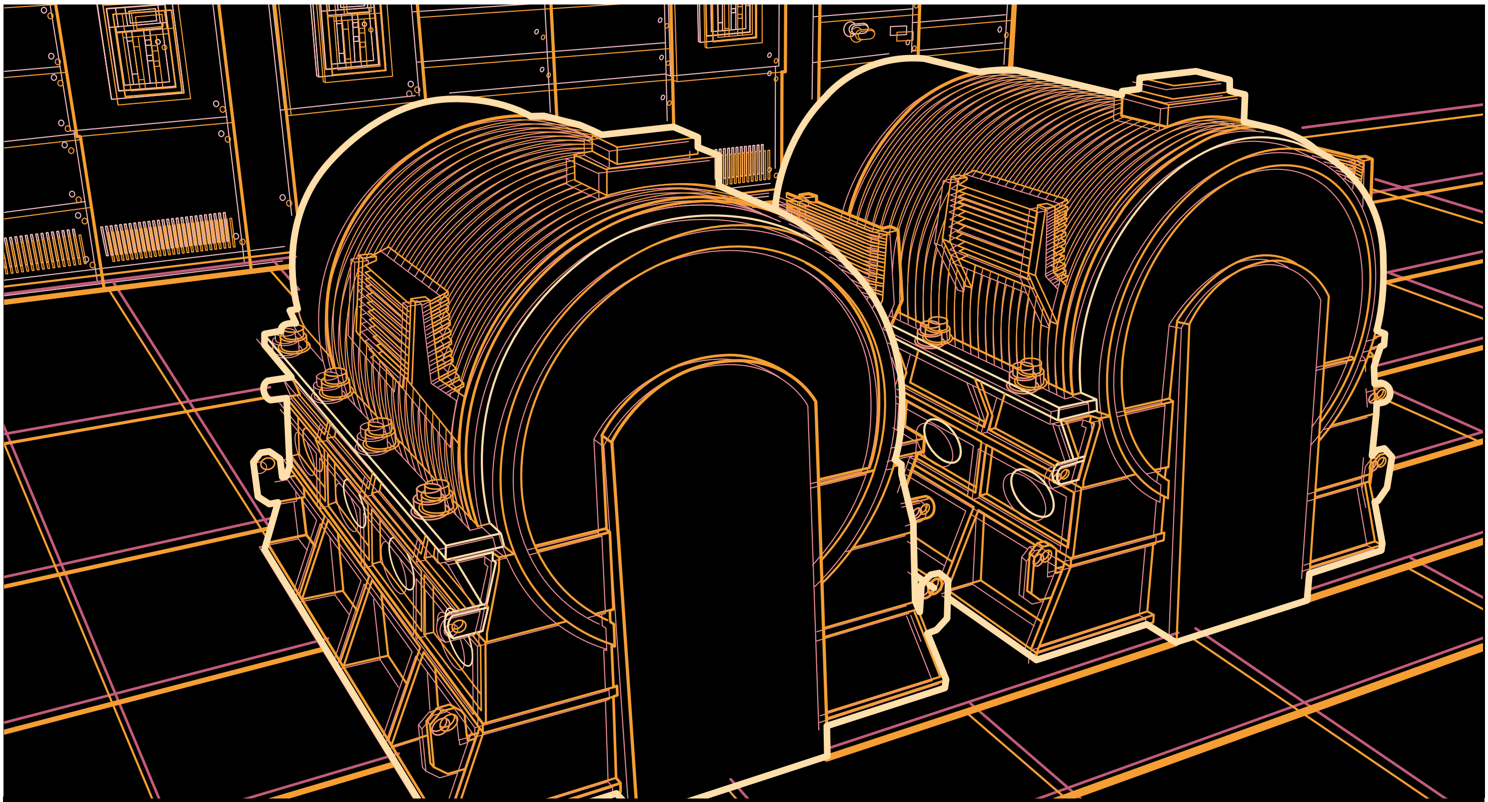

White paper

Generators protection: Ekip G trip unit for SACE Emax 2

Power and productivity for a better world™

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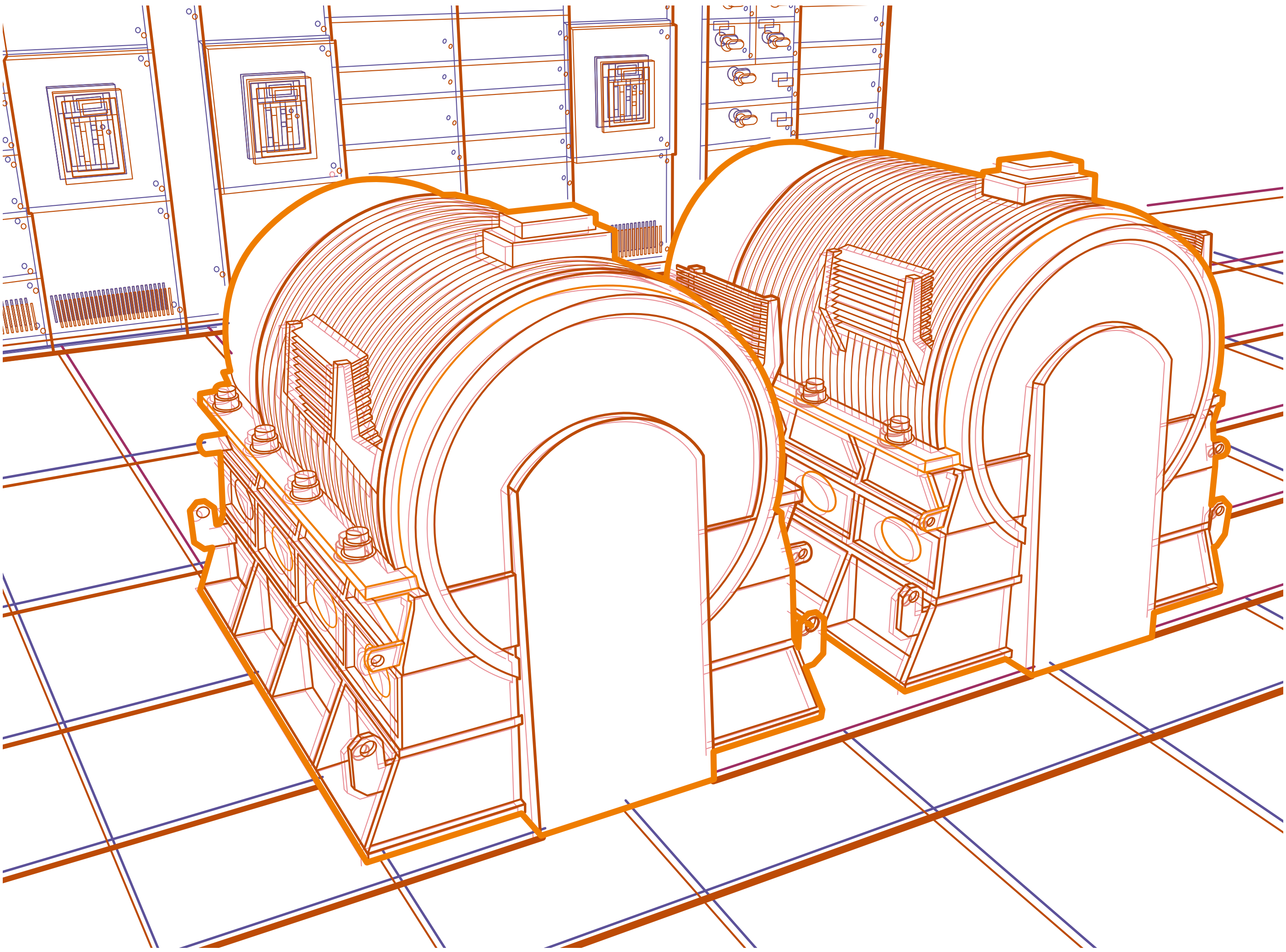
1. Introduction

Electric generators are rotating machines; as a consequence, they may easily be subjected to internal faults or anomalies arising from the system to which they are connected. That is why the protections used must be efficient and prompt to protect the generator adequately.

ABB SACE Emax 2 presents the new generation of trip unit for the protection of generators; the Ekip G (Fig.1-1). It offers an effective and reliable solution designed for the protection of low voltage generators. The following documentation illustrates the protection functions required for several different types of installations. The differences will be dependent on the function of the generator, the size in terms of rated power and the type of operation for which the generator was designed.

SACE Emax 2 Ekip G trip unit contains the functions necessary for the electrical protection of the machine and for monitoring the main critical parameters for the connection of the generator to the plant. These functions, generally provided by multifunction independent relays, are now integrated into SACE Emax 2 to guarantee a solution that is easy to install, compact, and reliable.

Figure 1-1



2. Generators and protections: application field

One of the application fields of the synchronous generators is found in the typical and modern context of energy saving by means of cogeneration. A common generator set may consist of a methane gas prime mover coupled with a three-phase synchronous alternator. It can be used for producing electrical power for self-supply and for the possible sale of power back to the network because of excess power produced.
Other applications for synchronous generators are either on ship, where the machine is the power supply source for the whole system, or as generator set providing emergency power for industrial plants.
In general, the generator set always consists of the interconnection of the electric machine with a prime mover and of the relevant switching and control panel. The unit is normally used to generate electric power under emergency conditions or to meet the peak demand (when paralleled to a live network), or as the sole source of continuosly rated power.
The generator is the most delicate and expensive part of such an electric system.

As a consequence, redundancy of the protection functions provided, partcularly those that protect the machine against the most serious faults, could be required. The protection system for a generator is complex and complicated both to define and to manage. For low-power machines the protection system can be simplified because certai protection functions can be eliminated and redundancy can be eliminated.

Low-voltage generators can normally be divided into:
- type A: those that are mounted permanently paralleled with the network and
- type B: those that have to work in island mode.
A typical example of type A are the autoproducers connected to the network: for the purposes of this paper we are referring to synchronous generators used in applications like cogeneration, mini hydroelectric plants, and plants supplied by biomass.
Type B applications are typically used in ships, where power generation is, by definition, island-mode generation.

We can now examine these two cases in detail:

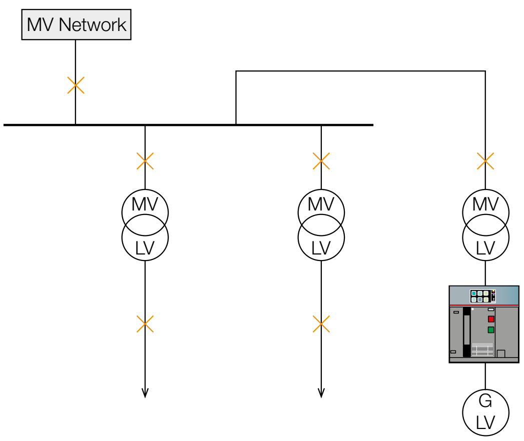
Autoproducers connected to the network: cogeneration, mini or small hydroelectric, biomass plants.
In this context we can distinguish between connection to the medium voltage public utility network (diagram A) or low voltage connection (diagram B).

In the connection to the MV public utility network (diagram A), the natural position of SACE Emax 2 circuit breaker with an Ekip G trip unit is as protection of single LV generators. The protections more commonly used in this field and defined according to the ANSI code are:

40	(loss of field or reverse reactive power protection)
27	(undervoltage protection)
59	(overvoltage protection)
50	(instantaneous overcurrent protection)
51, 50TD	(time-delayed overcurrent protection)
81H	(overfrequency protection)
81L	(underfrequency protection)
49	(overload protection)
32R	(reverse active power protection)
51V	(voltage controlled overcurrent protection)
59N-51N/G-50N/G TD	(earth fault protection)
46	(current unbalance protection)

All these protection functions are available on Ekip G.

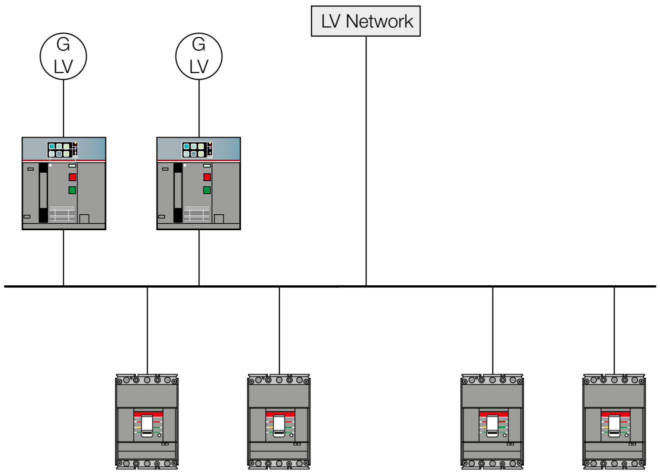
Diagram A



2. Generators and protections: application field

In the connection to the low voltage public utility network (diagram B), the most commonly used protections are the same as described in the previous paragraph, with the addition of two protections, if several low voltage generators are used: the protection function for controlling synchronism conditions (ANSI 25), which is necessary for checking that the machines or the machine run parallel to the network, and the protection 81R, which controls the rate of change of frequency and is used to prevent the generator from island- mode operation and to manage a load control logic.

Diagram B



Island-mode plants: ships

In this context, SACE Emax 2 circuit breakers can be used both as a machine circuit breaker as well as a "bus tie", as shown in diagram C and C1.

The protection functions most likely to be required in the position of machine circuit breaker are, according to the ANSI code:

32OF	(active overpower protection)
32R	(reverse active power protection)
40	(loss of field or reverse reactive power protection)
50	(instantaneous overcurrent protection)
51, 50TD	(time-delayed overcurrent protection)
59N	(residual overvoltage protection)
27	(undervoltage protection)
59	(overvoltage protection)
81H	(overfrequency protection)
81L	(underfrequency protection)
51V	(voltage controlled overcurrent protection)
59N-51N/G-50N/G TD	(earth fault protection)
46	(current unbalance protection)

In the "bus tie" position, in addition to the overcurrent protections, one function that may be frequently required is ANSI 25 (synchronism-check).
Ekip G is able to provide all these protections.

The protection functions available on Ekip G comply with the prescriptions of the main international Standards and rules that provide the instructions on the type of protections to be used for the control of the synchronous generator protections in (for example), ships or traditional plants. As an example, we can mention the Std. IEC 60034-1 "Rotating electrical machines – Part 1: Rating and performance" or IEEE C37.102 "Guide for AC Generator Protection" and the Std. IEEE 242 "Protection and Coordination of Industrial and Commercial Power Systems" or the prescriptions provided by the shipping registers, such as RINA, DNV, etc.

Diagram C

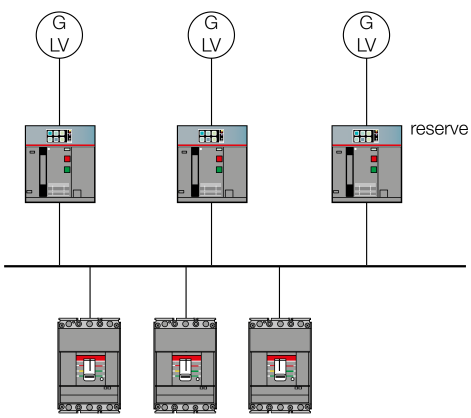
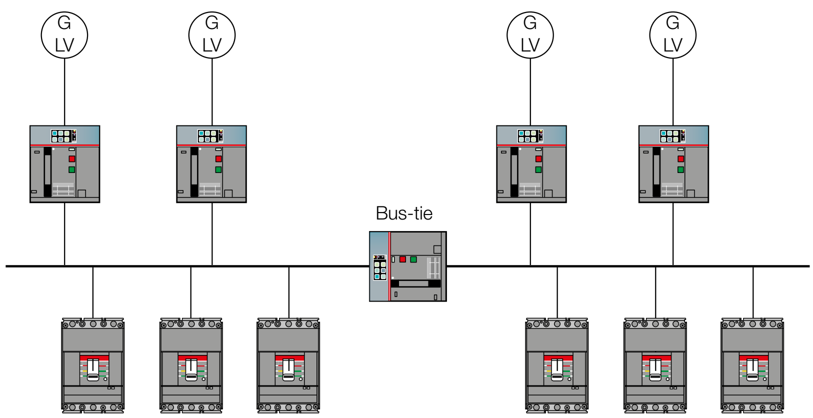


Diagram C1



The available protection functions are coded in compliance with the IEEE C37.2 “IEEE Standard for Electrical Power System Device Function Numbers, Acronyms, and Contact Designations” which is also known as the ANSI code.

The protections required depend on the type of plant and application, which makes standardization of protections/applications quite difficult. Nevertheless, the most commonly required protections according also to the indications given in the above mentioned Standards and rules can be summarized in Table 1-2.
The protection functions available on Ekip G can be activated individually, and thus enable the user to build the package of protections that meet the protection requirements of his own plants.

By assuming as voltage variation range for the generators used in first-category electrical systems the values from 400V to 1000V, and by considering a range of rated currents of the circuit breaker from 400A to 6300A (as available for Emax 2), it is possible to determine the range of power of the generators for which the new air circuit breaker could be used. It would result in an approximate range of 300kVA to 10MVA, according to the standardized power values provided by the different manufacturers.

Table 1-2

Protections for synchronous generators	SnG < 500kVA	500kVA < SnG < 1500kVA	SnG > 1500kVA
Protections against loss of prime mover:			
- Active power directional protection	•	•	•
Protections against overloads:			
- Overload and overcurrent	•	•	•
- Current unbalance	•	•	•
Protections against failures of the excitation system:			
- Loss of field	–	•	•
- Under/Overvoltage	•	•	•
Protections against frequency variations:			
- Under/Overfrequency	•	•	•
Protection against network loss:			
- Rate of change of frequency	–	•	•
Protection against failures of the insulation system:			
- Stator earth fault	•	•	•

3. Protections of EKIP G trip unit

The Ekip G trip unit is able to:

- monitor the frequency, voltage or earth faults inside the machine whereby tripping the machine main circuit breaker would isolate the generator from the rest of the plant without eliminating the fault;
- monitor the interaction conditions between the generator and the rest of the plant and provide for the separation and protection of the two systems when the conditions for interconnection are missing.

In both cases, programmable contacts are available that can be used to determine the shutdown of the generator, of the prime mover and of excitation.

Ekip G, which is supplied as standard with Ekip Measuring Pro module, is comprised of current, frequency, voltage and power protection functions specific for generators.

The available functions are listed in Table1-3, which shows both ABB as well as ANSI codes.

For a complete and detailed description of the available protections and of the relevant technical characteristics, please refer to the technical catalogue of SACE Emax 2 circuit breaker.

Table 1-3

Function	Description	ANSI	ABB
Synchrocheck	Control of adequate conditions for parallel connection	25	SC
Active overpower protection	Protection against active overpower supply	32OF	OP
Reactive overpower protection	Protection against reactive overpower supply	32OF	OQ
Reverse active power protection	Protection against active power absorption (reverse power)	32R	RP
Directional overcurrent protection	Protection against directional current	67	D
Active underpower protection	Protection against active underpower supply	32LF	UP
Loss of field or reverse reactive power protection	Protection against energizing anomalies, check of reactive power absorption	40/32R	RQ
Overload protection	Current protection against temperature rise	49	L
Instantaneous overcurrent protection	Instantaneous protection against phase overcurrents	50	I
Time-delayed overcurrent protection	Inverse/definite time protection against phase overcurrents	51 50TD	S
Earth fault protection	Inverse/definite and instantaneous time protection against earth overcurrents	51N 50NTD 50N; 51G 50GTD	G; Gext
Differential ground fault protection	Definite time protection against earth overcurrents in the generator windings	87N	Rc
Voltage controlled overcurrent protection	Protection against short circuit between phases with current threshold depending on voltage (controlled/restrained mode)	51V	S(V)
Residual overvoltage protection	Protection detecting loss of insulation in the machine	59N	RV
Undervoltage protection	Protection against voltage decrease	27	UV
Overvoltage protection	Protection against voltage increase	59	OV
Current unbalance protection	Protection against phase current unbalance	46	IU
Voltage unbalance protection	Protection against voltage unbalance and detection of rotation direction of phases	47	VU
Rate of change of frequency protection	Protection against rapid frequency variations	81R	Rocof
Overfrequency protection	Protection against frequency increase	81H	OF
Underfrequency protection	Protection against frequency reduction	81L	UF

Ekip G protection trip unit derives the electrical parameters of the machine directly from inside the circuit breaker and manages them directly without the interposition of external measuring transformers (up to 690V). This all inclusive and compact design presents a financial advantage to separately installed control and monitoring equipment.
The designer no longer has to consider added engineering, installation, wiring, (not to mention the errors that can arise from all of this extra work), as well as save space in the gear.

