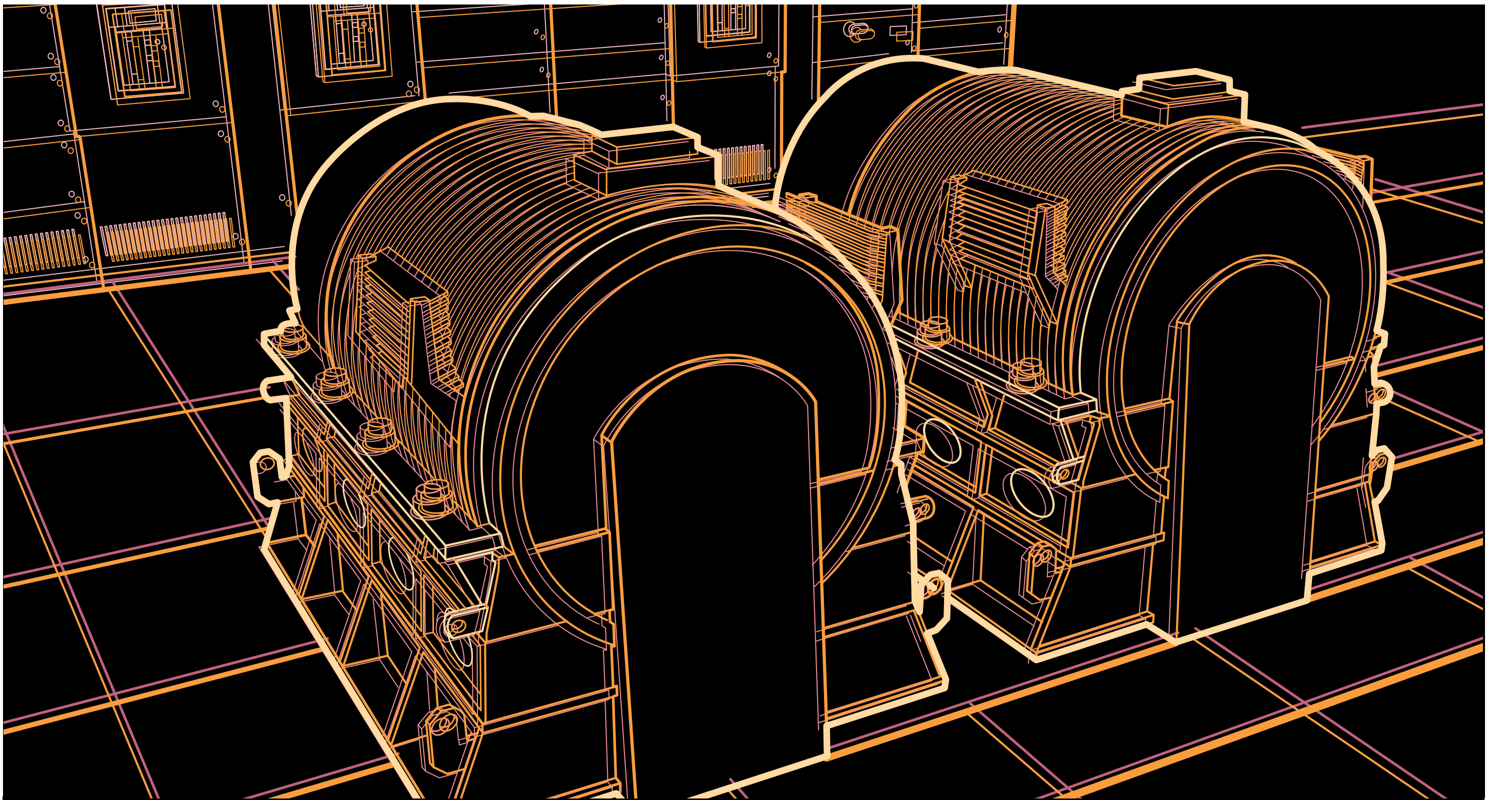


White paper

Generators protection: Ekip G trip unit for SACE Emax 2

Power and productivity
for a better world™

Generators protection: Ekip G trip unit for SACE Emax 2

Index

1. Introduction

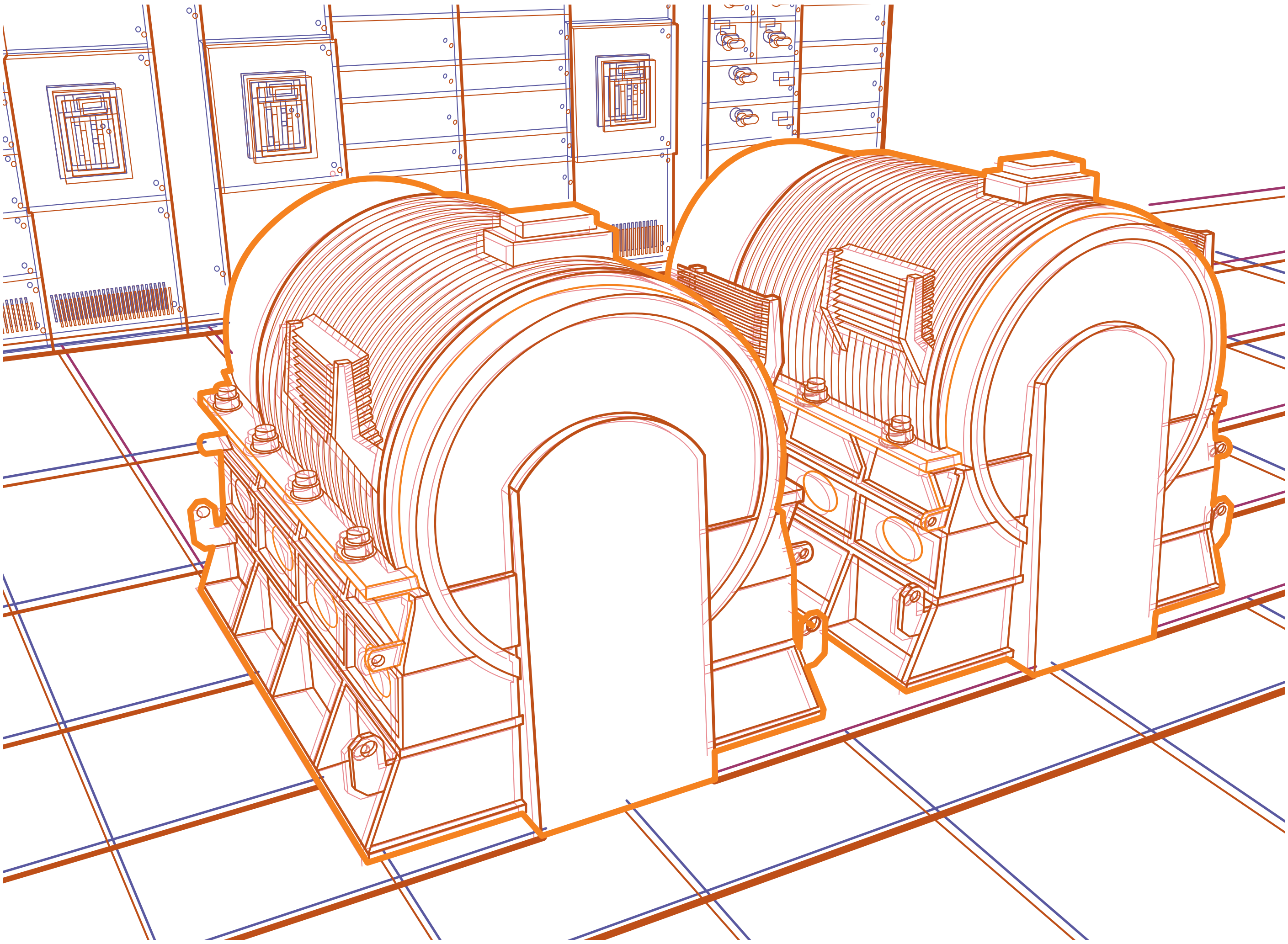
As electric generators are rotating machines, they may easily be subjected to internal faults or anomalies arising from the system to which they are connected. For this reason, the protections used must be efficient and prompt to protect the generator appropriately.

With the new generation of trip unit on ABB SACE Emax 2 Ekip G for protecting the generators, Fig. 1-1, SACE Emax 2 is providing an effective and reliable solution for protecting low-voltage generators. The following paragraphs illustrate the protections required for each type of installation, which are a function of the type of generator, its size in terms of rated power and the type of operation for which the generator is designed.

Ekip G is the new trip unit on SACE Emax 2 for protecting generators. It contains the functions for electric protection of the machine and for monitoring the main critical parameters for connecting the generator to the plant.

These functions are generally available via indirect multifunction relays and are now incorporated inside SACE Emax 2 to ensure a solution that is easy to install and compact and reliable.

Figure 1-1



2. Applications of generators and protections

One of the applications of the synchronous generator is found in the typical and modern field of energy saving by means of cogeneration. A general generating unit could consist of a first motor supplied with methane gas coupled with a three-phase synchronous alternator for producing electric power for home consumption and for possible sale to the network of the power produced or of excess power.
Other applications for synchronous generators are either on ships, where the machine is the source of electric power for the entire boat 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 first motor and with the relative command and control panel. The unit is normally used for producing emergency electric power or for meeting peak demand (when installed parallel to a power network) or as the sole source of continuously rated power.
The generator constitutes the most delicate and expensive part of such an electric system. Accordingly, redundancy of the protections provided, especially those that protect the machine from the heavy faults, could be required. The protection system for a generator is complex and complicated both to calibrate and to control. For low-power machines the protection system is simpler, the types of protection being reduced and redundancy, for example, being eliminated.

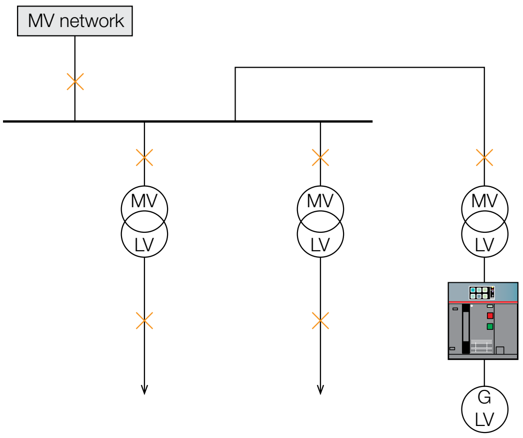
Low-voltage generators can normally be divided into those mounted permanently in parallel with the network and generators that have to work in island mode.
A typical example of the former are the autoproducers connected to the network: for the purposes of this publication we essentially think of synchronous generators used in applications like cogeneration, mini or small hydroelectric plants, plants powered by biomass and diesel power generator sets. The latter are typically used in ships, where power generation is by definition island-mode generation.

We can then examine these two cases in greater detail:

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

In medium-voltage connection to the public utility network (diagram A), the natural position of the SACE Emax 2 circuit-breaker with an Ekip G protection trip unit protects the single low-voltage generators. The protections most commonly used for this are those defined by the ANSI code:
40 (loss of excitation);
27 (minimum voltage);
59 (maximum voltage),
50 (maximum instantaneous current);
51 (maximum time-delayed current);
81H (maximum frequency);
81L (minimum frequency);
49 (overload);
32RP (active power consumption).
All these protection functions are found in Ekip G.

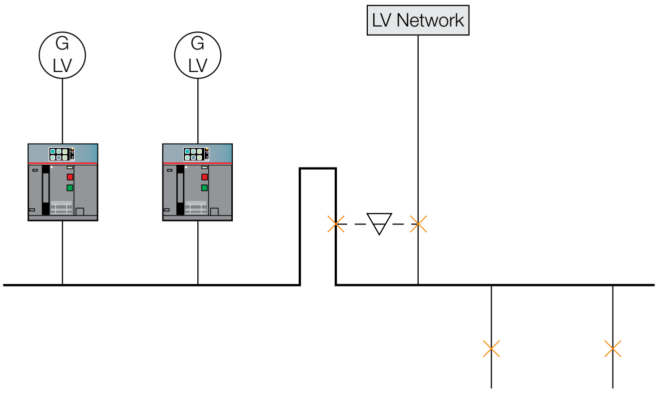
Diagram A



2. Applications of generators and protections

In the low-voltage connection to the public utility network (diagram B) the most commonly used protections are the same as those described in the previous paragraph with the addition, if several low-voltage generators are used, of a protection for controlling synchronism conditions (ANSI 25), which is necessary for checking that the machines or machine run parallel to the network.
In the configuration shown in diagram B, the protection has to have a set of protections comprising ANSI 25, 27, 59, 81H, 81L, 81R (anti-islanding protection based on frequency creep). Ekip G offers all these protections, including ANSI 25 and 81R.

