigger modes and period settings

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.

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.

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`.

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→2 and 2→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 505: 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

10.4.5 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 the 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 to some of the loads has a detrimental effect on their 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 such 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.

10.4.6 Signals

Table 506: VSQVUB Input signals

Name	Type	Default	Description
U_A	SIGNAL	0	Phase A voltage
U_B	SIGNAL	0	Phase B voltage
U_C	SIGNAL	0	Phase C voltage
U_1	SIGNAL	0	
U_2	SIGNAL	0	
U_0	SIGNAL	0	
BLOCK	BOOLEAN	0=False	Block all outputs except measured values

Table 507: 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

10.4.7 Settings

Table 508: VSQVUB Non group settings

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
User Def Obs period	1...168	h	1	168	User define observation period for statistic calculation
Obs period Str time	2008010100...2076010100		1	2011010101	Calendar time for observation period start given as YYYYMMDDhh

10.4.8 Monitored data

Table 509: 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

Table continues on next page

Name	Type	Values (Range)	Unit	Description
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 sec voltage
Time Max Unb Volt	Timestamp			Time stamp of 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 sec voltage
Time Max Unb Volt	Timestamp			Time stamp of 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 sec voltage
Time Max Unb Volt	Timestamp			Time stamp of voltage unbalance
VSQVUB	Enum	1=on 2=blocked 3=test 4=test/blocked 5=off		Status

10.4.9 Technical data

Table 510: VSQVUB Technical data

Characteristic	Value
Operation accuracy	±1.5% of the set value or ±0.002 x U_n
Reset ratio	Typical 0.96

Section 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.

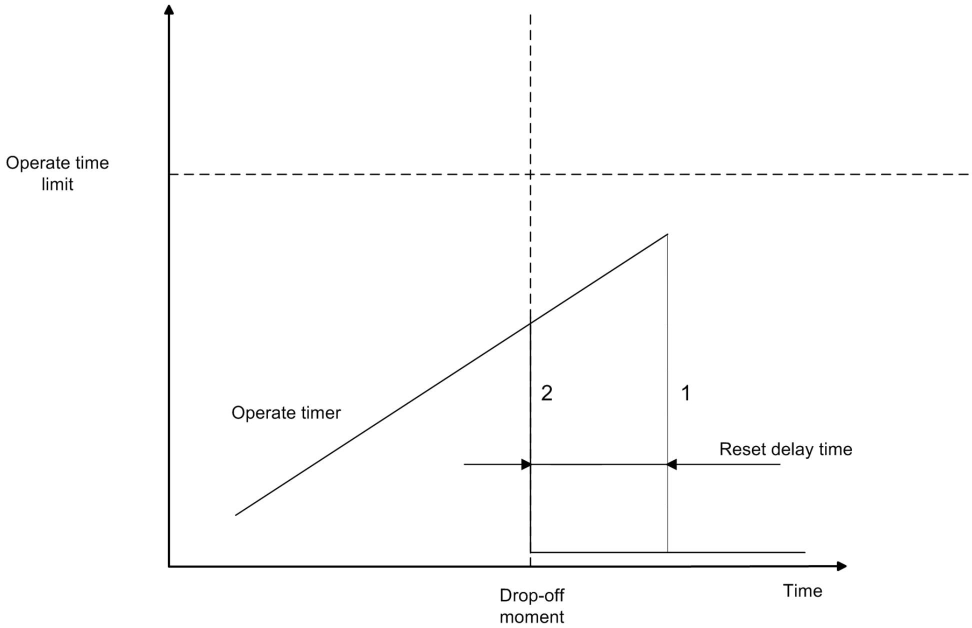


Figure 304: Operation of the counter in drop-off

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.

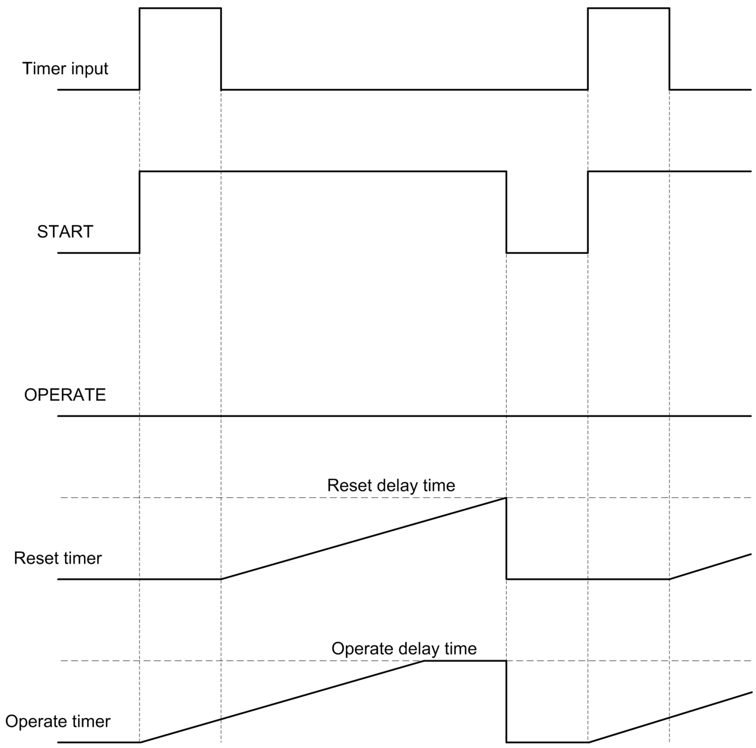


Figure 305: Drop-off period is longer than the set Reset delay time

When the drop-off period is longer than the set *Reset delay time*, as described in Figure 305, 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.

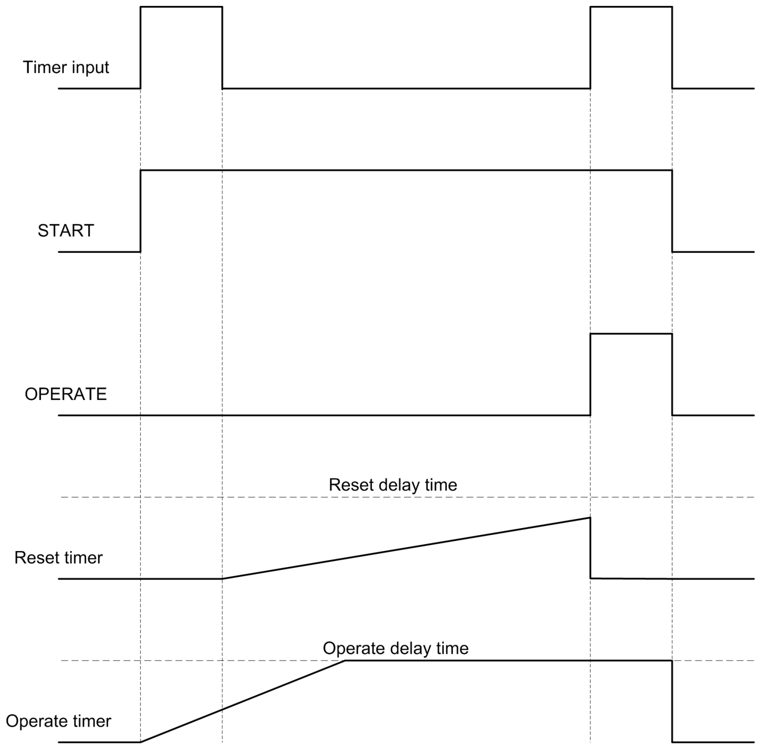


Figure 306: Drop-off period is shorter than the set Reset delay time

When the drop-off period is shorter than the set *Reset delay time*, as described in Figure 306, 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.

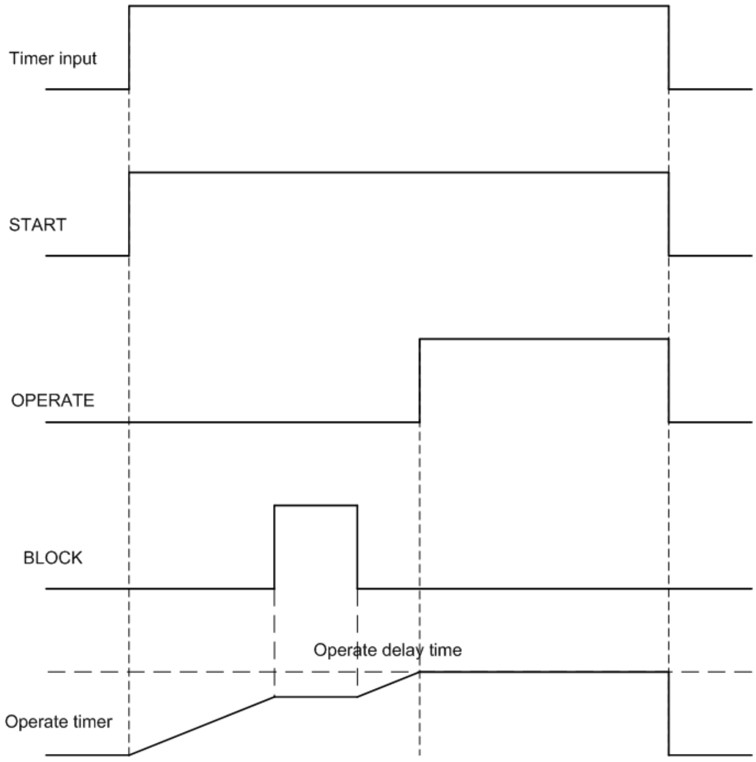


Figure 307: Operating effect of the `BLOCK` *input when the selected blocking mode is "Freeze timer"*

If the `BLOCK` input is activated when the operate timer is running, as described in Figure 307, 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 305, 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

The 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.

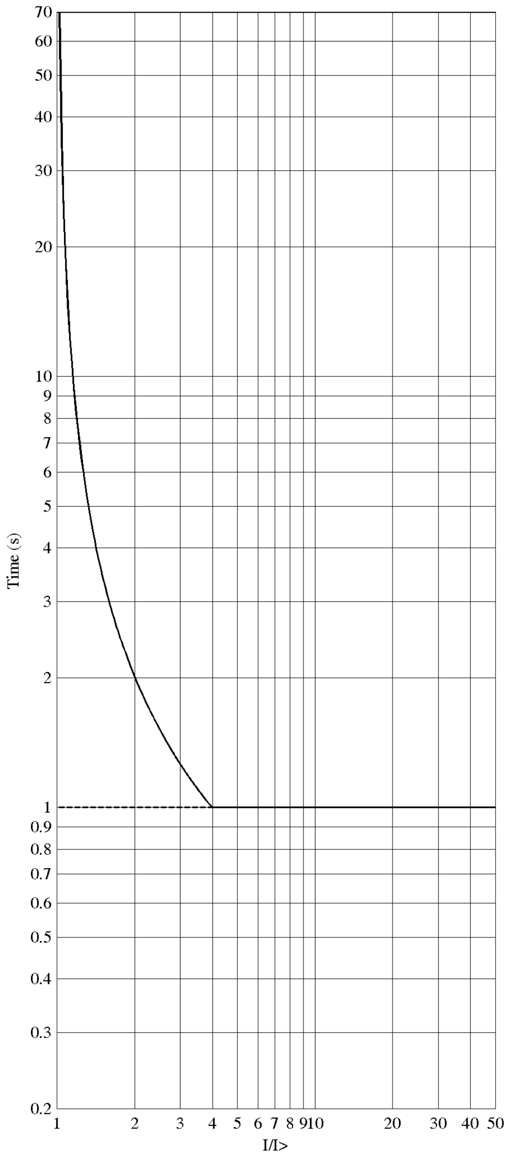


Figure 308: Operation time curve based on the IDMT characteristic leveled out with the Minimum operate time setting is set to 1000 milliseconds (the IDMT Sat point setting is set to maximum).

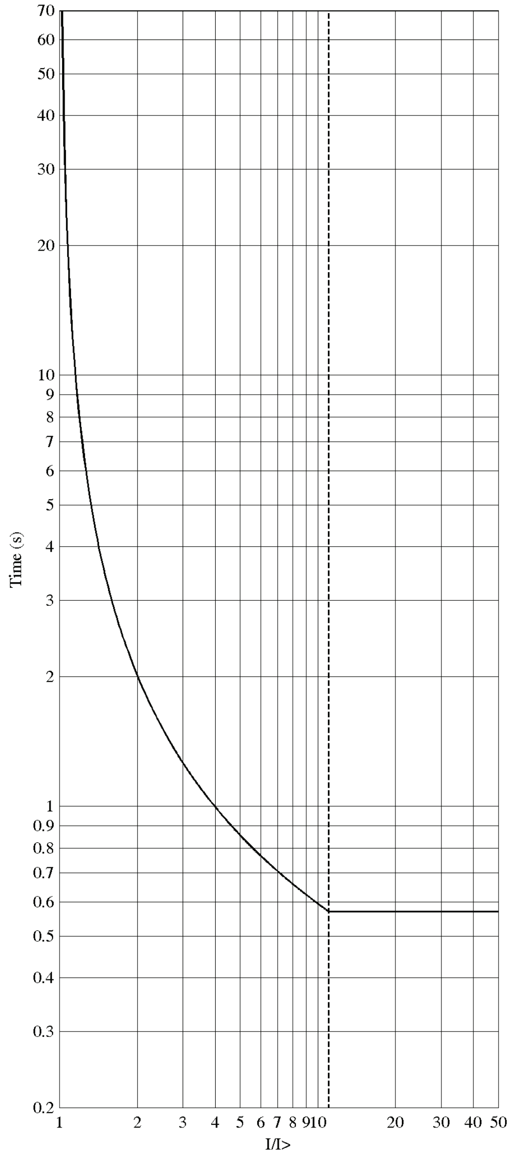


Figure 309: Operation time curve based on the IDMT characteristic leveled out with IDMT Sat point setting value "11" (the Minimum operate time setting is set to minimum).

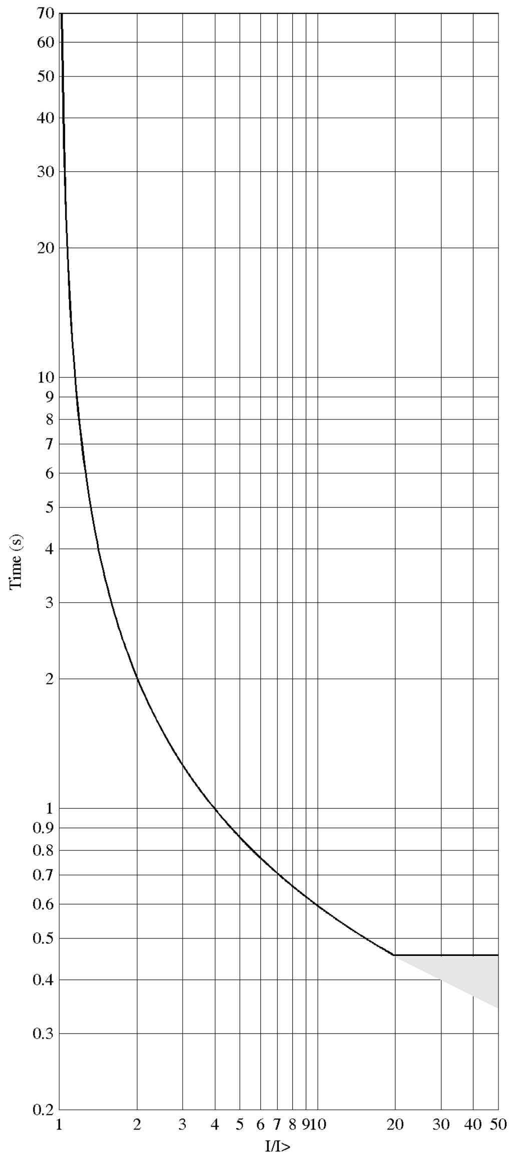


Figure 310: Example of how the inverse time characteristic is leveled out with currents over 50 x In and the Setting Start value setting "2.5 x In". (the IDMT Sat point setting is set to maximum and the Minimum operate time setting is set to minimum).

The grey zone in Figure 310 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 54)