The circuit breaker the voltage sockets to be fitted either on the lower side terminals (standard) or on the upper side terminals (upon request). Therefore, they can always be positioned on the generator side, thus enabling the voltage and frequency of the generator to be monitored (even if the circuit breaker is open).
The relevant protection functions are thus consequently active independently of the state of the circuit breaker and are able to signal any possible anomaly before the circuit breaker makes.

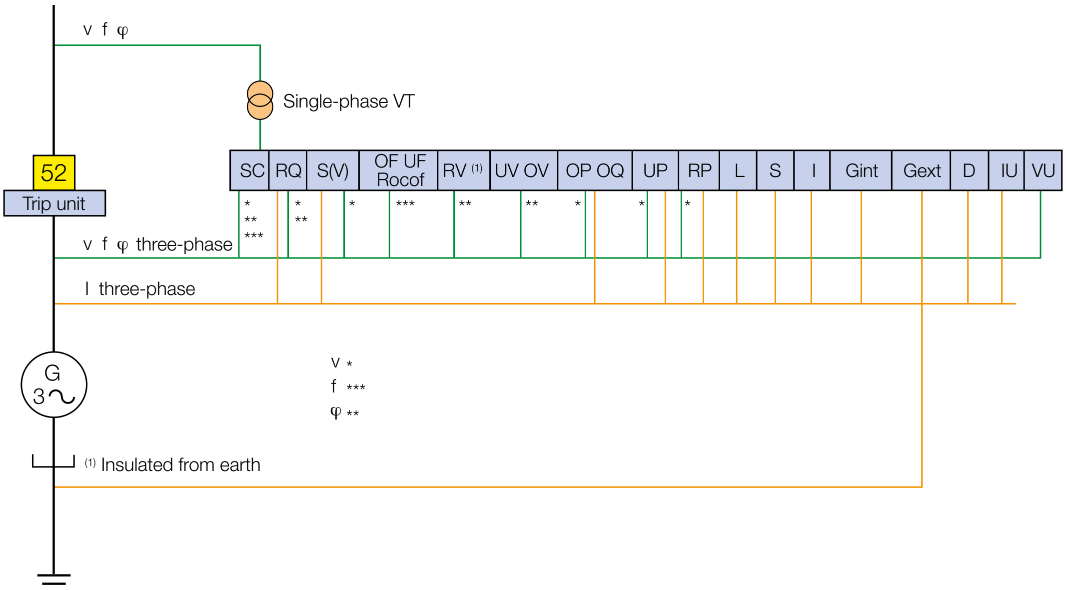
Figure 1-3 is a diagram showing the available functions and the electrical parameters measured for the operation of protections, based on the convention that voltage sockets face the generator.

In the following paragraphs, the single protection functions are considered; a short description of their purpose and their operating mode is provided, their main characteristic parameters are analyzed, and the setting range is defined. An example of setting of the tripping threshold is given.

Depending on the anomaly control mode selected, for each protection function, it is possible to decide whether the response to the fault should trip the circuit breaker or generate an alarm signal.
By means of the "Enable Trip" option, the protection trip unit will command the circuit breaker to open at the end of the set time delay.

During the time delay and after the circuit breaker has been tripped, an identifying signal is available. The signal can be relayed from a programmable relay contact or as a message from the data server carrying information on the protection function being delayed or which function caused the trip of the breaker.
If the trip is disabled, when the protection exceeds the set threshold, an immediate message is generated on the display; this signal can be associated to a programmable contact or can be sent by remote.

Figure 1-3



3. Protections of EKIP G trip unit

3.1 Voltage controlled overcurrent protection (S(V) - ANSI 51V)

In the event of a fault at the generator terminals, the initial value of the fault current is influenced by the value of the direct subtransient reactance X”d of the machine. The current magnitude evolves over time and is regulated by the direct transient reactance values X’d and synchronous reactance values Xd on the basis of the values of the corresponding time constants.
Thus, it is possible to move from an initial fault current value of about 6 to 10 times the rated current of the generator to a three-phase fault current value under steady state conditions that can be lower than the generator full-load rated current. This is because the synchronous reactance that regulates normal operation can be less than the synchronous reactance under fault steady conditions.
The voltage controlled overcurrent protection identified by the code S(V) or ANSI 51V allows adequate protection to be guaranteed under fault conditions even if the current settings are higher than the normal operating currents; in fact it can translate the current thresholds to lower trip values, in response to a given voltage decrease at the generator terminals, (which is a normal consequence of the fault).
The protection S(V) (in the event of a fault) provides current protection thresholds that are lowered in case of voltage reduction at the heads of the generator.
This could provide back-up protection in addition to the traditional time current protections.
The trip threshold of the voltage controlled current makes it possible to get, within the traditional time-current protection function, suitable settings that do not interfere with the steady state condition of the generator.
Besides, this function could be used to realize thermal protection by setting the tripping curve of the voltage controlled protection function below the curve that defines the thermal limit of the machine.

3.1.1 Operating modes of the protection

Here is described the operating principle of the voltage controlled overcurrent protection S(V).
The trip unit evaluates the minimum r.m.s. value of the three line-to-line voltages. When this value is lower than the set voltage parameter which constitutes the voltage reference for the beginning of the translation, the initially set current threshold is reduced by a correction coefficient.
At the same time, the r.m.s. value of the three phase currents is evaluated and compared with the repositioned current threshold. If the maximum r.m.s. value of the current is greater than the new recalculated threshold, and the condition persists for longer than the set delay, the protection trips.
As the protection S(V) is a current protection, any coordination thereof with the traditional overcurrent protection functions is facilitated. This is because of the fact that the protection S(V) is activated only in case of a voltage decrease, whereas for normal voltages the traditional protections S and I are active, and the current threshold of the S(V) is not translated.

3.1.2 Characteristics of the protection

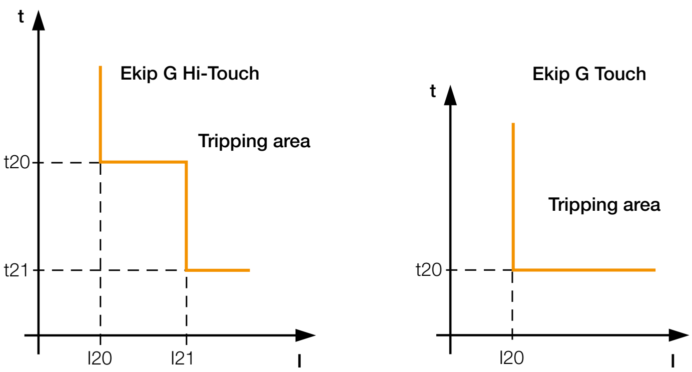
The voltage controlled overcurrent protection is available in the following modes:

- Ekip G Touch with definite time protection S(V), with adjustable time and current according to the parameters I20-t20; the protection can be disabled
- Ekip G Hi-Touch with two definite time protections S(V) and S2(V), completely independent one from the other, with adjustable time and current according to the parameters I20-t20 and I21-t21; each protection can be disabled.

Each protection, S(V) for Ekip G Touch and S(V) and S2(V) for Ekip G Hi-Touch, can be managed either in the voltage controlled mode or in the restrained mode.
Therefore, for example, with Ekip G Hi-Touch it is possible to have both protections in the voltage controlled mode, but with the voltage parameter for the translation beginning and current translation coefficient different for the two protections, or one protection in voltage controlled mode and the other one in voltage restrained mode.

These tripping curves are shown in Figure 1-3.1.

Figure 1-3.1



Controlled mode

As already said, one possibility to manage the available voltage is the "controlled" mode, whereby, after setting the parameters of the protection I20-t20 which defines the current threshold, it is necessary to set:

- Ul, which defines the level of the line-to-line voltage at which the translation of the current threshold I20 starts
- Ks, which defines the translation coefficient of the threshold.

Analogously, the parameters I21;t21;Ul2;Ks2 of the second threshold can also be set. Ul and Ul2, as well as Ks and Ks2, can be different.

If the voltage measured by the trip unit is higher than Ul and Ul2, which represent the voltage parameters set by the user for the beginning of the translation of the current threshold, the thresholds I20 and I21 are active.
If the voltage measured is lower than Ul, then the threshold I20 of the first protection is decreased by the set coefficient Ks. The tripping time remains unchanged. Then the new trip threshold shall be KsxI20; t20.
Analogously, for the second protection, if the voltage measured is lower than Ul2, then the threshold I21 is decreased by the set coefficient Ks2. The tripping time remains unchanged. Then the new trip threshold shall be Ks2xI21; t21.

The procedure described for the first protection can be applied also for the management of the single protection with the parameters I20; t20; Ks; Ul.
Ekip G makes the protection trip if the measured current exceeds the threshold set for a longer time than the set time.

Restrained mode

As already said, the other possibility to manage the available voltage is the "restrained" mode, whereby, after setting the parameters of the protection I20-t20 which define the current threshold, it is necessary to set:

- Uh, which defines the level of the line-to-line voltage at which the translation of the current threshold I20 starts, according to a parameter Ks* calculated by interpolation between Uh; 1 and Ul; Ks
- Ul, which defines the level of the line-to-line voltage at which the interpolation ends and below which the translation parameter is Ks
- Ks, which defines the translation coefficient linked to Ul.

Analogously for the parameters I21; t21; Uh2; Ul2; Ks2 of the second protection. Ul; Ul2 and Uh; Uh2 can be different as well as Ks and Ks2 and the partial values obtained by interpolation.
Thus, with reference to the graph in Figure 3-3.1, it is evident that for operate voltages higher than Uh, the threshold initially set for the first protection I20; t20 works, whereas, if the operate voltage value decreases below Uh, the trip unit shall calculate Ks*. The threshold I20 shall be lowered by the correction coefficient calculated by the trip unit. The tripping time shall remain unchanged. As a consequence, the new trip threshold shall become Ks*xI20; t20.
On the contrary, if the voltage falls below Ul, the protection shall use the translation coefficient set Ks and therefore the threshold I20 is decreased by the set coefficient; the new threshold shall be KsxI20; t20.
The same procedure can be applied to the second protection through the parameters Uh2; Ul2; Ks2.
The procedure described for the first protection can be applied also for the management of the single protection with parameters I20; t20; Ks; Ul; Uh.

For both modes (controlled or restrained), the trip unit controls the parameters Ks and Ks2 so that the translated current threshold does not go below 0.6xIn. Therefore, it shall be KsxI20>0.6xIn and Ks2xI21>0.6xIn.

Figure 2-3.1

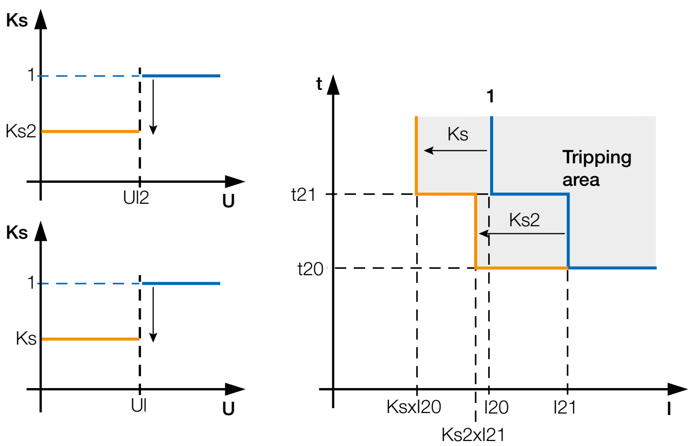
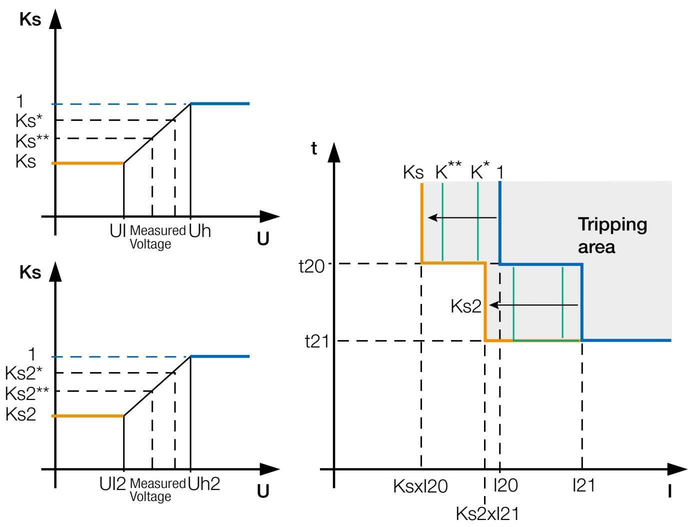


Figure 3-3.1



3.1.3 Setting range

The parameters the setting the voltage controlled overcurrent protection function available for Ekip G trip unit in all its versions are the following:

Voltage controlled overcurrent protection			
Controlled mode			
First/single protection	I20 = (0.6...10) x In	Threshold step	0.1 x In
First/single protection tripping time	t20 = (0.05...30)s	Time step	0.01s
Second protection	I21 = (0.6...10) x In	Threshold step	0.1 x In
Second protection tripping time	t21 = (0.05...30)s	Time step	0.01s
Voltage parameter	Ul = Ul2 = (20...100) %Un	Threshold step	1%Un
Threshold change parameter	Ks = Ks2 = (10...100) %	Threshold step	1%

Restrained mode			
First/single protection	I20 = (0.6...10) x In	Threshold step	0.1 x In
First/single protection tripping time	t20 = (0.05...30)s	Time step	0.01s
Second protection	I21 = (0.6...10) x In	Threshold step	0.1 x In
Second protection tripping time	t21 = (0.05...30)s	Time step	0.01s
Voltage high parameter	Uh = Uh2 = (20...100) %Un	Threshold step	1%Un
Voltage low parameter	Ul = Ul2 = (20...100) %Un	Threshold step	1%Un
Threshold change low parameter	Ks = Ks2 = (10...100) %	Threshold step	1%

For further details on the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

It should be noted that Ekip G Touch has a single protection that can be managed in both "controlled" and "restrained" mode, whereas the double protection is available for Ekip G Hi-Touch, which can also be managed in "controlled" and "restrained" mode.

3.1.4 Setting example

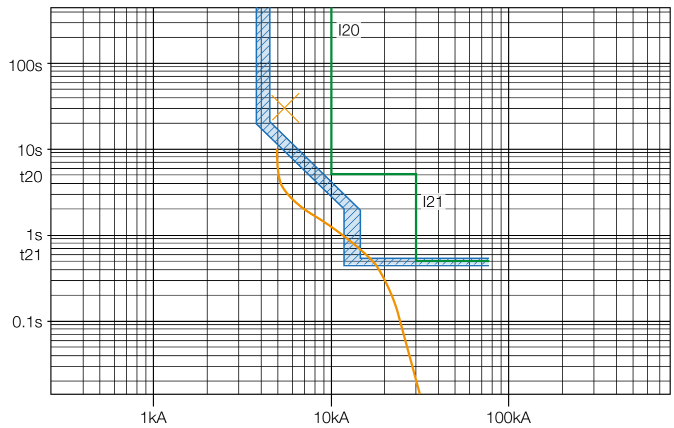
In the example, a generator with the following characteristics is taken into consideration:

Rated power	SnG	2500kVA
Rated voltage	VnG	400V
Subtransient reactance	X"d	11%
Rated current	InG	3610A
Maximum short-circuit current	IkG	32.8kA

The generator supplies an equivalent load that requires 3416A of current and, as a generator circuit breaker, we have chosen a 4000A SACE Emax 2 equipped with Ekip G Hi-Touch. The setting of the protections LSI is shown in the graph in Figure 4-3.1: the function L is set to the value of the rated current of the generator, the function I is turned to OFF as basic condition for selectivity towards the supply side and the function S is set to intercept the short-circuit curve of the generator.

The function S(V) is set to initial values that are higher than the previous parameters and are such as not to trip for the normal fault current of the generator.

Figure 4-3.1



Initial setting:

I20=2.5xIn=10000A t20=5s

I21=7.5xIn=30000A t21=0.5s

The "controlled" mode is selected on the display and then the following values are set:

setting Ul = Ul2 = 75% of Un (Un is the rated line-to-line voltage; it is set as reference value on the trip unit) setting

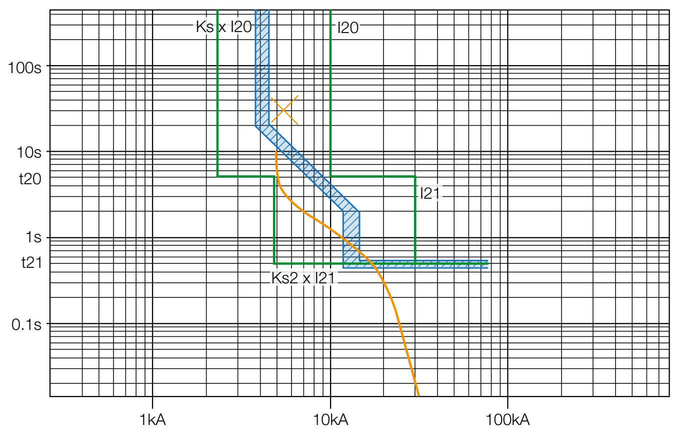
Ks = 0.24 and Ks2 = 0.16

Thus, for operate voltages below 0.75x400=300V, the new trip thresholds are shown in the graph in Figure 5-3.1 according to the following parameters:

Ks x I20=0.24x2.5xIn=2400A t20=5s

Ks2 x I21=0.16x7.5xIn=4800A t21=0.5s

Figure 5-3.1



The graph shows how after a voltage drop due to a fault at the output terminals of the generator circuit breaker, the protection S(V) can trip at currents lower than those that would be intercepted by the standard functions LSI.

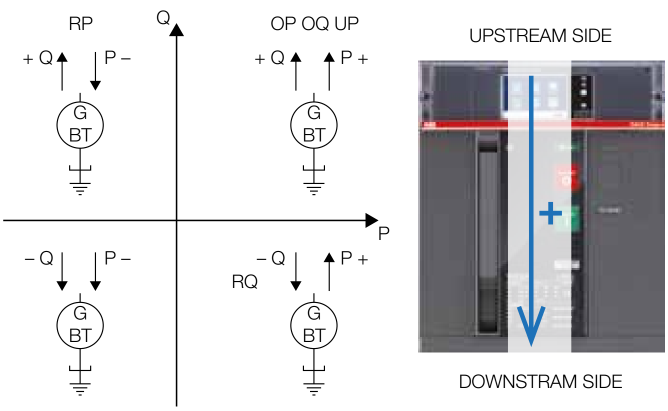
3.2 Power protections: introduction

The following power protections are available on the Ekip G trip unit:

- Protection against active overpower supplied by the generator (ANSI 32OF, ABB code OP): works controlling the positive active power, sets the active overpower value that the machine can supply.
- Protection against reverse active power absorbed by the generator (ANSI 32R, ABB code RP): works controlling the negative active power that flows in the opposite direction to the normal operation of the machine. It can also be called protection against reverse active power flow.
- Protection against reactive overpower supplied by the generator (ANSI 32OF, ABB code OQ): works controlling the positive reactive power supplied
by the generator, sets the reactive overpower value that the machine can supply.
- Protection against loss of field or reverse reactive power absorbed by the generator (ANSI 40 and ANSI 32R, ABB code RQ): works with the negative reactive power.
It can also be called protection against reverse reactive power flow.
- Protection against active power supplied by the generator (ANSI 32LF, ABB code UP): sets the active underpower value for the machine.