Diagram B



Island-mode plants: ships
In this context the SACE Emax 2 circuit-breaker can be used both as a machine circuit-breaker and as well as a "bus tie", as shown in diagram C and C1.

The protections that could be most easily required in the machine circuit-breaker position are, according to the ANSI code:

32P (maximum active supplied power);
32RP (reverse active power);
40 (loss of excitation);
50 (maximum instantaneous current);
51 (maximum time-delayed current);
59N (maximum homopolar voltage);
27 (minimum voltage);
59 (maximum voltage);
81H (maximum frequency);
81L (minimum frequency).

Ekip G is able to provide all these protections, including 59N.
In the "bus tie" position, in addition to the overcurrent protections, one function that may be frequently required is ANSI 25 (synchronism check).

The protections that are available in Ekip G meet the prescriptions of the main international standards and regulations that provide instructions on the correct control of the protections of synchronous generators in, for example, ships or traditional plants. As an example we can cite the standard IEC 60034-1 "Rotating electrical machines – Part 1: Rating and performance " or IEEE C37.102 "Guides for AC Generator Protection" or the prescriptions provided by shipping registers, like DNV, RINA etc.
The available protection functions are coded in accordance with IEEE C37.2 "Standard for electrical power system device function numbers, acronyms and contact designations" which is also known as the ANSI code.

Diagram C

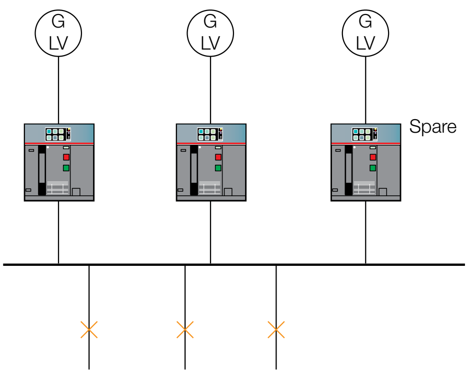
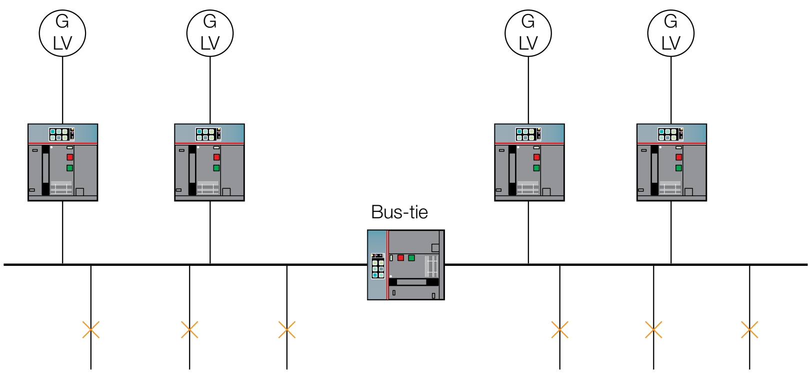


Diagram C1



The required protections depend on the type of plant and application, which makes standardization of protection/application difficult. Nevertheless, the most commonly required protections according also to the indications supplied by the previously cited standards or regulations can be summarised, for example, in Table 1.2.

The protection functions available in Ekip G are activated individually and thus enable the user to build the package of protections that meet the protection needs of plant.

If we assume as a variation range for the voltage of generators used in first-category electrical systems values comprises between 400V and 1000V, and considering that the range of the rated currents of the circuit-breaker varies from 400A to 6300A it is possible to determine the range of power of the generators for which the new air circuit-breaker could be used, which has an approximate range of 300kVA to 10MVA according to the standardised power values provided by the different manufacturers.

Table 1-2

Protections for synchronous generators	SnG < 500kVA	500kVA < SnG < 1500kVA	SnG > 1500kVA
Protection against fault on generator:			
- Directional active power	•	•	•
Protections against overloads:			
- Maximum current	•	•	•
- Current unbalance	–	–	•
Protections against energising system faults:			
- Loss of excitation	–	•	•
- Minimum-maximum voltage	•	•	•
Protection against frequency change:			
- Minimum-maximum frequency	•	•	•
Protection against network loss:			
- Frequency creep	–	•	•
Protection against insulation system faults:			
- Stator earth	–	•	•

3. Protections of Ekip G trip unit

The Ekip G trip unit is able to:
- monitor the faults inside the machine (in the windings or in the energising circuit) whereby tripping the machine's main circuit-breaker would isolate the generator from the rest of the plant without eliminating the fault;
- monitor the interaction between the generator and the rest of the plant causing the two systems to be separated and protected when the conditions for interconnection are missing.

In both cases, programmable contacts are available that can be used to determine the switch-off of the generator and the first motor.

Ekip G, which is supplied as standard with the Ekip Measuring Pro module, comprises protection functions for specific current, frequency, voltage and power protection for generator protection.
The available functions are listed in Table1-3 both with an ABB code and with an ANSI code. For a complete picture of the available protections and for all the relative technical characteristics, see the technical catalogue of the SACE Emax 2 circuit-breaker.

Table 1-3

Function	Description	ANSI	ABB
Synchronism control	Control of the conditions for paralleling	25	SC
Maximum active power	Protection for maximum active power supplied	32P	OP
Maximum reactive power	Protection for maximum reactive power supplied	32Q	OQ
Reverse power	Protection for active power consumption	32RP	RP
Maximum directional current	Protection for directional current	67	D
Minimum active power	Protection against minimum active power supplied	37P	UP
Minimum current	Protection against minimum current supplied	37	UC
Loss of excitation	Protection against an energising anomaly, check of reactive power supplied	40/32RQ	RQ
Overload current	Current protection against temperature rise	49	L
Maximum instantaneous current	Instantaneous protection against overcurrents between phases	50	I
Maximum time-delayed current	Time-delayed protection against overcurrents between phases	51	S
Maximum time-delayed earth current	Time-delayed protection against earth overcurrents	51N or 51G	Gint or Gext
Maximum current with voltage check	Protection against short circuit between threshold phases depending on voltage	51V	S(V)
Maximum homopolar voltage	Protection detecting loss of insulation in the machine	59N	RV
Minimum voltage in alternating current	Protection against voltage drop	27	UV
Maximum voltage in alternating current	Protection against voltage increase	59	OV
Negative sequence maximum current	Protection against unbalance of phase currents	46	IU
Negative sequence maximum voltage	Protection against voltage unbalance and detection of rotation direction of phases	47	VU
Frequency creep (frequency/voltage creep)	Protection against rapid frequency changes	81R	Rocof
Maximum frequency	Protection against frequency increase	81H	OF
Minimum frequency	Protection against frequency reduction	81L	UF

The Ekip G protection trip unit that is available in the new family of air circuit-breakers SACE Emax 2 takes the machine's electrical parameters directly from the circuit-breaker and controls them directly without the interposition of external measuring transformers up to 690V system. In addition to the financial advantage, a solution is also obtained that is built into the circuit-breaker and is compact on the front of the switchgear, so that the designer and fitter not have to choose the cabling of the measuring transducers.

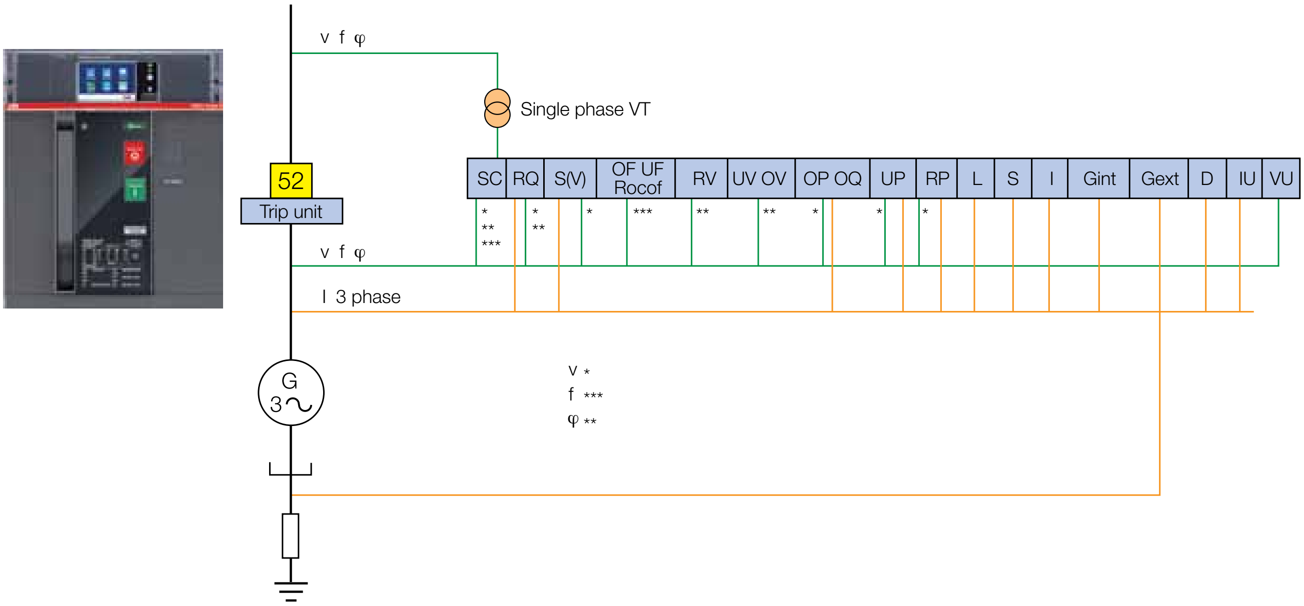
The circuit-breaker enables the voltage sockets to be fitted both to the lower side (standard) or upper side (upon request). They are therefore always positioned on the generator side, thus enabling the voltage and frequency of the generator to be monitored even if the circuit-breaker has been tripped. The relative protection functions are thus active independently of the status of the circuit-breaker and are able to signal anomalies before the circuit-breaker closes.

Fig. 1-3 is a diagram of the available functions and of the sizes measured for the operation of the protections, according to the convention that voltage sockets face the generator.

In the following paragraphs the single protection functions are considered, a short description of the protection and its mode of operation is provided, the main characteristic parameters are analysed and finally the setting range is defined and an example of a setting is given.

Depending on the anomaly control mode selected, for each protection it can be decided 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 a signal is available that can be a switch contact or a message from the data server carrying information on which protection is being delayed or on the tripping of the circuit-breaker and the function that caused it.
If the trip is disabled, when the protection exceeds the threshold, an immediate message is generated on the display, which can be assigned to a programmable contact or be sent remotely by the data server.

Figure 1-3



3. Protections of Ekip G trip unit

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

In the event of a generator terminals fault the initial value of the fault current depends on the value of the machine's direct subtransient reactance X"d. The size of the current 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.
It is thus possible to move from an initial fault current value that is about 6 – 10 times the rated current of the generator to a three-phase fault current in service conditions that can be lower than the generator's full-load rated current. This is because the synchronous reactance that governs normal operation can be less than synchronous reactance in fault service conditions.
The voltage controlled current protection identified by the code S(V) or ANSI 51V, has settings at a higher current than normal operating currents but provides appropriate fault protection because it can transfer the current thresholds to lower trip values in response to a given voltage decrease on the terminals of the generator that is a normal consequence of the fault.
Thus the protection S(V) that in the event of a fault provides current protection thresholds that are lowered with the voltage reduction at the heads of the generator could provide back-up protection in addition to traditional time-current protections.
The trip threshold of the voltage controlled current enables suitable settings to be obtained in the traditional time-current protection that do not interfere with normal operation of the machine.
Further, this function could be used to provide thermal protection by setting the trip curve of the voltage controlled protection function below the curve that sets the machine's thermal limit.

3.1.1 Working modes of the protection

Below you can find a description of the operating principle of the voltage controlled overcurrent protection which is available either with single trip threshold function - protection S(V) - for Ekip G Touch or with two-trip threshold – protection S2(V) – for Ekip G Hi-Touch. Both protections can be managed in threshold correction step mode or linear mode.

The trip unit evaluates the minimum rms value of the three network voltages and when it is lower than the set voltage parameter, which constitutes the voltage reference for the start of the translation, the initially set current threshold is reduced by the correction coefficient Ks.
At the same time, the rms value of the three phase currents is evaluated and compared with the repositioned current threshold. If the maximum rms value of the current is greater than the new calculated threshold, and the condition persists for longer than the set delay, the protection is tripped.
As this protection S(V) is a current protection, any coordination thereof with the traditional maximum current protection functions is facilitated, also because of the fact that this protection is activated only if voltage drops whereas for normal voltages the current protections S, I and S(V) are active whose parameters have not been reset.