t[s] Operate time in seconds

I measured current

I> set *Start value*

k set *Time multiplier*

Table 511: 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

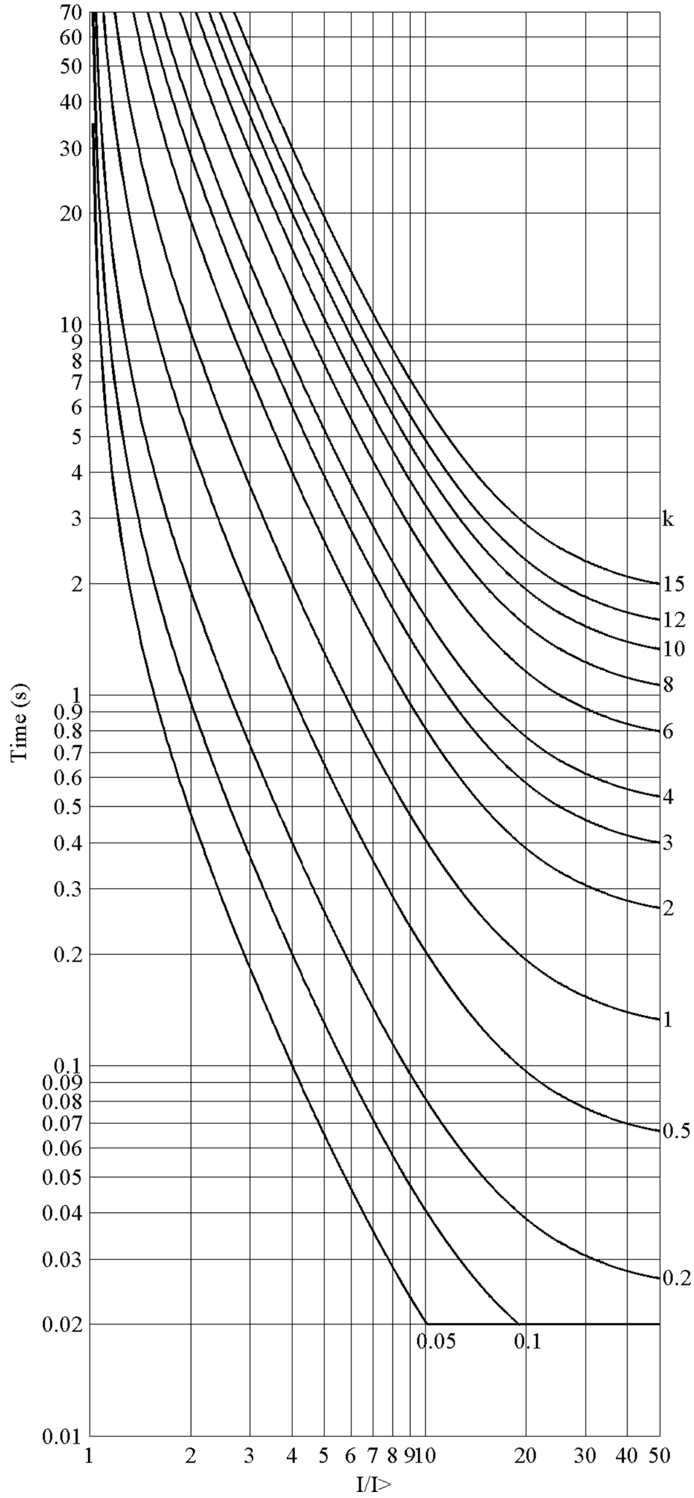


Figure 311: ANSI extremely inverse-time characteristics

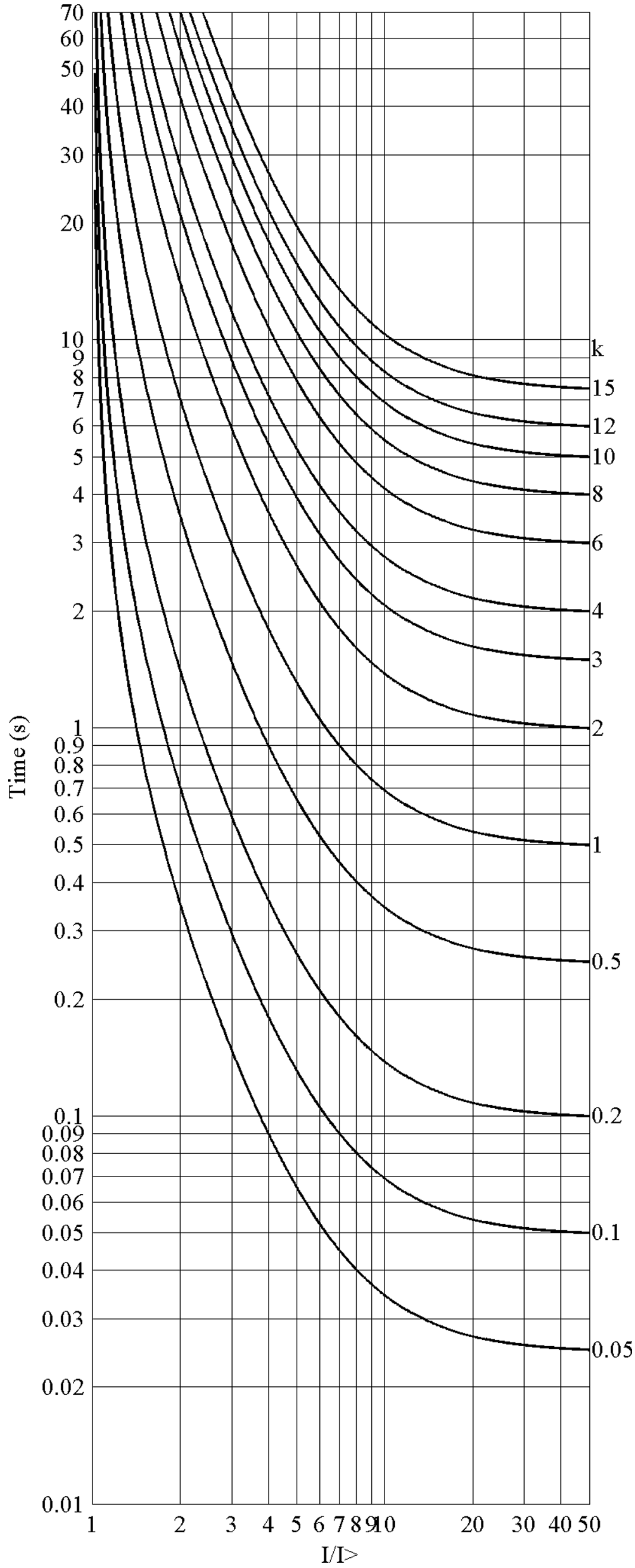


Figure 312: ANSI very inverse-time characteristics

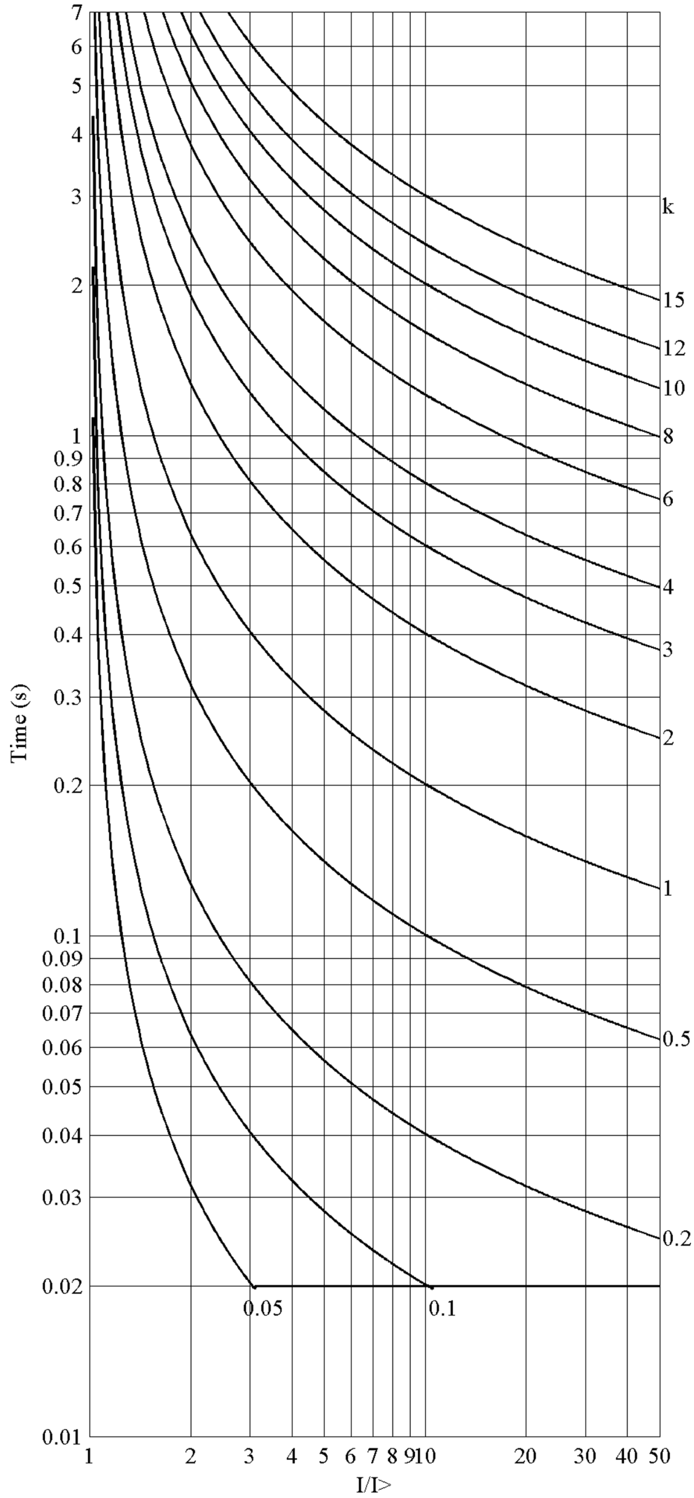


Figure 313: ANSI normal inverse-time characteristics

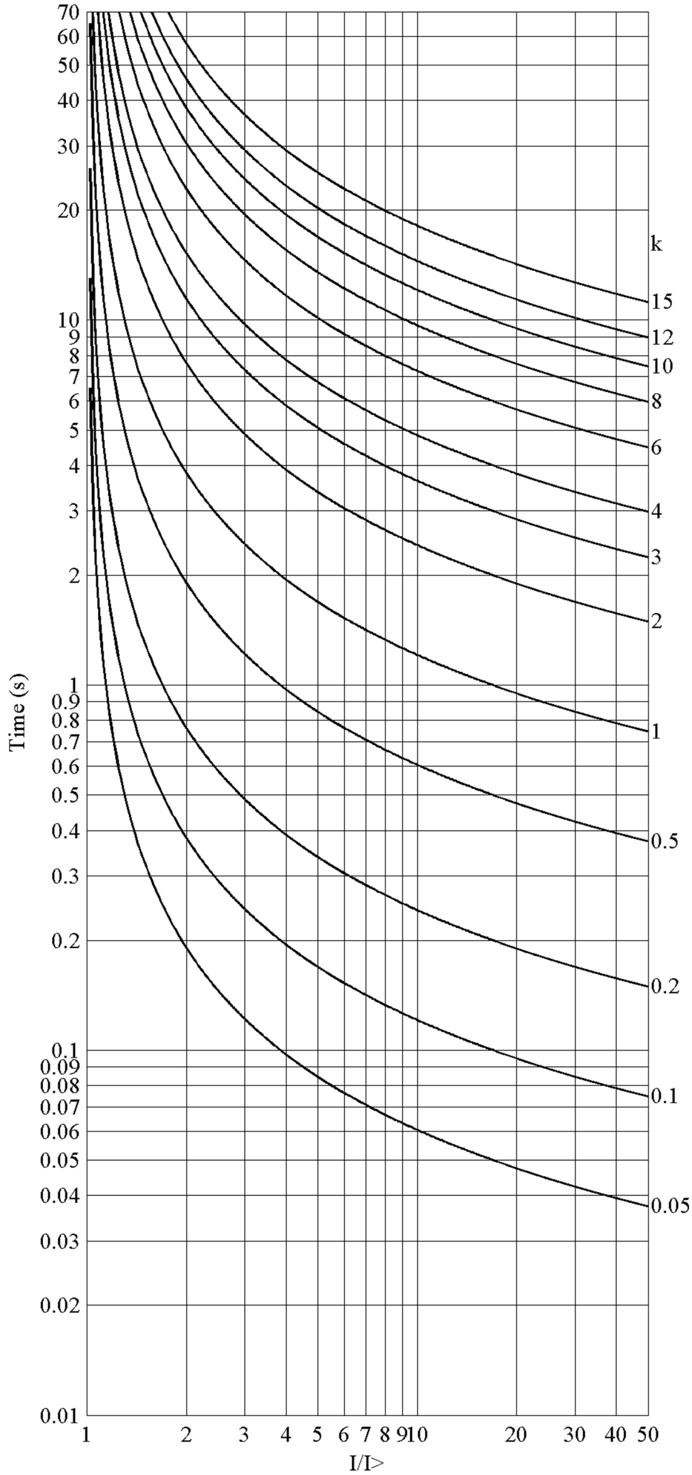


Figure 314: ANSI moderately inverse-time characteristics

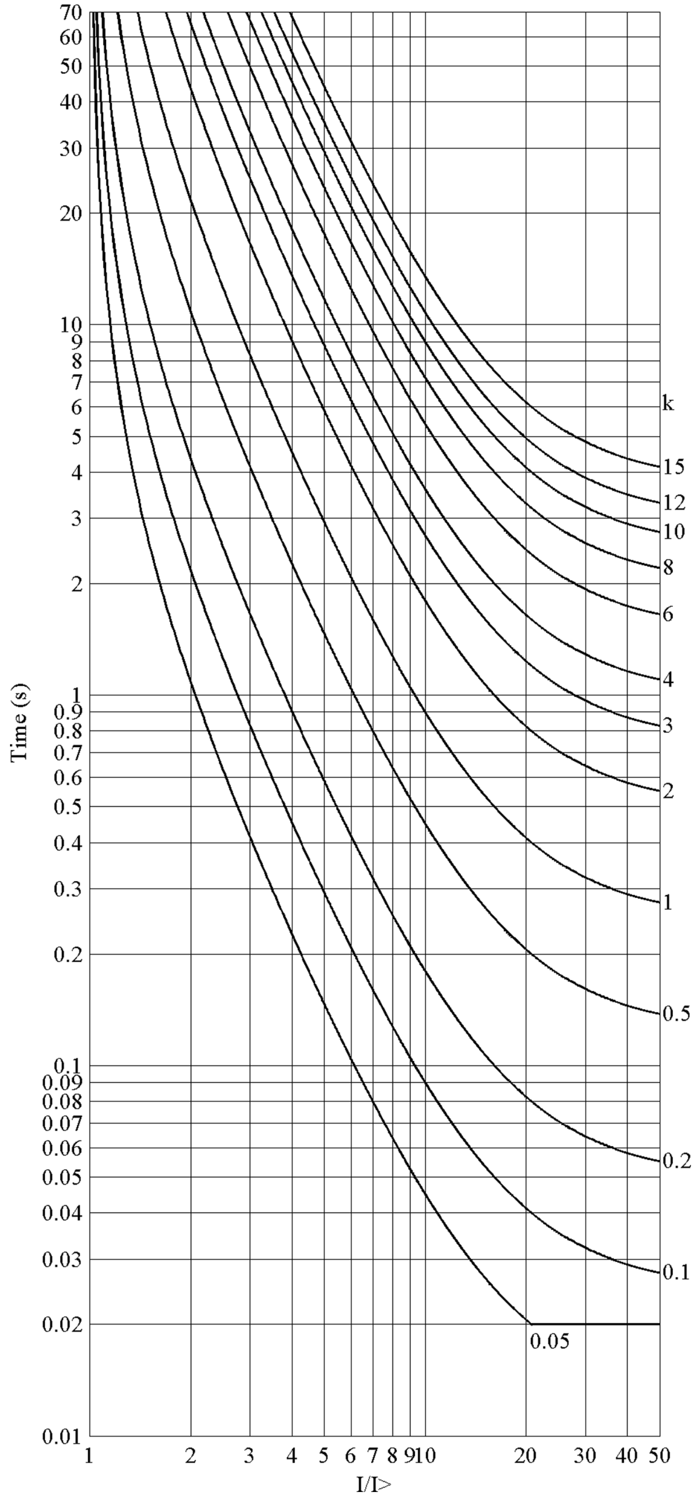


Figure 315: ANSI long-time extremely inverse-time characteristics

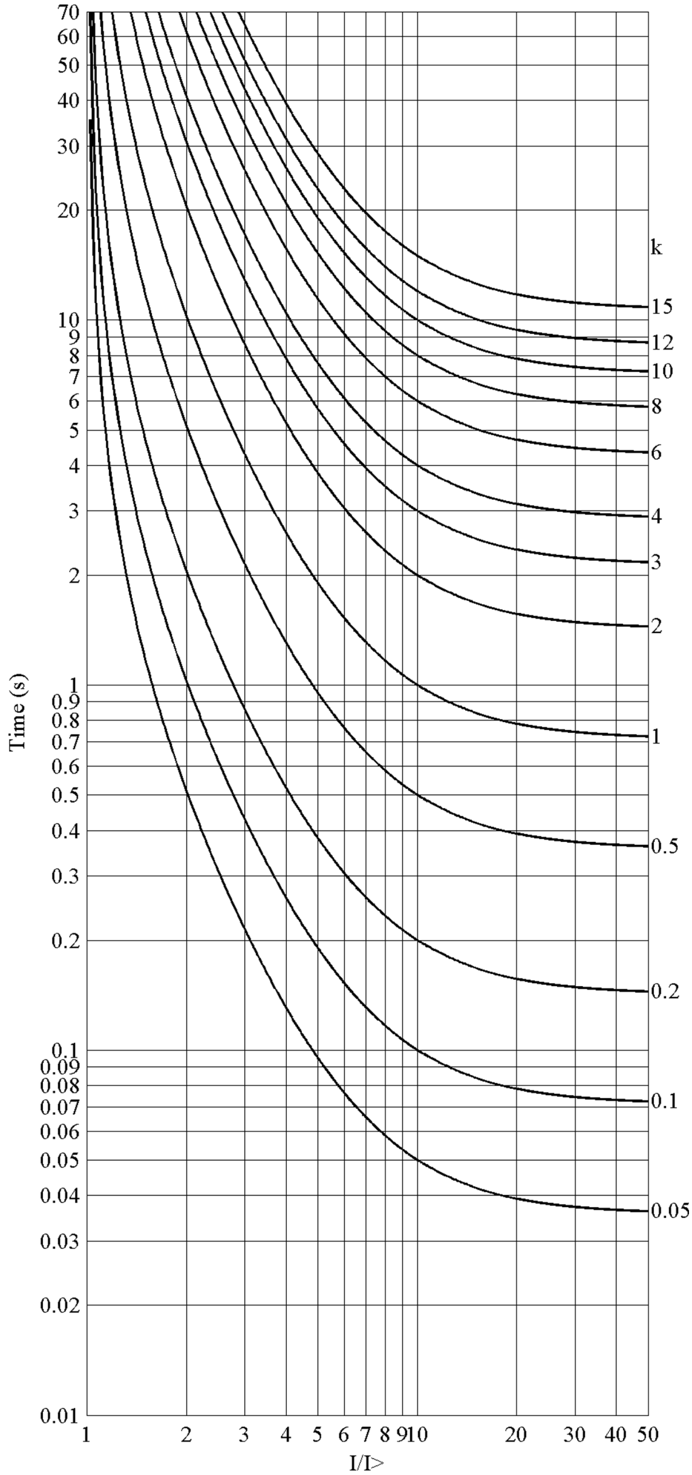


Figure 316: ANSI long-time very inverse-time characteristics