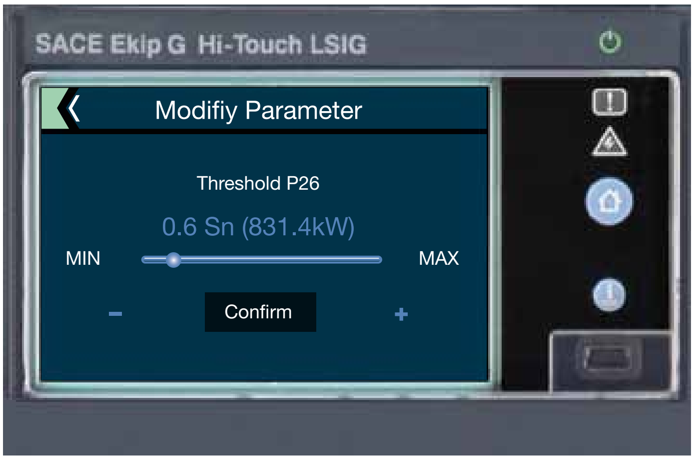
In the following paragraphs, the convention adopted and shown in Figure 1-3.2 is that the active and reactive power output of the generator has a plus sign.
In the standard configuration, the voltage sockets of Ekip G trip unit are on the lower side and must be on the generator side to guarantee a positive value for the power output of the generator. If the generator is connected to the upper terminals, the power direction set by the manufacturer will have to be reversed.

Figure 1-3.2



The setting of all the power functions refers to the rated power Sn of the trip unit calculated on the basis of the rated line-to-line or phase-to-phase voltage Un set on the trip unit and of the rated current of the circuit breaker (rating plug) according to the relation $\sqrt{3}$ x Un x In .
The graphic interface as in Figure 2-3.2 shows not only the setting as a multiple of Sn, but it also indicates the corresponding absolute value in [kW] or [kvar] to have a reference in absolute terms to compare with the power limits permitted for the machine.

Figure 2-3.2



3.2.1 Loss of field or reverse reactive power protection (RQ - ANSI 40 and 32R)

The loss of excitation in a synchronous generator mainly arises from faults in the energizing unit or in the field circuit. Consequently, the electromotive force in the generator is nullified and there is a reduction in the reactive power supplied. Then the machine starts to run as an asynchronous generator absorbing reactive power from the network.
This new operating condition, with the circulation of the reactive power supplied by the network, causes a temperature rise in the rotor circuit, in the field circuit and in the damper circuit.
This phenomenon is particularly evident in smooth rotor generators, whereas it is much less marked in salient pole generators. In addition to the phenomena involving the machine, the voltage is remarkably reduced with a consequent loss of stability for the system, due to the fact that the network might not be able to supply the reactive power required by the generator. The operating area of a generator can be described through the capability diagram shown on the R-X or P-Q plane is defined by the upper and lower limits of the characteristic curves referred to a cylindrical generator and a salient pole generator in the PQ coordinates of Figure 1-3.2.1.

3. Protections of EKIP G trip unit

The generator operating point usually falls in the first quadrant with active power P and reactive power Q of positive value and exiting from the generator.
Owing to anomalous conditions (for example a reduction or loss of excitation) the operating point moves to the fourth quadrant and the reactive power Q reverses its direction, thus becoming negative and being absorbed by the generator.

This new operating point is characterized by low stability and, if the network were able to supply reactive power without an excessive voltage drop, the synchronous generator could work as an asynchronous generator, but with a hazardous temperature rise in the windings.

The protection against loss of excitation implemented on the Ekip G trip unit works by taking as a reference the P-Q area of the diagram that indicates the underexcited operating limit of the machine.
This protection is obtained through a function with an operating curve represented, as in Figure 2-3.2.1, by a straight line with a single or double slope (option used to have the protection closer to the shape of the limit curve), which prevents the machine from functioning below its underexcited operating limit.
The protection sets the limit of the reactive power that the generator can absorb from the network and below which it is inadvisable to run the machine.

Figure 1-3.2.1

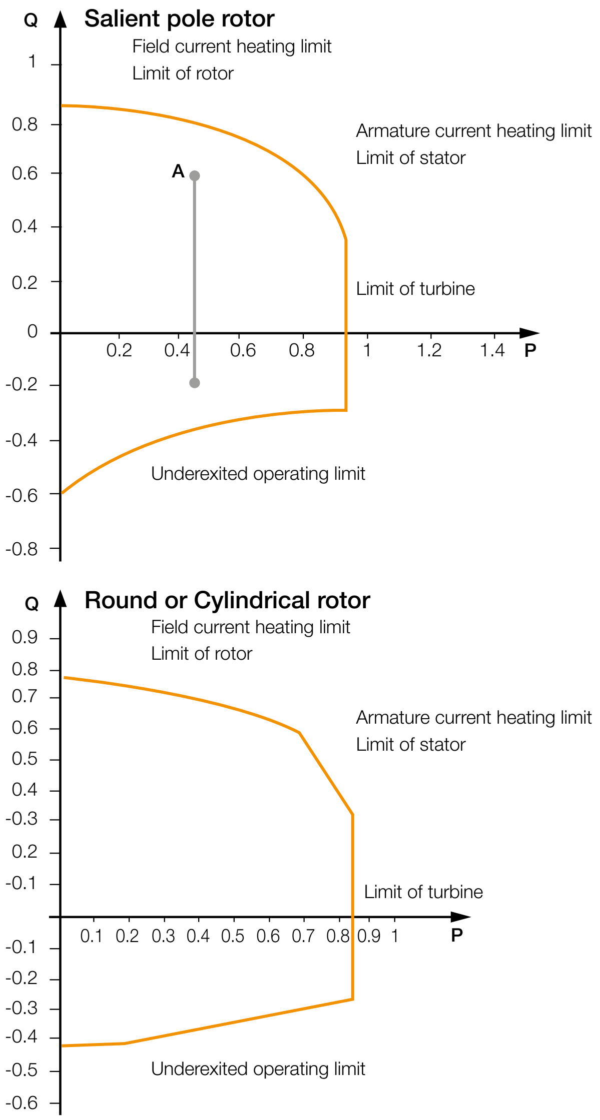
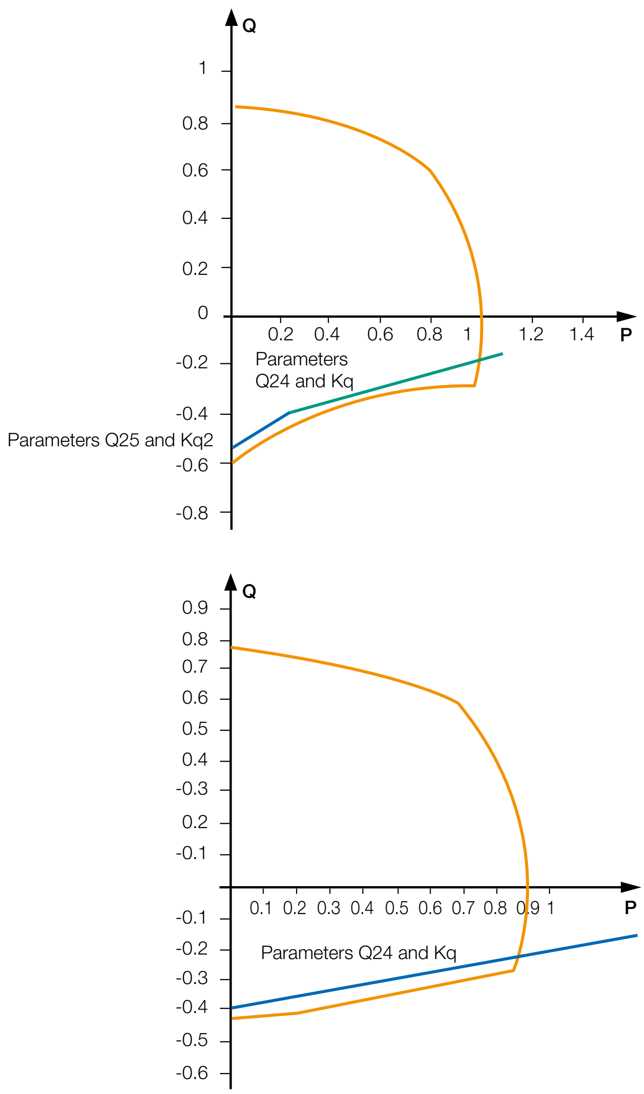


Figure 2-3.2.1



3.2.1.1 Operating modes of the protection

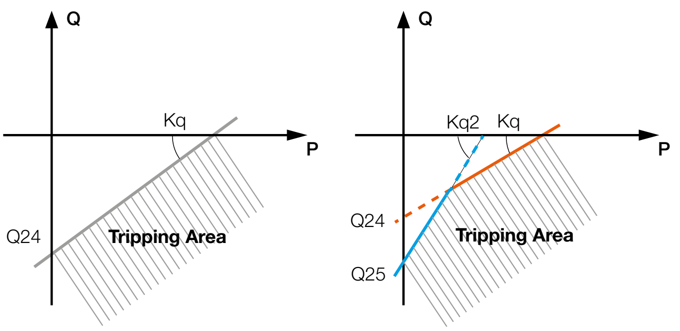
This protection limits the generator operating region with negative reactive power (i.e. absorbed power), by approaching its underexcited operating limit curve through a single- or double slope straight line that can be generally represented as Q=KqxP-Qi, where the setting parameters “Qi” defines the starting point on the reactive power axis and “Kq” indicates the slope of the protection function.

This protection works by acquiring the values of the total active and reactive power. If the operating point is below the set protection curve and this condition persists for a time greater than the set trip delay time, the protection trips, which can cause the circuit breaker opening or the generation of an alarm signal.

3.2.1.2 Characteristics of the protection

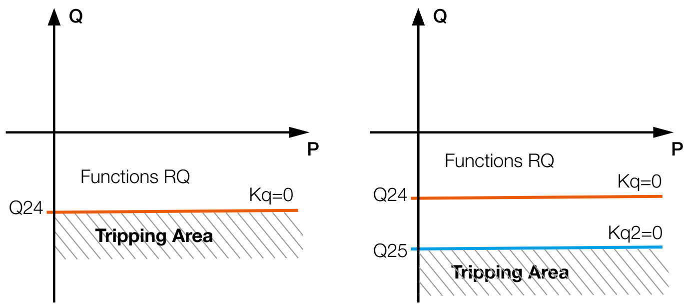
This protection operates by using a single-slope line (for Ekip G Touch) or a double slope line (for Ekip G Hi-Touch).
The single-slope trip line is defined by a parameter Kq and by the intercept Q24.
The double-slope trip curve is the result of the intersection of the two thresholds, that is of the two single-slope lines defined by the parameters Q24; Kq and Q25; Kq2, (with Q24 <Q25 and Kq < Kq2), as shown in Figure 3-3.2.1.
If the operating point of the generator remains in the tripping area for a time longer than the set delay time t24, the protection trips.

Figure 3-3.2.1



A special feature of the function 40 with single-slope is obtained by setting the parameter Kq=0: the trip curve becomes a straight line starting from the set parameter Q24 and is parallel to the P-axis. Analogously, with the double slope protection, by setting the parameters Kq=0 and Kq2=0, two straight lines are obtained, which start from the parameters Q24 and Q25 and run parallel to the P-axis. In this case, the protection intervenes for values in the half plane below the straight line, with the parameter Q of lower value (considered with the minus sign) between the two Q set.
An example of the trip curves is shown in Figure 4-3.2.1.
In this way the protection function against reverse reactive power identified by the ANSI code 32R is realized. For the double-slope protection it is possible to set one parameter relevant to the slope equal to zero (e.g. Kq=0), and the other one different from zero (e.g. Kq2≠0).

Figure 4-3.2.1



The user sets the parameters “Q24 and Q25” are set by the user as a % of Sn, which is the rated apparent power calculated by the trip unit with reference to the rated line-to-line voltage Un set on the trip unit and to the rated current (rating plug) of the circuit breaker.
This protection is enabled if the voltage measured in the plant is higher than the set voltage parameter.

3.2.1.3 Setting range

As illustrated in the previous sections, the parameters that characterize the protection function against the loss of excitation with control of the reactive power available for Ekip G (in all its versions) are the slope with respect to the P-axis (identified by the parameter “Kq”) and the intercept on the reactive power axis (identified by the parameter “Q”).
These parameters have the following setting range:

Loss of field or reverse reactive power			
Single-slope			
Parameter	Q24 = (1…0.1) x Sn	Threshold step	0.001 x Sn
Slope	Kq = (-2…2)	Step	0.01
Tripping time	t24 = (0.5…100)s	Time step	0.1s
First slope			
Parameter	Q24 = (1…0.1) x Sn	Threshold step	0.001 x Sn
Slope	Kq = (-2…2)	Step	0.01
Second slope			
Parameter	Q25 = (1…0.1) x Sn	Threshold step	0.001 x Sn
Slope	Kq2 = (-2…2)	Step	0.01
Tripping time	t24 = (0.5…100)s	Time step	0.1s

For further details on the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3. Protections of EKIP G trip unit

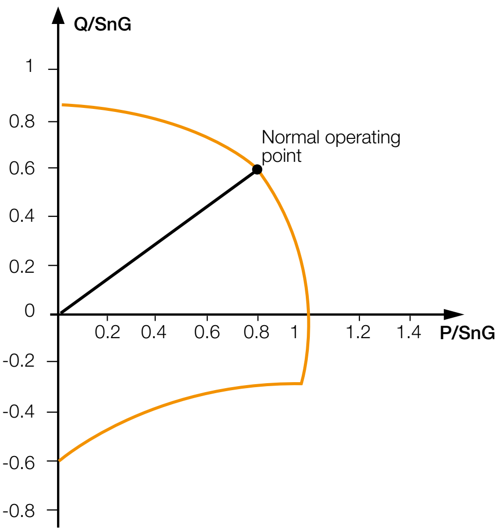
3.2.1.4 Setting example

The example shows a three-phase synchronous generator with salient poles characterized by:

- rated power SnG = 1530kVA
- rated voltage Un = 500V
- rated current InG = 1766A
- capability diagram PQ as in Figure 5-3.2.1 showing the various stator, rotor and underexcited operating limits.

Taking into account the rated current of the generator, an ABB SACE Emax 2 circuit breaker with 2000A rating plug can be used.
With reference to these parameters, the trip unit calculates its rated power as S =1.73 x500x2000 = 1732kVA.

Figure 5-3.2.1



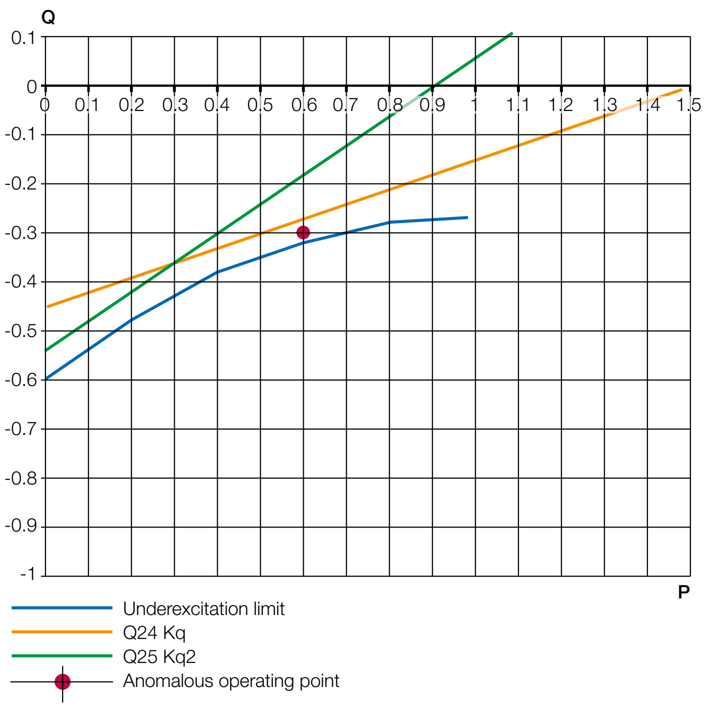
The diagram PQ of the machine shows that the underexcitation operating limit curve starts from a reactive power value equal to Q_G=-0.6xSnG=-918kvar. The shape of the protection curve Q=KqxP+Q25 thus enables Ekip G to be set to protect the machine appproprìately.
In particular, the following relationship must be complied with: Q25xSn < Q_G i.e. Q25 < 918/1732 = 0.53.

The value of the intercept of the first protection on the Q-axis can then be set, for example, at Q25=0.48, which corresponds to 831kvar, as shown on the trip unit display.
The parameter Kq2 is set to 0.6.
With Ekip G Hi-Touch, it is also possible to have a second protection curve that approximates more faithfully to the shape of the generator limit curve. The study of the settings leads to the following settings: Q24=0.4, which corresponds to 693kvar as shown on the display of the trip unit, and the parameter Kq, which is set to 0.3.

If, due to an anomaly, the operating point of the generator falls in the tripping area delimited by the two set curves, the protection trips with the set delay time t24=3s.

The result shown on the P-Q diagram of the generator (i.e. with Q24 and Q25 recalculated according to the ratio Sn/SnG, see Figure 6-3.2.1), shows how the set trip curve follows the shape of the underexcitation operating limit of the machine, and, in the event of an anomaly that makes the generator operate with the following power values Q = 1040kvar and P = 520kW, Ekip G trip unit will intervene eliminating the fault within the time t24.

Figure 6-3.2.1



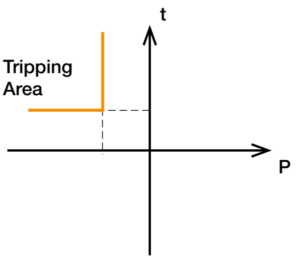
3.2.2 Reverse active power protection (RP - ANSI 32R)

Under normal operating conditions, the generator supplies active power to a load or a network, the active power flow being conventionally assumed to be positive. In case of operations with reverse power flow, i.e. with active power absorbed by the generator, which thus acts as a motor, the prime mover or the turbine are driven. A similar operating condition occurs when, for example, the mechanical action of the prime mover fails or when there is a fault on the speed control system.
By using the protection RP of Ekip G, it is possible to protect the machine in a precise and reliable way thanks to the great sensitivity, wide thresholds and delay times that can be set to avoid unwanted trips in case of transients.

3.2.2.1 Operating modes and characteristics of the protection

The protection against reverse active power RP has a definite time-delay characteristic curve with single threshold, as shown in Figure 1-3.2.2.
Its power threshold can be set as a % of the Sn, and its direction (the direction of the power that is considered to be positive) and tripping time can be set as well. If the total active power is greater than the set threshold and the direction is reverse, protection tripping is delayed.