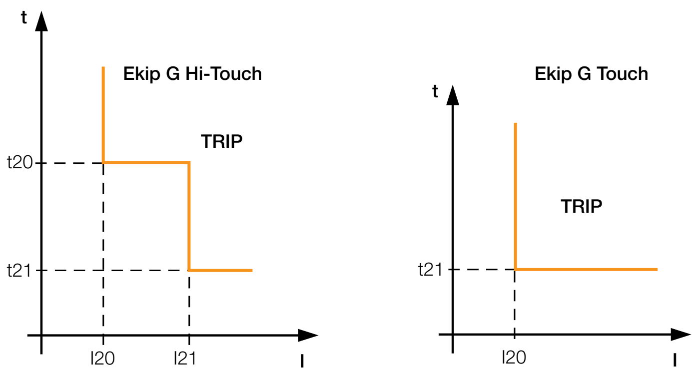
3.1.2 Protection Characteristics

Voltage controlled overcurrent function is available with the following protection modes:
- single trip threshold, with adjustable current and time I20;t20 and time constant curve (Ekip G Touch)
or
- two-trip threshold, with adjustable current and time: first threshold with adjustable I20;t20 and second threshold with adjustable I21;t21 (Ekip G Hi-Touch); both with time constant curve.

In the case of two-threshold protection, the selected control mode (either step or linear) is applied to both thresholds (first threshold I20 and second one I21); on the contrary, the applied translation coefficient and the voltage parameter at which the translation begins can be different for the first and the second threshold.

The trip curves are shown in Fig. 1-3.1.

Figure 1-3.1



Step Mode

With the double threshold function in step mode, it is possible to set:

- I20;t20 which define the first threshold;
- U which defines the voltage level at which the translation of the current threshold I20 begins;
- Ks which defines the translation coefficient of the threshold.

Analogously, the parameters I21;t21;U2;Ks2 of the second threshold can also be set. U and U2, as well as Ks and Ks2, can be different.

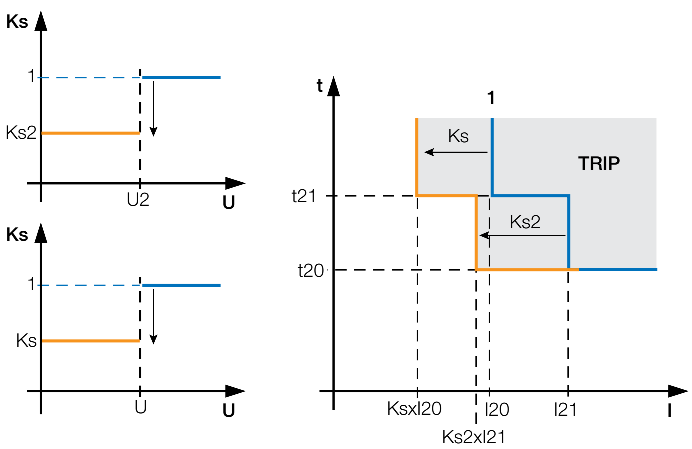
If the voltage measured by the trip unit is higher than U and U2, which is the voltage parameter set by the user as starting point for the translation of the current threshold, the thresholds I20 and I21 are active.

If the voltage measured is lower than U, then the threshold I20 of the first step is decreased by the set coefficient Ks. The trip time remains unchanged. Then the new trip threshold shall be KsxI20 ; t20.
Analogously for the second step of protection: if the voltage measured is lower than U2, then the threshold I21 is decreased according to the set factor Ks2. The trip time remains unchanged. Then the new trip threshold shall be Ks2xI21 ; t21.

The procedure described for the first threshold can be applied also to manage the single threshold protection with parameters I20;t20;Ks;U.

Ekip G trips the protection if the measured current is greater than the threshold set for a longer time than the set time.

Figure 2-3.1



Linear Mode

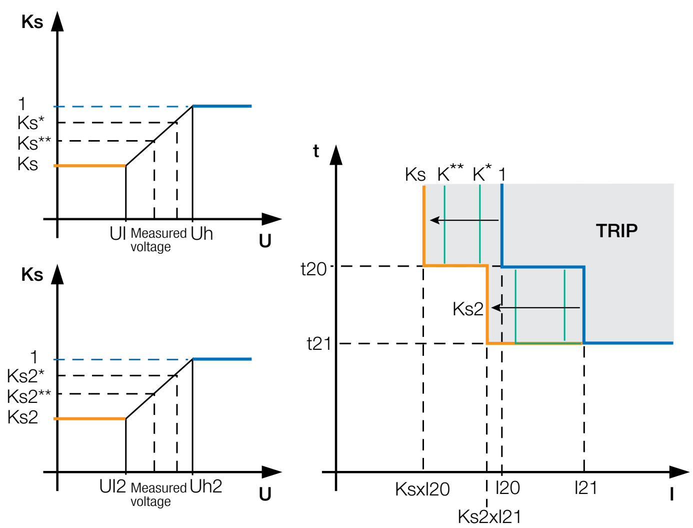
With the double threshold function in linear mode, it is possible to set:

- I20;t20 which define the first threshold
- Uh which defines the voltage level at which the translation of the current threshold I20 begins according to a coefficient Ks* calculated by interpolation between Uh;1 and Ul;Ks.
- Ul defines the voltage level at which the interpolation ends and below which the translation coefficient is Ks.
- Ks which defines the translation parameter linked to Ul.

Analogously, the parameters I21;t21;Uh2;Ul2;Ks2 of the second threshold can also be set. Ul;Ul2 e Uh;Uh2, as well as Ks and Ks2, and also the partial values obtained by the interpolation can be different.

Therefore, as the graph in Figure 3-3.1 shows, for operate voltages higher than Uh, the threshold initially set for the first step I20;t20 is active, whereas if the operate voltage falls below Uh, the trip unit shall calculate Ks*. The threshold I20 is decreased according to the correction factor calculated by the trip unit. The trip time remains unchanged. As a consequence, the new trip threshold becomes Ks*xI20 ; t20.
On the contrary, when the voltage falls below Ul, the protection shall use the set translation coefficient Ks and therefore the threshold I20 is decreased by the set coefficient; the new threshold becomes KsxI20 ; t20.
The same procedure, through the parameters Uh2;Ul2;Ks2, can be applied to the second threshold.
The procedure described for the first threshold can be applied also to manage the single threshold protection with parameters I20;t20;Ks;Ul,Uh.

Figure 3-3.1



3. Protections of Ekip G trip unit

3.1.3 Range of possible settings

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

Step mode			
First threshold	I20 = (0.6...10) x In	Threshold step	0.1 x In
Tripping time	t20 = (0.05...30)s	Time step	0.01s
Second threshold	I21 = (0.6...10) x In	Threshold step	0.1 x In
Tripping time	t21 = (0.05...30)s	Time step	0.01s
Voltage parameter	U = U2 = (0.2...1) x Vn	Threshold step	0.01 x Vn
Threshold change parameter	Ks = Ks2 = (0.1...1)	Threshold step	0.01

Linear mode			
First threshold	I20 = (0.6...10) x In	Threshold step	0.1 x In
Tripping time	t20 = (0.05...30)s	Time step	0.01s
Second threshold	I21 = (0.6...10) x In	Threshold step	0.1 x In
Tripping time	t21 = (0.05...30)s	Time step	0.01s
Voltage high parameter	Uh = Uh2 = (0.2...1) x Vn	Threshold step	0.01 x Vn
Voltage low parameter	Ul = Ul2 = (0.2...1) x Vn	Threshold step	0.01 x Vn
Threshold change low parameter	Ks = Ks2 = (0.1...1)	Threshold step	0.01

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

It should be noted that Ekip G Touch has a single threshold that is controllable in both step and linear mode whereas the dual threshold is available for Ekip G Hi-Touch, which is always controllable in step or linear mode.

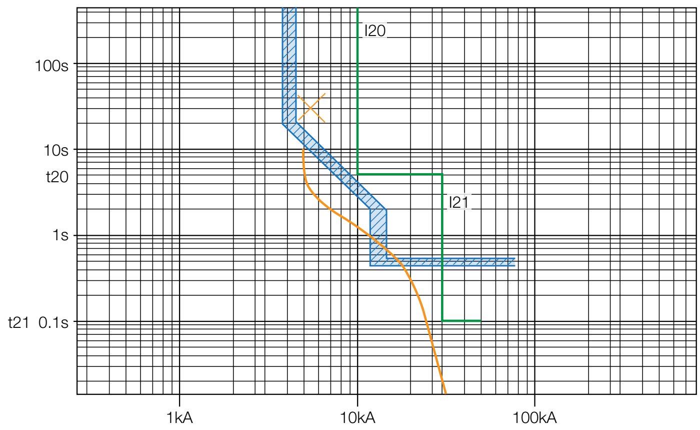
3.1.4 Setting example

In the example a generator with the following characteristics is considered:

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

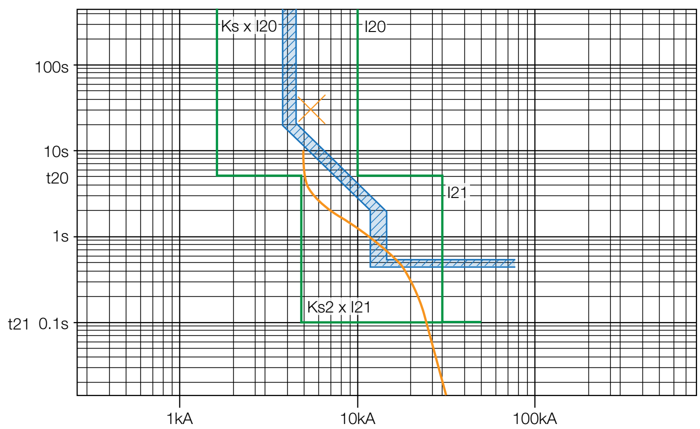
The generator supplies an equivalent load that requires 3416A of current and as a generator device we choose a 4000A SACE Emax 2 circuit-breaker with Ekip G Hi-Touch.
The setting of the LSI protections is shown in the graph in Fig. 4-3.1. The function L is set on the value of the rated current of the generator, the function I is turned to OFF as a condition for selectivity downstream and the function S is set to intercept the generator's short circuit curve.
The function S(V) is set at initial values that are higher than the previous settings and are such as not to be tripped by the generator's normal fault current.

Figure 4-3.1



Initial setting:
I20=2.5xIn=10000A t20=5s
I21=7.5xIn=30000A t21=0.1s
The trip mode is selected on the display and then the following values are set:
Setting Ul=Ul2=75% of Un (Un is the rated voltage of the plant, it is set as reference on the trip unit)
Setting Ks=Ks2=0.16
Thus for operate voltages below 0.75x400=300V the new trip thresholds are shown in the graph in Fig. 5-3.1 according to the following parameters:
Ks x I20=0.16x2.5xIn=1600A t20=5s
Ks2 x I21=0.16x7.5xIn=4800A t21=0.1s

Figure 5-3.1



The graph shows that after a voltage drop at the terminals of the generator caused by a fault the protection S(V) can be tripped by currents that are lower than those that would be intercepted by normal LSI functions.

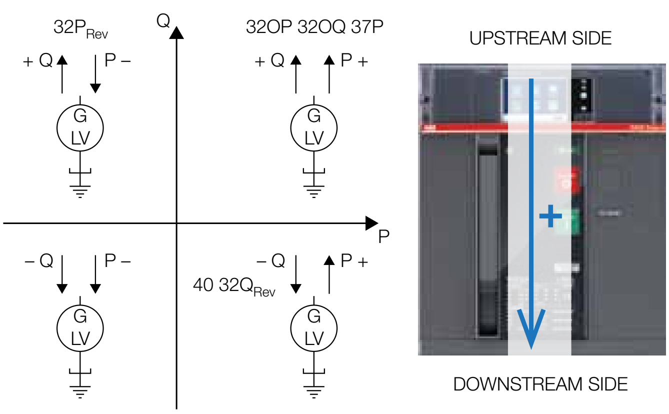
3.2 Power protections: introduction

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

- active power protection supplied by the generator (ANSI 32P code ABB OP): works for positive active power, sets the maximum active power value that the machine can supply.
- active power protection consumed by the generator (ANSI 32RP code ABB RP): works for negative active power flowing in the opposite direction to normal operation of the machine. It can also be called protection against reverse active power flow.
- reactive power protection supplied by the generator (ANSI 32Q code ABB OQ): works for positive reactive power, sets the maximum reactive power value that the machine can supply.
- reactive power protection consumed by the generator (ANSI 40 and ANSI 32RQ code ABB RQ): works for negative reactive power. It can also be called protection against reverse reactive power flow.
- active power protection supplied by the generator (ANSI 37P code ABB UP): sets the minimum active power value for the machine.