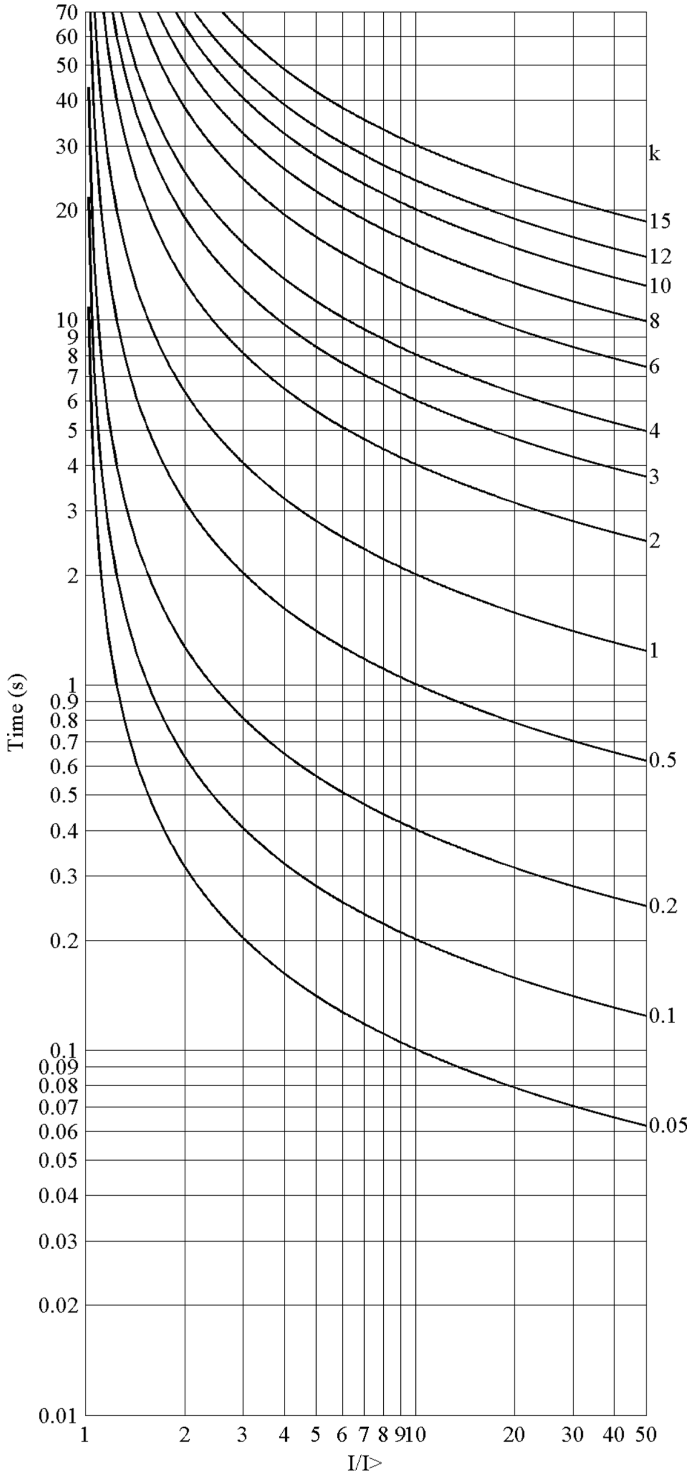


Figure 317: ANSI long-time inverse-time characteristics

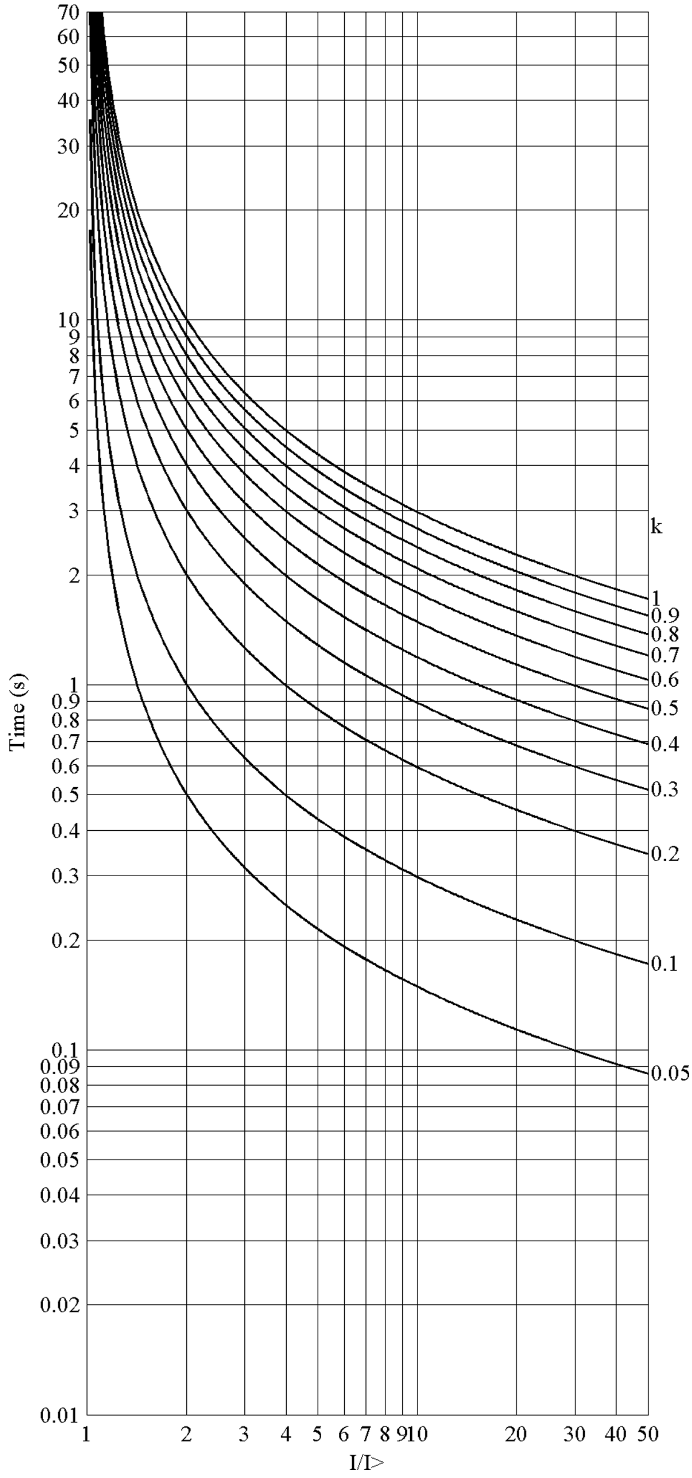


Figure 318: IEC normal inverse-time characteristics

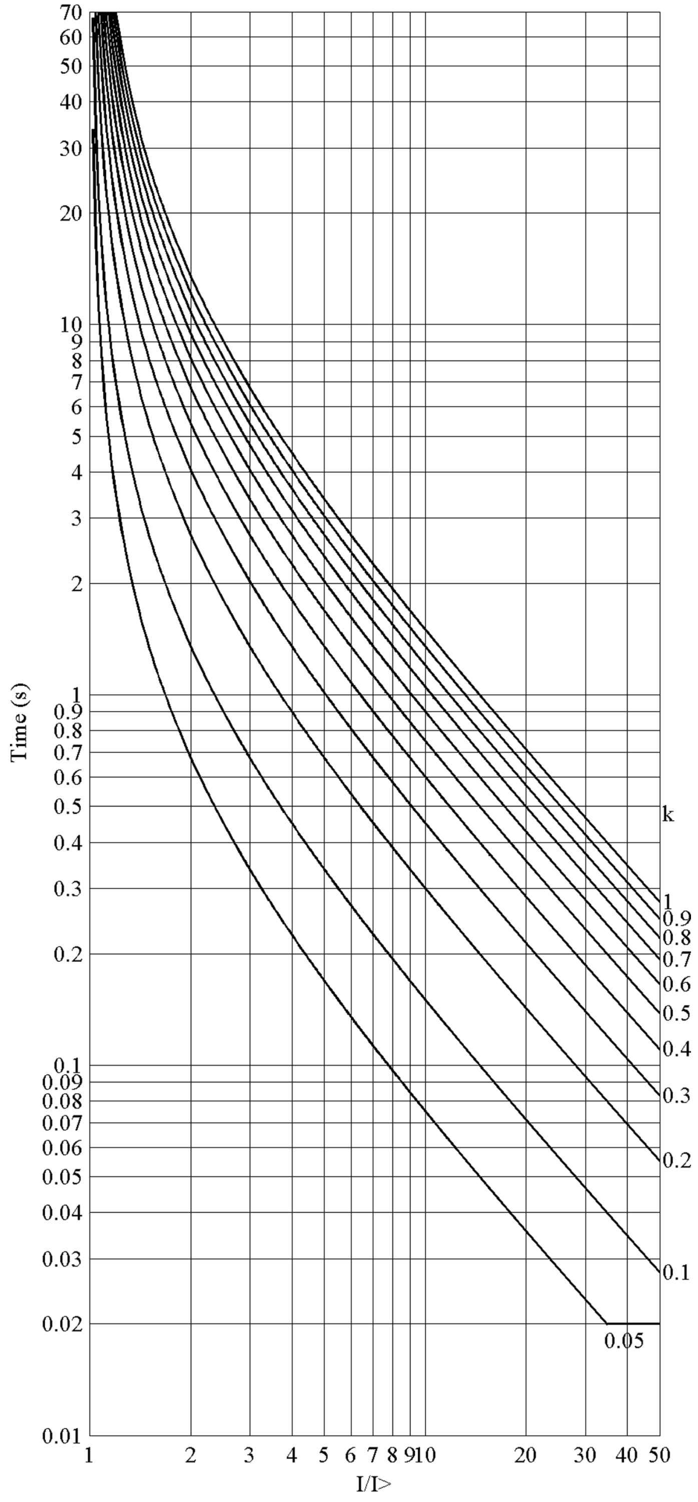


Figure 319: IEC very inverse-time characteristics

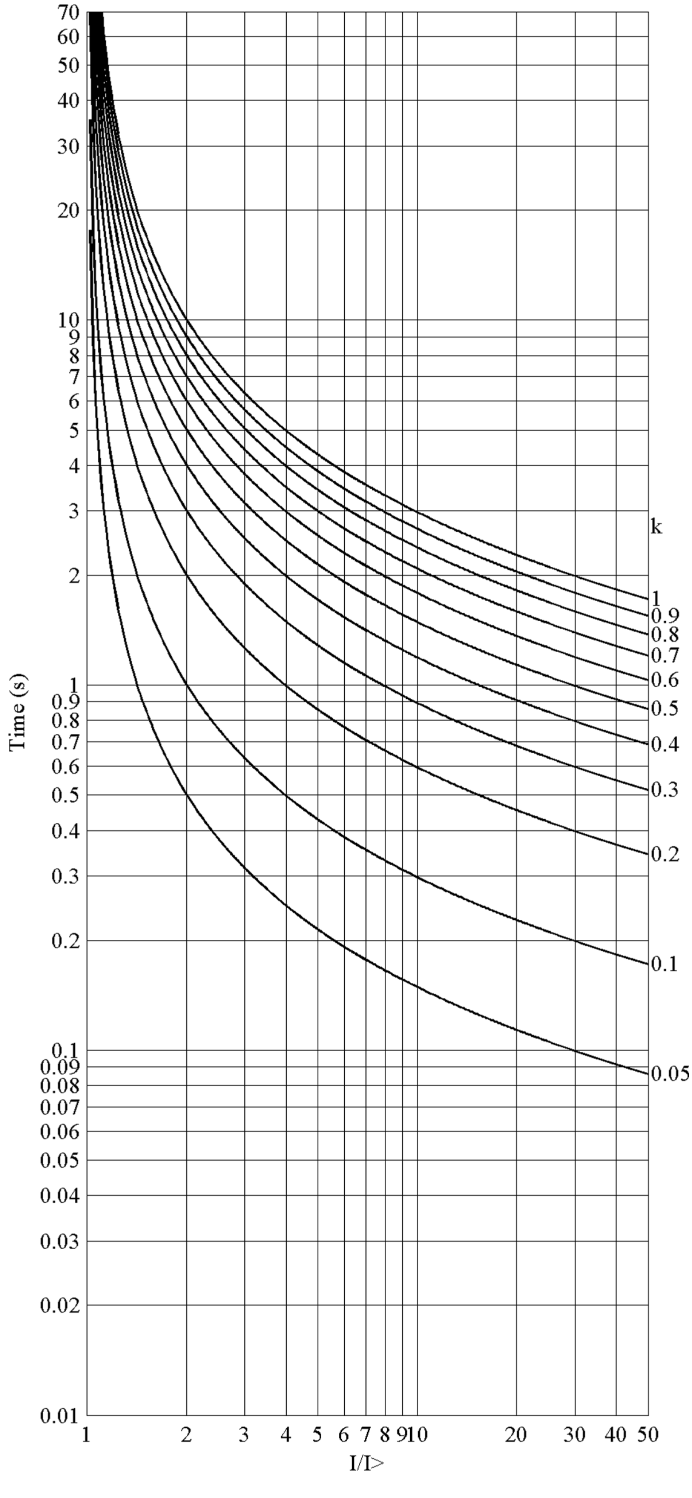


Figure 320: IEC inverse-time characteristics

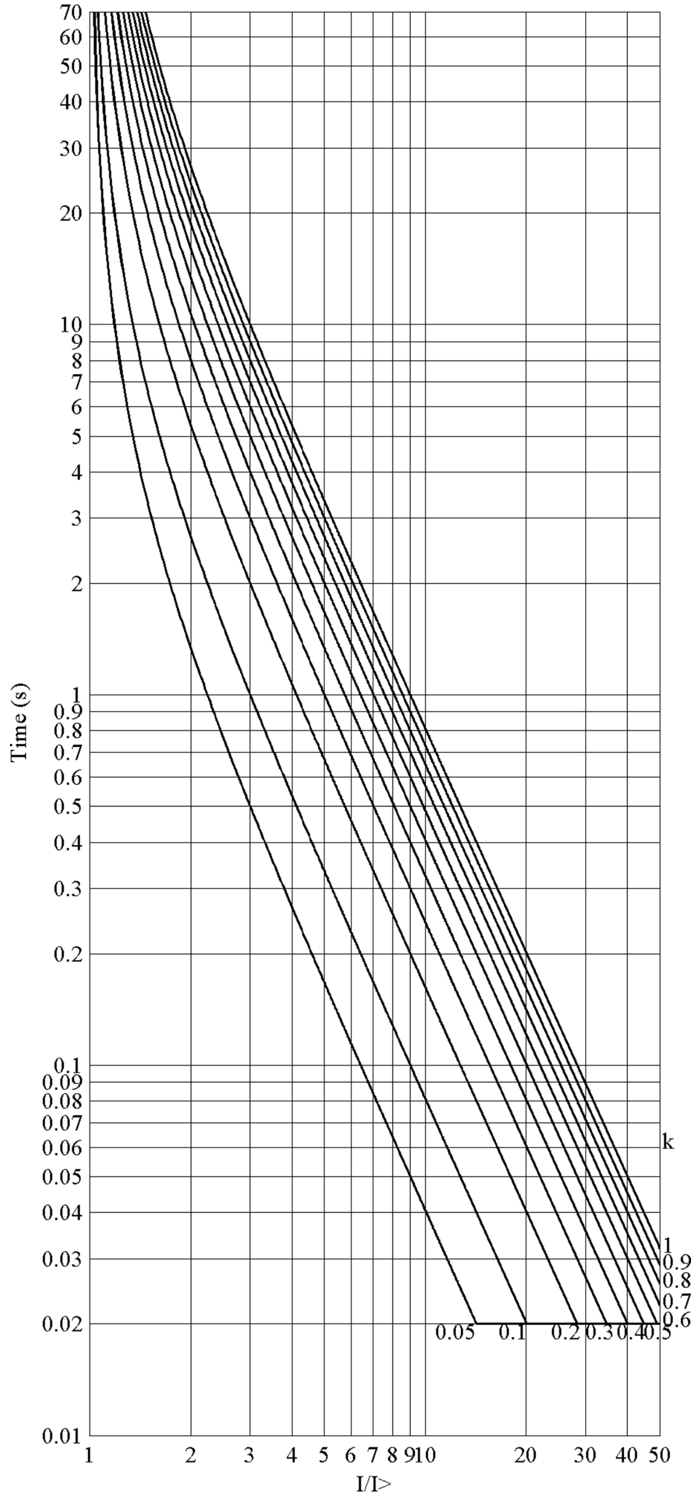


Figure 321: IEC extremely inverse-time characteristics

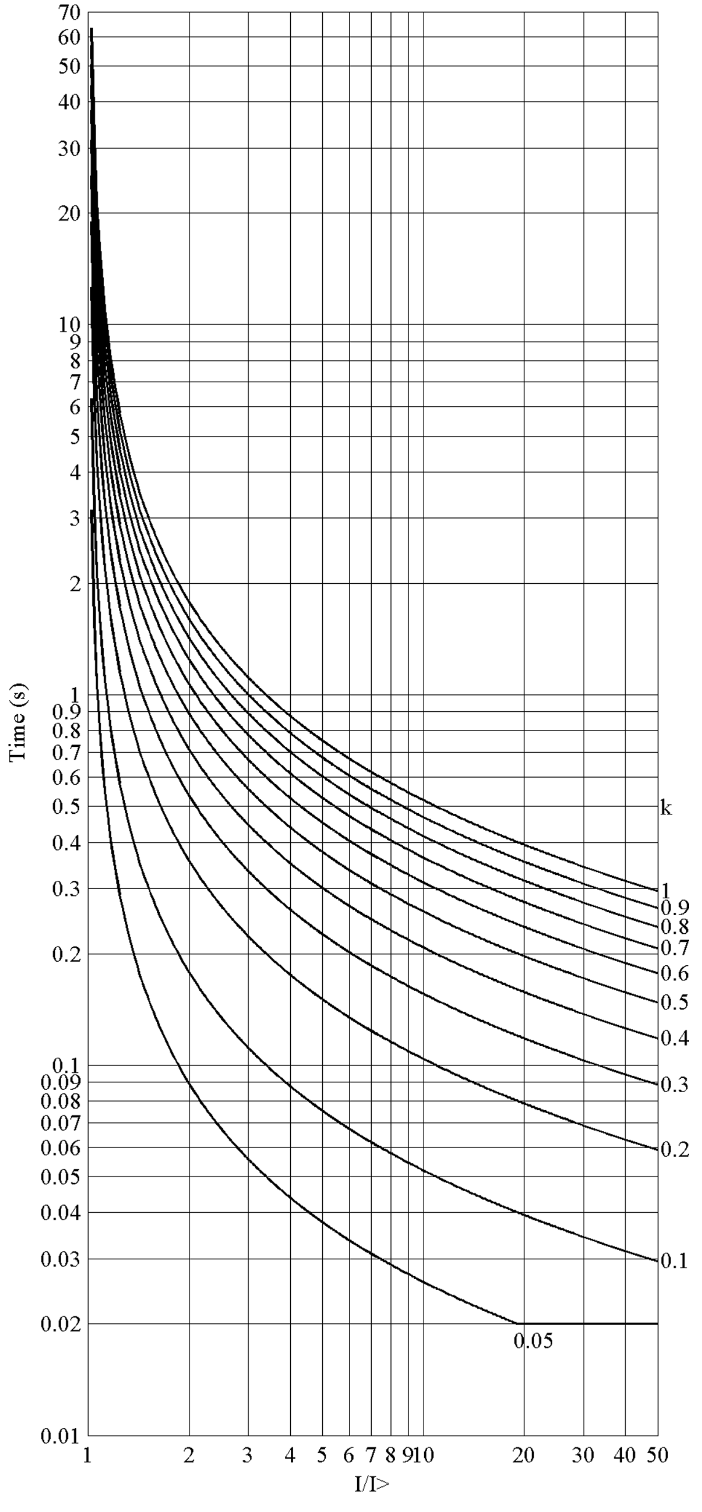


Figure 322: IEC short-time inverse-time characteristics

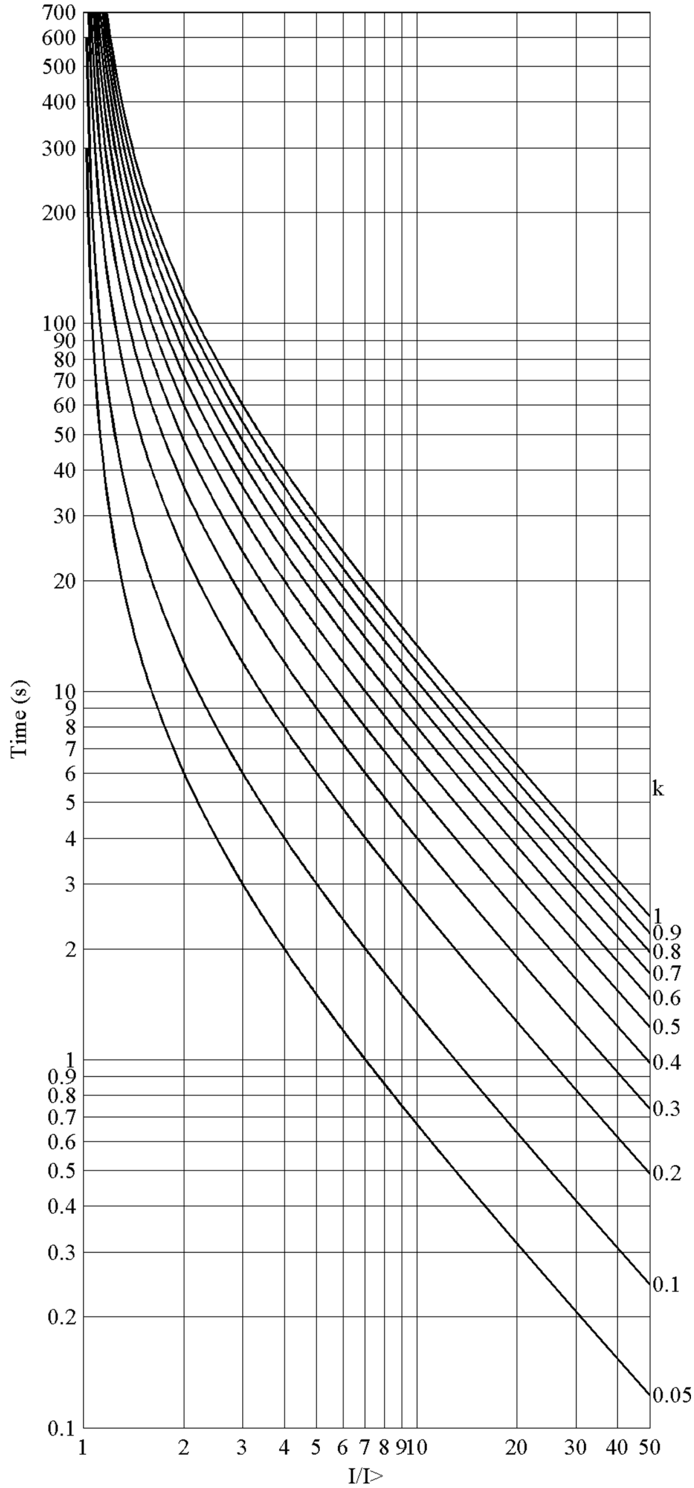


Figure 323: IEC long-time inverse-time characteristics

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 55)