Figure 1-3.2.2



3.2.2.2 Setting range

The setting parameters for the function against reverse power flow available on all versions of Ekip G are the following:

Reverse active power protection			
Parameter	P11 = (-1...-0.05) x Sn	Threshold step	0.001 x Sn
Tripping time	t11 = (0.5...100)s	Time step	0.1s
Power direction	Predefined direction from the upper side to the lower side (see clause 3.2)		

For further details on the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.2.3 Active overpower protection (OP - ANSI 32OF) Reactive overpower protection (OQ - ANSI 32OF)

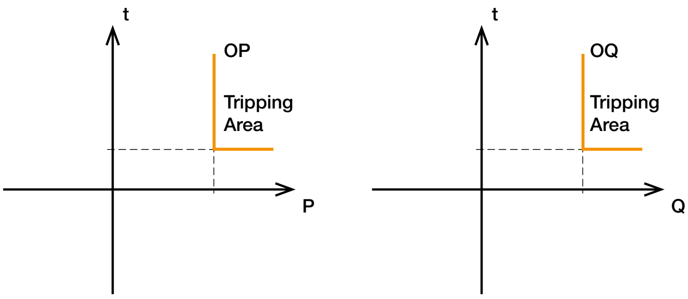
In plants operating in island-mode, the power required from the generator may be higher than the maximum power that the machine is able to supply. This condition entails step loss, which results in the loss of rotor synchronism in relation to the operating frequency and gives rise to oscillations in the voltages of the electrical system.
To provide protection against this condition, or generally when we wish to prevent the generator from supplying too much power, the OP protection of Ekip G can be used to control the active power supplied by the machine.
In the event of overexcitation of the generator (caused for example by a load disconnection with no modification of energizing because of a control system fault), the generator responds by increasing the reactive power supplied.
To provide protection against this condition, the protection OQ of Ekip G can be used, which guarantees the control of the reactive power supplied by the machine.

3.2.3.1 Operating modes and characteristics of the protection

The power protections OP and OQ have a definite time-delay characteristic curve with a single threshold as shown in Figure 1-3.2.3, and their power and tripping time can be both set. Setting of power is a percentage of the rated power of the trip unit.

When the total active or reactive power calculated as a sum of the power in the three phases exceeds the set active or reactive power threshold, the protection delays for the set time and then trips or sends instantaneously an alarm signal.

Figure 1-3.2.3



3.2.3.2 Setting range

The setting parameters for the active and reactive overpower functions available on all versions of Ekip G are the following:

Active overpower protection			
Parameter	P26 = (0.4…2) x Sn	Threshold step	0.001 x Sn
Tripping time	t26 = (0.5…100)s	Time step	0.5s

Reactive overpower protection			
Parameter	Q27 = (0.4…2) x Sn	Threshold step	0.001 x Sn
Tripping time	t27 = (0.5…100)s	Time step	0.5s

For further details on the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

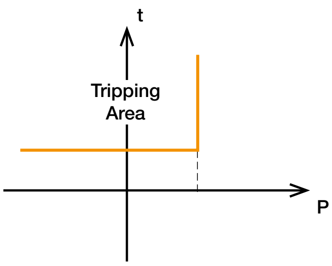
3.2.4 Active underpower protection (UP - ANSI 32LF)

Under normal operating conditions of the machine, a protection function can also be provided against an excessive dip in the active power supplied by the generator connected to the network.
The function intended for this type of protection is the active underpower protection UP identified by the ANSI code 32LF, which could be used to trip the circuit breaker of a machine operating in island mode. This is to prevent overspeed of the generator set owing to operations on the turbine, for example, or more simply to disconnect the generator owing to an excessive disconnection of the loads, with a consequent decrease in the power used.

3.2.4.1 Operating modes and characteristics of the protection

The power protection UP has a definite time-delay characteristic curve with a single threshold as shown in Figure 1- 3.2.4, with adjustable power and tripping time. The power setting is a percentage of the rated power of the trip unit.
As can be seen in the graph, this function works also for negative power values.
In this way, protection against negative power becomes possible also for the values that are not within the RP tripping area and, for the power values that fall in the RP tripping range, the UP could also trip when both protections are enabled.

Figure 1-3.2.4



3.2.4.2 Setting range

The setting parameters for the active underpower function available on all versions of Ekip G are:

Active underpower protection			
Parameter	P23 = (0.1…1) x Sn	Threshold step	0.001 x Sn
Tripping time	t23 = (0.5…100)s	Time step	0.5s

For further details on the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.2.5 Setting example of power protection functions

For this example, a three-phase synchronous generator with the following characteristics is considered:

SnG		1200kVA
VnG		400V
InG		1732A
PnG	0.8xSnG	960kW
QnG	0.6xSnG	720kvar
Pmax supplied	0.9xPnG	864kW
Pmin supplied	0.145xPnG	139.2kW
Qmax supplied	1xQnG	720kvar
Pmin absorbed	0.15xPnG	144kW

With reference to the rated current of the generator, a SACE Emax 2 circuit breaker with a trip unit with 2000A rated current is considered. The rated power of the trip unit for the calculation of the settings of the protections results to be Sn = 1385.6kVA.
The settings for the different protections are determined below.

Protection OP:
For the setting of the protection, the active power value allowed for the generator must be related to the rated power of the trip unit according to the ratio 864/1385.6=0.624.
For example, the protection will be set to P26=0.600, which corresponds to 831.384kW with a time t26=5s. Thus, when the generator supplies active power in excess with this condition persisting for a time longer than the set delay, the protection shall trip.

Protection UP:
For the setting of the protection, the active power value allowed for the generator must be related to the rated power of the trip unit according to the ratio 139.2/1385.6=0.1.
For example, the protection will be set to P23=0.11, which corresponds to 152.4kW with a time t23=5s. Thus, when the generator supplies a lower active power with this condition persisting for a time longer than the set delay, the protection shall trip.

Protection OQ:
For the setting of the protection, the reactive power value allowed for the generator must be related to the rated power of the trip unit according to the ratio 720/1385.6=0.52.
For example, the protection will be set to Q27=0.6, which corresponds to 831.36kvar with a time t27=5s.

Thus, when the generator supplies reactive power in excess and this condition persists for a time longer than the set delay, the protection shall trip.

Protection RP:
For the setting of the protection, the active power value allowed for the generator must be related to the rated power of the trip unit according to the ratio 144/1385.6=0.104.
For example, the protection will be set to P11=0.1, which corresponds to 138.56kvar with a time t11=3s.
Thus, when the generator consumes (opposite direction to the direction set as a reference) a higher active power with this condition persisting for a time longer than the set delay, the protection shall trip.
To be represented on the graph showing the limit value permitted for the generator, the tripping threshold of the different protections must be related to the reference power of the generator.

Table 1-3.2.5 and graphs 1-3.2.5 to 3-3.2.5 summarize and show the values of the different power protection functions of the example.

Table 1-3.2.5

	GenLimitSn	Ekip G Setting	P[kW] Q[kvar] trip	Time [s]	Value referred to the generator
OP	0.624	0.6	831.384	5	0.866
UP	0.1	0.11	152.4	5	0.158
OQ	0.52	0.6	831.36	5	1.155
RP	0.104	0.1	138.564	3	0.144

Figure 1-3.2.5

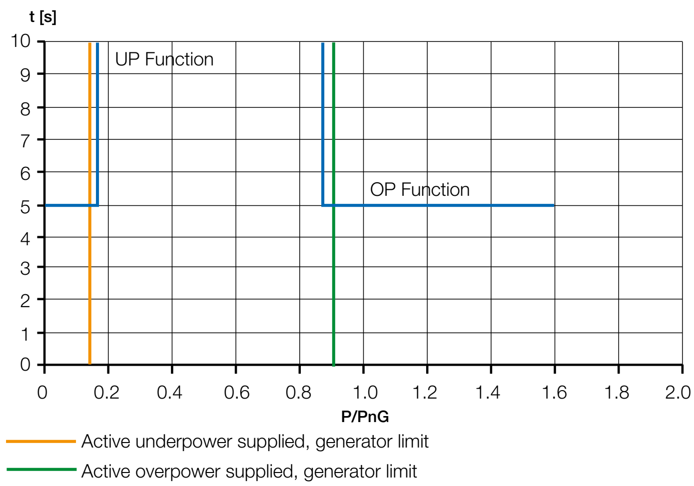


Figure 2-3.2.5

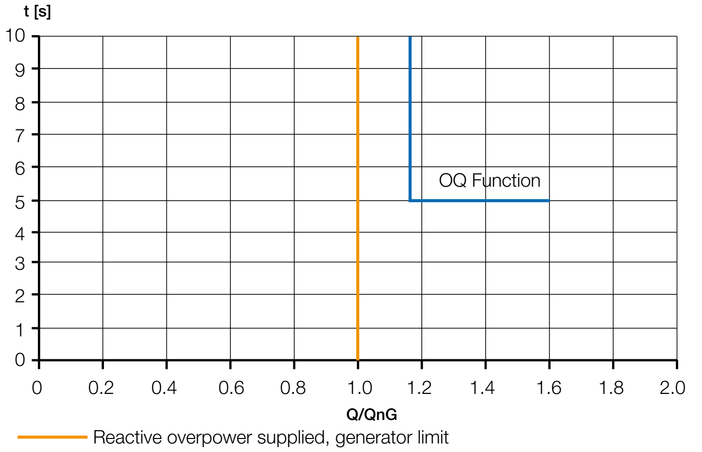
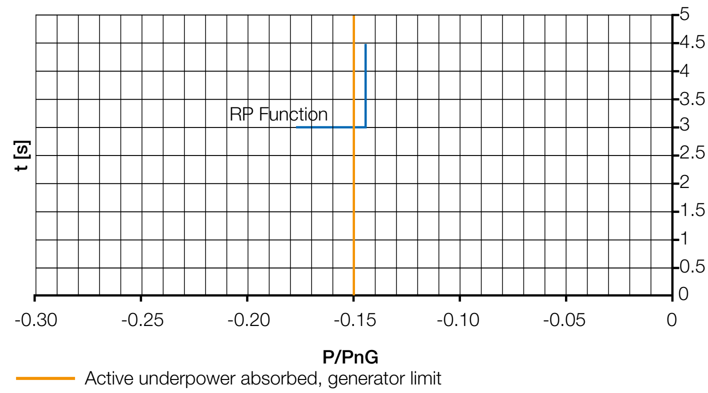


Figure 3-3.2.5



3.3 Overfrequency protection (OF - ANSI 81H) Underfrequency protection (UF - ANSI 81L)

An increase in frequency above the rated value is a consequence of excess of driving-power compared with the active power required by the load connected to the machine. This condition arises, for example, because of a load disconnection due to the elimination of a part of the plant affected by fault.
Normally, the control circuit of the generator is activated by the speed regulator to manage the anomaly and adjusts the prime mover in order to restore the frequency to the rated value.
If the generator control device cannot restore the rated frequency, to avoid mechanical damage to the turbine/alternator unit and to prevent the loads from being supplied at frequency values exceeding the set limits, Ekip G function OF, which protects against overfrequency, can be used.
On the other hand, the reduction in frequency in comparison with the rated value is caused by a drop in the power supplied by the generator due to a load condition requiring greater power than which can be supplied by the generator.

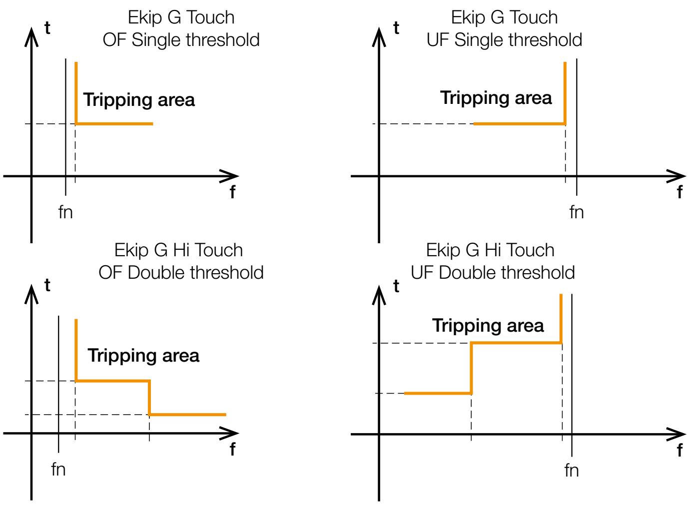
3. Protections of EKIP G trip unit

This occurs for example in case of network loss and consequent switching to island-mode operation supported by the generator.
Under this condition, the disconnection of the loads can be regarded as a procedure to restore the balance between the power flows and consequently to bring the frequency back to its rated value. Ekip G protection against underfrequency (UF) can be used to activate a load disconnection logic or to disconnect the generator.
The restoration of frequency or even the disconnection are used to safeguard the mechanical source that drives the generator, especially if this is a steam turbine.

3.3.1 Operating modes and characteristics of the protection

This protection monitors the frequency on the generator side and therefore the protection is active even if the circuit breaker is open. Under this condition, in the event of an anomaly, the protection generates an alarm signal. If the anomaly occurs with the circuit breaker closed, in addition to the alarm signal, the user can also set the circuit breaker opening.
For the control of under- and overfrequency, Ekip G Touch trip unit provides a single protective function with a definite time characteristic curve. Overfrequency protection OF can be set according to the parameters f13-t13; underfrequency protection UF can be set according to the parameters f12-t12.
Instead, Ekip G Hi-Touch provides a double protection for the control of overfrequency and a double protection for the control of underfrequency.
This characteristic allows any frequency anomalies to be managed in the most proper way, for example by making the protection generate an alarm signal with long time-delay for small variations with respect to the nominal frequency and an opening signal for the circuit breaker with shorter delays for higher variations.

Figure 1-3.3



The double protections for the control of both overfrequency (OF) and underfrequency (UF) are independent one from the other, and have definite time curves.
An overfrequency protection OF can be set through the parameters f13-t13 and the other OF2 through the parameters f18-t18.
An underfrequency protection UF can be set through the parameters f12-t12 and the other UF2 through the parameters f17-t17.
All the frequency control functions (single and double over- and underfrequency protections) have definite time characteristic curve, can be excluded and can be set with a trip threshold according to a multiple of the rated frequency set on the trip unit and with a definite trip time delay. The characteristic curves of these protections are shown in Figure 1-3.3.

3.3.2 Setting range

The setting parameters for the over- and underfrequency function available on all versions of Ekip G trip unit are:

Underfrequency protection UF			
Single threshold UF			
Parameter	f12= (0.9....0.99) x fn	Threshold step	0.01 x fn
Tripping time	t12 = (0.2...120)s	Time step	0.1s
Double threshold UF UF2			
Parameter	f12= (0.9....0.99) x fn	Threshold step	0.01 x fn
Tripping time	t12 = (0.2...120)s	Time step	0.1s
Parameter	f17= (0.9....0.99) x fn	Threshold step	0.01 x fn
Tripping time	t17 = (0.2...120)s	Time step	0.1s

Overfrequency protection OF			
Single threshold OF			
Parameter	f13= (1.01...1.1) x fn	Threshold step	0.01 x fn
Tripping time	t13 = (0.2...120)s	Time step	0.1s
Double threshold OF OF2			
Parameter	f13= (1.01...1.1) x fn	Threshold step	0.01 x fn
Tripping time	t13 = (0.2...120)s	Time step	0.1s
Parameter	f18= (1.01....1.1) x fn	Threshold step	0.01 x fn
Tripping time	t18 = (0.2...120)s	Time step	0.1s

For further details about the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.3.3 Setting example

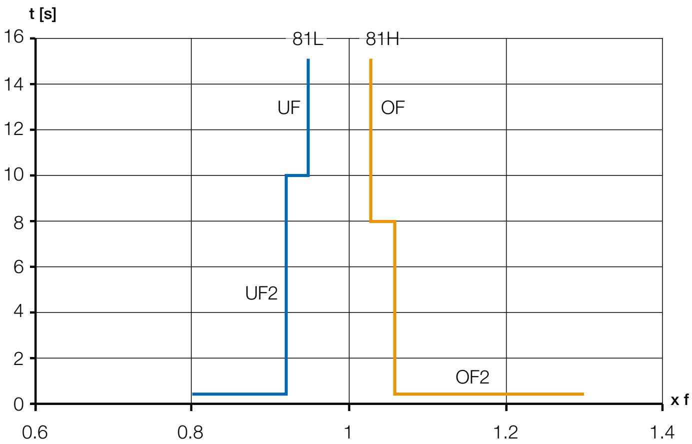
For a generator with a rated frequency of 50Hz and compatibly with the management requirements of the plant and of the generator, a double-threshold protection is recommended for the over- and underfrequency functions, with the following tripping parameters:
Overfrequency function
Low threshold 51.5Hz with tripping time 8s
High threshold 53Hz with tripping time 0.5s
Underfrequency function
High threshold 47.5Hz with tripping time 10s
Low threshold 46Hz with tripping time 0.5s.

Considering the characteristic required for the protection, an Ekip G Hi-Touch trip unit with double protection functions must be used.
As already said, the settings are to be referred to the rated frequency set on the trip unit, and therefore, in the given example, the following settings are to be carried out:

OF	f13 = 51.5/50=1.03xfn	t13 = 8s
OF2	f17 = 53/50=1.06xfn	t17 = 0.5s
UF	f12 = 47.5/50=0.95xfn	t12 = 10s
UF2	f18 = 46/50=0.92xfn	t18 = 0.5s

The above values generate the tripping curves of the frequency protections shown in Figure 2-3.3.
It is possible to have an analogous representation also for UL applications, by reproducing the same example, but with the admitted deviation from the rated frequency referred to 60Hz.

Figure 2-3.3



3.4 Undervoltage protection (UV - ANSI 27) Overvoltage protection (OV - ANSI 59)

The function UV intended for the control of the undervoltage level at the generator terminals is identified by the ANSI code 27. For generators, continuous operation with rated power and frequency and with minimum voltage of 95% is normally permitted.
At lower voltages, undesiderable phenomena could arise, such as: a change in stability conditions, a reactive power quota drawn from the network, a malfunctioning of the connected loads.
It is common practice to associate an alarm signal to the undervoltage protection to enable the operator to take the due precautions (for example by acting on the automatic voltage regulator to remedy an anomalous situation), but in this case also the circuit breaker trip can be exploited to disconnect the machine.
The undervoltage protection could also be considered as a back-up protection in the event of a short-circuit on the generator and failure of the dedicated protection functions, or as a protection against prolonged voltage reductions uncontrolled by the automatic voltage regulator because of a fault on this device.

A typical example of voltage drop, or decrease, may be that in which in a plant supplied by several generators one of them disconnects. Thus, there is an unbalance between the power supplied and the power required by the load.
The generators that remain connected react by trying to compensate for the lack of power with an increase in the current and a reduction in the input voltage at their terminals. Ekip G undervoltage protection can be used to avoid anomalous operating conditions of the machine.
The function OV intended for the control of the overvoltage level at the generator terminals is identified by the ANSI 59 code. Generators are usually designed to operate continuously at their rated power and frequency, at a voltage level that can reach 105% of the rated voltage of the machine. Maintaining an overvoltage exceeding the permitted limits can cause overexcitation and excessive stress on the insulation system.
An anomalous overvoltage condition on the generator could occur following a fault on the voltage regulator or after a change in the speed of the prime mover following a sudden loss of load.
Ekip G protection OV enables the plant to be protected against this condition, which is particularly risky for hydrogenerators or gas turbines.
The voltage protections are completed by the protection VU against voltage unbalance and detection of the rotation direction of the phases (ANSI 47).