In the following paragraphs the convention adopted and shown in Fig. 1-3.2 is that the active and reactive power exiting the generator is positive. In the standard configuration the Ekip G trip unit's voltage sockets are on the lower side and must be on the generator side to have a positive measurement of the power exiting the generator. If the generator is connected to the upper terminals the power direction set by the manufacturer will have to be reversed.

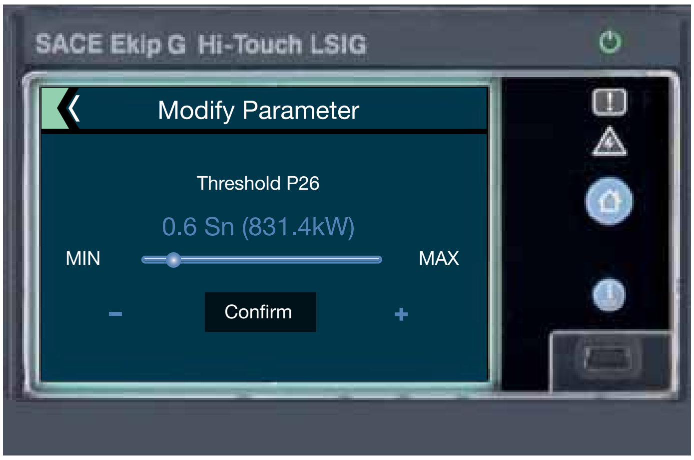
Figure 1-3.2



The setting of all the power functions refers to the rated power Sn of the trip unit calculated on the basis of the rated voltage and the rated current of the circuit-breaker (rating plug).

The graphic interface in Fig. 2-3.2 not only shows the setting as a multiple of Sn but also indicates the corresponding absolute value in [kW] or [kvar], to have a reference in absolute terms to be compared with the permitted power limits for the machine.

Figure 2-3.2



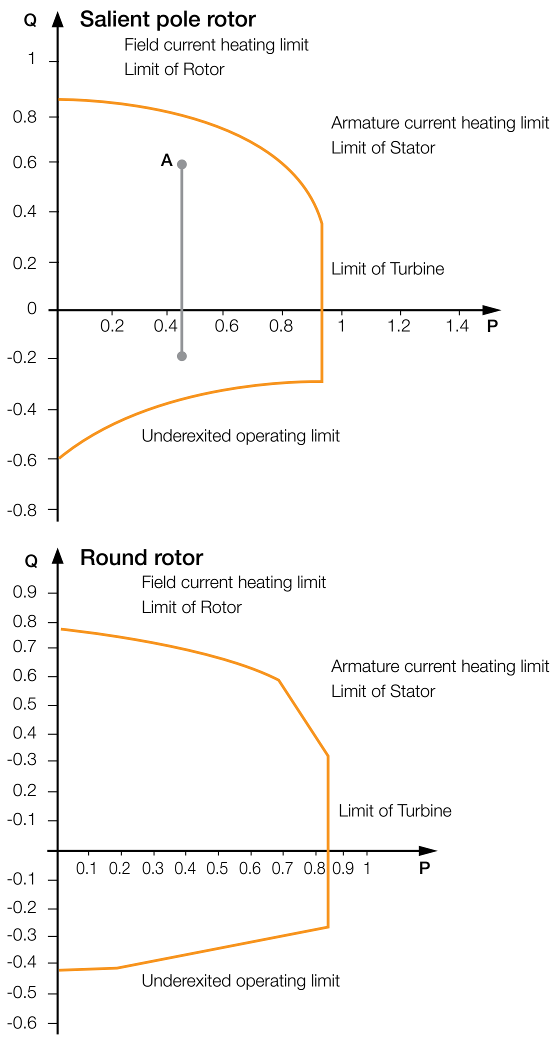
3.2.1 RQ Loss of excitation and reverse reactive power (ANSI 40 and 32RQ)

The loss of excitation in a synchronous generator mainly arises from faults in the energising unit or in the field circuit. Consequently, the electromotive force in the generator is disabled and there is a reduction in the active power supplied. The machine then operates as an asynchronous generator that consumes reactive power from the network. The new operating condition, with the circulation of reactive power supplied by the network, increases the temperature in the rotor, field and arrestor circuit. This phenomenon is particularly evident in round rotor generators and is much less marked in salient pole rotor generators. In addition to the phenomena that involve the machine, voltage is reduced significantly, with consequent loss of system stability, owing to the fact that the supplied plant might not be able to supply the reactive power required by the generator.
The work area for a generator can be described by the capability diagram shown on a plane R-X or P-Q and consisting in the upper and lower limits of the characteristic curves shown for a round rotor generator and salient pole rotor generator in the PQ coordinates by Fig. 1-3.2.1.

3. Protections of Ekip G trip unit

The generator's working point is normally in the first quadrant with active power P and reactive power Q with a positive value and exiting from the generator. In consequence of anomalous conditions, for example reduction or loss of excitation, the working point transfers to the fourth quadrant and the reactive power Q changes direction, thus becoming negative and being consumed by the generator.

Figure 1-3.2.1



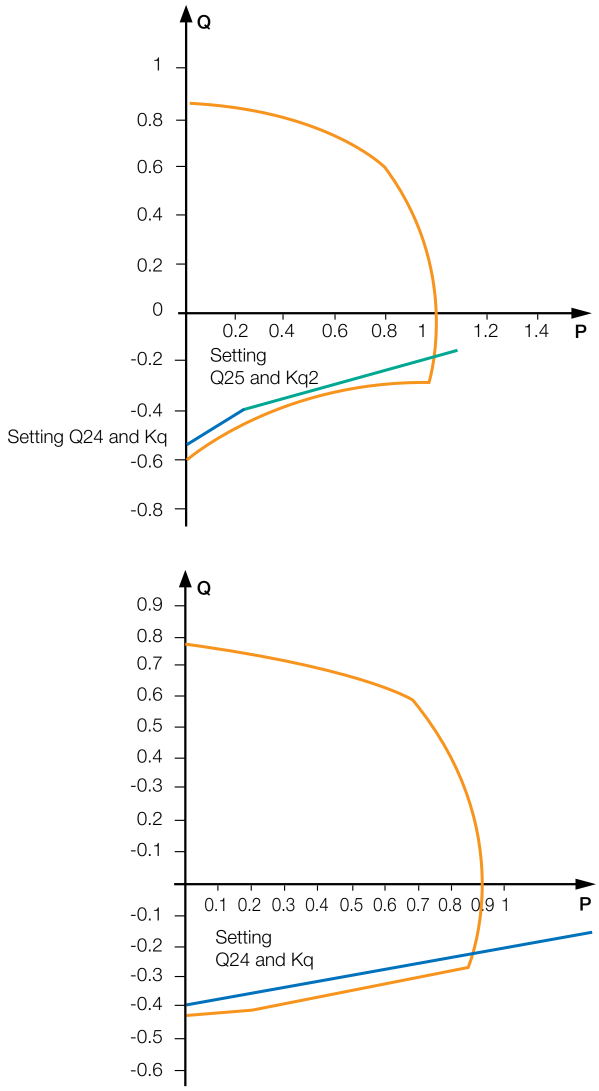
This new working point has low stability and if the network were able to provide reactive power without an excessive voltage drop the synchronous generator could work as an asynchronous generator but with a dangerous temperature rise in the windings.

The protection against loss of excitation implemented in the Ekip G trip unit works by taking as a reference the P-Q area of the diagram that indicates the machine's underexcited operating limit.

This protection is obtained by a function with a working curve shown, as in Fig. 2-3.2.1, by a straight line with a single or double slope (option used to make the protection match more closely the shape of the limit curve), that prevents the machine from working below its underexcited operating limit.

The protection sets the reactive power limit that the generator can receive from the network and below which it is inadvisable to run the machine.

Figure 2-3.2.1

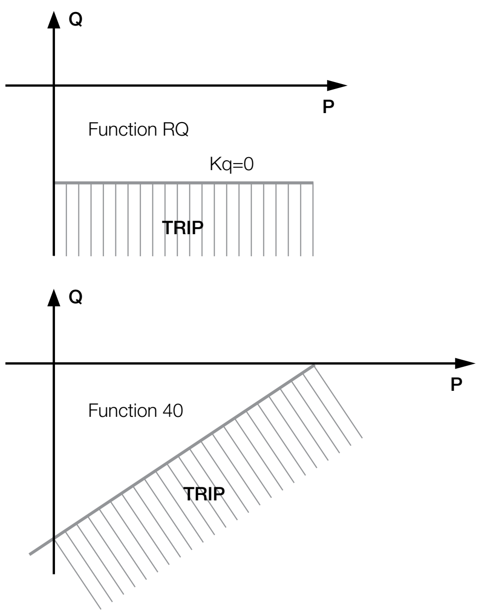


3.2.1.1 Working modes of the protection

The protection limits the generator's work area with negative reactive power, i.e. consumed power, approximately matching its underexcited operating limit curve by a straight line with a single or double slope that with a general reference to the setting parameters "Qi" (defines the starting point on the reactive power axis) and "Kq" (indicates the slope of the protection function) can be generally represented as Q=KqxP+Qi.

The protection works by acquiring the total active and reactive power values. If the working point is below the set protection line and this condition persists for a time greater than the set trip delay time, the protection tripps to open the circuit-breaker or generate an alarm signal.
A special feature of function 40 with single slope is that by setting parameter Kq=0 the trip curve becomes a straight line that starts from the set parameter "Q" and is parallel to the axis of the P, as shown in Fig. 3-3.2.1, thus performing the traditional function against reverse reactive power defined by the acronym ANSI 32RQ.

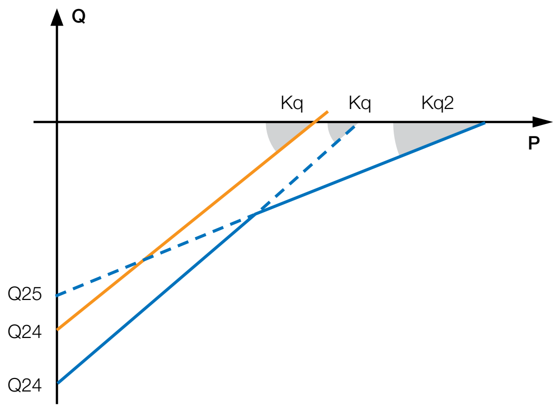
Figure 3-3.2.1



3.2.1.2 Protection characteristics

The 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, i.e. of the two single-slope lines defined by the parameters Q24; Kq and Q25; Kq2, according to what is shown in Fig. 4-3.2.1. When the measured power is less than the intersection point of the two protection lines, the protection uses the curve with Q24 and Kq. Otherwise, it uses the curve corresponding to Q25 and Kq2. The parameters "Q24 and Q25" are set by the user as a % of Sn, which is the apparent rated power calculated by the trip unit with reference to the rated voltage Un of the plant and to the rated current (rating plug) of the circuit-breaker.

Figure 4-3.2.1



3.2.1.3 Range of possible settings

As illustrated in the previous paragraphs, the parameters that characterise the protection function against the loss of excitation with check of the reactive power available for Ekip G in all its versions are the slope with respect to the axis of the Ps 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:

First 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	0.5s

Second slope

Parameter	Q25 = (-1…-0.1) x Sn	Threshold step	0.001 x Sn
Slope	Kq2 = (-2…2)	Step	0.01
Tripping time	t25 = (0.5…100)s	Time step	0.5s

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

3.2.1.4 Setting example

The example shows a three-phase synchronous generator with salient poles characterised by:
- rated power SnG=1530kVA
- rated voltage 500V
- rated current 1766A
- load diagram PQ as in Fig. 5-3.2.1 showing the various stator, rotor and underexcited operating limits.

The generator's rated current enables a SACE Emax 2 circuit-breaker with a rating plug of 2000A to be used.
With reference to these parameters, the trip unit calculates its rated power as Sn=1.73x500x2000=1732kVA

Figure 5-3.2.1

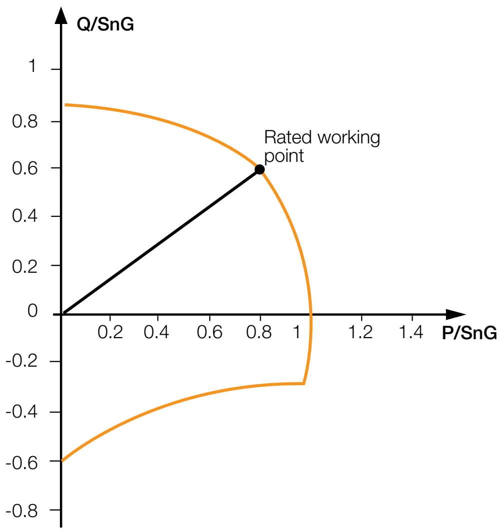


Diagram PQ of the machine shows that the underexcited operating limit curve starts from a reactive power value equal to QG=-0.6xSnG=-918kvar. The shape of the protection curve Q=KqxP+Q24 thus enables Ekip G to be set to protect the machine appropriately. In particular, the following ratio must be complied with:
Q24xSn < QG i.e. Q24 < 918/1732 = 0.53.