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 56)

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 57)

t[s]	Operate time (in seconds)
k	set *Time multiplier*
I	Measured current
I>	set *Start value*

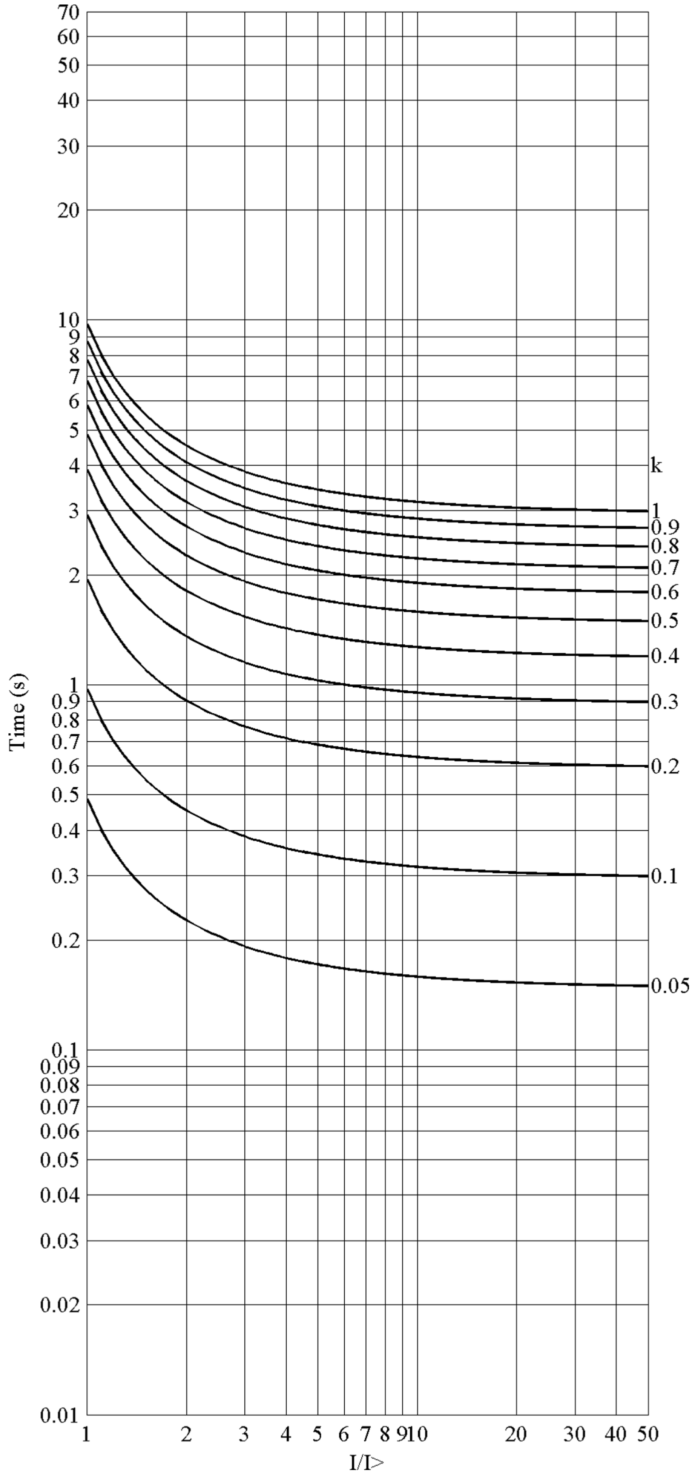


Figure 324: RI-type inverse-time characteristics

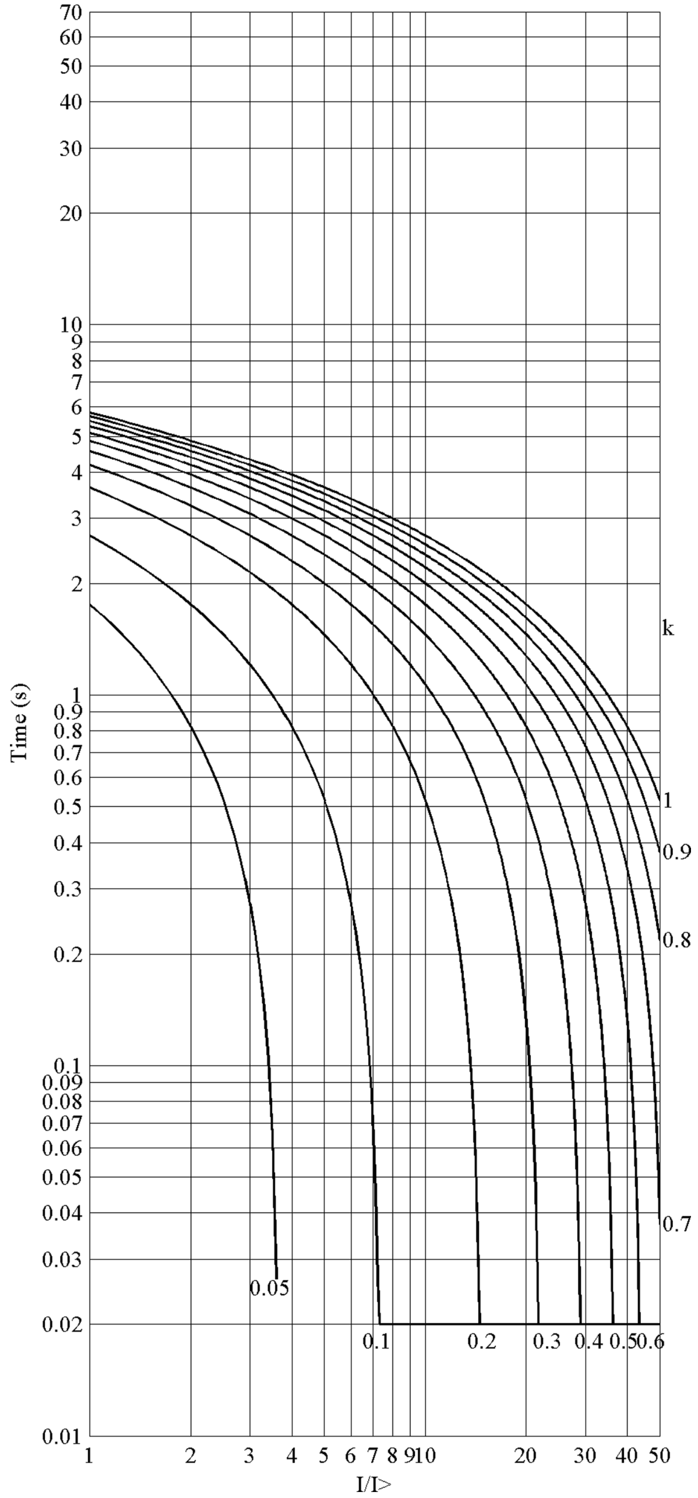


Figure 325: RD-type inverse-time characteristics

11.2.2 Reset in inverse-time modes

The user can select the reset characteristics by using the *Type of reset curve* setting.

Table 512: 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 58)

t[s] Reset time (in seconds)