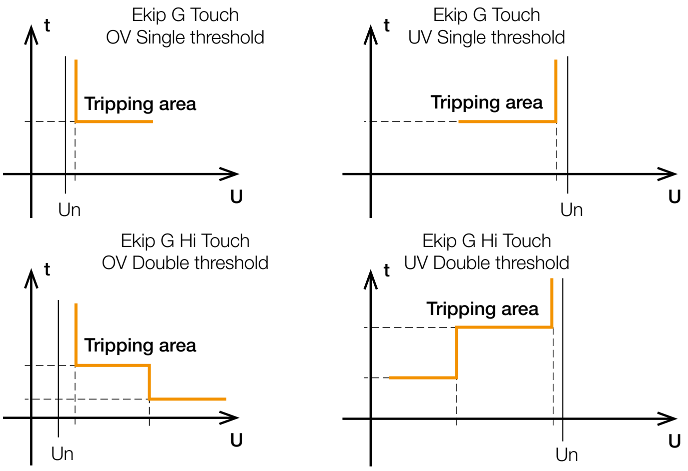
3.4.1 Operating modes of the protection

The trip unit monitors the three phase voltages on the generator side even when the machine circuit breaker is open.
In this case, a voltage anomaly that exceeds the set threshold generates an alarm signal that can be managed through the machine check logic.
If the anomaly is generated with the circuit breaker closed, in addition to the alarm signal, the circuit breaker may trip.
For the undervoltage and overvoltage control, Ekip G Touch trip unit provides a single protection function with definite time characteristic curve. The overvoltage protection OV can be adjusted according to the parameters U9-t9; the undervoltage protection UV can be adjusted according to the parameters U8-t8.
Instead, Ekip G Hi-Touch provides a double protection for the control of overvoltage and a double protection for undervoltage. This characteristic allows any voltage anomalies to be managed in the most proper way, for example by making the protection generate an alarm signal for long time-delay for small variations with respect to the rated voltage and an opening signal for the circuit breaker with shorter delays for higher variations.
Double protections for the control of both overvoltage (OV) and undervoltage (UV) are independent one from the other, and have definite time curves.

3. Protections of EKIP G trip unit

An overvoltage protection OV can be set through the parameters U9-t9 and the other OV2 through the parameters U16-t16.
An undervoltage protection UV can be set through the parameters U8-t8 and the other UV2 through the parameters U15-t15.
All the voltage control functions (single and double over- and undervoltage protections) have definite time characteristic curve, can be excluded and can be set with trip threshold according to a multiple of the rated line-to-line voltage set on the trip unit and with a definite time delay for tripping.
Figure 1-3.4 shows the characteristic curves of these protections.

Figure 1-3.4



3.4.2 Setting range

The setting parameters for the over- and undervoltage protection functions available on all versions of Ekip G are:

Undervoltage protection UV			
Single threshold UV			
Parameter	U8 = (0.5….0.98) x Un	Threshold step	0.001 x Un
Tripping time	t8 = (0.05…120)s	Time step	0.01s
Double threshold UV UV2			
Parameter	U8 = (0.5….0.98) x Un	Threshold step	0.001 x Un
Tripping time	t8 = (0.05…120)s	Time step	0.01s
Parameter	U15= (0.5….0.98) x Un	Threshold step	0.001 x Un
Tripping time	t15 = (0.05…120)s	Time step	0.01s
Overvoltage protection OV			
Single threshold OV			
Parameter	U9= (1.02….1.5) x Un	Threshold step	0.001 x Un
Tripping time	t9 = (0.05…120)s	Time step	0.01s
Double threshold OV OV2			
Parameter	U9= (1.02….1.5) x Un	Threshold step	0.001 x Un
Tripping time	t9 = (0.05…120)s	Time step	0.01s
Parameter	U16= (1.02….1.5) x Un	Threshold step	0.001 x Un
Tripping time	t16 = (0.05…120)s	Time step	0.01s

For voltages ≥ 690V the maximum setting is 1.2xUn.
For further details about the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.4.3 Setting example

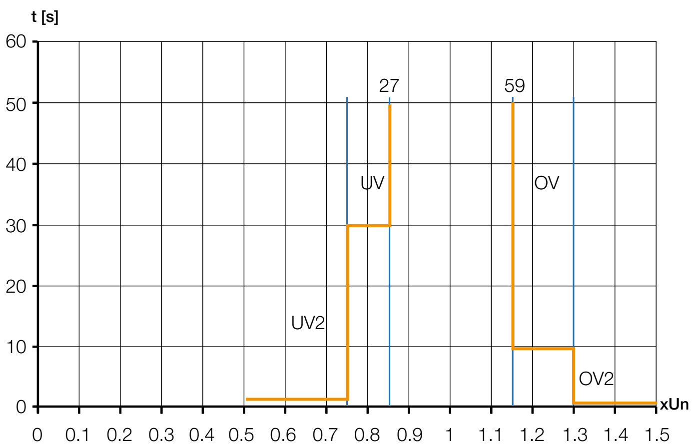
An undervoltage and overvoltage protection with two trip thresholds is required. Therefore Ekip G Hi-Touch trip unit must be used because it provides the required protection with two definite time functions.
The set thresholds are a function of the rated line-to-line voltage set on the trip unit, e.g. 400V, or 480V for UL applications.

For the undervoltage protection UV, a long tripping time is required for voltage lower than 0.85 times the generator rated voltage and a faster tripping time for rated voltage lower than 0.75 times the generator rated voltage.

For the overvoltage protection OV, a long tripping time is required for voltage greater than 1.15 times the generator rated voltage and a faster tripping time for rated voltage greater than 1.3 times the generator rated voltage.
In order to comply with the voltage constraints of this example, the selected settings are summarized below and their relevant tripping curves are shown in Figure 2-3.4.

Function UV			
First threshold UV	U8	0.85xUn	with tripping time t8 = 30s
Second threshold UV2	U15	0.75xUn	with tripping time t15 = 1.5s
Function OV			
First threshold OV	U9	1.15xUn	with tripping time t9 = 10s
Second threshold OV2	U16	1.3xUn	with tripping time t16 = 0.1s

Figure 2-3.4



3.5 Rate of change of frequency protection ROCOF (ANSI 81R)

The protection function that is sensitive to rapid frequency variations is identified by the ANSI code 81R and is known as rate of change of frequency protection. It is available for Ekip G Hi-Touch only and is identified with the acronym ROCOF. This protection enables both positive and negative frequency variations to be detected rapidly and with greater sensitivity, thus ensuring a protection faster than what is possible to obtain with traditional under- and overfrequency functions.

This protection can be applied in the type of plant where the generator is connected in parallel to the main supply (network of the public utility) and to other generators.

Under these conditions, when there is a fault in the distribution network, the network device trips. Consequently the main source is disconnected from the rest of the plant. In this case, the generator shall supply the plant (in island-mode operation) and shall change its electric parameters which will no longer be synchronised with those of the network.

In order to prevent the automatic connection of a non-synchronized generator to the network, the generator has to be disconnected immediately by its circuit breaker. The closing into this non-synchronized condition may cause consequential damage to generator.

Anti-islanding may be a necessary choice to manage the plant in cases where the generator (passing from parallel operation with the network to island-mode operation) may be unable to support the loads (power demand from the loads greater than the generator power output). Instability phenomena could arise that could damage both the generator as well as particularly sensitive types of load. Besides, anti-islanding can be used to avoid continuing to supply a part of the plant which has been isolated from the public utility because of fault or for maintenance.

The ROCOF protection then becomes important as it was designed to prevent the above conditions from occurring. It will trip the generator's breaker in these conditions.

If there were several generators, each generator circuit breaker would need its own rate of change of frequency protection.

In normal operation, the generator has frequency variations that are due, for example, to the control of the loads in the plant or to changes that derive from the prime mover (e.g. fuel injection).

These variations are minor and slower than those that occur for disconnection from the network and therefore they are not detected by the protection.

3.5.1 Operating mode and characteristics of the protection

The protection trip unit measures the frequency variation on the generator side. The trip unit menu can thus be used to select whether to monitor only positive frequency variations (i.e. changes caused by a sudden frequency increase) or only negative frequency variations (i.e. variations caused by a sudden frequency decrease), or both.

This protection function has a single protection step with a definite time curve, and a threshold that is adjustable in terms of frequency variation Hz/s and of trip time delay, which differ from the threshold set for Hz/s variation.

This permits very rapid tripping in response to high frequency variations while ensuring great precision for slow changes. When the threshold of the rate of change of frequency is exceeded, the protection generates an alarm signal or trips the circuit breaker, depending on the selected fault control mode.

3.5.2 Setting range

The setting parameters for the rate of change of frequency function available on Ekip G Hi-Touch trip unit are:

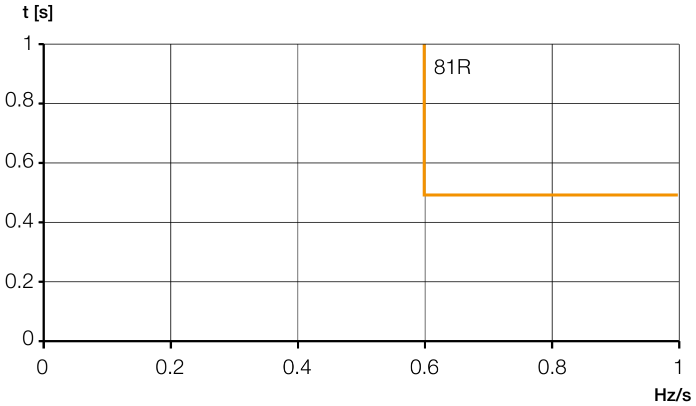
Rate of change of frequency			
Frequency change threshold	f28 = (0.4....10)Hz/s	Threshold step	0.2Hz/s
time threshold	t28 = (0.5...10)s	Time step	0.1s
Selection option for monitoring positive, negative or both type variations			

For further details about the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.5.3 Setting example

The plant management must prevent the generator from remaining in service after a network fault and from keeping "live" not only the production site network but also part of the public utility network; that is to say, unwanted islanding must be avoided.
As small-size synchronous generators are particularly sensitive to network disturbances, Ekip G Hi-Touch trip unit can set up the protection based on the rate of change of frequency for which a setting of f28=0.6Hz/s, and a trip delay t28=500ms are selected.
The tripping curve is shown in Figure 1-3.5.

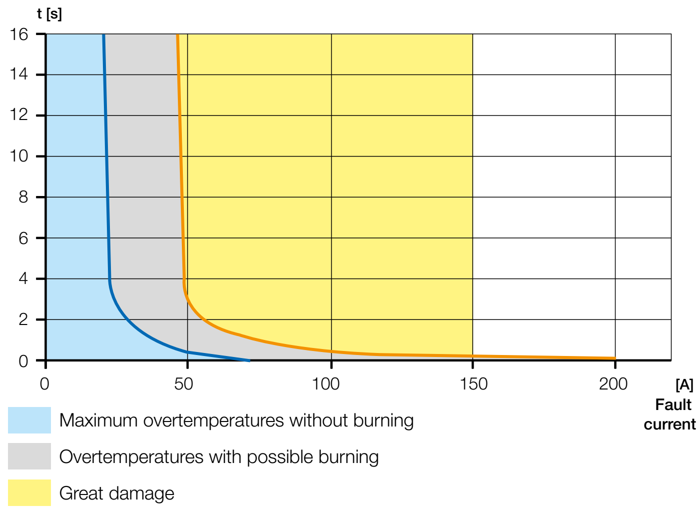
Figure 1-3.5



3.6 Residual overvoltage protection (RV - ANSI 59N)

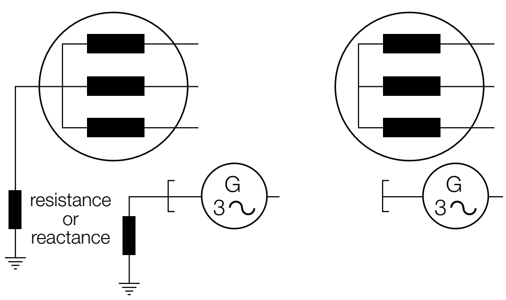
An earth fault in the stator windings is the most common type of fault to which a generator may be subject and is one of the main causes of operation failure of the machine.
This type of fault could be caused by deterioration in the insulation of the windings, for example due to hostile environmental conditions because of the presence of humidity. The condition may also be aggravated by oil or dirt on the surfaces of the coils outside the stator slots. Therefore, the generator must be protected against this condition to prevent the machine from operating under anomalous conditions with consequent instability of the electrical parameters. Also to prevent the earth fault from developing into a short-circuit between the phases with destructive consequences for the generator.
Obviously, the risk of damage is reduced for small fault currents and short extinction times.
In general terms, this concept is represented graphically by the curves which reproduce the withstand capability of earth faults.
They are given by the generator manufacturer and have a shape similar to that shown in Figure 1-3.6.

Figure 1-3.6



The method of protection against an earth fault in a generator depends on the structure of the plant and on the type of grounding of the generator, as shown in Figure 2-3.6.
Often, in order to limit the effects of the earth fault on the generator, it is common practice to connect to earth the neutral point of the machine. This may be required when there is high impedance or resistance, or when the generator has the neutral point isolated from the earth. In general, the greater the resistance or the impedance of the earth connection (up to the limit case of the isolated neutral), the smaller the fault current, which becomes difficult to detect.

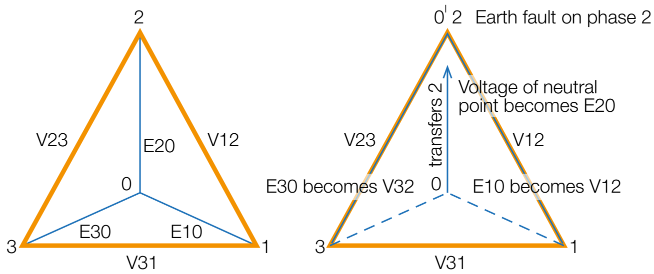
Figure 2-3.6



An anomalous event that causes a fault to earth of a phase or of a winding increases the voltage in the other two unaffected phases and on the neutral point. The voltage variation depends on the position of the fault on the winding, on the fault resistance and on the possible earthing impedance.

Assuming that a bolted fault occurs at the generator output terminals (100% of the winding in thus affected) in a system isolated from earth, the two healthy phases will carry all the line-to-line voltage and the star point will carry the phase-to-neutral voltage, as shown in Figure 3-3.6.
If the fault occurs in the winding and near the neutral point, the voltage variation shall be small and difficult for the protection to detect.

Figure 3-3.6



To protect the generators with the neutral isolated from earth or connected to earth with high impedance against earth faults in the stator windings or in external points, the residual overvoltage function RV of Ekip G can be used.
This protection enables up to 90% of the stator windings to be monitored starting from the line terminals of the generator.

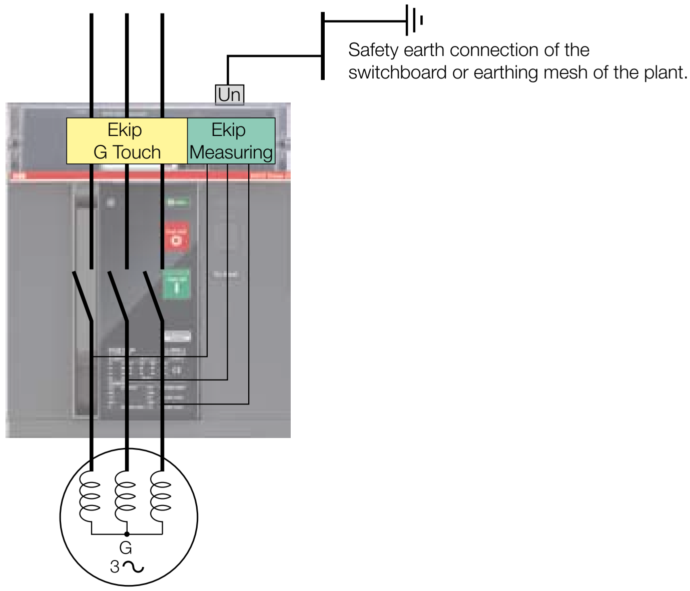
3.6.1 Operating modes of the protection

The RV protection of Ekip G provides residual overvoltage protection without making necessary to purchase and cable external voltage transformers.
The calculation of the residual voltage and the checks necessary for the operation of the protection are completely controlled by the trip unit mounted on the circuit breaker.
With reference to Figure 3-3.6 above, in the event of a bolted fault on phase 2, E10 becomes E10' and E30 becomes E30', whereas E20 is equal to zero.
In this case, the sum of the phase vectors E10+E20+E30, which under normal conditions is nil, can be expressed as E10'+E30' with the hypothesised fault. As 0' coincides with point 2, the previous relationship can be rewritten as V12+V32, which provides the result 3E.
Therefore, by generalizing this concept, we see that the measure provided by the protection is 3 times the voltage taken on by the star point in its shifting.
This protection also works with the circuit breaker open; under this condition, an alarm signal is generated following an anomaly above the threshold.
On the other hand, when the circuit breaker is closed, only the alarm that signals a fault inside the machine, or the trip command can be selected, which because of the nature of the anomaly, does not interrupt the fault circuit.

3.6.2 Characteristics of the protection

The residual overvoltage protection has a definite time-delay characteristic curve with single trip threshold and adjustable voltage; the voltage setting can be a multiple of the rated voltage set on the trip unit. The tripping time can also be set.
For correct operation of this protection, it is necessary to connect the earth reference to the dedicated clamp, available on Ekip Measuring Pro module. For example, this reference could be the safety earth connection of the switchboard where the circuit breaker is installed, or the earthing mesh of the plant.
Figure 4-3.6 schematizes this connection.

Figure 4-3.6



3.6.3 Setting range

The setting parameters for the residual overvoltage function RV available on all versions of Ekip G trip unit are:

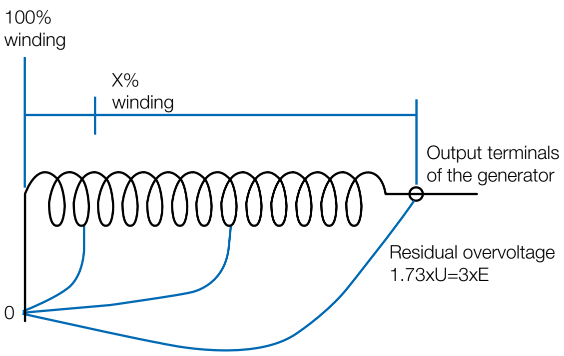
Residual overvoltage protection			
voltage variation threshold	U22 = (0.05....0.5) x Un	Threshold step	0.001 x Un
tripping time	t22 = (0.5...120)s	Time step	0.01s with curve t = k

For further details about the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.6.4 Setting example

Here is a setting example for a generator with the neutral point isolated from earth, and with line-to-line voltage V12=V23=V31=U=400V (480V for UL applications) and therefore phase voltages E10=E20=E30=E=230V (277V for UL).
Depending on the operating modes of the protection, for a bolted fault at the generator terminals, the maximum residual overvoltage read by the protection results to be 3xE=1.732xV=690V (831V for UL).
Let us assume you want to set a control on the residual voltage to prevent a value higher than 15% of the maximum residual voltage from occurring.
As the protection reads 3xE, the protection threshold results to be 104V (125V for UL).
However, when considering that the setting of the protection refers to the rated line-to-line voltage Un, the ratio 104/400 (125/480 for UL) gives a value equal to 0.26.
Therefore, a lower setting parameter must be set on the trip unit, for example U22=0.24, which gives a trip threshold of 96V (115V for UL), that represents 14% of the maximum residual overvoltage. The tripping time is set to t22=3s.
By applying the ratio that links the maximum residual overvoltage with all the winding and can be expressed by the following formula (1.73xUn):(100%)=(U*):(1-x%) it is possible to determine how the setting (U*=U22xUn=96V or 115V for UL) can protect about 86% of the winding from the output terminals of the generator, as shown in Figure 5-3.6.