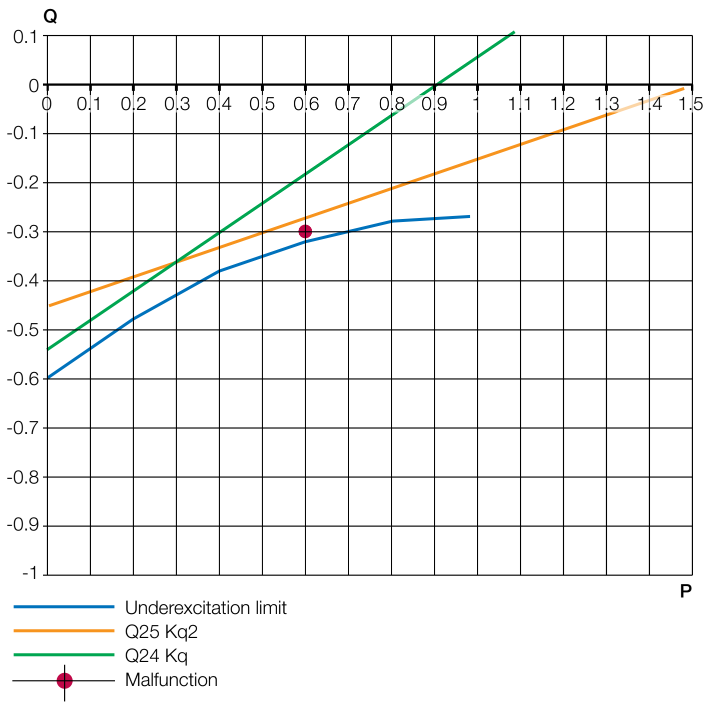
The setting of the intercept of the first protection on Q-axis can then be set at Q24=0.48, which corresponds to 831kvar, as shown on the trip unit display. The parameter Kq is set at 0.6 and the tripping time t24 is set at 0.7s.

With Ekip G Hi-Touch, it is also possible to use a second protection curve that approximates more faithfully to the shape of the generator's limit curve. The settings study leads to the following Q25=0.4 settings, which corresponds to a display of the 693kvar trip unit.

The parameter Kq2 is set at 0.3 and the tripping time t25 is set at 0.5s.

The result shown on the diagram P-Q of the generator (therefore with Q24 and Q25 recalculated according to the ratio Sn/SnG) (Fig. 6-3.2.1) shows how the set trip curve follows the shape of the machine's underexcited operating limit and in the event of an anomaly that makes the generator operate with the following power values Q=1040kvar and P= 520kW, the Ekip G trip unit will intervene to eliminate the fault within the time t25.

Figure 6-3.2.1



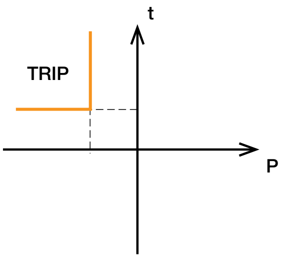
3.2.2 RP Reverse active power flow (ANSI 32RP)

In normal generator operating conditions the generator supplies a flow of active power to a load or a network, the active power being conventionally assumed to be positive. In operation with reverse power flow, i.e. with active power consumed by the generator, which thus acts as a motor, the first motor or turbine is driven. A similar operating condition arises when, for example, the mechanical action of the first motor fails or the speed adjusting system develops a fault.
Using the RP protection of Ekip G it is possible to protect the machine precisely and reliably, owing to the great sensitivity, ample thresholds and delay times that can be set to avoid accidental trips in the case of transients.

3.2.2.1 Working mode and protection characteristics

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

Figure 1-3.2.2



3.2.2.2 Range of possible settings

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

Parameter	P11 = (-1...-0.1) x Sn	Threshold step	0.001 x Sn
Tripping time	t11 = (0.5...100)s	Time step	0.5s
Power direction	Preset from the upper side to the lower side (see paragraph 3.2)		

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

3.2.3 OP Maximum active power (ANSI 32P) OQ Maximum reactive power (ANSI 32Q)

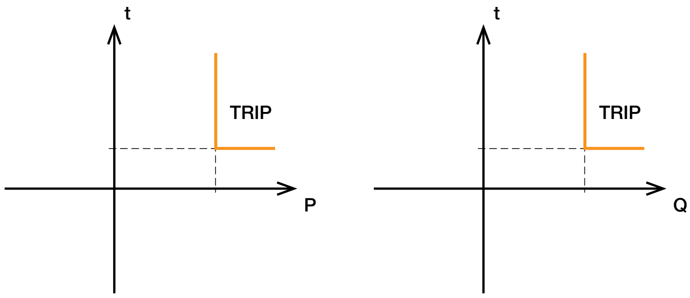
In island-mode plants, the power required from the generator may be greater than the maximum power that the machine is able to supply. This condition entails step loss, which is reflected in loss of rotor synchronism in relation to operating frequency and gives rise to oscillations in the voltage of the electrical system.
In order to protect against this condition, or generally when we wish to prevent the generator 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, caused for example by a load disconnection with no modification of energizing because of a control system fault, the generator responds with an increase in the reactive power supplied. In order to protect against this condition, it is possible to use Ekip G's OQ protection, which enables the reactive power supplied by the machine to be controlled.

3.2.3.1 Working modes and protection characteristics

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

When total active or reactive power calculated as a sum of the power of the 3 phases is greater than the set active power threshold the protection delays for the set time and is then tripped or an alarm signal is sent immediately.

Figure 1-3.2.3



3.2.3.2 Range of possible settings

The following parameters for setting the maximum active and reactive power function are available in all versions of Ekip G:

Maximum active power protection			
Parameter	P26 = (0.1…2) x Sn	Threshold step	0.001 x Sn
Tripping time	t26 = (0.5…100)s	Time step	0.5s

Maximum reactive power protection			
Parameter	Q27 = (0.1…2) x Sn	Threshold step	0.001 x Sn
Tripping time	t27 = (0.5…100)s	Time step	0.5s

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

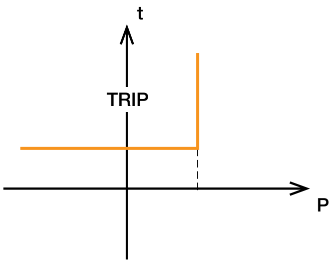
3.2.4 UP Minimum active power (ANSI 37)

In normal machine operating conditions 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 dedicated to this type of protection is the UP minimum active power protection identified by the ANSI 37 code, which could be used to trip the circuit-breaker of a machine operating in island mode to prevent overspeed of the unit following operations, for example, on the turbine or more simply to disconnect the generator following excessive disconnection of the loads, thus with a decrease in the power used.

3.2.4.1 Working modes and protection characteristics

The UP power protections have a definite time-delay characteristic curve with single threshold as shown in Fig. 1-3.2.4 and their power and tripping time can be set.
The power setting is a % of the rated power of the trip unit.
As can be seen from the graph, the function also works for negative power. In this manner, protection against negative power is also possible for the values that are not within the RP tripping area, and for power values that are part of the RP's tripping range, the UP could also be tripped if both are activated.

Figure 1-3.2.4



3.2.4.2 Range of possible settings

The following parameters for setting the minimum active power UP function are available in all versions of Ekip G:

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

3.2.5 Setting example of power protection functions

In the 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 er	0.9xPnG	864kW
Pmin er	0.25xPnG	240kW
Qmax er	0.7xQnG	504kvar
Pmin ass	0.15xPnG	144kW

With reference to the rated current of the generator, a SACE Emax 2 circuit-breaker with trip unit rated current of 2000A is considered. The rated power of the trip unit for calculating the settings of the protections is Sn = 1385.6kVA.
The settings for the various protections are then determined.

OP protection:
To set the protection, the permitted active power data for the generator must be proportional to the trip unit's rated power, according to the ratio 864/1385.6=0.624. For example, the protection will be set at P26=0.600, which corresponds to 831.384kW with a time t26=0.5s. Thus when the generator supplies greater active power and this condition remains for a longer time than the set delay the protection will be tripped.

UP protection:
To set the protection, the permitted active power data for the generator must be proportional to the trip unit's rated power, according to the ratio 240/1385.6=0.173. For example, the protection will then be set at P23=0.180, which corresponds to 249.415kW with a time t23=0.5s. Thus when the generator supplies a lower active power, and this condition remains for a longer time than the set delay, the protection will be tripped.

OQ protection:
To set the protection, the permitted reactive power data for the generator must be proportional to the trip unit's rated power, according to the ratio 504/1385.6=0.364. For example, the protection will be set at Q27=0.355, which corresponds to 491.902kW with a time t27=0.5s. Thus when the generator supplies a higher reactive power, and this condition remains for a longer time than the set delay, the protection will be tripped.

RP protection:
To set the protection, the permitted active power data for the generator must be proportional to the trip unit's rated power, according to the ratio 144/1385.6=0.104.
For example, the protection will be set at P11=0.1, which corresponds to 138.56kW with a time t11=3s. Then when the generator consumes a higher active power (opposite direction to the direction set as a reference) and this condition remains for a longer time than the set delay, the protection will be tripped.

The setting of the various protections on the graph showing the permitted limiting value for the generator must refer to the generator's reference power.

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

Table 1-3.2.5

	LimGen/Sn	Setting Ekip G	P[Kw] Q[kvar] trip	Time [s]	Setting referring to generator
OP	0.624	0.6	831.384	0.5	0.866
UP	0.173	0.18	249.415	0.5	0.26
OQ	0.364	0.355	491.902	0.5	0.683
RP	0.104	0.1	138.564	3	0.144

Figure 1-3.2.5

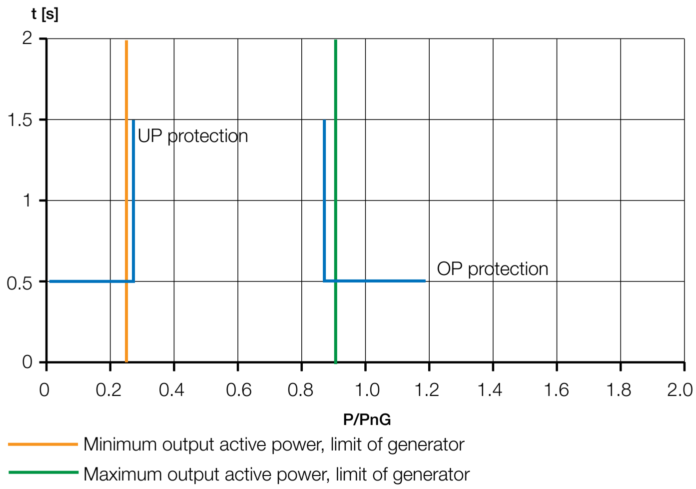


Figure 2-3.2.5

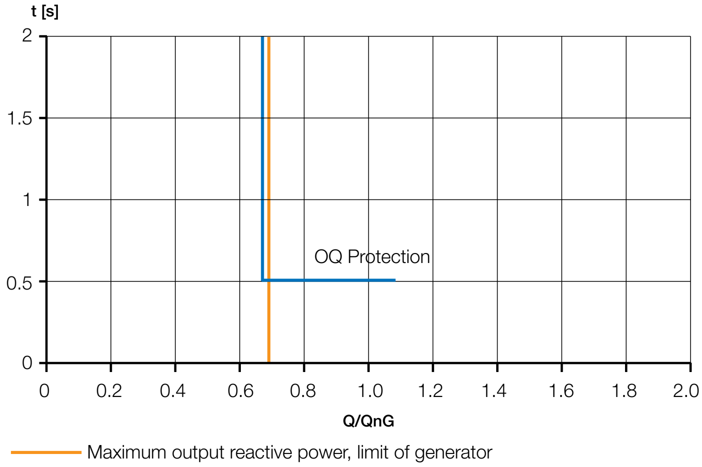
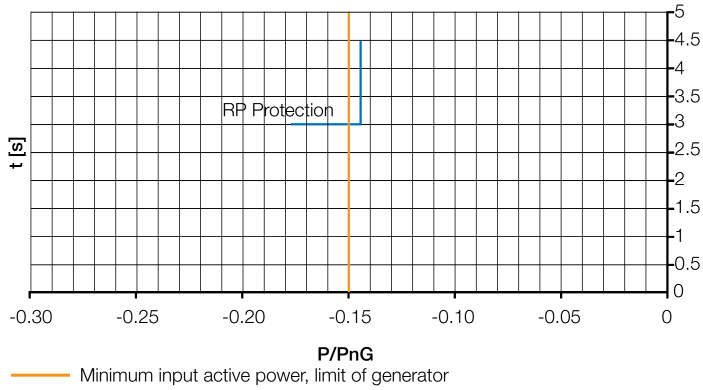