k set *Time multiplier*

I Measured current

I> set *Start value*

Table 513: 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

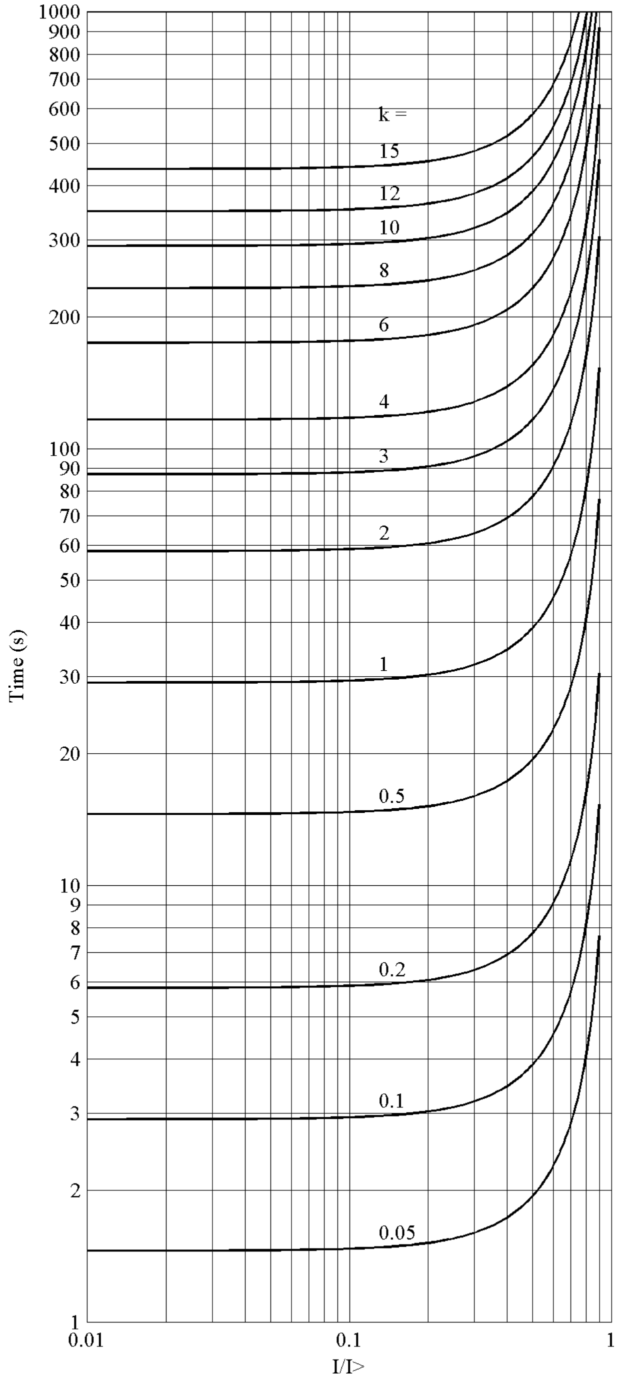


Figure 326: ANSI extremely inverse reset time characteristics

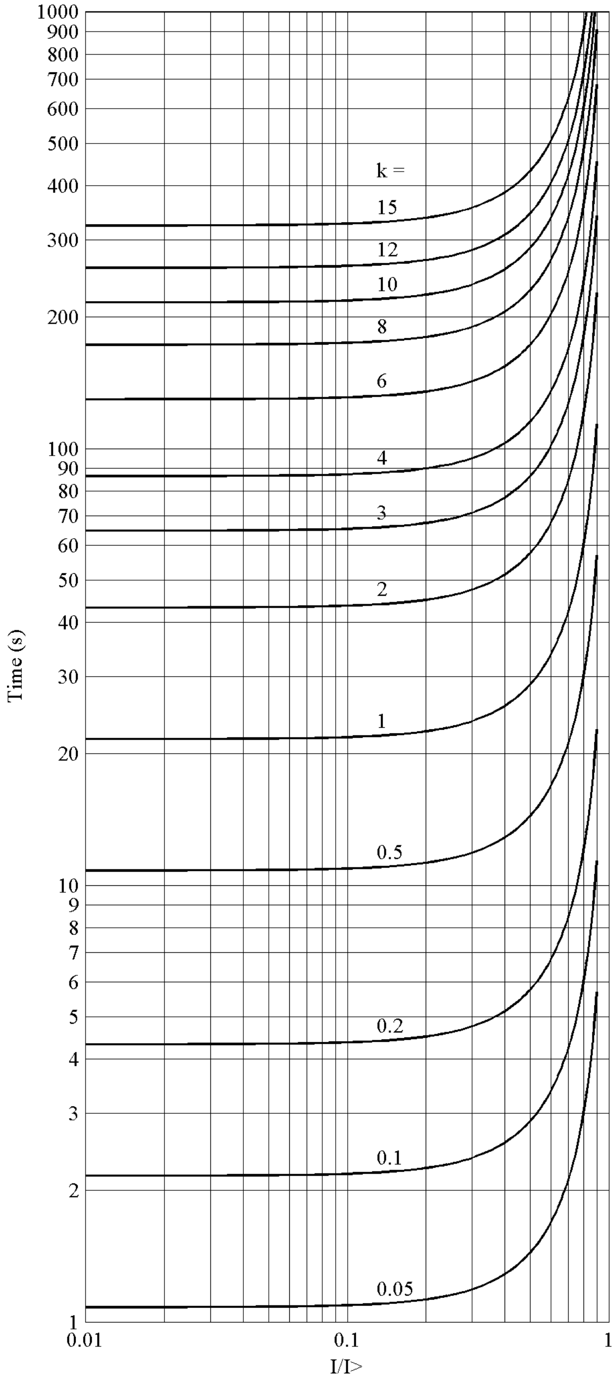


Figure 327: ANSI very inverse reset time characteristics

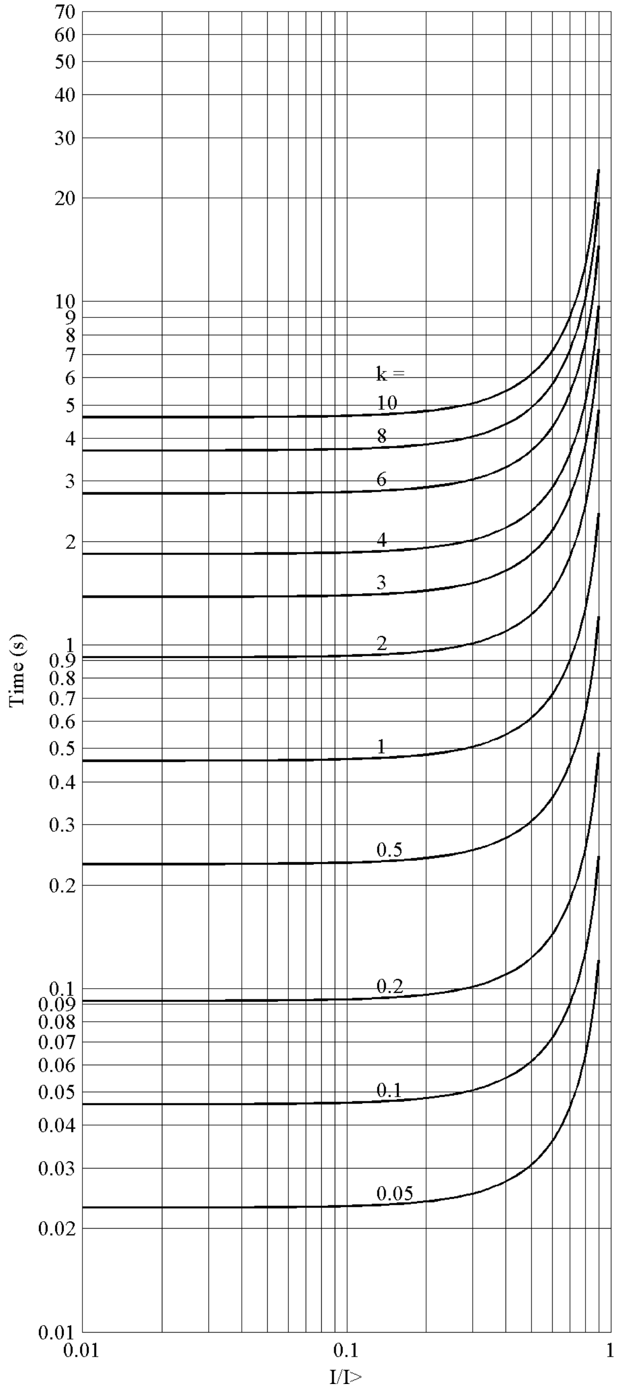


Figure 328: ANSI normal inverse reset time characteristics

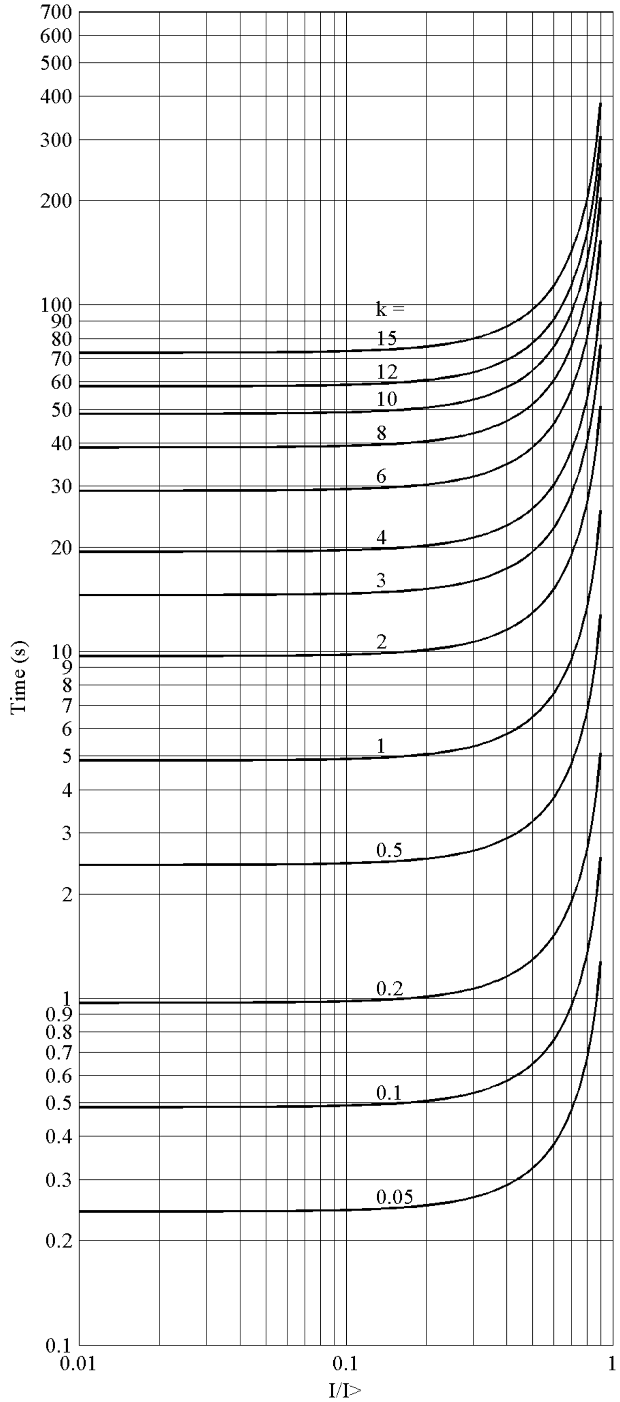


Figure 329: ANSI moderately inverse reset time characteristics

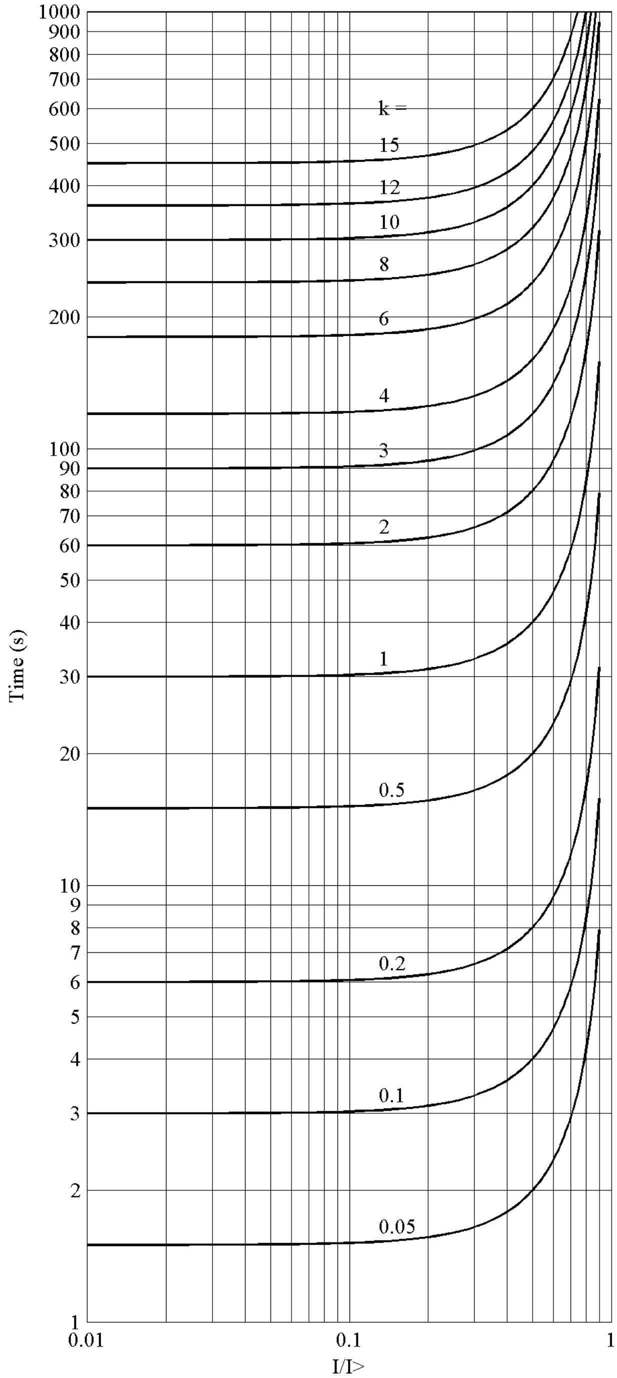


Figure 330: ANSI long-time extremely inverse reset time characteristics

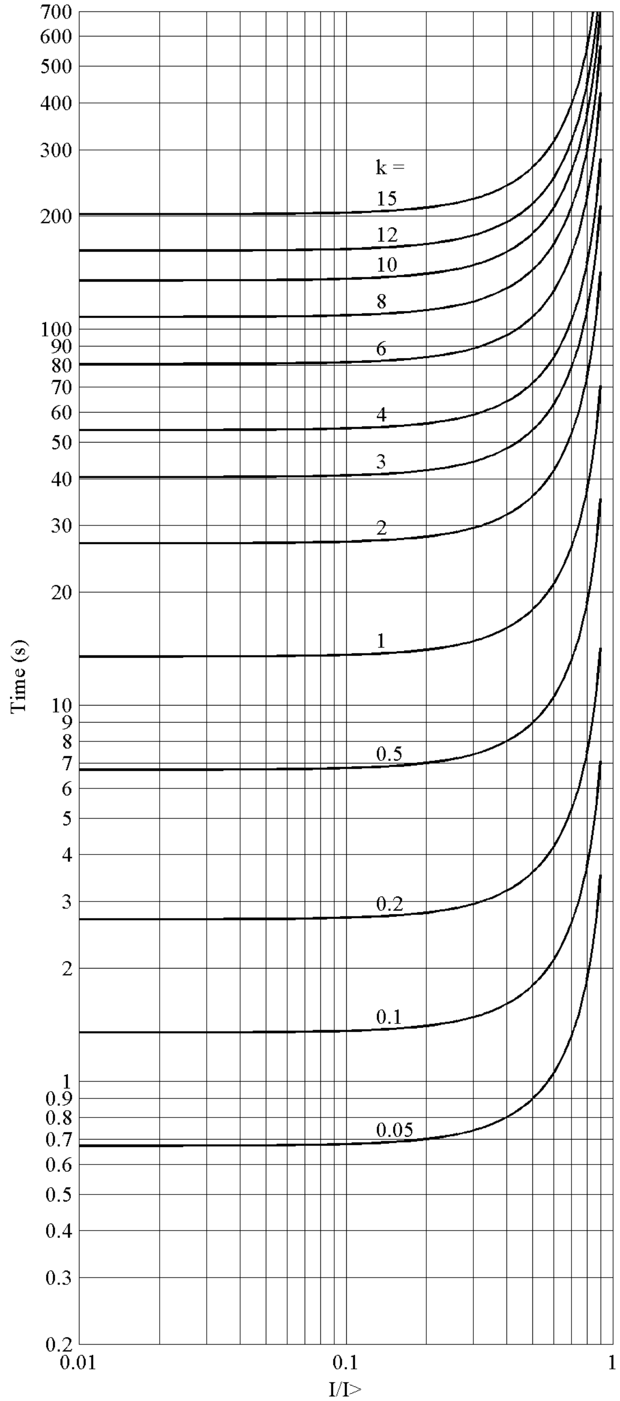


Figure 331: ANSI long-time very inverse reset time characteristics

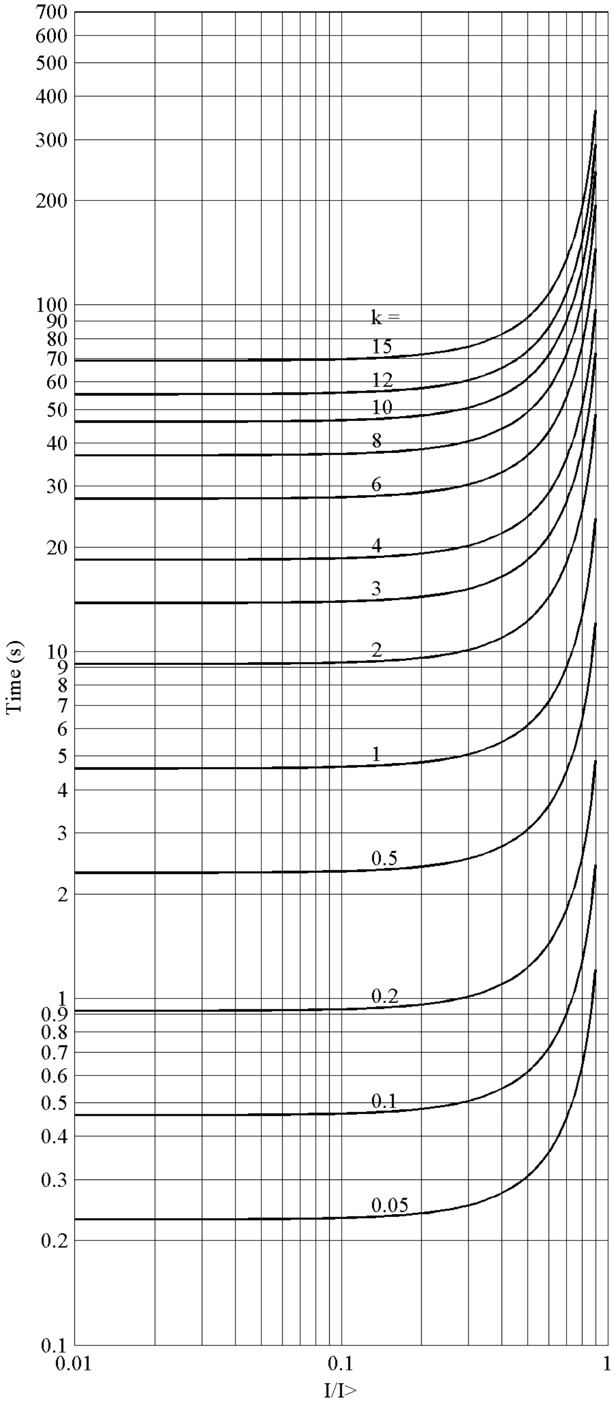


Figure 332: ANSI long-time inverse reset time characteristics

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 59)

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 an IED needs to be blocked to enable the definite-time operation of another IED 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:

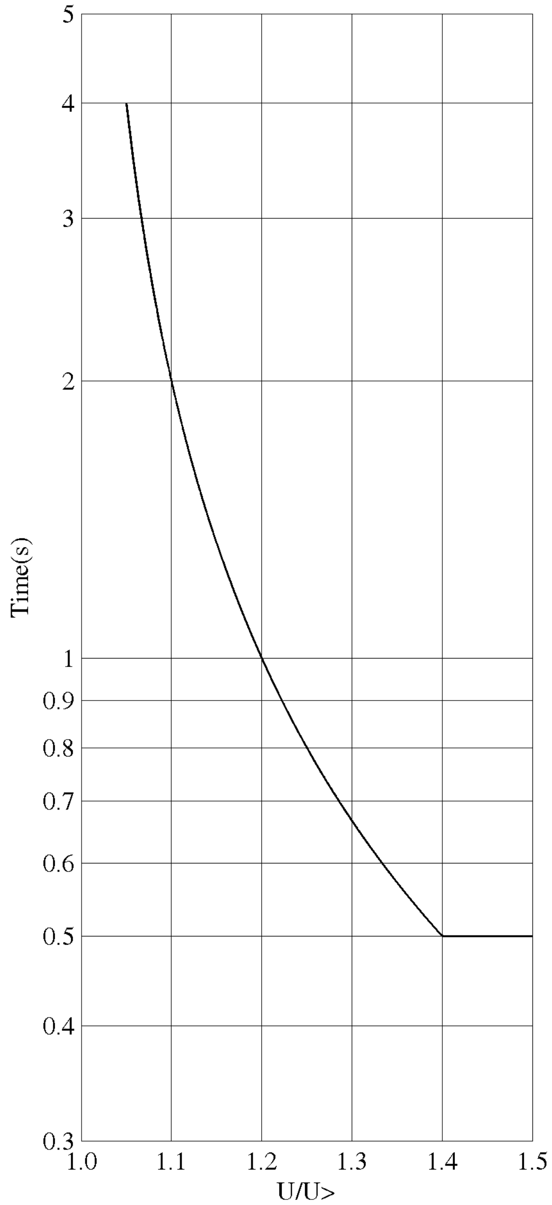


Figure 333: Operate time curve based on IDMT characteristic with Minimum operate time set to 0.5 second

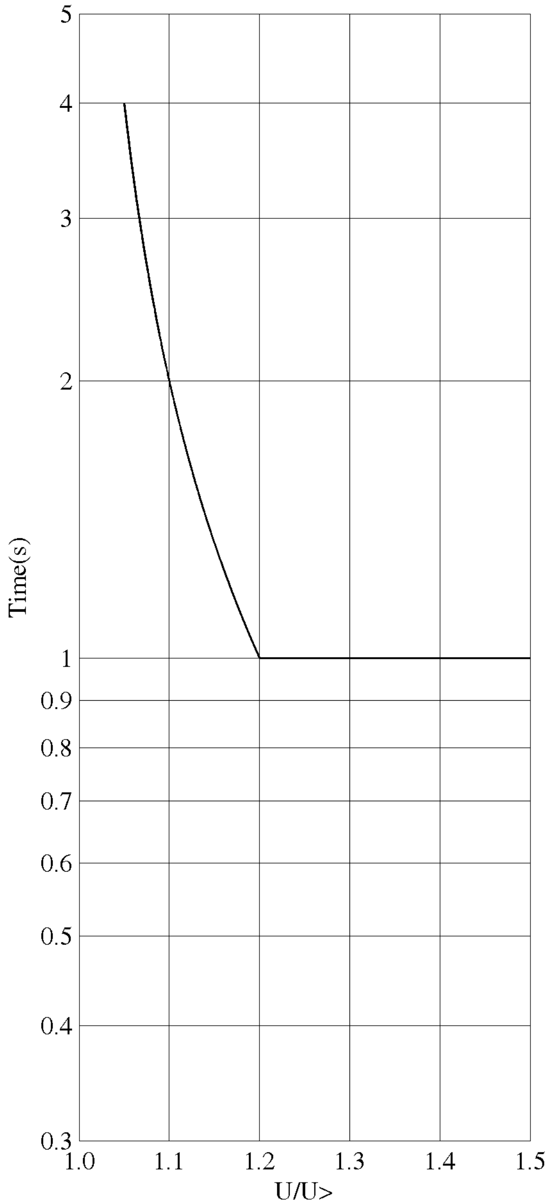


Figure 334: Operate time curve based on IDMT characteristic with Minimum operate time set to 1 second

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 60)

t [s] operate time in seconds

U measured voltage

U> the set value of *Start value*

k the set value of *Time multiplier*

Table 514: 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

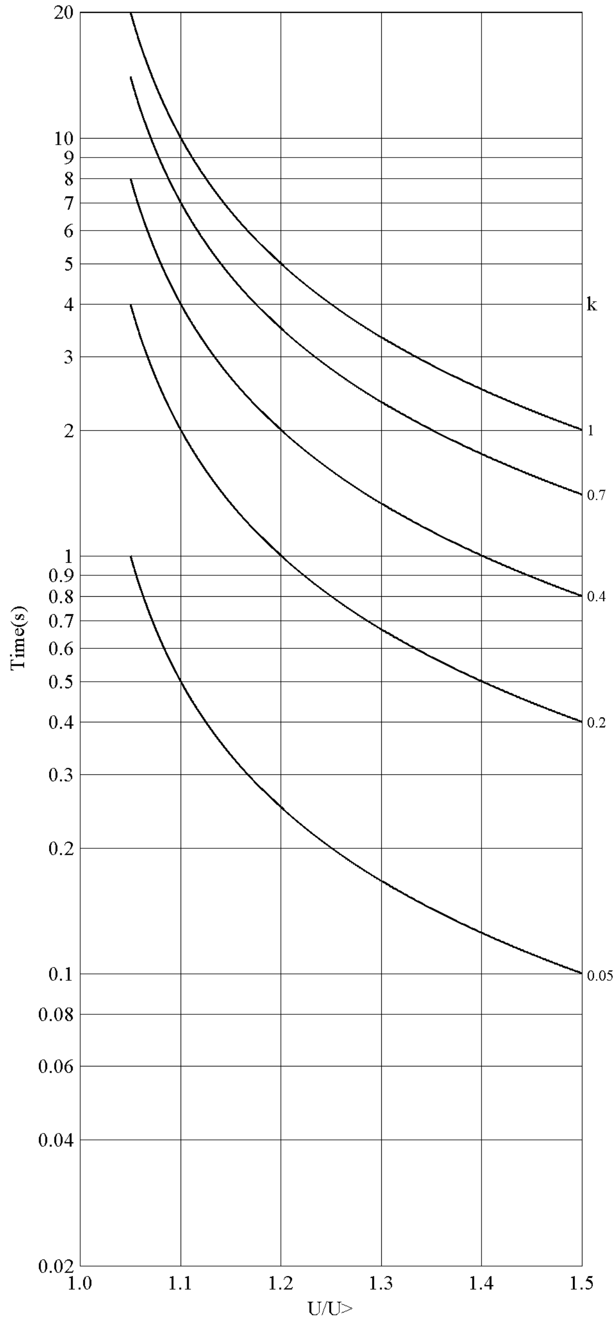


Figure 335: Inverse curve A characteristic of overvoltage protection

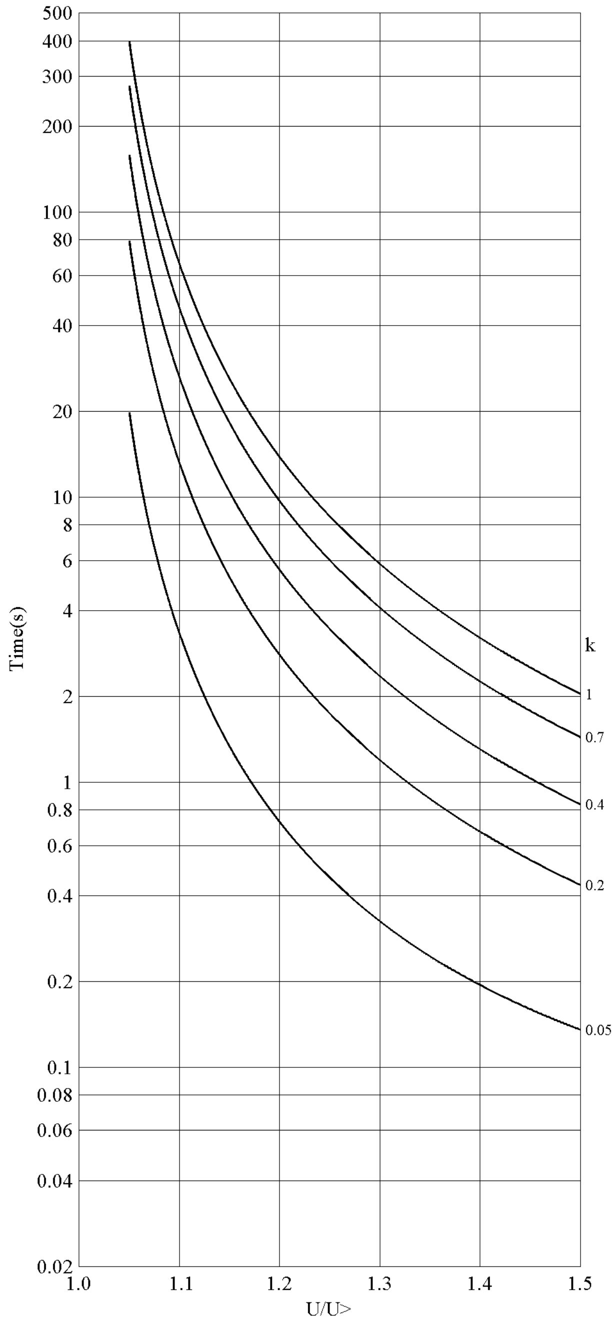


Figure 336: Inverse curve B characteristic of overvoltage protection

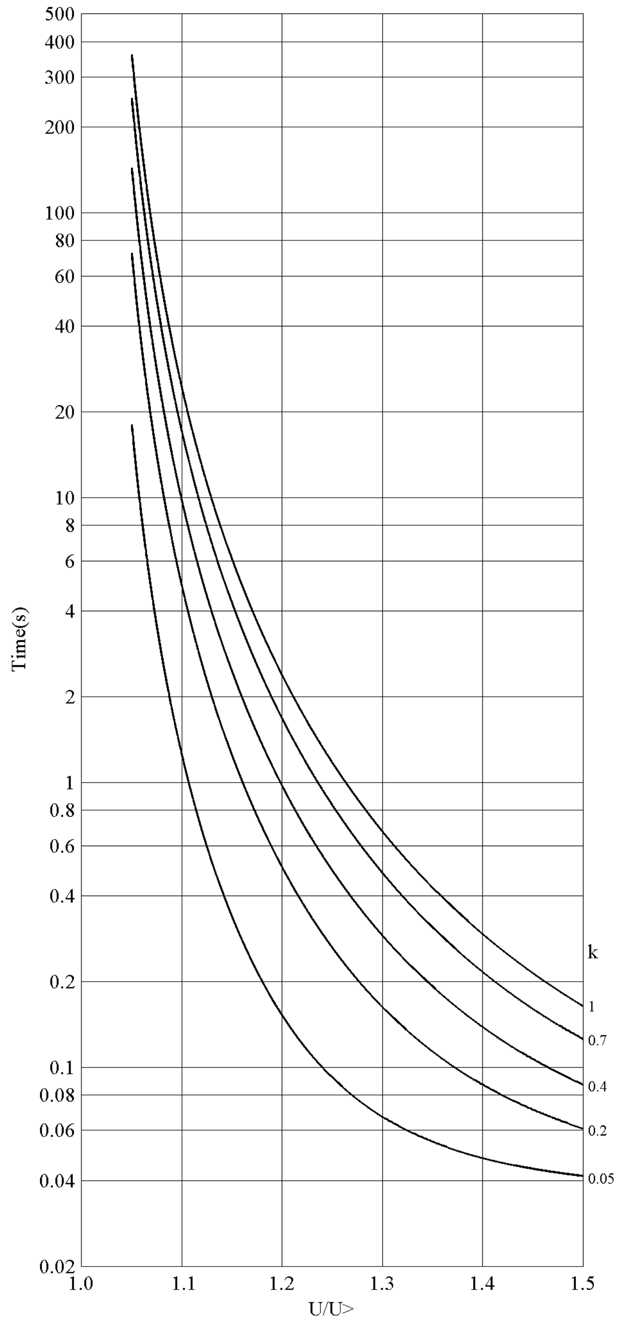


Figure 337: Inverse curve C characteristic of overvoltage protection

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:

$$t\left[s\right]=\frac{k\cdot A}{\left(B\times\frac{U-U>}{U>}-C\right)^{E}}+D$$

(Equation 61)

t[s]	operate time in seconds
A	the set value of *Curve parameter A*
B	the set value of *Curve parameter B*
C	the set value of *Curve parameter C*
D	the set value of *Curve parameter D*
E	the set value of *Curve parameter E*
U	measured voltage
U>	the set value of *Start value*
k	the 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 62)

t [s]	operate time in seconds
U	measured voltage
U<	the set value of the *Start value* setting
k	the set value of the *Time multiplier* setting