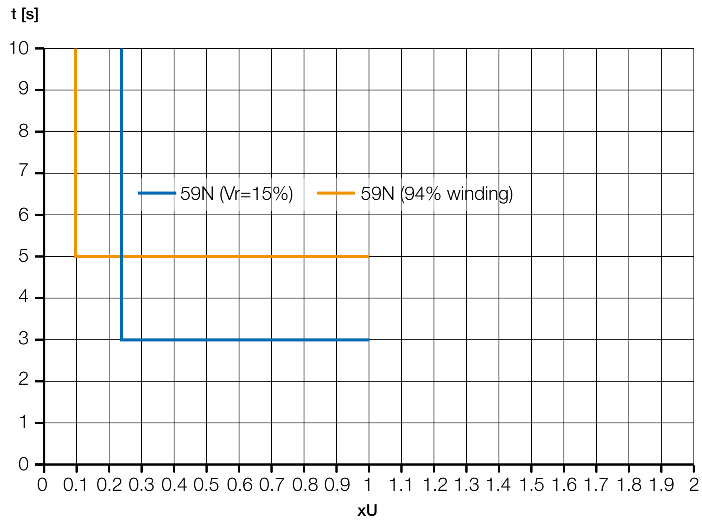
Figure 5 -3.6



To take another example, improving the protection level, let us suppose that we wish to protect 94% of the winding with a tripping time of 5 seconds.
The above formula is used to determine the value U*, which represents the residual voltage read by the protection.
This value, related to the voltage set for the trip unit, enables the reference for the setting to be determined, which is equal to 0.104. Therefore, by setting the protection to U22=0.1 t22=5s, a trip threshold is obtained that satisfies the hypothesized protection requirements.

The settings in the two previous examples give rise to the tripping curves shown in Figure 6-3.6 for the function 59N.

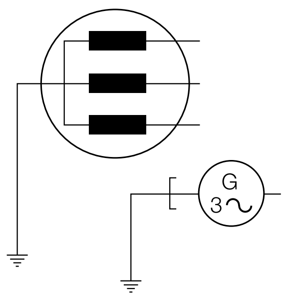
Figure 6-3.6



3.7 Earth fault protection (G - ANSI 51N/G or 50N/G TD 50N) Differential ground fault protection (Rc – ANSI 87N)

In low-power applications, the generators are directly connected to earth (effective grounding) as per the diagram in Figure 1-3.7. In this case, the function 59N previously discussed cannot be used to provide protection against insulation loss in the windings. In fact, in the presence of a ground fault, the potential of the star point is constrained by direct grounding. As a consequence, the conditions necessary for the development of the residual voltage, fundamental for the operation of function 59N, are not present, and however the earth fault currents are such as to be monitored by a current protection (for example through a toroid on the connection to earth of the star point of the machine).

Figure 1-3.7



Therefore, for the protection against ground faults in the stator windings or in other points outside the machine, it is possible to use the traditional protection function against residual earth overcurrent.

3.7.1 Operating modes and characteristics of the protections

Ekip G Touch and Ekip G Hi-Touch trip units allow the following current protection modes against earth fault to be realized:

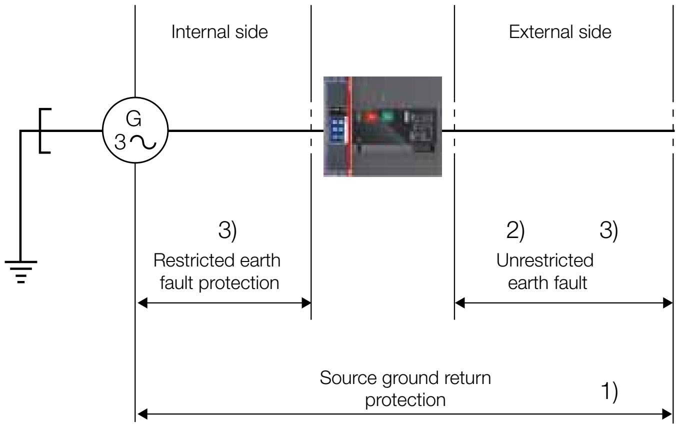
- earth fault protection obtained when the trip unit manages the signal relevant to the three phase currents (or relevant to the currents of the three phases and of the neutral) detected directly by the circuit breaker. The trip unit calculates the vectorial sum, thus realizing the protection called G, which basically corresponds to the code ANSI 51N for inverse time curves and ANSI 50NTD for definite time curves. This function has the possibility to set t4=instantaneous to get protection function ANSI 50N.
  In this way a protection is realized against the earth faults which occur on the load side only (distribution or external side) of the generator circuit breaker, thus implementing unrestricted earth fault protection;

- earth fault protection obtained when the trip unit manages only the signal coming from the toroid positioned on the connection to earth of the generator neutral point, thus realizing the protection called G_{ext}, which basically corresponds to the code ANSI 51G for inverse time curves and ANSI 50GTD for definite time curves. In this way, the protection defined source ground return is realized. This protection provides for the opening of the circuit breaker for all the earth faults, those occurring on the load side (external side) of the circuit breaker, thus implementing a real protection (i..e circuit breaker opening and fault isolation), as well as on the generator side (internal side), without interrupting the fault circuit, but with the possibility of sending a signal to control the excitation or the prime mover;

- earth fault protection, obtained when the trip unit manages both signals, one coming from the toroid positioned on the connection to earth of the generator neutral point (Gext), and the other one coming directly from the trip unit (G), thus implementing restricted earth fault protection.
  If the fault is internal, the signal arrives from the external toroid only, with the possibility to associate the generation of an alarm signal that indicates an anomaly on the windings or which acts on the excitation circuit.
  If the fault is external, besides coming from the external toroid, the signal comes also from the sensors onboard the trip unit. In this case, it is possible to obtain the circuit breaker opening by setting selective thresholds or tripping times of functions G and Gext. In practice, by setting G faster than Gext, the circuit breaker opens with the interruption of the fault in the plant.

The three protection modes are shown in Figure 2-3.7.

Figure 2-3.7

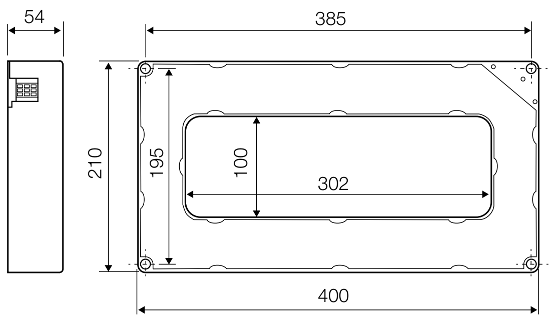


1) G_{ext} only, with the toroid on the connection to earth of the generator neutral point
2) G only, with sensors onboard the tripping unit
3) with the toroid on the connection to earth of the generator neutral point and with sensors onboard the tripping unit.

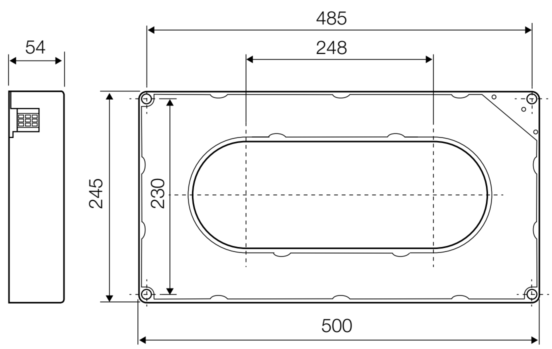
When the sum of the currents or the current that comes from the toroid exceeds the set current threshold, and this condition persists for a time longer than the set delay, the protection trips and the circuit breaker opens or an alarm signal is generated, according to the selected mode.
The protection against earth fault has definite time curves or inverse time curves with constant I^2t. Current threshold and tripping delay can be set.

3. Protections of EKIP G trip unit

Besides, there is the possibility of using a dedicated toroid, which can be positioned on the rear part of the circuit breaker, thus realizing Rc protection.
The presence of a dedicated rating plug is required.
The toroid for the differential protection is available in two sizes:
- a “small” one for E1.2 3p and 4p and for E2.2 3p



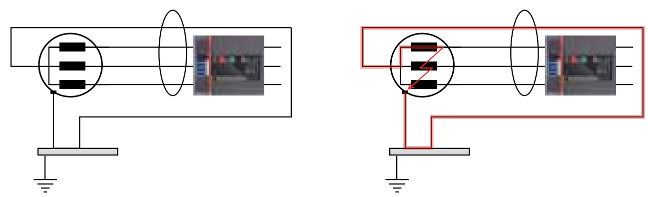
- a “medium” one for E2.2 4p and for E4.2 3p.



This option allows the protection against earth fault identified by ANSI code 87N to be achieved. This protection function is particularly useful to detect, also in selective mode, any earth fault in the generator. The insertion scheme to be realized (as shown for example in the IEEE Standards) requires that the toroid embraces the live conductors and the earthing conductor, as shown in Figure 3-3.7.
According to the dimension of the available toroids, in order to have a homogeneous distribution of the conductors in the toroid window, we would recommend the use of the protection 87N on the following circuit breakers:
E1.2 4p with toroid of E2.2 4p
E1.2 3p with relevant toroid
E2.2 3p with toroid of E2.2 4p
By making the conductors pass through the toroid window and by guaranteeing a homogeneous distribution, it would be possible to use the protection 87N also for E2.2 4p, E4.2 3p and E4.2 4p with the relevant toroid (medium size).
Such operation could be quite difficult to carry out.

For Ekip G Touch trip unit the use of the function Rc excludes the other protections against earth fault G and G_{ext}, whereas for Ekip G Hi-Touch the functions Rc and G can be used at the same time.

Figure 3-3.7



3.7.2 Setting range

The parameters for the setting of the earth fault protection function available on all versions of Ekip G trip unit are:

Earth fault protection				
G with t=k and I2t=k curves; it can be set according to the rated current In of the circuit breaker, and operates through its internal current sensors;	Current threshold	I4 = (0.1…1) x In	Threshold step	0.001 x In
	Time threshold	t4 = (0.1…1)s t4=inst. (for curves t=k)	Time step	0.05s
G_{ext} with t=k and I2t=k curves; it can be set according to the rated current In of the external toroid	Current threshold	I4 = (0.1…1) x In	Threshold step	0.001 x In
	Time threshold	t4 = (0.1…1)s	Time step	0.05s
Rc protection Dedicated rating plug from 100A to 4000A. Definite time curve t=k	Current threshold	3A, 5A, 7A, 10A, 20A, 30A		
	Time threshold	0.06s, 0.10s, 0.20s, 0.30s, 0.40s, 0.50s, 0.80s		

The parameter In represents the rated current of the circuit breaker or of the external toroid, depending on whether G or G_{ext} is operating. For UL version the maximum admitted current I4 is equal to 1200A.

For further details about the setting parameters, see the technical catalogue of the new air circuit breaker SACE Emax 2.

3.7.3 Setting example

Let us take the case of a generator with neutral point connected directly to ground, characterized by the electric parameters listed in the following table

SnG	1600kVA
VnG	400V
x"d%	16%
x0%	3.60%
x2%	16%
InG	2309A
ZnG	0.1ohm
X"d	0.083ohm
X0	0.019ohm
X2	0.087ohm
R earth fault	0ohm

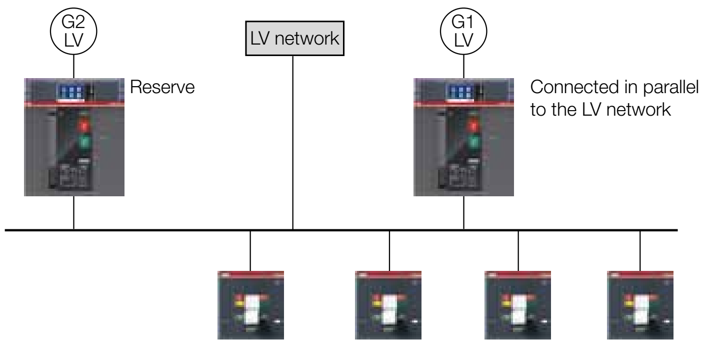
A protection against earth fault is obtained without particular problems by positioning an external toroid having rated current 800A on the connection to ground of the neutral point of the generator, and setting I4 =0.6, which fix the trip threshold at 480A with a tripping time set, for example, to t4=0.5s.

3.8 Synchrocheck (SC - ANSI 25)

The synchronism control function available on Ekip protection trip units, identified by the ANSI code 25, is used in case of paralleling of two independent supply systems.
This application is typical in the following plant engineering situations:

- when islanding occurs (condition arising after loss of network); a reserve generator G2 shall connect in parallel to a generator G1 already connected to the plant, as shown in Figure 1-3.8, and the reserve generator G2 contributes to supplying of the users that cannot remain disconnected. This procedure is actuated to adequate the supply power to the power required by the loads to prevent excess users from being disconnected;
- on a marine installation, in which a faulty generator is replaced by connecting another emergency generator to the live busbar;
- when a bus tie closes thus forming a loop in the distribution system;
- as a safety condition, to prevent a production system (generator) from connecting to a dead plant and energizing it;
- short parallel condition, in which before disconnecting a machine (for example for maintenance, in order to avoid a plant being placed out of service), for a short period the plant also operates with the reserve machine connected.

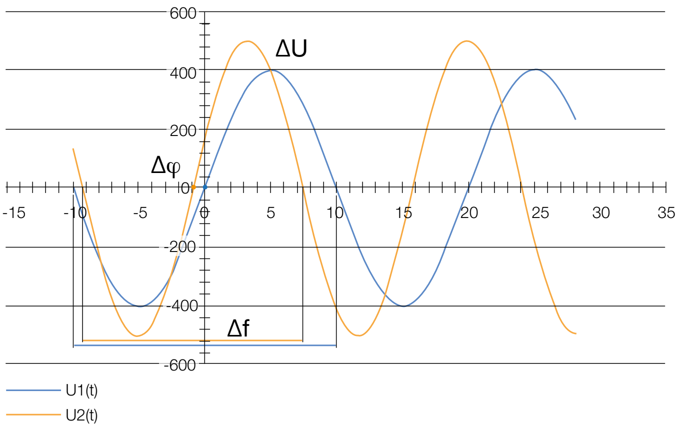
Figure 1-3.8



3. Protections of EKIP G trip unit

In general, the generator is started up and runs under no-load condition; the synchronisation process aligns the generator voltages with the reference voltages.
At this point, under suitable connection conditions, the generator is connected in parallel and the loads are associated to it, according to the planned load connection logic.
The parallelism suitability condition is monitored by the function SC available on the Ekip Synchrocheck module. This module uses a contact to supply the information that parallelism conditions have been reached. This information, integrated into the control logic, will close the parallel circuit breaker.
As perfect synchronism is not possible between the three-phase voltage sets of the two systems to be interconnected, tolerance ranges for amplitude, frequency and phase shift as shown in Figure 2-3.8 are permitted, within which the parallel operation can be carried out as well.

Figure 2-3.8



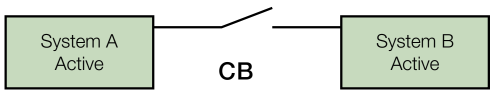
3.8.1 Operating modes of the protection

The synchronism control function enables the two types of interconnection shown in Figure 3-3.8 to be controlled through two different operating modes, namely:

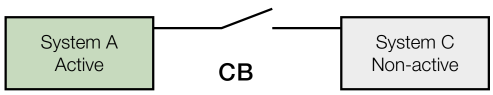
- "live busbar" mode, which allows the generator closing or a portion of live plant on a live busbar to be controlled;
- "dead busbar" mode, which allows the generator closing or a portion of live plant on a dead busbar to be controlled.

Figure 3-3.8

"live busbar" mode



"dead busbar" mode



In the "live busbar" mode, Ekip Synchrocheck module enables:

- checking that the live system, "system B", to which the connection is to be made, is actually live, having a value that is greater than the set control threshold Ulive, for a time that is longer than the set time;
- choosing whether to check the synchronism condition by monitoring, for the two live systems, the following parameters:
  - voltage only
  - voltage and frequency
  - voltage, frequency, phase
- choosing whether to link the signaling contact state to the circuit breaker position (open/closed);
- setting the persistence time tsyn desired for synchronism;
- with reference to the set time tsyn, this module allows setting of the values Δf Δφ that realize a synchronism condition persisting at least for the set time tsyn;
- when this module detects that the conditions for ΔU Δf Δφ meet the set values and the circuit breaker is in open position, the contact OSC (contact signaling the synchronism condition) excites, switching from the standby condition.

Once the set conditions for synchronism have been verified, the contact OSC switches, thus giving its assent, and maintains this position for at least 200ms.

After this time has elapsed and if the paralleling circuit breaker is still open, the contact OSC remains excited if the synchronism conditions are still verified. Otherwise, if one of the suitability condition for synchronism fails, the contact OSC returns to the rest position.
When the power circuit breaker closes, if the option relating to the dependence of the contact OSC on the circuit breaker state is set to “YES”, the contact OSC de-excites; on the contrary, if the option is set to “NO”, the contact OSC remains excited.

In the “dead busbar” mode, the Ekip Synchrocheck module checks that the value of the line-to-line voltage in the “non-active” system C is lower than the set control voltage Udead and that the generator side has a voltage Ulive exceeding the set threshold. Both conditions must persists for the set time to establish that the two systems have a voltage condition suitable for interconnection.

The “live” or “dead” busbar side, with respect to the external connection side of the Ekip Synchrocheck can be selected through the relevant parameter.

The operating mode of this module, excluding the check on ΔU, tsyn, Δφ and Δf can be summarized as described for the “live busbar" mode.

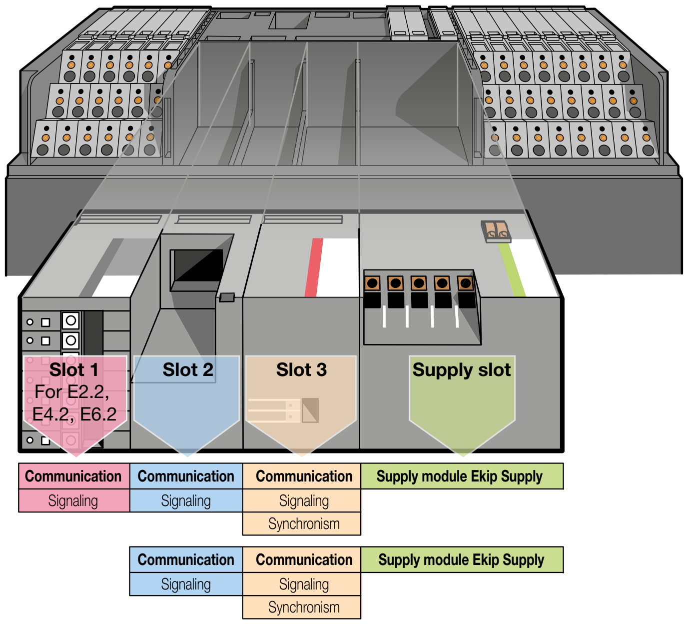
3.8.2 Characteristics of the protection

The synchronism control function SC for paralleling two lines is available through an external module (Synchrocheck module). This module can be used with the Ekip Touch and Ekip Hi-Touch trip units in the version for distribution and in the version for generator protection already equipped from factory with the Ekip Measuring Pro module.

The Ekip Synchrochek module acquires the voltage between two phases of the line by means of an external single-phase voltage transformer and the three line-to-line voltages by means of the Ekip Measuring Pro module. Also on the braker side, for voltages above 690V, a three-phase VT must be provided.