Figure 3-3.2.5



3.3 OF Maximum frequency (ANSI 81H) and UF minimum frequency (ANSI 81L)

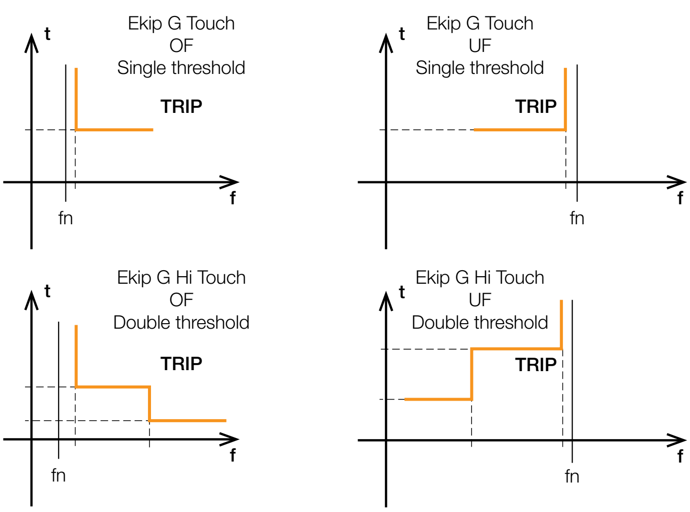
An increase of frequency above the rated value is a consequence of excess driving power compared with the active power required by the load connected to the machine.
This condition arises, for example, because of load disconnection following elimination of part of the plant affected by a fault.
Normally, the generator's control circuit is activated by the speed adjuster to deal with the anomaly and adjusts the first motor to return the frequency to the rated value.
If the generator's control device is unable to restore rated frequency, to avoid mechanical damage to the turbine/alternator unit and to prevent the loads being supplied at frequency values above the set limits, the Ekip G OF function can be used to protect against over frequency.
On the other hand, the reduction in frequency compared with the rated value is due to a drop in the power supplied by the generator that is due to a load condition that requires greater power than what can be supplied by the generator, for example following disconnection from the network and switch to island-mode operation supported by the generator.

In this condition the load disconnection can be a procedure and an action for restoring the balance between the types of power and thus restoring the rated value of the frequency.
Ekip G's protection against UF frequency drops can be used to activate a load disconnection logic or to disconnect the generator.
Restoring the frequency or even the disconnection are used to safeguard the mechanical source that drives the generator, especially if it is a steam turbine.

3.3.1 Working modes and protection characteristics

The protection monitors frequency on the generator side, so the protection is active even if the circuit-breaker is tripped. In this condition, in the event of an anomaly the protection generates an alarm signal. If the anomaly occurs with the circuit-breaker closed after the alarm signal, the user can also set the circuit-breaker trip.
The frequency protections for the Ekip G Touch trip unit have, as shown in Fig. 1-3.3, a definite time-delay characteristic curve with a single threshold defined by the parameters f13-t13 for the OF maximum frequency and f12-t12 for the UF minimum frequency; or for Ekip G Hi-Touch, still with a definite time-delay characteristic curve, but with a double threshold defined by the parameters f12-t12 ; f17-t17 for the OF maximum frequency and f13-t13; f18-t18 for the UF minimum frequency. For both options the frequency protections can be set as a % of the set rated frequency and the trip delay time can also be set. The functions OF and UF can be excluded. The dual threshold, for example, provides protection both from minor prolonged and major short changes.

Figure 1-3.3



3.3.2 Range of possible settings

The following parameters for setting the maximum and minimum frequency function are available in all versions of Ekip G:

UF minimum frequency protection			
First threshold			
Parameter	f12= (0.9....0.99) x fn	Threshold step	0.01 x fn
Tripping time	t12 = (0.5...60)s	Time step	0.1s
Second threshold			
Parameter	f17= (0.9....0.99) x fn	Threshold step	0.01 x fn
Tripping time	t17 = (0.5...60)s	Time step	0.1s

OF maximum frequency protection			
First threshold			
Parameter	f13= (1.01...1.1) x fn	Threshold step	0.01 x fn
Tripping time	t13 = (0.5...60)s	Time step	0.1s
Second threshold			
Threshold step	f18= (1.01....1.1) x fn	Threshold step	0.01 x fn
Time step	t18 = (0.5...60)s	Time step	0.1s

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

3.3.3 Setting example

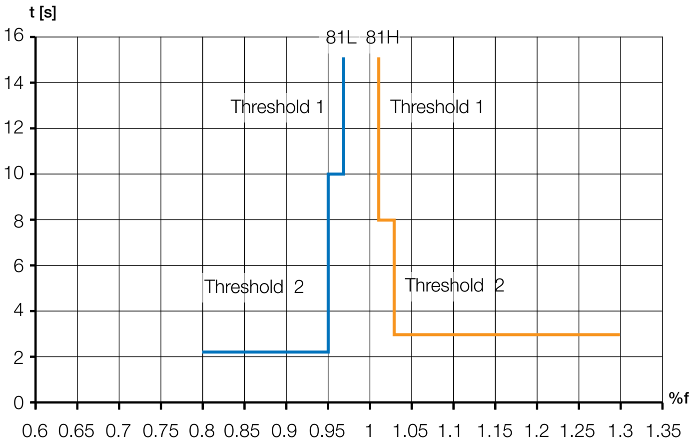
For a generator with a rated frequency of 50Hz and compatibly with the control requirements of the plant and of the generator, a dual threshold protection is envisaged for the maximum and minimum frequency functions with the following trip parameters:
OF function
Low threshold 50.5Hz with tripping time of 8s.
High threshold 51.5Hz with tripping time of 3s.
UF function
High threshold 48.5Hz with tripping time of 10s.
Low threshold 47.5Hz with tripping time of 2.2s.

In view of the characteristic required for the protection, an Ekip G Hi-Touch trip unit needs to be used. As said, the adjustments must be adapted to the rated frequency, so in the case of the example the following settings must be made:

OF	f13 = 50.5/50=1.01xfn	t13 = 8s
OF	f17 = 51.5/50=1.03xfn	t17 = 3s
UF	f12 = 48.5/50=0.97xfn	t12 = 10s
UF	f18 = 47.5/50=0.95xfn	t18 = 2.2s

which generate the tripping curves of the frequency protections shown in Fig. 2-3.3.

Figure 2-3.3



3.4 UV Minimum voltage (ANSI 27) and OV Maximum voltage (ANSI 59)

The UV function dedicated to controlling the minimum voltage level on the generator terminals is identified by the ANSI 27 code. For generators, continuous operation with rated power and frequency, and with minimum voltage of 95% is normally permitted. For lower voltages, undesirable phenomena can arise such as: a change of stability conditions, a reactive power percentage taken from the network, and an anomaly of the connected loads.

It is common practice to assign an alarm signal to the minimum voltage protection in such a manner as to enable the operator to take the due precautions, for example by acting on the automatic voltage regulator to remedy an irregular situation but the tripping of the circuit-breaker can also be used to disconnect the machine.

The minimum voltage 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 protections to intervene, or as a protection against prolonged uncontrolled voltage reductions of the automatic voltage regulator, because of a fault thereof.

A typical example of voltage decrease may be that in which in a plant supplied by several generators one of the machines disconnects. There is thus an unbalance between the power supplied and the power required by the load. The generators that remain connected react by attempting to compensate for the lack of power with an increase of the current and a reduction of the voltage at their terminals. Ekip G's minimum voltage protection can be used to avoid machine operating faults.

The OV function dedicated to controlling the maximum voltage level on the generator's terminals is identified by the ANSI 59 code. The generators are normally designed to operate continuously at their rated power and frequency, at a voltage level that can reach 105% of the machine's rated voltage. Maintaining overvoltage above the permitted limits can cause overexcitation and excessive stress to the insulation system.

Anomalous overvoltage in the generator could occur following a fault in the voltage regulator or after a change in the speed of the first motor following a sudden loss of load.

Ekip G's OV protection enables the plant to be protected from this condition, which is particularly risky for hydrogenerators or gas turbines.

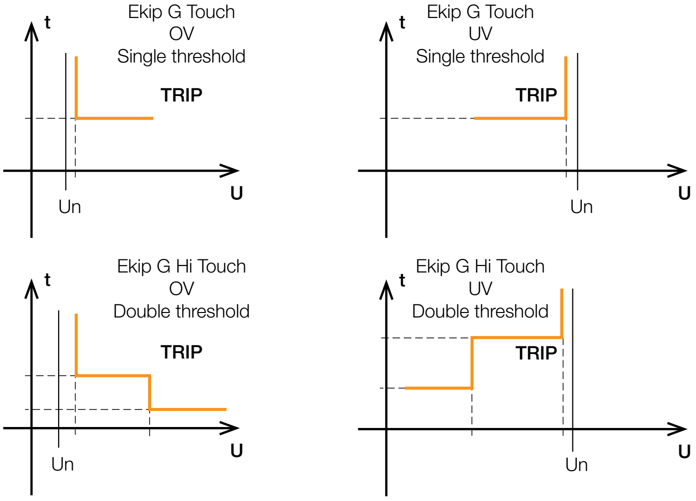
The voltage protections are completed by the VU protection against voltage unbalance and detection of the rotation direction of the phases (ANSI 47).

3.4.1 Working modes of the protection

The trip unit monitors the three phase voltages on the generator side even when the machine's circuit-breaker is open. In this case, a voltage anomaly that exceeds the set threshold generates an alarm signal that can be controlled in the machine's check logic. If the anomaly is generated with the circuit-breaker closed, in addition to the alarm signal, the circuit-breaker may be tripped.

Both protections for Ekip G Touch have a definite delay trip curve with a single threshold defined by the parameters U8-t8 for UV and by the parameters U9-t9 for OV, whereas for Ekip G Hi-Touch they are dual-threshold and the voltage and trip delay time can be adjusted according to the following parameters U8-t8 U15-t15 for UV and U9-t9 U16-t16 for OV, as shown in Fig. 1-3.4. The dual threshold enables major short-term changes and minor longer-term changes to be controlled.

Figure 1-3.4



3.4.2 Range of possible settings

The following parameters for setting the maximum and minimum voltage function are available in Ekip G.

UV minimum voltage protection			
First threshold			
Parameter	U8 = (0.5….0.98) x Un	Threshold step	0.001 x Un
Tripping time	t8 = (0.1…60)s	Time step	0.05s
Second threshold			
Parameter	U15= (0.5….0.98) x Un	Threshold step	0.001 x Un
Tripping time	t15 = (0.1…60)s	Time step	0.05s

OV maximum voltage protection			
First threshold			
Parameter	U9= (1.02….1.2) x Un	Threshold step	0.001 x Un
Tripping time	t9 = (0.1…60)s	Time step	0.05s
Second threshold			
Parameter	U16= (1.02….1.2) x Un	Threshold step	0.001 x Un
Tripping time	t16 = (0.1…60)s	Time step	0.05s

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

3.4.3 Setting example

Minimum and maximum voltage protection with two trip thresholds is required. The Ekip G Hi-Touch trip unit must therefore be used that provides the required protection with two constant time thresholds.

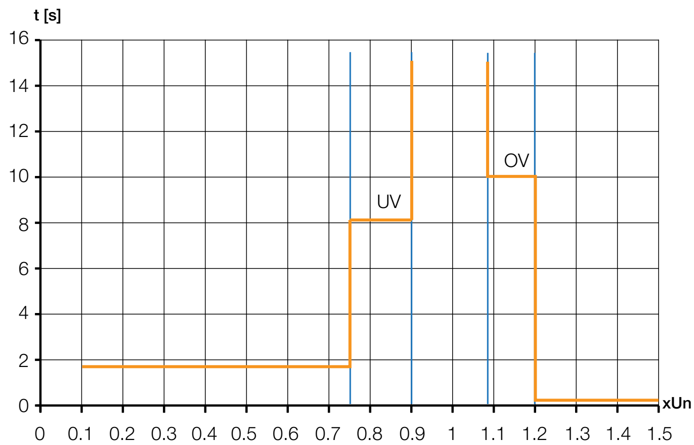
The set thresholds depend on the set rated voltage, which coincides with the generator's rated voltage, which we assume to be 690V.

For UV minimum voltage protection, a longer tripping time is required for voltage below 0.9 of the generator's rated voltage and a more rapid tripping time for rated voltage below 0.75 of the generator's rated voltage.
For OV maximum voltage protection, a longer tripping time is required for voltage above 1.08 of the generator's rated voltage and a more rapid tripping time for rated voltage above 1.2 of the generator's rated voltage.