Table 515: 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

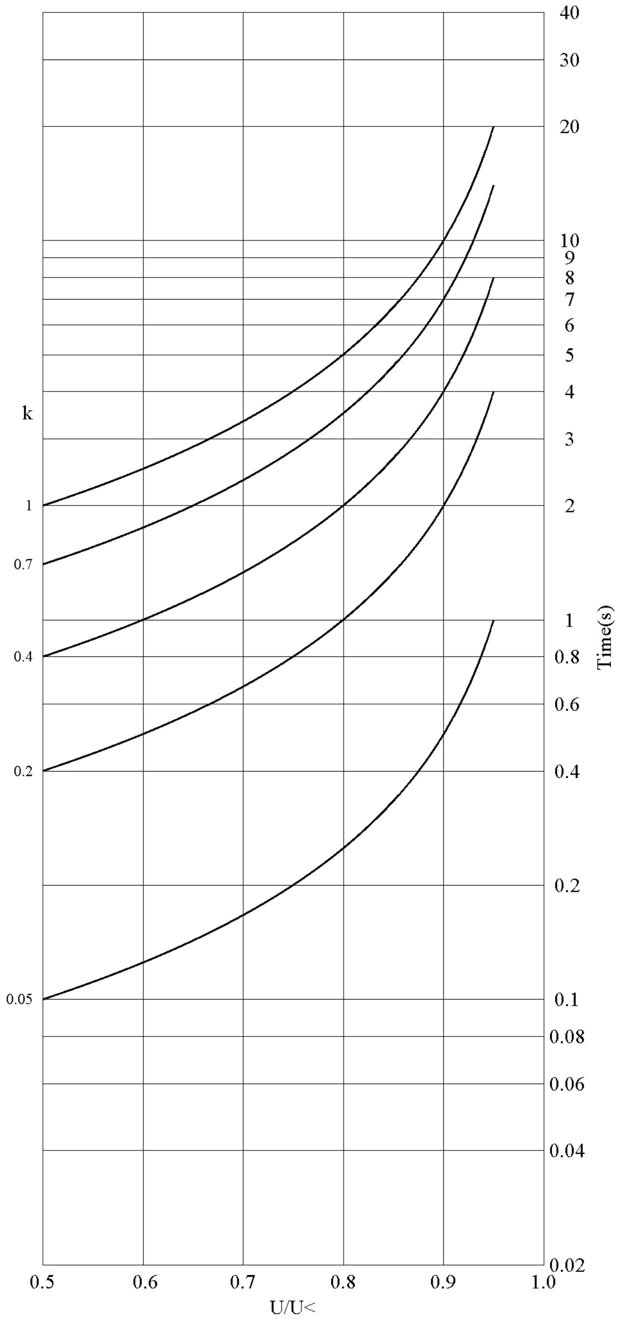


Figure 338: : Inverse curve A characteristic of undervoltage protection

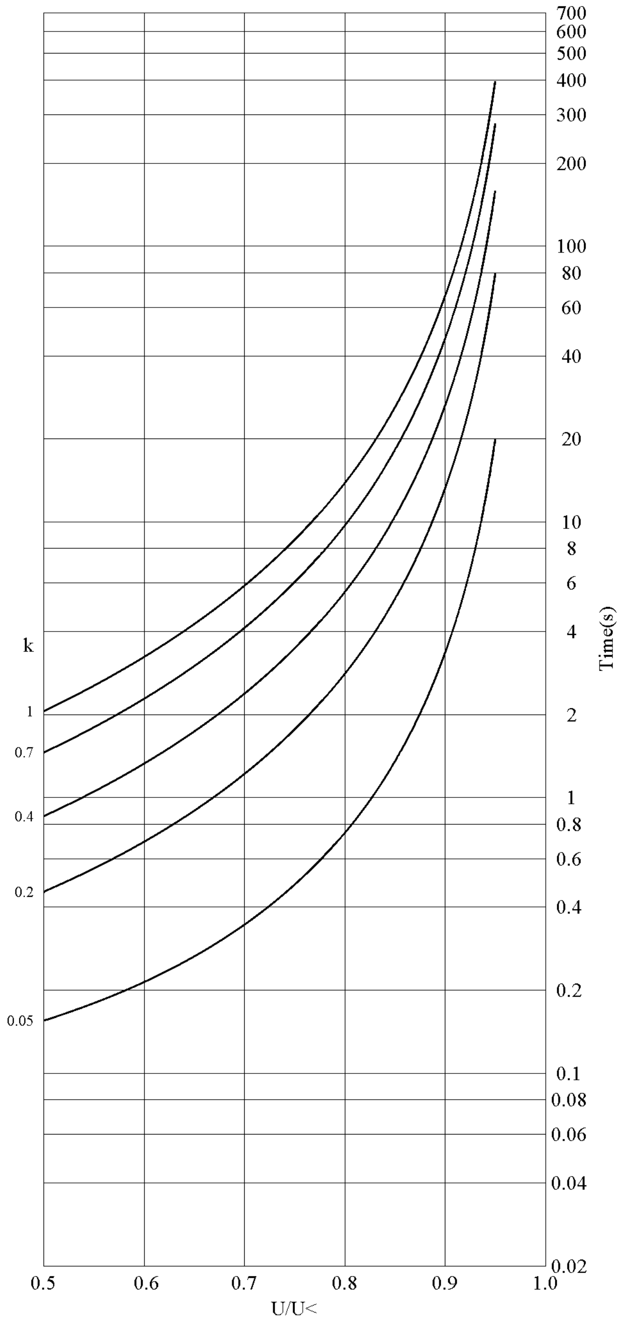


Figure 339: Inverse curve B characteristic of undervoltage protection

11.3.2.2 User-programmable inverse-time characteristics for undervoltage protection

The user can define curves by entering parameters into the standard formula:

$$t\left[s\right]=\frac{k\cdot A}{\left(B\times\frac{U<-U}{U<}-C\right)^{E}}+D$$

(Equation 63)

t[s]	operate time in seconds
A	the set value of *Curve parameter A*
B	the set value of *Curve parameter B*
C	the set value of *Curve parameter C*
D	the set value of *Curve parameter D*
E	the set value of *Curve parameter E*
U	measured voltage
U<	the set value of *Start value*
k	the 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 xFn to 1.5 xFn. 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 x Un at Fn.
- 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 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 Measurement modes

In many current or voltage dependent function blocks, there are four alternative measuring principles:

- RMS
- DFT which is a numerically calculated fundamental component of the signal
- Peak-to-peak
- Peak-to-peak with peak backup

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 64)

n the number of samples in a calculation cycle

I_i the 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 IED 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.

11.6 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 65)

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 66)

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 67)

$$\overline{I}_1 = (\overline{I}_A + a \cdot \overline{I}_B + a^2 \cdot \overline{I}_C)/3$$

(Equation 68)

$$\overline{I}_2 = (\overline{I}_A + a^2 \cdot \overline{I}_B + a \cdot \overline{I}_C)/3$$

(Equation 69)

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 70)

$$\overline{U}_1 = (\overline{U}_A + a \cdot \overline{U}_B + a^2 \cdot \overline{U}_C)/3$$

(Equation 71)

$$\overline{U}_2 = (\overline{U}_A + a^2 \cdot \overline{U}_B + a \cdot \overline{U}_C)/3$$

(Equation 72)

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 73)

$$\overline{U}_2 = (\overline{U}_{AB} - a \cdot \overline{U}_{BC})/3$$

(Equation 74)

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 75)

$$\overline{U}_B = \overline{U}_0 + \left(\overline{U}_{BC} - \overline{U}_{AB}\right) / 3$$

(Equation 76)

$$\overline{U}_C = \overline{U}_0 + \left(\overline{U}_{CA} - \overline{U}_{BC}\right) / 3$$

(Equation 77)

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 78)

$$\overline{U}_{BC} = \overline{U}_B - \overline{U}_C$$

(Equation 79)

$$\overline{U}_{CA} = \overline{U}_C - \overline{U}_A$$

(Equation 80)

Section 12 Requirements for measurement transformers

12.1 Current transformers

12.1.1 Current transformer requirements for non-directional 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 IED 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 516: 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 IED.

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 IED.

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

The 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 IED 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 IED. 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 x (I_{kmin} / I_{1n})

I_{1n} is the nominal primary current of the CT.

The factor 0.7 takes into account the protection IED 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 IED operation. To ensure the time selectivity, the delay must be taken into account when setting the operate times of successive IEDs.

With definite time mode of operation, the saturation of CT may cause a delay that is as long as the time the 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.

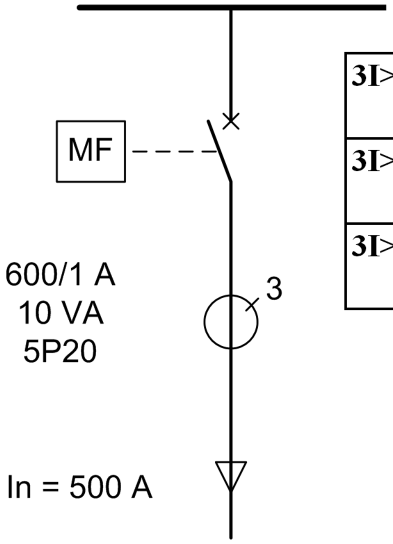
With inverse time mode of operation and when the high-set stages are not used, the AC component of the fault current should not saturate the CT less than 20 times the starting current. Otherwise, the inverse operation time can be further prolonged. Therefore, the accuracy limit factor F_a should be chosen using the formula:

$F_a > 20 \cdot$ *Current start value* $/ I_{1n}$

The *Current start value* is the primary start current setting of the IED.

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 340: 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 IED (not visible in the figure above). 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 IED 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 the figure above.

For the application point of view, the suitable setting for instantaneous stage (I>>>) in this example is 3 500 A (5.83 x I_{2n}). For the CT characteristics point of view, the criteria given by the current transformer selection formula is fulfilled and also the IED 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.

Section 13 IED physical connections

13.1 Protective earth connections

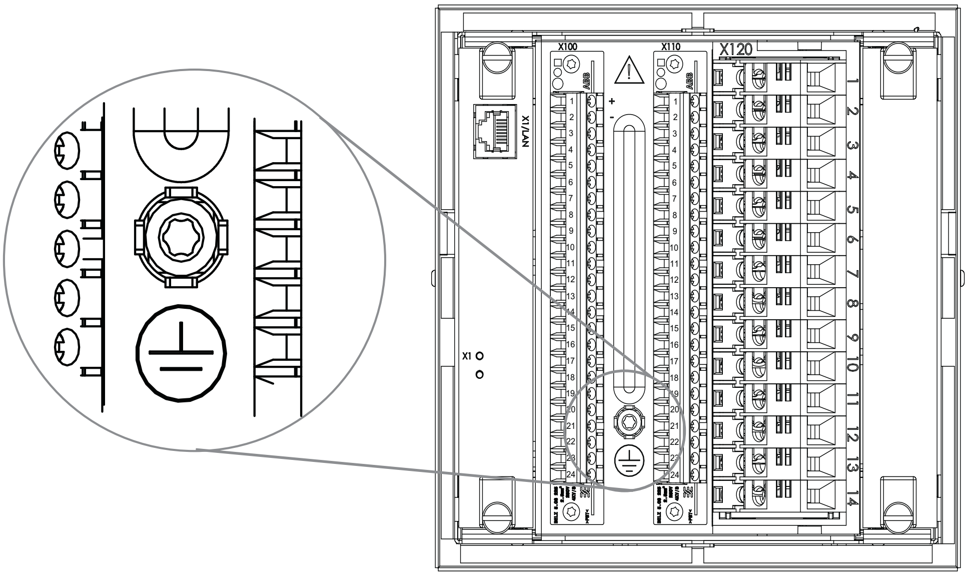


Figure 341: The protective earth screw is located between connectors X100 and X110

The earth lead must be at least 6.0 mm^2 and as short as possible.

13.2 Binary and analog connections

All binary and analog connections are described in the product specific application engineering guides.

13.3 Communication connections

The front communication connection is an RJ-45 type connector used mainly for configuration and setting.

- Galvanic RJ-45 Ethernet connection
- Optical LC Ethernet connection
- ST-type glass fibre serial connection
- EIA-485 serial connection
- EIA-232 serial connection

Never touch the end face of an optical fiber connector.

Always install dust caps on unplugged fiber connectors.

If contaminated, clean optical connectors only with fiber-optic cleaning products.

13.3.1 Ethernet RJ-45 front connection

The IED is provided with an RJ-45 connector on the LHMI. The connector is intended for configuration and setting purposes. The interface on the PC side has to be configured in a way that it obtains the IP address automatically. There is a DHCP server inside IED for the front interface only.

The events and setting values and all input data such as memorized values and disturbance records can be read via the front communication port.

Only one of the possible clients can be used for parametrization at a time.

- PCM600
- LHMI
- WHMI

The default IP address of the IED through this port is 192.168.0.254.

The front port supports TCP/IP protocol. A standard Ethernet CAT 5 crossover cable is used with the front port.

The speed of the front connector interface is limited to 10 Mbps.

13.3.2 Ethernet rear connections

The Ethernet station bus communication module is provided with either galvanic RJ-45 connection or optical multimode LC type connection, depending on the product variant and the selected communication interface option. A shielded twisted-pair cable CAT 5e is used with the RJ-45 connector and an optical multi-mode cable (≤2 km) with the LC type connector.

In addition, communication modules with multiple Ethernet connectors enable the forwarding of Ethernet traffic. The variants include an internal switch that handles the Ethernet traffic between an IED and a station bus. In this case, the used network can be a ring or daisy-chain type of network topology. In loop type topology, a self-healing Ethernet loop is closed by a managed switch supporting rapid spanning tree protocol. In daisy-chain type of topology, the network is bus type and it is either without switches, where the station bus starts from the station client, or with a switch to connect some devices and the IEDs of this product series to the same network.

Communication modules including Ethernet connectors X1, X2, and X3 can utilize the third port for connecting any other device (for example, an SNTP server, that is visible for the whole local subnet) to a station bus.

The IED's default IP address through rear Ethernet port is 192.168.2.10 with the TCP/IP protocol. The data transfer rate is 100 Mbps.

13.3.3 EIA-232 serial rear connection

The EIA-232 connection follows the TIA/EIA-232 standard and is intended to be used with a point-to-point connection. The connection supports hardware flow control (RTS, CTS, DTR, DSR), full-duplex and half-duplex communication.

13.3.4 EIA-485 serial rear connection

The EIA-485 communication module follows the TIA/EIA-485 standard and is intended to be used in a daisy-chain bus wiring scheme with 2-wire half-duplex or 4-wire full-duplex, multi-point communication.

The maximum number of devices (nodes) connected to the bus where the IED is used is 32, and the maximum length of the bus is 1200 meters.

13.3.5 Optical ST serial rear connection

Serial communication can be used optionally through an optical connection either in loop or star topology. The connection idle state is light on or light off.

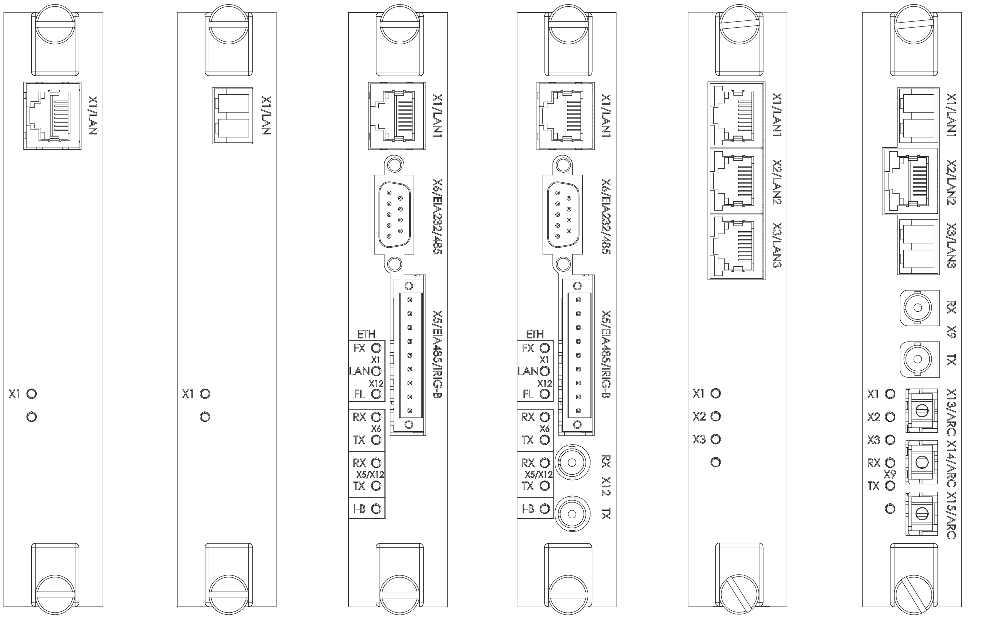
13.3.6 Communication interfaces and protocols

The communication protocols supported depend on the optional rear communication module.