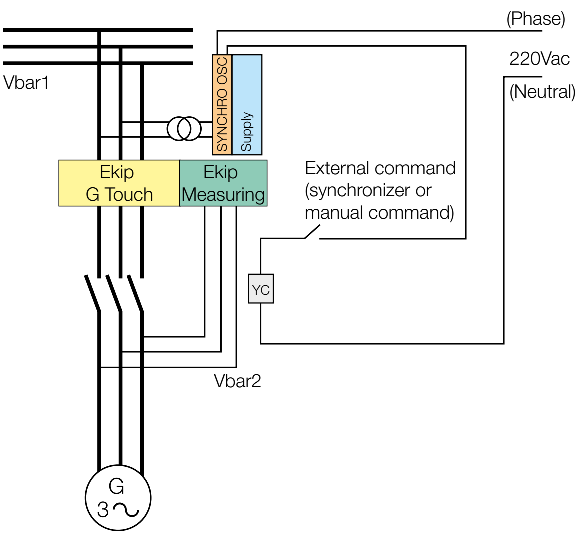
The Ekip Synchrochek module can be mounted directly in the terminal box area of the fixed circuit breaker or in the fixed part (cradle) of the withdrawable circuit breaker and occupies (as shown in Figure 4-3.8) one of the two spaces available in E1.2 or one of the three spaces available in E2.2, E4.2 and E6.2.

Figure 4-3.8



The connection between the Ekip Synchrocheck module and the protection trip unit is made through the Ekip Supply module, which supplies both the trip unit and the Synchrocheck module.
The voltages of Ekip Supply that can be used for the supply of the Synchrocheck module are from 110 Vac/dc to 220 Vac/dc or from 24Vdc to 48Vdc. In the Synchrocheck module, an output contact OSC is available that is activated when synchronism is reached and allows the circuit breaker to be closed directly through wiring with the shunt closing release YC (at 220 Vac) or to be inserted into the check logic of the generator, according to the diagram in Figure 5-3.8.

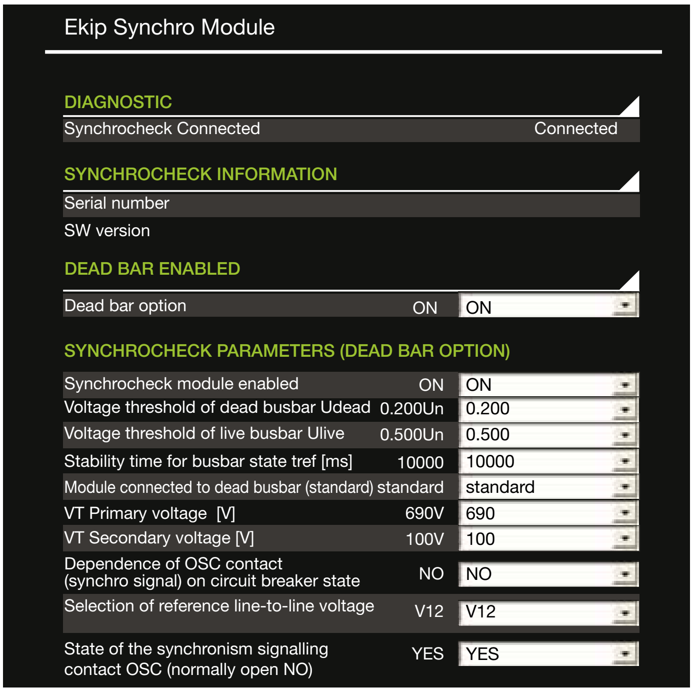
Figure 5-3.8



3.8.3 Setting range

The operating parameters of the Synchrocheck module are set through Ekip Connect, which has the graphic interface of Figure 6-3.8 for the option "dead busbar" and of Figure 6-3.8a for the option "live busbar".

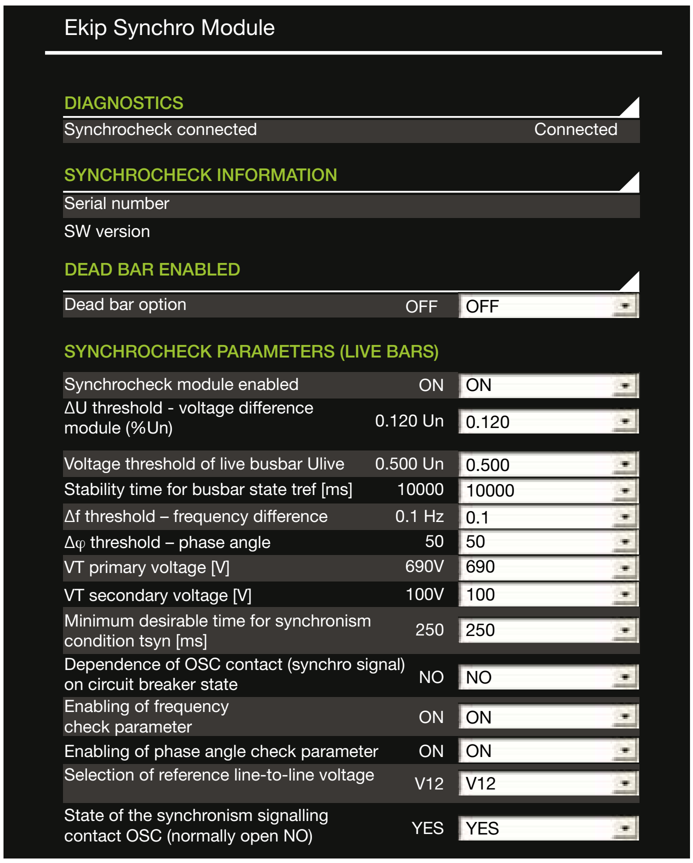
Figure 6-3.8



Ekip Synchro Module

DIAGNOSTIC		
Synchrocheck Connected	Connected	
SYNCHROCHECK INFORMATION		
Serial number		
SW version		
DEAD BAR ENABLED		
Dead bar option	ON	ON
SYNCHROCHECK PARAMETERS (DEAD BAR OPTION)		
Synchrocheck module enabled	ON	ON
Voltage threshold of dead busbar Udead	0.200Un	0.200
Voltage threshold of live busbar Ulive	0.500Un	0.500
Stability time for busbar state tref [ms]	10000	10000
Module connected to dead busbar (standard)	standard	standard
VT Primary voltage [V]	690V	690
VT Secondary voltage [V]	100V	100
Dependence of OSC contact (synchro signal) on circuit breaker state	NO	NO
Selection of reference line-to-line voltage	V12	V12
State of the synchronism signalling contact OSC (normally open NO)	YES	YES

Figure 6-3.8a



Ekip Synchro Module

DIAGNOSTICS		
Synchrocheck connected	Connected	
SYNCHROCHECK INFORMATION		
Serial number		
SW version		
DEAD BAR ENABLED		
Dead bar option	OFF	OFF
SYNCHROCHECK PARAMETERS (LIVE BARS)		
Synchrocheck module enabled	ON	ON
ΔU threshold - voltage difference module (%Un)	0.120 Un	0.120
Voltage threshold of live busbar Ulive	0.500 Un	0.500
Stability time for busbar state tref [ms]	10000	10000
Δf threshold – frequency difference	0.1 Hz	0.1
Δφ threshold – phase angle	50	50
VT primary voltage [V]	690V	690
VT secondary voltage [V]	100V	100
Minimum desirable time for synchronism condition tsyn [ms]	250	250
Dependence of OSC contact (synchro signal) on circuit breaker state	NO	NO
Enabling of frequency check parameter	ON	ON
Enabling of phase angle check parameter	ON	ON
Selection of reference line-to-line voltage	V12	V12
State of the synchronism signalling contact OSC (normally open NO)	YES	YES

The parameters to be set for functioning of the protection are shown in the following table.

Setting parameters for “live busbar” option			
1)	Syncrocheck module enabled	YES/NO	
2)	ΔU threshold - voltage difference module (%Un)	range (0.02... 0.12) x Un	step 0.01 x Un
3)	Voltage threshold of live busbar Ulive	range (0.5...1.1) x Un	step 0.01 x Un
4)	Stability time for busbar state tref [ms]	range (0.1... 30)s	step 0.1s
5)	Δf threshold – frequency difference	range (0.1...1)Hz	step 0.1Hz
6)	Δφ threshold – phase angle difference	range (5°...50°)	step 5°
7)	VT Primary voltage [V]	100, 115, 120, 190, 208, 220, 230, 240, 277, 347, 380, 400, 415,440, 480, 500, 550, 600, 660, 690, 910, 950, 1000, 1150	
8)	TV Secondary voltage [V]	100, 110, 115, 120	
9)	Enabling of frequency check parameter	ON/OFF	
10)	Enabling of phase angle check parameter	ON/OFF	
11)	Selection of reference line-to-line voltage	U12, U23, U31	
12)	State of the synchronism signalling contact OSC (normally open NO)	YES/NO	
14)	Dead bar option	ON/OFF	
16)	Minimum desirable time for synchronism condition tsyn [ms]	(0.1-3)s	step 0.1s
17)	Dependence of OSC contact (synchro signal) on circuit breaker state	YES/NO	

Setting parameters for “dead busbar” option			
1)	Syncrocheck module enabled	YES/NO	
3)	Voltage threshold of live busbar Ulive	range (0.5...1.1) x Un	step 0.01 x Un
4)	Stability time for busbar state tref [ms]	range (0.1... 30)s	step 0.1s
7)	VT Primary voltage [V]	100, 115, 120, 190, 208, 220, 230, 240, 277, 347, 380, 400, 415,440, 480, 500, 550, 600, 660, 690, 910, 950, 1000, 1150	
8)	TV Secondary voltage [V]	100, 110, 115, 120	
11)	Selection of reference line-to-line voltage	U12, U23, U31	
12)	State of the synchronism signalling contact OSC (normally open NO)	YES/NO	
13)	Voltage threshold of dead busbar Udead	range (0.02...0.2) x Un	step 0.01 x Un
14)	Dead bar option	YES/NO	
15)	Module connected to dead busbar (standard)	standard or reverse	
17)	Dependence of OSC contact (synchro signal) on circuit breaker state	YES/NO	

NOTE: the number reference has been given to facilitate reading; it does not appear in the protection.
For further details on the setting parameters, please refer to the technical catalogue of the new air circuit breaker SACE Emax 2.

U_n is the rated line-to-line voltage that can be set on the display of the trip unit. Naturally, this value shall coincide with the primary voltage of the VT, since the two systems to be connected together shall have the same rated voltage.
A short explanation of the different setting parameters of the protection follows.
Parameter 1)
enables the synchronism control module;
Parameter 2)
relates to the permitted difference between the modules of the voltage selected as a reference for the two systems;
Parameter 3)
relates, in “live busbar” mode, to the voltage value of the system to which the connection will be made and which must be greater than the value set for the relevant time setting. Condition to verify voltage stability in the live system;
Parameter 4)
relates to the persistence time of the check voltage set on the live busbar (3) and dead busbar (13);
Parameter 5)
relates to the permitted difference between the frequency values of the voltage selected as a reference for the two systems;
Parameter 6)
relates to the permitted difference between the phase angles of the voltage selected as a reference for the two systems;
Parameter 7)
relates to the choice of the primary voltage of the external VT on the synchronism module side;
Parameter 8)
relates to the choice of the secondary voltage of the external VT on the synchronism module side;
Parameter 9)
relates to enabling of the frequency check;
Parameter 10)
relates to enabling of the phase check (angle);
Setting OFF for the frequency parameter cuts out the phase parameter, whatever selection has been made. In this way, the synchronism check is run on the voltage only.
Setting ON for the frequency and phase parameter enables the synchronism check by monitoring the three parameters voltage module, frequency and phase.

Setting ON for the frequency parameter and OFF for the phase parameter enables the synchronism check by monitoring the parameters voltage module and frequency

Parameter 11)
relates to the selection of the reference line-to-line voltage on the generator side (voltage sockets).
It enables one of the line-to-line voltages U12 U23 U31 to be set as voltage reference according to how the VT has been connected on the network side

Parameter 12)
relates to the position of the contact OSC for signalling the condition that is suitable for parallelism. It can be set as normally open (it closes under suitable condition) or normally closed (it opens under suitable condition);

Parameter 13)
relates, in "dead busbar" mode, to the voltage value of the system to which the connection will be made and which must be lower than the value set to consider the busbar as not live;

Parameter 14)
relates to the operating mode of the module: choose "YES" to enable "dead busbar" operating mode; choose "NO" to enable "live busbar" operating mode;

Parameter 15)
relates to the "dead busbar" condition and refers to the presence of the Synchrocheck module on the dead busbar side (normal configuration);

Parameter 16)
relates to the persistence time wanted for the synchronism conditions. The values Δf and Δφ that can be set to control the synchronism conditions are influenced by the set value tsyn. The protection carries out internal checks thus making possible only the choice of the parameters Δf and Δφ that allow a synchronism condition persisting at least for the set time tsyn. As a first approximation, the values of Δf and Δφ that are coherent and are accepted by the protection can be assessed through the following relation $360° \times \Delta f \times t \leq 2 \times \Delta\varphi°$;

Parameter 17)
relates to the fact that the signaling contact OSC changes or not its state when the power circuit breaker closes.
The contact OSC de-excites when the power circuit breaker closes by setting the parameter to "YES".
The contact OSC does not de-excites when the power circuit breaker closes by setting the parameter to "NO".

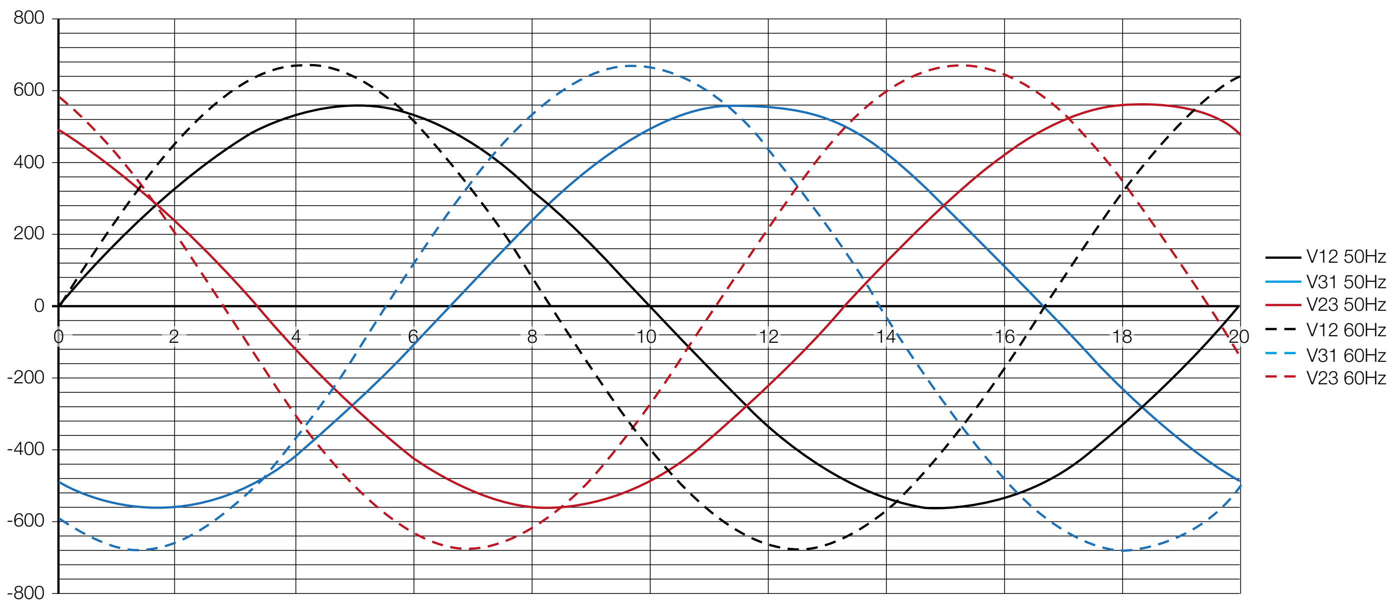
3.8.4 Setting example

This example considers a portion of the electrical plant characterised by:

- live busbar, with the set of three voltages as shown in Figure 7-3.8, and having the following parameters:
  line-to-line voltage U12: module U=400V (480V for UL);
  phase angle φ_{12}=0;
  line-to-line voltage U23: module U=400V (480V for UL);
  phase angle φ_{23}=120°;
  line-to-line voltage U31: module U=400V (480V for UL);
  phase angle φ_{31}=240°;
- voltage frequency f=50Hz (60 Hz for UL)
- presence of a generator that shall be connected in parallel to the busbar.

For the control of the connection network/generator shown in

Figure 7-3.8



the example, we assume to set a time tsyn=250ms.
After the internal checks, the function Synchrocheck allows, for example, the following parameters to be set, which comply with the set time limits:

2) ΔU threshold - voltage difference module: 10%
5) Δf threshold – frequency difference: 0.2Hz
6) Δφ threshold – phase angle difference 10°

In fact, it results that the synchronism condition persists for about 278ms.
If the requirement had been to set a parameter Δφ=7°, maintaining the parameter Δf=0.2Hz, the trip unit, by calculating a persistence time of synchronism of about 194ms (that results to be lower than the set time tsyn) would not have made the setting of the desired Δφ possible.
The requirement to have the parameter Δφ=7° and a persistence time of synchronism coherent with the set tsyn can be satisfied by setting Δf to a value equal to or lower than 0.15Hz.

As regards the plant characteristics, the parallel operation involves connecting a generator to a live busbar, so the following settings must be made in addition to those enabling the synchronism module:

14) Dead bar option:	setting "NO" to enable the "live busbar" mode and to set up the protection for the control of two live busbars.
3) Voltage threshold of live busbar Ulive	setting 80% of Un.
4) Stability time for busbar state tref	setting 10s; These settings, tailored to meet the assumed plant requirements, allow verifying that the voltage of the live network has an appropriate and steady value.
11) Selection of reference line-to-line voltage	U12; The selected voltage is taken as a reference for the synchronism check.
9) Enabling of frequency check parameter:	setting ON.
10) Enabling of phase angle check parameter	setting ON; It allows the synchronism condition to be checked on the three parameters of voltage, phase and frequency in compliance with the check mode assumed for this example.
12) State of the synchronism signalling contact OSC (normally open NO)	setting YES; The plant control logic requires that the condition of synchronism suitability is signalled by the closing of the dedicated contact. Than the normally open state is set.
7) VT Primary voltage [V]	according to the network voltage indicated in the initial data, the value 400V shall be set.
8) VT Secondary voltage [V]	according to the secondary voltage of the selected VT (for example 100V), the value 100V shall be set on the trip unit.
17) Dependence of OSC contact (synchro signal) on circuit breaker state	YES; the state of the contact OSC is made dependent on the state of the power circuit breaker.

Generator synchronisation is carried out by the operator or is performed by the system control logic, which, for example, acts on the energizing unit to control the voltage amplitude or the action on the prime mover for phase and frequency checks.
When the set of three generator voltages, in particular the voltage set as reference with respect to the corresponding network voltage, takes on voltage, frequency and phase values suitable to the set parameters, the synchronism control module gives its consent.

This signal can be integrated into the control logic to enable the generator circuit breaker to close and then realize parallel connection.
Figure 8-3.8 shows the typical shape of two sinusoidal voltages with differences in the module, phase and frequency.