In order to comply with the voltage constraints of this example, the selected settings are listed below and the tripping curves are shown in Fig. 2-3.4.

UV function			
First threshold	U8	0.9xUn	with tripping time t8 = 8s
Second threshold	U15	0.75xUn	with tripping time t15 = 1.5s
OV function			
First threshold	U9	1.08xUn	with tripping time t9 = 10s
Second threshold	U16	1.2xUn	with tripping time t16 = 0.1s

Figure 2-3.4



3.5 ROCOF Frequency creep (ANSI 81R)

The protection function that is sensitive to rapid frequency changes is identified by the ANSI 81R code and is known as frequency creep protection. It is identified in Ekip G by the acronym ROCOF. This protection enables both positive and negative frequency changes to be detected rapidly and with greater sensitivity, thus ensuring a protection that is faster than what is possible with traditional minimum or maximum frequency functions. It is a protection that is applied in those types of plant where the generator is connected in parallel to the main supply (network of the public utility company) and to other generators.
In these conditions, owing to a fault in the distribution network, the network device trips and consequently the main source is disconnected from the rest of the plant. In this case, the generator supplies the plant (island-mode operation) and changes its electric parameters that are no longer synchronised with those of the network.

In order to prevent the automatic reconnection of the network device finding the generator in a non-synchronised condition, with a consequent risk of damage to the machine, and to prevent the generator supplying the plant in islanding during the period required to restore the normal conditions of the main supply, the generator has to be disconnected immediately by its circuit-breaker.

Antiislanding may be necessary for controlling the plant because if the generator is unable to support the individual user (power required by load greater than generator power) instability phenomena arise that could damage both the generator and certain types of load which are more sensitive.
Thus in order to prevent the above conditions occurring, the action of the ROCOF protection becomes important because it immediately disconnects the generator by tripping the generator's circuit-breaker.
If there are several generators, each generator circuit-breaker would need its own frequency creep protection.
The immediate disconnection of the generator by 81R can also be viewed as a potential safety factor because it prevents parts of the plant continuing to carry voltage that exposes people working on the plant to electrical risk.
In normal operation, the generator has frequency changes that are, for example, due to the control of loads in the plant or to changes that derive from the first motor (e.g. fuel injection). These changes are minor and are slower than those that occur through disconnection from the network and are not therefore detected by the protection.

3.5.1 Working modes and protection characteristics

The protection trip unit measures the frequency change on the generator side; the trip unit menu can thus be used to select whether to monitor only positive frequency changes, i.e. changes due to a sudden frequency increase or only negative frequency changes, i.e. changes due to a sudden frequency decrease, or both.

The protection has a single protection step with a constant time curve with a threshold that is adjustable in terms of frequency Hz/s and of trip delay, which differ from the set of the threshold in Hz/s. This permits very rapid tripping in response to high frequency changes but ensures great precision for slow changes.

When the frequency creep threshold is exceeded the protection generates an alarm signal or trips the circuit-breaker, depending on the fault control mode selected.

3.5.2 Range of possible settings

The following parameters for setting the frequency creep function are available in all versions of Ekip G:

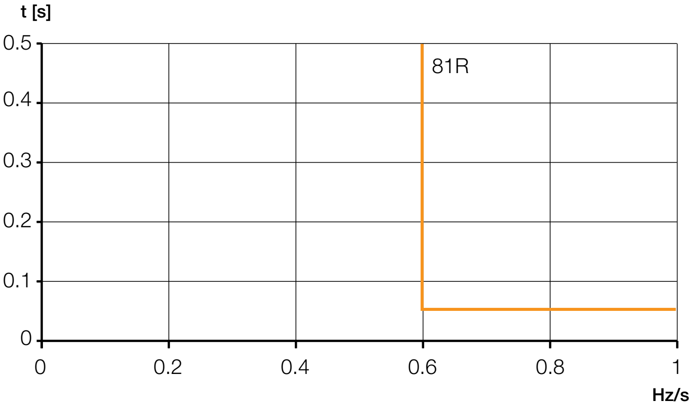
Frequency change threshold	f28 = (0.2....10)Hz/s	Threshold step	0.2Hz/s
time threshold according to setting f28			
t28 = (0.6...10)s	con f28 = 0.2Hz/s	Time step	0.1s
t28 = (0.5...10)s	con f28 = (0.4...1)Hz/s	Time step	0.1s
t28 = (0.22...10)s	con f28 = (1.2...5)Hz/s	Time step	0.1s
t28 = (0.15...10)s	con f28 > (5.2...10)Hz/s	Time step	0.1s
Selection option for monitoring positive. negative or both changes			

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

3.5.3 Setting example

Plant control must prevent the generator remaining in operation after a network fault event and maintaining voltage not only inside the production site but also in part of the public utility network; undesired islanding must be prevented.
As small synchronous rotating generators are particularly sensitive to network disturbances, the Ekip G Hi-Touch trip unit can set up the protection based on the voltage frequency creep for which a f28=0.6H/s setting is selected.
The set threshold enables a time window that can be adjusted between 0.5s -10s; a t28=500ms trip delay is selected. The trip curve is shown in Fig. 1-3.5.

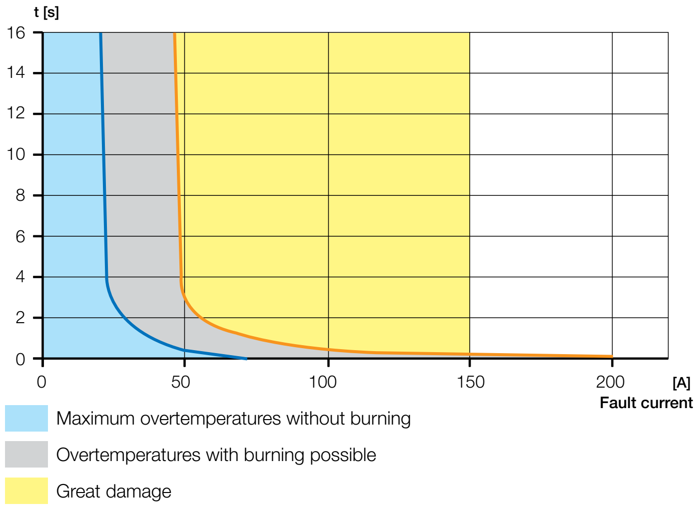
Figure 1-3.5



3.6 RV Maximum homopolar voltage (ANSI 59N)

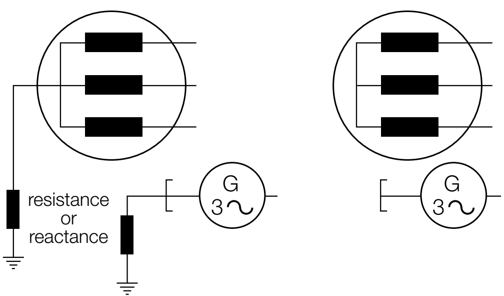
An earth fault in the stator windings is the most common type of fault to which a generator may be subject and is one of the main causes of operation failure of the machine.
This type of fault could be caused by deterioration in the insulation of the windings due, for example, to environmental conditions that are unfavourable because of the presence of humidity, aggravated by the presence of oil or dirt that deposits on the surfaces of the coils outside the stator slots.
The generator must therefore be protected from this condition to prevent the machine working in anomalous conditions with consequent oscillations on the electrical parameters and to prevent the earth fault 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 if the fault is eliminated rapidly.
Generally, the concept is represented graphically by curves that reproduce the earth fault tolerance provided by the machine manufacturer and have a shape that is similar to the shape reproduced in Fig. 1-3.6.

Figure 1-3.6



The protection method for an earth fault in a generator depends on the structure of the plant and on the type of earthing of the generator, as shown in Fig. 2-3.6.
Often, in order to limit the effects of the earth fault on the generator, it is a good idea to earth the machine's neutral point, for example by high impedance or resistance, and in some cases the generator can have the neutral point insulated from the earth. In general, the greater the resistance or impedance of the earth connection, which may even go as far as insulating the neutral point, the smaller the fault current will be, which will in fact become difficult to detect.

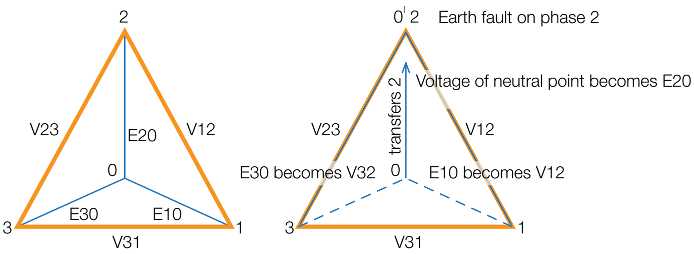
Figure 2-3.6



A fault that takes a phase or a winding to earth, increases the voltage on the other two healthy phases and on the neutral point.
The change of voltage depends on the position of the fault in the winding, on the resistance of the fault and on any earthing impedance.
If a system has been insulated from earth and there is an

earth dead short at the generator's output terminals (100% of the winding is thus affected) the two healthy phases will carry all the network voltage and the star centre will carry the phase/neutral voltage, as shown in Fig. 3-3.6. If the fault occurs in the winding and near the neutral point the size of the voltage change will be small and difficult for the protection to detect.

Figure 3-3.6



In order to protect generators with neutral isolated from earth or perhaps connected to earth with high impedance against earth fault in the stator windings or in external points, the maximum residual voltage RV function of Ekip G can be used. This protection enables about up to 90% of the stator windings to be monitored from the generator's line terminals.

3.6.1 Working modes of the protection

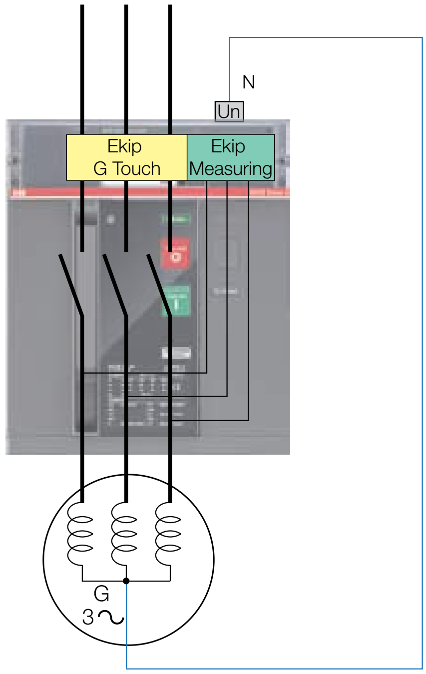
Ekip G RV protection enables the customer to provide maximum homopolar voltage protection without having to resort to cabling external voltage transformers.
Calculation of homopolar voltage and the checks required for the protection operation are all controlled by the trip unit.
With reference to Fig. 3-3.6 above, in the event of an earth dead short of phase 2, E10 becomes E10' and E30 becomes E30', whereas E20 is disabled. In this case, the sum of the phase vectors E10+E20+E30, which in normal conditions is nil, can be expressed as E10'+E30' with the hypothesised fault.
As 0' coincides with point 2 the previous formula can be rewritten as V12+V32, which provides the result 3E. Thus by generalising the concept, we see that the measure provided by the protection is 3 times the voltage taken on by the star centre in its shift.
The protection also works with the circuit-breaker open; in this condition, an alarm signal is generated following a fault above the threshold.

On the other hand, when the circuit-breaker is closed, only the alarm that reports a fault inside the machine or the trip command can be selected, which however, owing to the nature of the anomaly, does not interrupt the fault circuit.

3.6.2 Protection characteristics

The homopolar voltage protection has a definite time-delay characteristic curve with a single trip threshold and the voltage setting can be a multiple of the rated voltage set on the trip unit. Tripping time can also be set. For correct operation, the protection needs the star centre reference of the generator's winding. The connection must be made on the neutral terminal of the Ekip Measuring module, as shown in Fig. 4-3.6.

Figure 4-3.6



3.6.3 Range of possible settings

The following parameters for setting the residual voltage check RV function are available in all versions of Ekip G:

Voltage change threshold	U22 = (0.05....5) x Un	Threshold step	0.001 x Un
Tripping time	t22 = (0.5...60)s	Time step	0.05s with curve t = k

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

3.6.4 Setting example

Below there is a setting example for a generator with a neutral point insulated from earth, having a rated network voltage V12=V23=V31=U=400V, thus phase voltages V10=V20=V30=E=230V.

Depending on the working modes of the protection, for a dead short on the terminals of the generator, which thus affects 100% of the windings, the maximum residual voltage read by the protection is 3xE=1.732xU=690V.