Table 517: Supported station communication interfaces and protocols

Interfaces/ Protocols	Ethernet		Serial	
	100BASE-TX RJ-45	100BASE-FX LC	EIA-232/EIA-485	Fibre-optic ST
IEC 61850	●	●	-	-
MODBUS RTU/ ASCII	-	-	●	●
MODBUS TCP/IP	●	●	-	-
DNP3 (serial)	-	-	●	●
DNP3 TCP/IP	●	●	-	-
IEC 60870-5-101	-	-	●	●
IEC 60870-5-104	●	●	-	-
● = Supported				

13.3.7 Rear communication modules



COM0001 RJ-45	COM0002 LC	COM0022 RJ-45+ RS232/485+ IRIG-B	COM0023 RJ-45+ RS232/485+ RS485+ST+ IRIG-B	COM0031 3xRJ-45	COM0032 2xLC+RJ-45+ ST+ARC

Figure 342: Communication module options

Table 518: Station bus communication interfaces included in communication modules

Module ID	RJ-45	LC	EIA-485/ EIA-232	EIA-485	ST
COM0001	1	-	-	-	-
COM0002	-	1	-	-	-
COM0022	1	-	1	-	-
COM0023	1	-	1	1	1
COM0031	3	-	-	-	-
COM0032	1	2	-	-	1

Table 519: LED descriptions for COM0001 and COM0002

LED	Connector	Description[1)]
X1	X1	X1/LAN link status and activity (RJ-45 and LC)
RX1	X5	COM2 2-wire/4-wire receive activity
TX1	X5	COM2 2-wire/4-wire transmit activity
Table continues on next page		

LED	Connector	Description[1]
RX2	X5	COM1 2-wire receive activity
TX2	X5	COM1 2-wire transmit activity
I-B	X5	IRIG-B signal activity

1) Depending on the COM module and jumper configuration

Table 520: LED descriptions for COM0022 and COM0023

LED	Connector	Description[1]
FX	X12	Not used by COM0023
X1	X1	LAN Link status and activity (RJ-45 and LC)
FL	X12	Not used by COM0023
RX	X6	COM1 2-wire / 4-wire receive activity
TX	X6	COM1 2-wire / 4-wire transmit activity
RX	X5 / X12	COM2 2-wire / 4-wire or fiber-optic receive activity
TX	X5 / X12	COM2 2-wire / 4-wire or fiber-optic transmit activity
I-B	X5	IRIG-B signal activity

1) Depending on the jumper configuration

Table 521: LED descriptions for COM0031 and COM0032

LED	Connector	Description
X1	X1	X1/LAN1 link status and activity
X2	X2	X2/LAN2 link status and activity
X3	X3	X3/LAN3 link status and activity
RX	X9	COM1 fiber-optic receive activity
TX	X9	COM1 fiber-optic transmit activity

13.3.7.1 COM0022 and COM0023 jumper locations and connections

The optional communication module COM0022 supports EIA-232/EIA-485 serial communication (X6 connector). Only COM1 (X6 connector) is used for serial communication.

Connector X5 on COM0022 is dedicated to IRIG-B.

Table 522: Configuration options of the communication port for COM0022

COM1 connector X6
EIA-232
EIA-485 2-wire
EIA-485 4-wire

The optional communication module COM0023 supports EIA-232/EIA-485 serial communication (X6 connector), EIA-485 serial communication (X5 connector) and optical ST serial communication (X12 connector).

Two independent communication ports are supported by COM0023. The two 2-wire ports use COM1 and COM2. Alternatively, if only one 4-wire port is configured, it uses COM2. The fibre-optic ST connection uses the COM1 port.

Table 523: Configuration options of the communication ports for COM0023

COM1 connector X6	COM2 connector X5 or X12
EIA-232	Optical ST (X12)
EIA-485 2-wire	EIA-485 2-wire (X5)
EIA-485 4-wire	EIA-485 4-wire (X5)

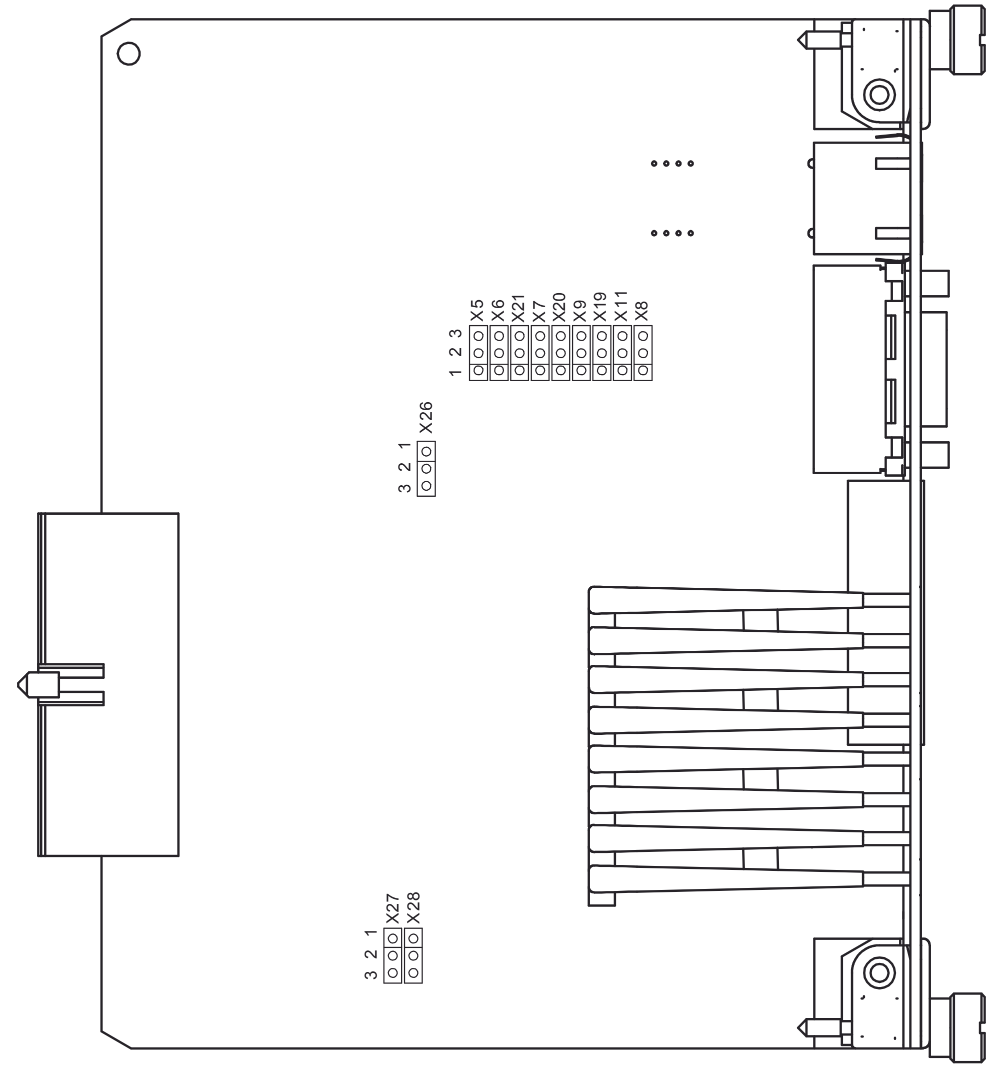


Figure 343: Jumper connections on communication module COM0022 revisions A-F

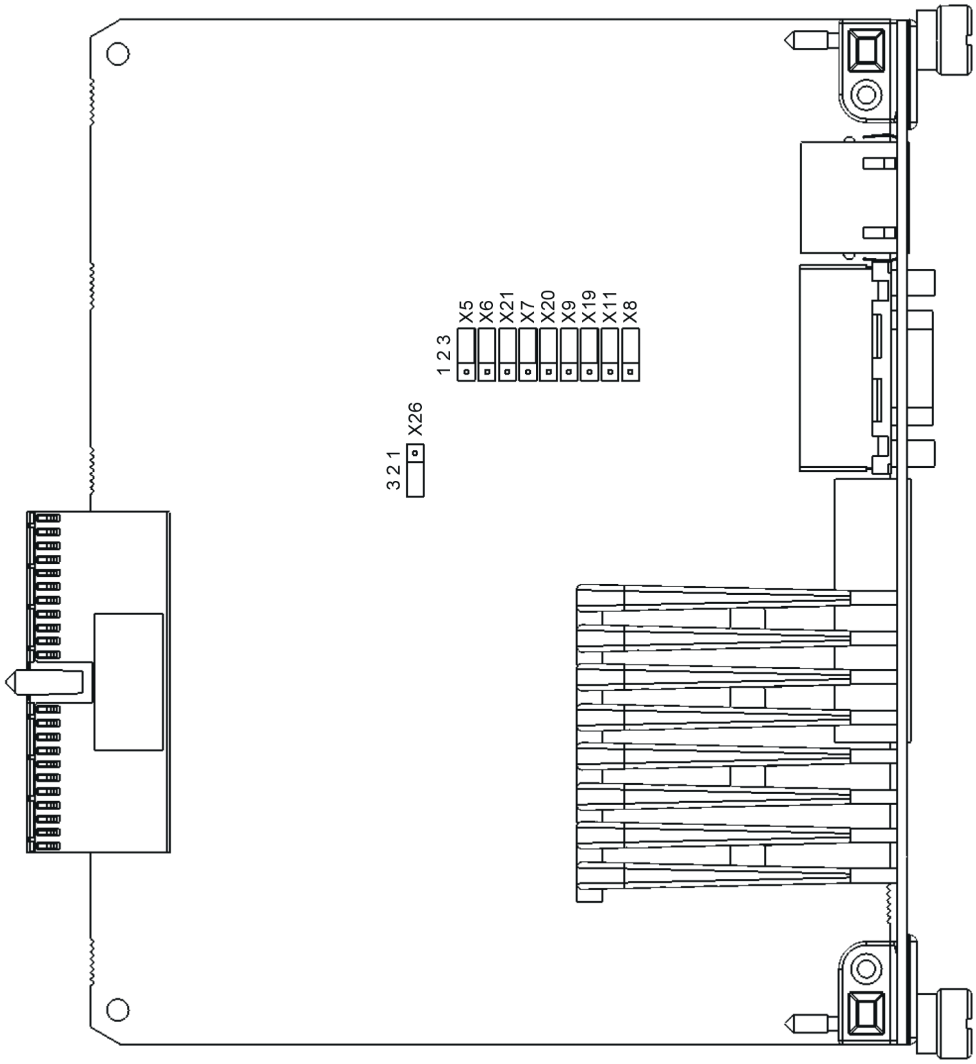


Figure 344: Jumper connections on communication module COM0022 revision G or later

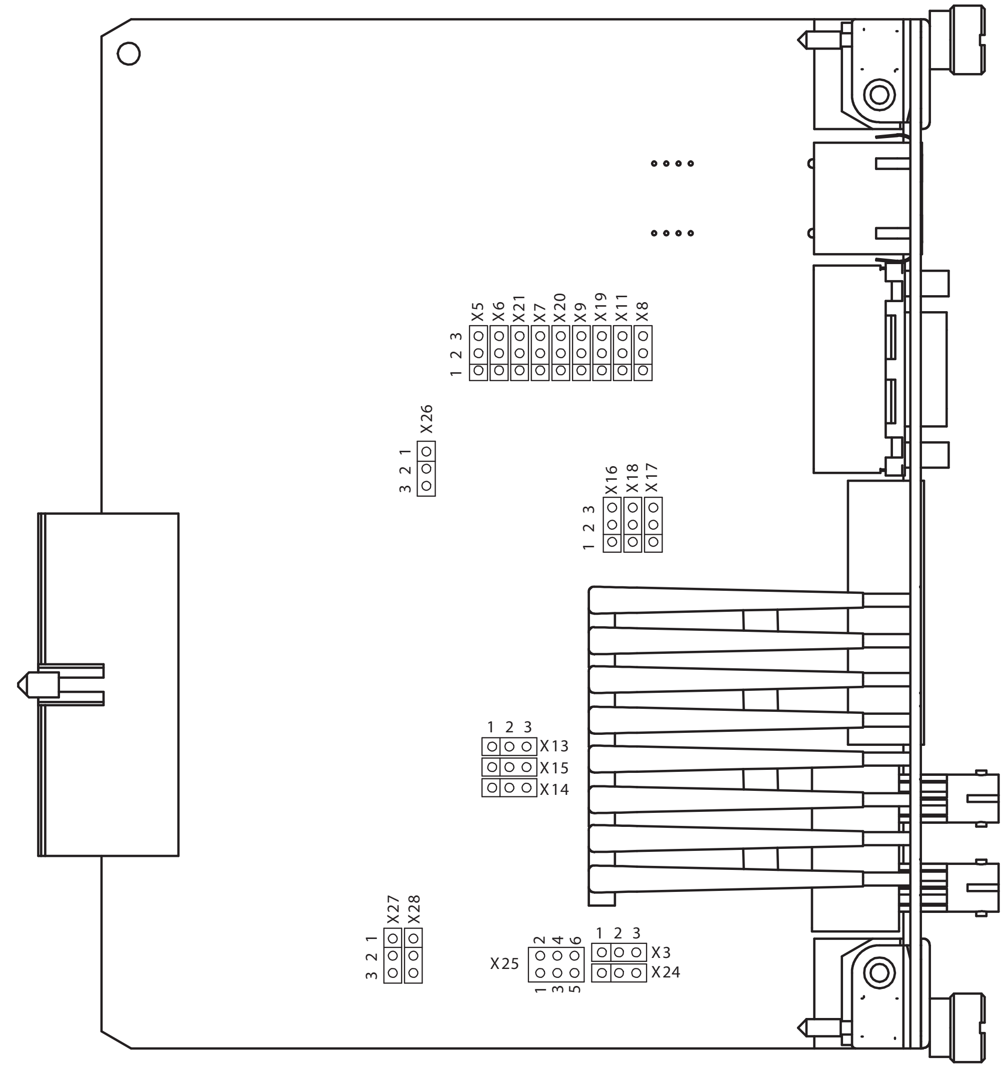


Figure 345: Jumper connections on communication module COM0023 revisions A-F

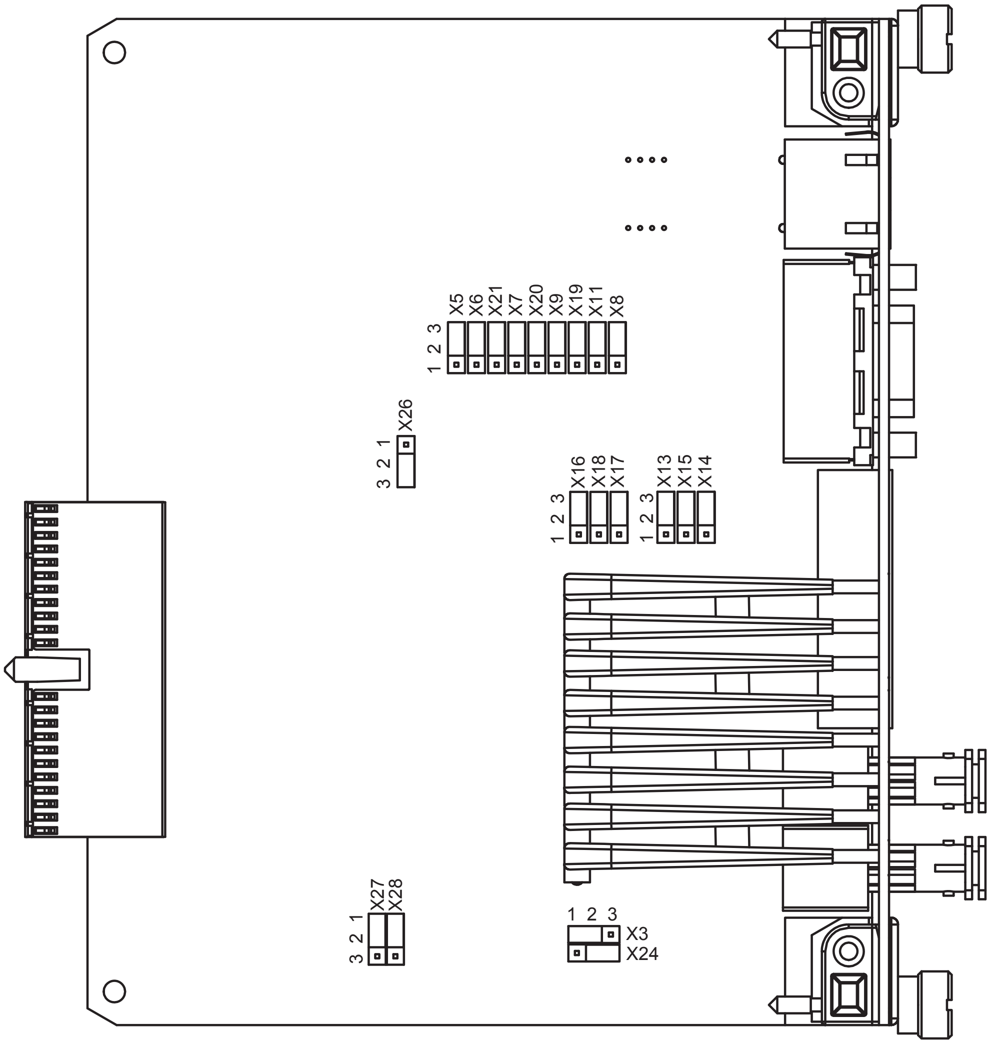


Figure 346: Jumper connections on communication module COM0023 revision G

COM1 port connection type can be either EIA-232 or EIA-485. The type is selected by setting jumpers X19, X20, X21 and X26. The jumpers are set to EIA-232 by default.

Table 524: EIA-232 and EIA-485 jumper connectors for COM1

Group	Jumper connection	Description
X19	1-2 2-3	EIA-485 EIA-232
X20	1-2 2-3	EIA-485 EIA-232
X21	1-2 2-3	EIA-485 EIA-232
X26	1-2 2-3	EIA-485 EIA-232

To ensure fail-safe operation, the bus is to be biased at one end using the pull-up and pull-down resistors on the communication module. In the 4-wire connection, the pull-up and pull-down resistors are selected by setting jumpers X5, X6, X8, X9 to enabled position. The bus termination is selected by setting jumpers X7, X11 to enabled position.

The jumpers have been set to no termination and no biasing as default.

Table 525: 2-wire EIA-485 jumper connectors for COM1

Group	Jumper connection	Description	Notes
X5	1-2 2-3	A+ bias enabled A+ bias disabled[1]	COM1 Rear connector X6 2-wire connection
X6	1-2 2-3	B- bias enabled B- bias disabled[1]	
X7	1-2 2-3	Bus termination enabled Bus termination disabled[1]	

1) Default setting

Table 526: 4-wire EIA-485 jumper connectors for COM1

Group	Jumper connection	Description	Notes
X5	1-2 2-3	A+ bias enabled A+ bias disabled[1]	COM1 Rear connector X6 4-wire TX channel
X6	1-2 2-3	B- bias enabled B- bias disabled[1]	
X7	1-2 2-3	Bus termination enabled Bus termination disabled[1]	
X9	1-2 2-3	A+ bias enabled A+ bias disabled[1]	4-wire RX channel
X8	1-2 2-3	B- bias enabled B- bias disabled[1]	
X11	1-2 2-3	Bus termination enabled Bus termination disabled[1]	

1) Default setting

COM2 port connection can be either EIA-485 or optical ST. Connection type is selected by setting jumpers X27 and X28.