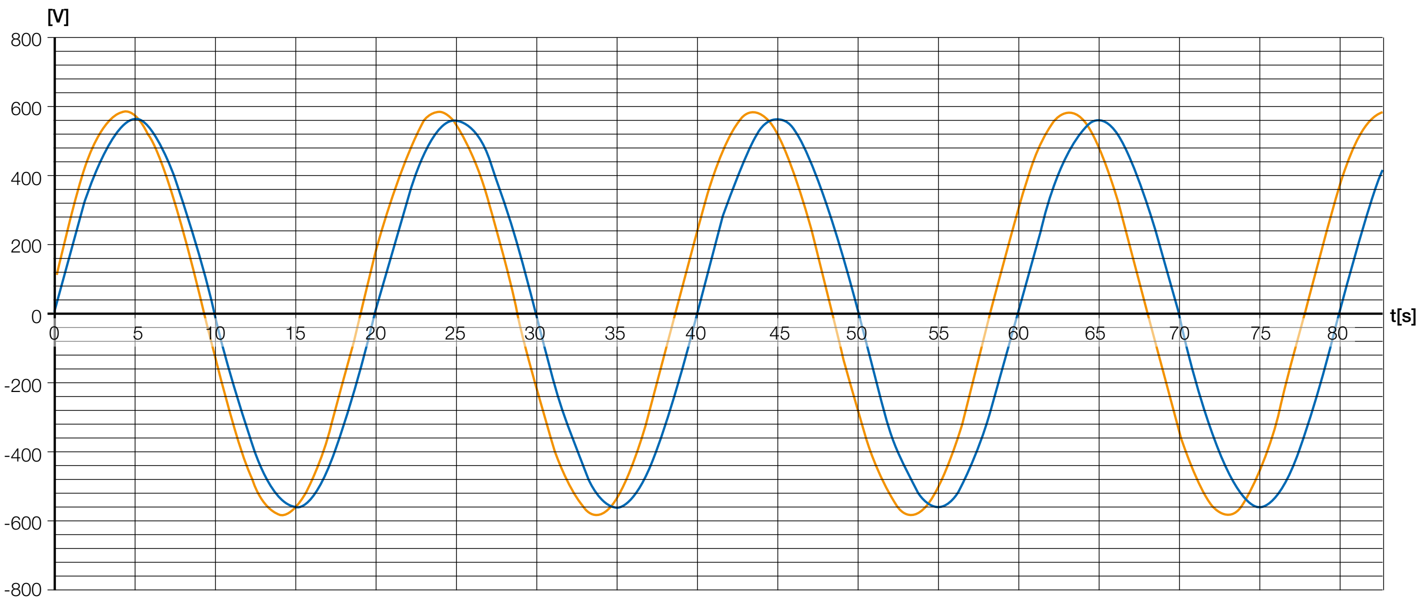
3.9 Protections against overload and short-circuit

These protection functions are the traditional current functions that are usually available in the electronic protection trip units fitted into ABB SACE Emax 2 air circuit breakers and normally used for common plant applications. Their use for protection purposes and their control in terms of trip thresholds shall be considered according to the peculiar requirements for generator protection and depend on these.

3.9.1 Overload protection (L - ANSI 49)

Overcurrents can cause overheating of the stator windings and must be eliminated before the temperature reaches critical levels for the machine.
The temperature rise above values that could be critical for the machine is avoided by monitoring the current that the generator is called to supply under normal operating conditions.
This protection can be typically realized by the traditional current protection function against overload L (ANSI 49 code) or, for higher current values which require shorter tripping times, the function against delayed short-circuit can be used.
In principle, the prescriptions for the overload limit of the generator, given by a typical time/current overload curve or by single points representing current-withstand characteris-

Figure 8-3.8



tics, are generally stated in the main national and international Standards or in the Shipping Registers' Regulations.
As an example, we can report the permitted characteristic for generators according to IEEE Standard C37.102. They are characterized by the following points:

Stator current as % of the rated current of the machine	218	150	127	115
Current withstand time in seconds	10	30	60	120

A further limit point is specified by the main Shipping Registers and is characterized by:

Stator current as % of the rated current of the machine	300
Current withstand time in seconds	2

The international Standard IEC 60034-1 states that generators must be able to withstand a current that is 1.5 times the rated current for at least 30s.
Therefore this prescription corresponds with a point in the overload curve permitted by IEEE.

3.9.2 Time-delayed overcurrent protection S (ANSI 50TD – 51) and instantaneous overcurrent protection I (ANSI 50)

The maximum instantaneous overcurrent protection (ANSI 50 or protection I) or time-delayed protection (ANSI 51 and 50TD or protection S) are used as protection against short-circuits on the network side.
This condition is viewed by the generator as a large power and current request with a consequent slowing down of the machine. In addition to the typical reduction of network voltage at the fault point, this would trigger an energization check that makes the generator supply the traditional short-circuit current value that in the very first instants is considered to be about 6-8 times the rated current in relation to the machine parameter X"d.
The main problem that arises from this is the deterioration of the stator and rotor windings due to the high temperature rises that are generated by the currents and problems linked to the mechanical structure of the machine.
As a consequence, the functions against delayed or instantaneous short-circuit can be used to disconnect the generator from the plant area affected by the fault.
They can be considered to be the main protections for small generators or as back-up protections functions for larger generators.

In addition, the time-delayed protection 51 and 50TD or S could be used as previously mentioned also as protection against the high overload currents that may occur under normal operation and have to be interrupted quickly so as to prevent the machine from operating beyond its thermal limits.
The time-delayed protection function against short-circuit with definite time characteristic (curves t=K) is available also with two independent protection thresholds which can be active at the same time.
Besides, it is available also the directional protection against short-circuit D (ANSI code 67), which is a protection very similar to the time-delayed function S with definite time characteristic and which in addition offers the possibility to recognize the direction of the current during the fault period, based on a current reference set on the trip unit. The direction of the current makes it possible to detect if the fault is either on the load or on the supply side of the circuit breaker and to trip with different times according to the direction. This protection, with definite time delayable characteristic, can be excluded.

3.9.3 Operating modes and characteristics of the protections

The current protection functions LSI work on the basis of the r.m.s. value of the currents of the three phases and of neutral, if present.
The protection L has curves which:
- comply with the Standard IEC 60947-2, with thermal memory function,
- comply with the Standard IEC 61255-3, according to the typical parameters k α of the Standard
- comply with the relationship given in the Standard IEC 61255-3, but according to the parameters k=80 and α=4, which allow a curve I^4t to be obtained.
  In order to increase the number of curves with the same slope, ABB has introduced a parameter that is automatically calculated by the protection and conditions the passage of the curves for the current value 3xIn in the set time range from 3s-144s.

The function L can be set in current threshold and trip delay. Normally, this protection cannot be excluded, but exclusion becomes possible through a dedicated rating plug.
The protection S has constant time or inverse time curves with I^2t constant and with thermal memory function.
Current threshold and trip delay can be set. This protection can be excluded.
The protection I can be set in current threshold. Intentional delays cannot be set and this protection can be excluded.
When one of the currents exceeds the set current threshold, and this condition persists for a period longer than the set delay, for the functions L and S, or instantaneously for the function I (i.e. with intentional delay zero), the circuit breaker opens.

3.9.4 Setting range

The following parameters for setting the overload and short circuit protection functions are available in all versions of Ekip G:

Overload protection L				
Current threshold	I1 = (0.4...1) x In	Threshold step	0.001 x In	
Time threshold	t1 = (3...144)s with I = 3xI1	Time step	1s	Charact. $I^2t=k$
Time threshold	t1 = (3...144)s with I = 3xI1 to increase the number of curves with the same slope	Time step	1s	Charact. IEC60255-3 (k=0.14 α=0.02) (k=13.5 α=1) (k=80 α=2)
Time threshold	t1 = (3...144)s with I = 3xI1 to increase the number of curves with the same slope	Time step	1s	Charact. (k= 80α= 4) $t = b \times \frac{k \times t1}{\left(\frac{If}{I1}\right)^{\alpha} - 1}$

Delayable short-circuit protection S			
First current threshold	I2 = (0.6...10) x In	Threshold step	0.1 x In
Time threshold Charact. t=k (*)	t2 = (0.05...0.8)s t2 = (0.05...0.4)s for UL	Time step	0.01s
Time threshold Charact. $I^2t=k$	t2 = (0.05...0.8)s with I = 10xI1 t2 = (0.05...0.4)s for UL	Time step	0.01s
Second current threshold	I5 = (0.6...10) x In	Threshold step	0.1 x In
Time threshold Charact. t=k	t5 = (0.05...0.8)s t5 = (0.05...0.4)s for UL	Time step	0.01s

(*) possibility of enabling zone selectivity (ANSI 68) with time t2sel =(0.04...0.2)s Time step = 0.01s

Instantaneous short-circuit protection I			
Current threshold	I3 = (1.5...15) x In	Threshold step	0.1 x In
Time threshold	instantaneous		

For further details about the setting parameters, please refer to the technical catalogue of the new air circuit breaker SACE Emax 2.

3.9.5 Setting example

In the example a three-phase synchronous generator with the following rated parameters is considered :
- rated power SnG=1050kVA
- rated voltage Un=400V
- rated current InG=1515A

characterized by the reactance values shown in Table 1-3.9.

Table 1-3.9

Direct synchronous reactance	xd	260%
Direct transient reactance	x'd	28.80%
Direct subtransient reactance	x"d	13.60%
Quadrature sub-transient reactance	x"q	14.20%
Negative sequence reactance	x2	13.90%
Direct sequence reactance	x0	3.80%
Subtransient time constant	T"d	14ms
Armature time constant	Ta	32ms
Transient time constant	T'd	2.5s

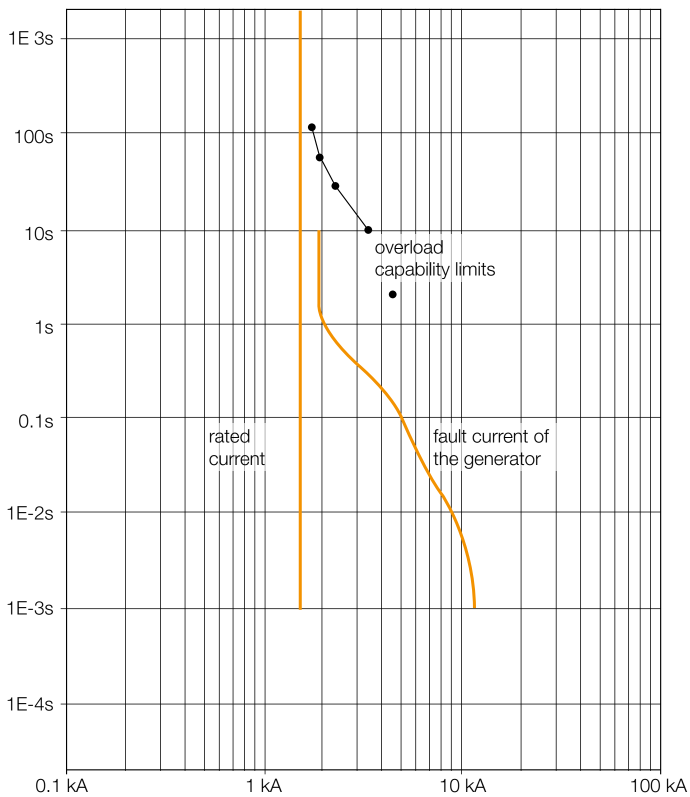
and by the following overload limits referred to the rated current and shown in Table 2-3.9.

Table 2-3.9

multiples InG	current [A]	time [s]
2.18	3302.7	10
1.5	2272.5	30
1.27	1924.05	60
1.15	1742.25	120
3	4545	2

The parameters of the above tables, represented on a time/current chart, originate the curves in Figure 1-3.9, which show the shape of the fault current and the overload capability limits of the generator.

Figure 1-3.9



The aim of this example is to find settings that are suitable for the functions LSI of the generator circuit breaker to obtain a protection curve appropriate to the machine characteristics, paying attention (if possible), to create a possible selectivity condition towards the circuit breaker of the loads supplied . With reference to the rated current of the generator (1515A), we can assume to use a circuit breaker with 2000A rated current.
The chosen settings identify a trip curve of the circuit breaker, as shown in Figure 2-3.9. The protection intercepts the short-circuit curve of the machine, by isolating it from the network fault (detail in Figure 3-3.9), or protecting it, during normal operation, against the critical overloads (detail in Figure 4-3.9) which would otherwise cause the thermal limits to be exceeded.

In the example, the following settings have been chosen:

overload L or 49	I1=0.75xIn t1=3s
delayed short-circuit S or 50TD	I2=1.2xIn constant time curve; t2=0.30s
instantaneous short-circuit I or 50	I3=OFF

Figure 2-3.9

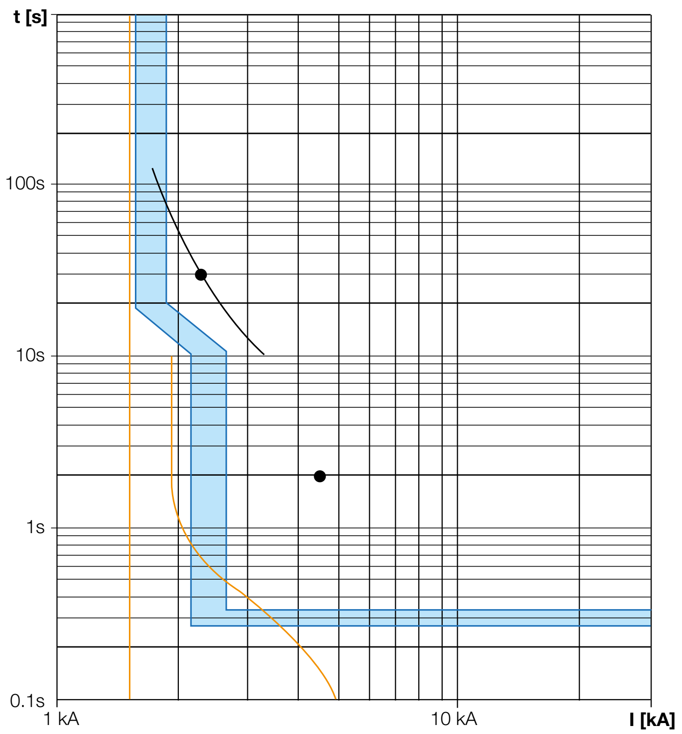


Figure 3-3.9

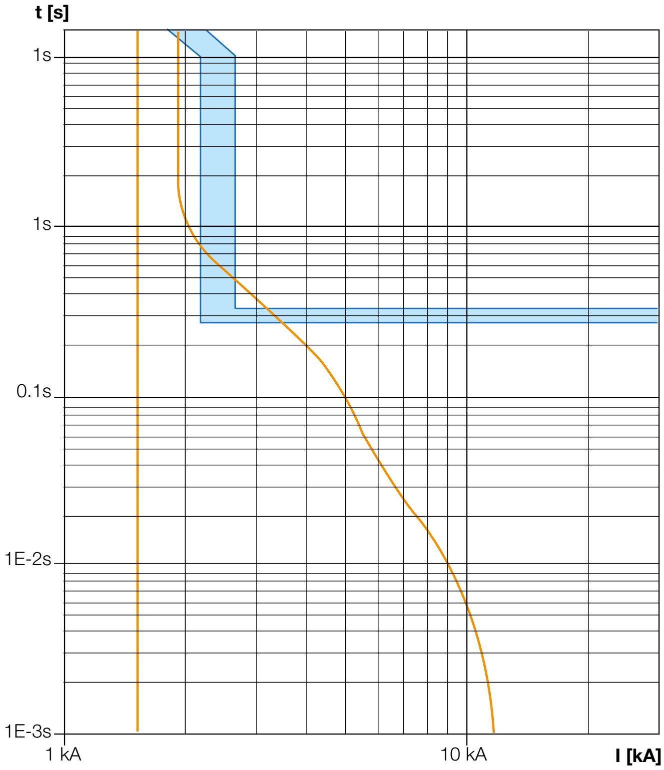
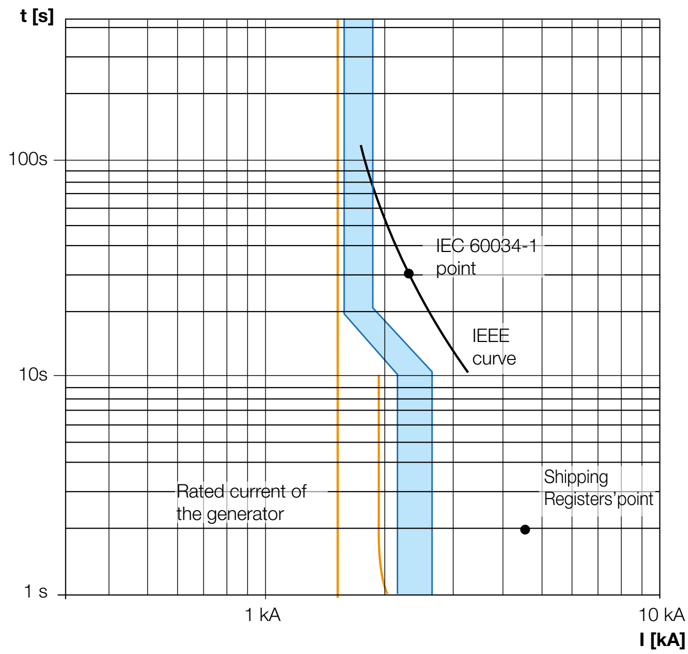


Figure 4-3.9



From the settings and from the relevant diagrams it can be deduced that the protection function thus implemented is quite a limit condition, considering both how the fault current curve of the generator is intercepted as well as in terms of selectivity towards the downstream circuit breakers. To improve this situation the function 51V could be useful, as previously pointed out.

3.10 Current unbalance protection (IU - ANSI 46) Voltage unbalance protection (VU - ANSI 47)

Generators are designed to function with a three-phase balanced load, but the possibility that a current unbalance occurs cannot be excluded.
The unbalance can be due to different causes, such as the presence of non-symmetrical systems (for example for distribution lines without phase transposition), unbalanced loads, fault or interruption on one of the phases.
This unbalance manifests itself with the appearance of a current of negative sequence in the generator. This current flows through the stator and induces in the rotor a current with double frequency, with consequent damage of the rotor due to the quick temperature rise. If this condition persisted for a long time, the generator would be seriously damaged. For these reasons, it is necessary to provide the generator with a protection function against current unbalance.
Two types of protection are normally used: one operating according to the negative sequence of the current and the other one according to current unbalance as accepted by the Standard IEEE 242.
The operating principle of the protection against current unbalance implemented on Ekip G trip unit is based on the control of the difference between the modules of the r.m.s. values of the current between the phases, in compliance with the following relationship

$$IU = \frac{|I_{max}| - |I_{min}|}{|I_{max}|} \times 100$$

and causes the protection trip when the unbalance exceeds a set percentage value I6 persisting for a period longer than the set time t6. Phase difference angles are not considered since only the modules are involved.
The current threshold I6 and the trip delay t6 of this protection can be set, according to the values given below. This protection has definite time trip characteristic and can be excluded.
The available settings are:
I6=(2..90)% xIn with step 1% (In is the rated current "rating plug" of the trip unit)
t6=(0.5..60)s with step 0.5s.

The operating principle of the protection against voltage unbalance implemented on Ekip G trip unit, instead, in compliance with NEMA definition, considers the maximum difference of the r.m.s. value of the voltage in the phases from the average value, referred to the average value and expressed as a percentage. Phase difference angles are not considered because only the modules are involved.

$$VU = \frac{\text{maximum deviation of the line voltage from its average value}}{\text{average value of the line voltage}} \times 100$$

The voltage threshold U14 and the trip delay t14 of this protection function can be set according to the values given below.
This protection has definite time trip characteristic and can be excluded.
The available settings are:
U14= (2..90)% xUn with step 1% (Un is the rated voltage set on the trip unit)
t14= (0.5..60)s with step 0.5s.

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1SDC007409G0202 - 06/2014

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