Table 527: COM2 serial connection X5 EIA-485/ X12 Optical ST

Group	Jumper connection	Description
X27	1-2 2-3	EIA-485 Optical ST
X28	1-2 2-3	EIA-485 Optical ST

Table 528: 2-wire EIA-485 jumper connectors for COM2

Group	Jumper connection	Description
X13	1-2 2-3	A+ bias enabled A+ bias disabled
X14	1-2 2-3	B- bias enabled B- bias disabled
X15	1-2 2-3	Bus termination enabled Bus termination disabled

Table 529: 4-wire EIA-485 jumper connectors for COM2

<table>
<tr><th>Group</th><th>Jumper connection</th><th>Description</th><th>Notes</th></tr>
<tr><td>X13</td><td>1-2
2-3</td><td>A+ bias enabled
A+ bias disabled</td><td rowspan="3">COM2
4-wire TX channel</td></tr>
<tr><td>X14</td><td>1-2
2-3</td><td>B- bias enabled
B- bias disabled</td></tr>
<tr><td>X15</td><td>1-2
2-3</td><td>Bus termination enabled
Bus termination disabled</td></tr>
<tr><td>X17</td><td>1-2
2-3</td><td>A+ bias enabled
A+ bias disabled</td><td rowspan="3">4-wire RX channel</td></tr>
<tr><td>X18</td><td>1-2
2-3</td><td>B- bias enabled
B- bias disabled</td></tr>
<tr><td>X19</td><td>1-2
2-3</td><td>Bus termination enabled
Bus termination disabled</td></tr>
</table>

Table 530: Optical ST connection (X12)

Group	Jumper connection	Description
X3	1-2 2-3	Star topology Loop topology
X24	1-2 2-3	Idle state = Light on Idle state = Light off

Table 531: EIA-232 connections for COM0022 and COM0023 (X6)

Pin	EIA-232
1	DCD
2	RxD
3	TxD
4	DTR
5	AGND
6	-
7	RTS
8	CTS

Table 532: EIA-485 connections for COM0022 and COM0023 (X6)

Pin	2-wire mode	4-wire mode
1	-	Rx/+
6	-	Rx/-
7	B/-	Tx/-
8	A/+	Tx/+

Table 533: EIA-485 connections for COM0023 (X5)

Pin	2-wire mode	4-wire mode
9	-	Rx/+
8	-	Rx/-
7	A/+	Tx/+
6	B/-	Tx/-
5	AGND (isolated ground)	
4	IRIG-B +	
3	IRIG-B -	
2	-	
1	GND (case)	

13.3.7.2 COM0032 jumper locations and connections

The optional communication modules include support for optical ST serial communication (X9 connector). The fibre-optic ST connection uses the COM1 port.

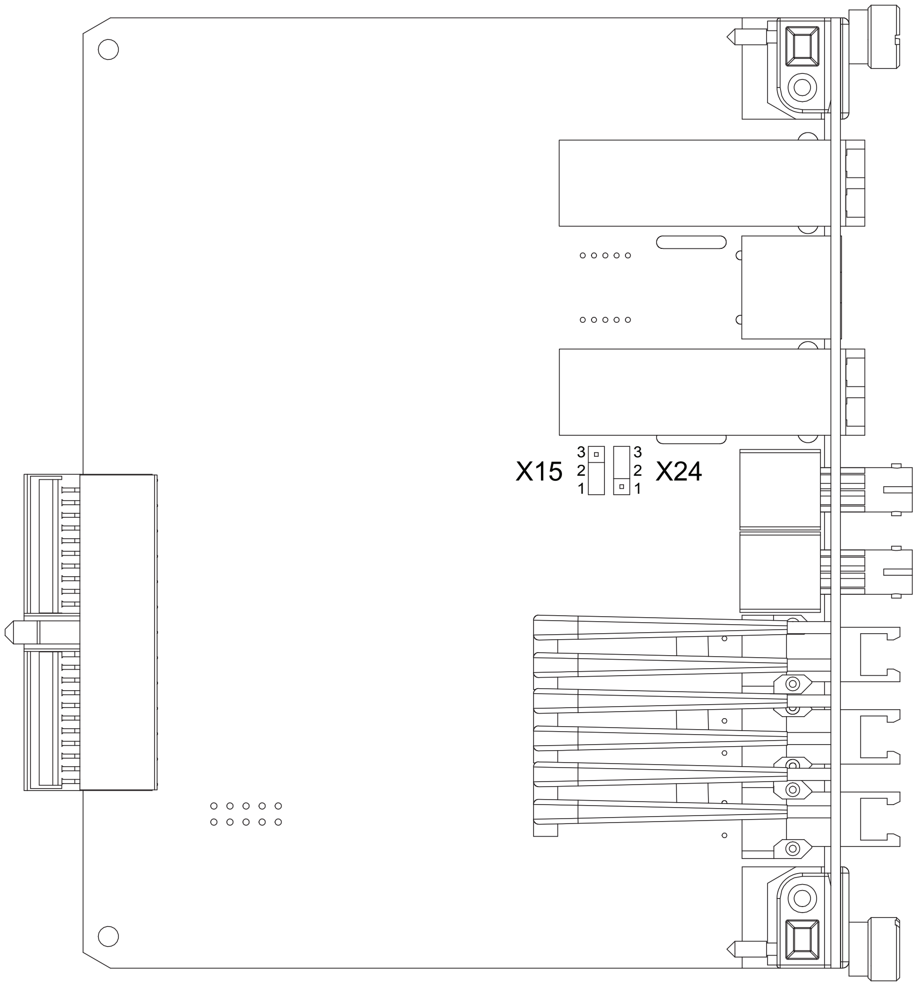


Figure 347: Jumper connections on communication module COM0032

Table 534: X9 Optical ST jumper connectors

Group	Jumper connection	Description
X15	1-2 2-3	Star topology Loop topology
X24	1-2 2-3	Idle state = Light on Idle state = Light off

Section 14 Technical data

Table 535: Dimensions

Description	Value	
Width	frame	177 mm
	case	164 mm
Height	frame	177 mm (4U)
	case	160 mm
Depth		201 mm (153 + 48 mm)
Weight	complete relay	4.1 kg
	plug-in unit only	2.1 kg

Table 536: Power supply

Description	Value
U_{aux}nominal	24, 30, 48, 60 V DC
Maximum interruption time in the auxiliary DC voltage without resetting the relay	
U_{aux}variation	50...120% of U_n (12...72 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 <12.0 W (nominal)/<18.0 W (max.)
Ripple in the DC auxiliary voltage	Max. 15% of the DC value (at frequency of 100 Hz)
Fuse type	T4A/250 V

Table 537: Energizing inputs

Description		Value	
Rated frequency		50/60 Hz	
Current inputs	Rated current, I_n	0.2/1 A[1)]	1/5 A[2)]
	Thermal withstand capability • Continuously • For 1 s	 4 A[1)] 100 A[1)]	 20 A 500 A
	Dynamic current withstand • Half-wave value	 250 A[1)]	 1250 A
	Input impedance	<100 mΩ[1)]	<20 mΩ

Table continues on next page

Description		Value
Voltage inputs	Rated voltage	60...210 V AC
	Voltage withstand • Continuous • For 10 s	 240 V AC 360 V AC
	Burden at rated voltage	<0.05 VA

1) Ordering option for residual current input
2) Residual current and/or phase current

Table 538: Energizing inputs of SIM0001

Description		Value
Voltage sensor input	Rated voltage	5 kV...38 kV 1)
	Continuous voltage withstand	125 V AC 2)
	Input impedance at 50/60 Hz	1 MΩ 3)
Voltage inputs	Rated voltage	60...210 V AC
	Voltage withstand • Continuous • For 10 s	 240 V AC 360 V AC
	Burden at rated voltage	<0.05 VA

1) This range is covered with sensor division ratio of 10 000:1
2) Test to this voltage
3) Neutral input impedance is close to zero

Table 539: Energizing inputs of SIM0002

Description		Value
Current sensor input	Rated current voltage (in secondary side)	75 mV...2812.5 mV 1)
	Continuous voltage withstand	125 V
	Input impedance at 50/60 Hz	2...3 MΩ 2)
Voltage sensor input	Rated voltage	6 kV...30 kV 3)
	Continuous voltage withstand	50 V
	Input impedance at 50/60 Hz	3 MΩ

1) Equals the current range of 39...4000 A with a 80 A, 3 mV/Hz Rogowski
2) Depending on the used nominal current (hardware gain)
3) This range is covered (up to 2*rated) with sensor division ratio of 10 000:1

Table 540: 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
Threshold voltage	18...176 V DC
Reaction time	3 ms

Table 541: Signal output with high make and carry

Description	Value 1)
Rated voltage	250 V AC/DC
Continuous contact carry	5 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	1 A/0.25 A/0.15 A
Minimum contact load	100 mA at 24 V AC/DC

1) X100: SO1
X110: SO1, SO2
X130: SO1, SO2 when REC615 is equipped with BIO0006

Table 542: Signal outputs and IRF output

Description	Value 1)
Rated voltage	250 V AC/DC
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

1) X100: IRF,SO2
X110: SO3, SO4
X130: SO3 when REC615 is equipped with BIO0006

Table 543: Double-pole power outputs with TCS function X100: PO3 and PO4

Description	Value
Rated voltage	250 V AC/DC
Continuous contact carry	8 A
Make and carry for 3.0 s	15 A
Make and carry for 0.5 s	30 A
Table continues on next page	

Description	Value
Breaking capacity when the control-circuit time constant L/R <40 ms, at 48/110/220 V DC (two contacts connected in a series)	5 A/3 A/1 A
Minimum contact load	100 mA at 24 V AC/DC
Trip-circuit monitoring (TCS)	
• Control voltage range	20...250 V AC/DC
• Current drain through the monitoring circuit	~1.5 mA
• Minimum voltage over the TCS contact	20 V AC/DC (15...20 V)

Table 544: Single-pole power output relays X100: PO1 and PO2

Description	Value
Rated voltage	250 V AC/DC
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 545: Ethernet interfaces

Ethernet interface	Protocol	Cable	Data transfer rate
Front	TCP/IP protocol	Standard Ethernet CAT 5 cable with RJ-45 connector	10 MBits/s
Rear	TCP/IP protocol	Shielded twisted pair CAT 5e cable with RJ-45 connector or fibre-optic cable with LC connector	100 MBits/s

Table 546: Serial rear interface

Type	Counter connector
Serial port (X5)	10-pin counter connector Weidmüller BL 3.5/10/180F AU OR BEDR or 9-pin counter connector Weidmüller BL 3.5/9/180F AU OR BEDR[1)]
Serial port (X16)	9-pin D-sub connector DE-9
Serial port (X12)	Optical ST-connector

1) Depending on the optional communication module

Table 547: Fibre-optic communication link

Connector	Fibre type	Wave length	Max. distance	Permitted path attenuation[1]
LC	MM 62.5/125 or 50/125 μm glass fibre core	1300 nm	2 km	<8 dB
ST	MM 62.5/125 or 50/125 μm glass fibre core	820...900 nm	1 km	<11 dB

1) Maximum allowed attenuation caused by connectors and cable together

Table 548: IRIG-B

Description	Value
IRIG time code format	B004, B005[1]
Isolation	500V 1 min
Modulation	Unmodulated
Logic level	TTL level
Current consumption	2...4 mA
Power consumption	10...20 mW

1) According to the 200-04 IRIG standard

Table 549: Degree of protection of flush-mounted relay

Description	Value
Front side	IP 54
Rear side, connection terminals	IP 20

Table 550: Environmental conditions

Description	Value
Operating temperature range	-25...+55ºC (continuous)
Short-time service temperature range	-40...+85ºC (<16h)[1)2)]
Relative humidity	<93%, non-condensing
Atmospheric pressure	86...106 kPa
Altitude	Up to 2000 m
Transport and storage temperature range	-40...+85ºC

1) Degradation in MTBF and HMI performance outside the temperature range of -25...+55 ºC
2) For relays with an LC communication interface the maximum operating temperature is +70 ºC

Section 15 IED and functionality tests

Table 551: 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 60255-22-1, class III IEEE C37.90.1-2002
3 MHz, 10 MHz and 30 MHz burst disturbance test • Common mode	 2.5 kV	IEC 61000-4-18 IEC 60255-22-1, class III
Electrostatic discharge test • Contact discharge • Air discharge	 8 kV 15 kV	IEC 61000-4-2 IEC 60255-22-2 IEEE C37.90.3-2001
Radio frequency interference test	10 V (rms) f = 150 kHz...80 MHz	IEC 61000-4-6 IEC 60255-22-6, class III
	10 V/m (rms) f = 80...2700 MHz	IEC 61000-4-3 IEC 60255-22-3, class III
	10 V/m f = 900 MHz	ENV 50204 IEC 60255-22-3, class III
	20 V/m (rms) f = 80...1000 MHz	IEEE C37.90.2-2004
Fast transient disturbance test • All ports	 4 kV	IEC 61000-4-4 IEC 60255-22-4 IEEE C37.90.1-2002
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 60255-22-5
Power frequency (50 Hz) magnetic field immunity test • Continuous • 1...3 s	 300 A/m 1000 A/m	IEC 61000-4-8

Table continues on next page

Description	Type test value	Reference
Pulse magnetic field immunity test	1000 A/m 6.4/16 μs	IEC 61000-4-9
Damped oscillatory magnetic field immunity test • 2 s • 1 MHz	 100 A/m 400 transients/s	IEC 61000-4-10
Power frequency immunity test • Common mode • Differential mode	Binary inputs only 300 V rms 150 V rms	IEC 61000-4-16 IEC 60255-22-7, class A
Emission tests • Conducted 0.15...0.50 MHz 0.5...30 MHz • Radiated 30...230 MHz 230...1000 MHz	 <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	EN 55011, class A IEC 60255-25

Table 552: Insulation tests

Description	Type test value	Reference
Dielectric tests	2 kV, 50 Hz, 1 min 500 V, 50 Hz, 1 min, communication	IEC 60255-5 and IEC 60255-27
Impulse voltage test	5 kV, 1.2/50 μs, 0.5 J 1 kV, 1.2/50 μs, 0.5 J, communication	IEC 60255-5 and IEC 60255-27
Insulation resistance measurements	>100 MΩ, 500 V DC	IEC 60255-5 and IEC 60255-27
Protective bonding resistance	<0.1 Ω, 4 A, 60 s	IEC 60255-27

Table 553: Mechanical tests

Description	Reference	Requirement
Vibration tests (sinusoidal)	IEC 60068-2-6 (test Fc) IEC 60255-21-1	Class 2
Shock and bump test	IEC 60068-2-27 (test Ea shock) IEC 60068-2-29 (test Eb bump) IEC 60255-21-2	Class 2
Seismic test	IEC 60255-21-3	Class 2

Table 554: Environmental tests

Description	Type test value	Reference
Dry heat test	• 96 h at +55ºC • 16 h at +85ºC1)	IEC 60068-2-2
Cold test	• 96 h at -25ºC • 16 h at -40ºC	IEC 60068-2-1
Damp heat test	• 6 cycles (12 h + 12 h) at +25°C…+55°C, humidity >93%	IEC 60068-2-30
Change of temperature test	• 5 cycles (3 h + 3 h) at -25°C...+55°C	IEC60068-2-14
Storage test	• 96 h at -40ºC • 96 h at +85ºC	IEC 60068-2-1 IEC 60068-2-2

1) For relays with an LC communication interface the maximum operating temperature is +70ºC

Table 555: Product safety

Description	Reference
LV directive	2006/95/EC
Standard	EN 60255-27 (2005) EN 60255-1 (2009)

Table 556: EMC compliance

Description	Reference
EMC directive	2004/108/EC
Standard	EN 50263 (2000) EN 60255-26 (2007)

Section 16 Applicable standards and regulations

EN 50263

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

Section 17 Glossary

AC	Alternating current
ACT	1. Application Configuration tool in PCM600 2. Trip status in IEC 61850
CAT 5	A twisted pair cable type designed for high signal integrity
CAT 5e	An enhanced version of CAT 5 that adds specifications for far end crosstalk
CBB	Cycle building block
CPU	Central processing unit
CT	Current transformer
CTS	Clear to send
DC	1. Direct current 2. Disconnector 3. Double command
DCD	Data carrier detect
DFT	Discrete Fourier transform
DHCP	Dynamic Host Configuration Protocol
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.
DPC	Double-point control
DSR	Data set ready
DT	Definite time
DTR	Data terminal ready
EEPROM	Electrically erasable programmable read-only memory
EIA-232	Serial communication standard according to Electronics Industries Association
EIA-485	Serial communication standard according to Electronics Industries Association
EMC	Electromagnetic compatibility
Ethernet	A standard for connecting a family of frame-based computer networking technologies into a LAN

FIFO	First in, first out
FPGA	Field-programmable gate array
FTP	File transfer protocol
GOOSE	Generic Object-Oriented Substation Event
HMI	Human-machine interface
IDMT	Inverse definite minimum time
IEC	International Electrotechnical Commission
IEC 60870-5-101	Companion standard for basic telecontrol tasks
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
IED	Intelligent electronic device
IP	Internet protocol
IP address	A set of four numbers between 0 and 255, separated by periods. Each server connected to the Internet is assigned a unique IP address that specifies the location for the TCP/IP protocol.
IRF	1. Internal fault 2. Internal relay fault
IRIG-B	Inter-Range Instrumentation Group's time code format B
LAN	Local area network
LC	Connector type for glass fibre cable
LCD	Liquid crystal display
LED	Light-emitting diode
LHMI	Local human-machine interface
MMS	1. Manufacturing message specification 2. Metering management system
MV	Medium voltage
Modbus	A serial communication protocol developed by the Modicon company in 1979. Originally used for communication in PLCs and RTU devices.
PC	1. Personal computer 2. Polycarbonate
PCM600	Protection and Control IED Manager
PLC	Programmable logic controller

PPS	Pulse per second
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 backup	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
RAM	Random access memory
RCA	Also known as MTA or base angle. Characteristic angle.
REC615	Remote protection and control IED in grid automation
RJ-45	Galvanic connector type
RMS	Root-mean-square (value)
ROM	Read-only memory
RSTP	Rapid spanning tree protocol
RTC	Real-time clock
RTS	Ready to send
RoHS	Restriction of the use of certain hazardous substances in electrical and electronic equipment
SBO	Select-before-operate
SCL	XML-based substation description configuration language defined by IEC 61850
SMT	Signal Matrix tool in PCM600
SNTP	Simple Network Time Protocol
SOTF	Switch on to fault
ST	Connector type for glass fibre cable
SW	Software
Single-line diagram	Simplified notation for representing a three-phase power system. Instead of representing each of three phases with a separate line or terminal, only one conductor is represented.
TCP/IP	Transmission Control Protocol/Internet Protocol
TCS	Trip-circuit supervision
UTC	Coordinated universal time

VT	Voltage transformer
WAN	Wide area network
WHMI	Web human-machine interface

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