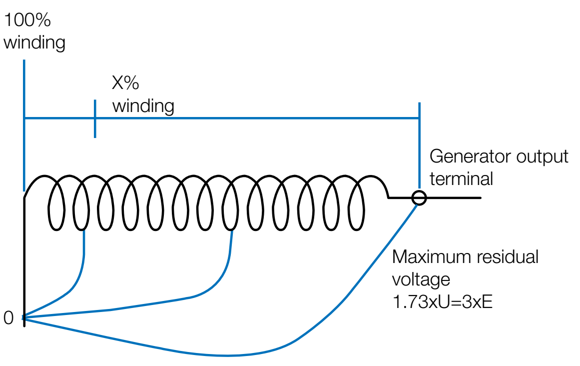
Let us assume that we wish to set a residual voltage control that is greater than or the same as 15% of maximum residual voltage.

As the protection reads 3xE, the protection threshold value is 104V. However, if the setting of the protection refers to the rated network voltage Un, the ratio 104/400 provides a value equal to 0.26.

A lower setting parameter must therefore be set in the trip unit, for example U22=0.24, which provides a trip threshold of 96V. Tripping time is set at t22=3s.

The ratio that links the maximum residual voltage with all the winding and can be expressed by the following formula (1.73xU):(100%)-(U*):(1-x%) enables it to be determined that the setting (U*=U22xUn=96V) can protect about 86% of the winding from the output terminals of the generator, as shown in Fig. 5-3.6.

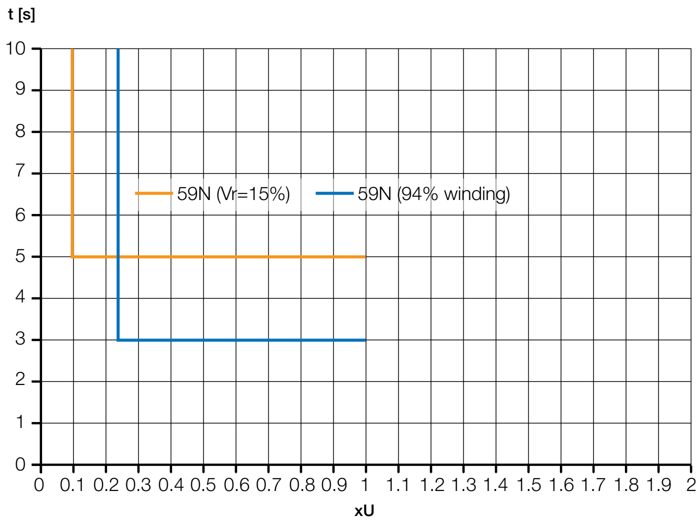
Figure 5 -3.6



To take another example, let us suppose that we wish the protection to protect, for example, 94% of the winding with a tripping time of 5 seconds. The preceding formula is used to determine the value U* representing the residual voltage read by the protection, which, proportioned to the voltage set for the trip unit, enables the reference for the setting to be determined, which is equal to 0.104. Thus if the protection is set at U22=0.1 t22=5s a trip threshold is obtained that provides the required protection.

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

Figure 6-3.6



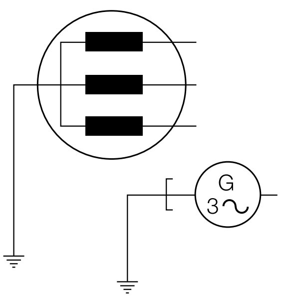
3.7 G Earth faults protection (ANSI 51N or 51G)

In low-power applications, the generators have a zero-resistance earth contact as per diagram in Fig. 1-3.7. In this case function 59N discussed previously cannot be used to provide protection against insulation loss in the windings.

In fact, in the presence of an earth fault, the star centre potential is constrained by the direct earth connection.

The conditions necessary for the appearance of residual voltage on which the operation of function 59N is based are therefore not present.

Figure 1-3.7



For protection against earth faults in stator windings or in other points outside the machine it is therefore possible to use the traditional function G providing maximum residual earth current protection.

Residual current can be measured:

- by running on the trip unit the 3 phase currents signal (or signal of the currents of the three phases and of neutral), which will make the vector sum, making what is called $G_{internal}$, and basically corresponds to the ANSI 51N code;
- by running on the trip unit the signal coming from the summing toroid located on the earth connection of the neutral point of the generator, making what is called the $G_{external}$, which corresponds to the ANSI 51G code.

3.7.1 Working modes and characteristics of the protections

The G protection against the earth fault made inside the trip unit is obtained by vectorially summing the phase currents and neutral. If it is made by an external toroid, the trip unit controls the current induced on the winding of the toroid, which is proportional to the fault current in transit in the toroid.

When the sum of the currents or the current that comes from the toroid is greater than the set current threshold and this condition persists for a longer time than the set delay, the circuit-breaker is tripped.

The G protection has constant time curves or dependent time curves with constant I^2t. The G protection can be tripped by the current threshold or tripping can be delayed

3.7.2 Range of possible settings

The following parameters for setting the earth fault protection function are available in all versions of Ekip G:

$G_{internal}$ with constant time curves t=k and I^2t constant; can be set according to the rated current In of the circuit-breaker. and operates via its internal toroids;	Current threshold	I4 = (0.1...1) x In	Threshold step	0.001 x In
	Time threshold	t4 = (0.1...1)s	Time step	0.01s
$G_{external}$ with constant time curves t=k and I^2t constant; 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	0.01s

The parameter In shows the rated current of the circuit-breaker or of the external toroid. depending on whether $G_{internal}$ or $G_{external}$ is working

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

3.7.3 Setting example

Let us take the case of a generator with neutral point connected directly to earth, characterised by the electric parameters set out in the following table.

SnG	1600kVA
VnG	400V
x"d%	16%
x0%	3.60%
x2%	16%
I2nG	2309A
ZnG	0.1 ohm
X"d	0.083 ohm
X0	0.019 ohm
X2	0.087 ohm
R earth fault	0 ohm

Let us assume that the single-phase earth fault current on the terminals of the generator, i.e. considering all the winding, is about Ikg=3660A.

By positioning an external toroid on the connection of the neutral point on the earth of the generator having rated current 800A and setting I4=0.6 to fix the trip threshold at 480A with a tripping time set at t4=0.1s protection against earth faults is obtained without particular problems.

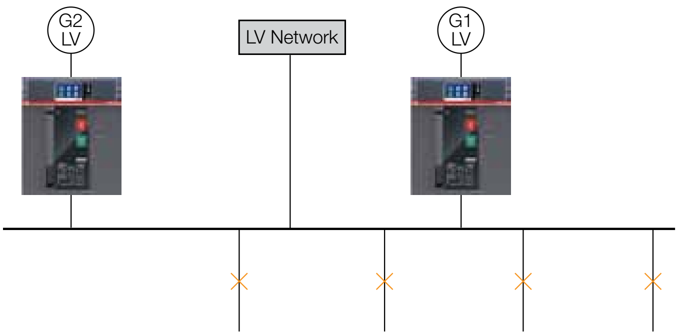
3.8 SC Controlling synchronism conditions (ANSI 25)

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

- when islanding occurs (condition that arises after disconnection from network) in which another reserve generator G2 is connected in parallel to a generator G1 already connected to the plant shown in Fig. 1-3.8 and the other reserve generator G2 contributes to supplying the users that cannot be disconnected. This procedure is actuated to adapt the supply power to the power required by the loads to avoid excess users being disconnected;
- in a ship's plant in which a faulty generator is replaced by connecting another emergency generator to the live busbar;
- in the event of closure of a bus tie that forms a loop in the distribution system;
- as a safety protection to prevent a production system (generator) connecting to a disconnected plant and starting it up;

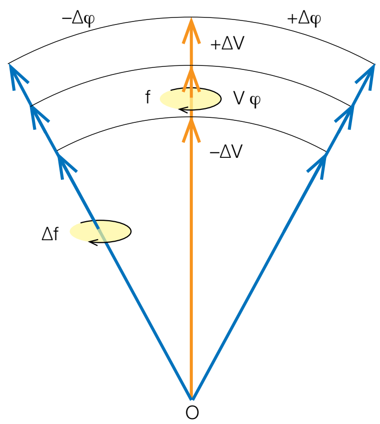
- short parallel condition, in which before disconnecting a machine, for example for maintenance, in order to avoid a plant being placed out of service, for a short period the plant also operates with the reserve machine connected.

Figure 1-3.8



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

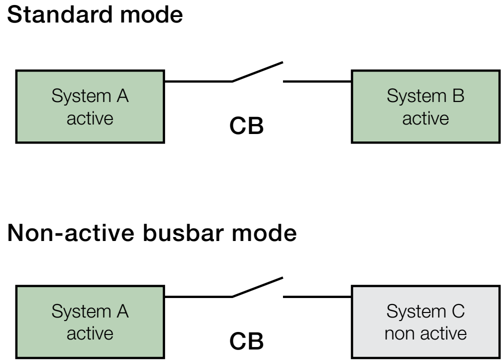
Figure 2-3.8



3.8.1 Working modes of the protection

The synchronism control function enables two types of interconnection shown in Fig. 3-3.8 to be controlled by two different working modes, namely:
- “active busbar” mode that enables the generator closing or a portion of active plant on an active busbar to be controlled;
- “dead busbar” mode that enables the generator closing or a portion of active plant on a non-active busbar to be controlled.

Figure 3-3.8



In “active busbar” mode the Ekip Synchrocheck Module enables:
- checking that the active 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, for a time that is longer than the set time;
- choosing whether to control the synchronism condition by monitoring the following parameters for the two active systems:
- only voltage;
- voltage and frequency;
- voltage, frequency, phase.

When the controlled parameters meet the set conditions, the contact is activated to signal that the condition for making the parallel connection has been fulfilled.

In “dead busbar” mode the Ekip Synchrocheck Module checks that the value of the network voltage of the non-active system C is lower than the control voltage set by the user for the relative set time; this is to establish that the busbar can be actually considered to be non active. The active or dead busbar side relative to the circuit-breaker can be selected by the relative parameter.

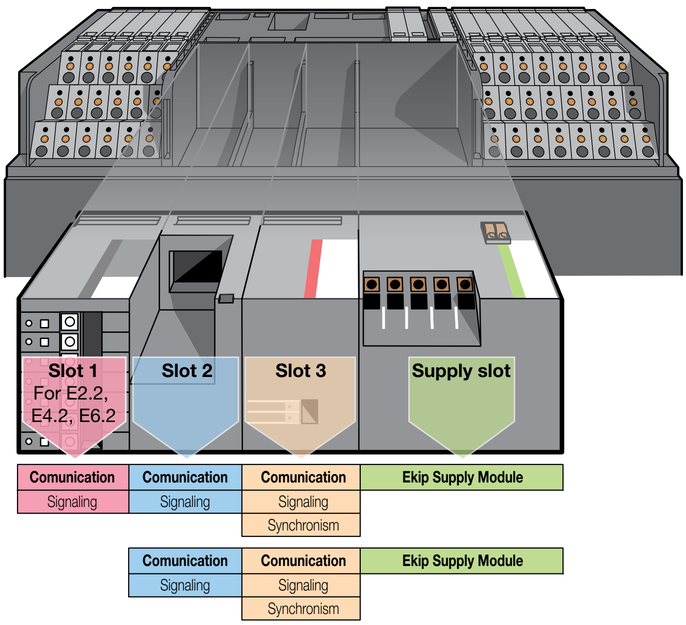
Independently of the selected mode, the protection has the following characteristics:
- the protection checks that the circuit-breaker of the system to be connected is open;

- the module compares homologous voltages, i.e. for example V13 of the system B according to the single-phase voltage transformer connection and V13 for the active system A, set on the trip unit between the three network voltages, read by the voltage sockets inside the circuit-breaker;
- the parallel-connection consent contact is deactivated when one of the monitored synchronism suitability conditions is missing;
- the protection considers 100ms the minimum synchronism matching time, considered as the minimum time necessary for closing the parallel-connection circuit-breaker.

3.8.2 Protection characteristics

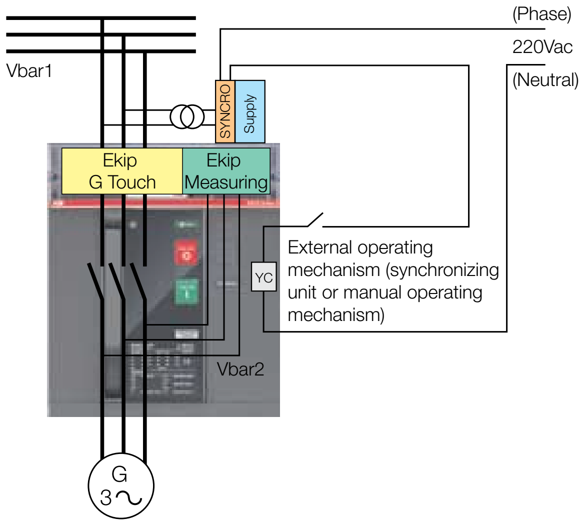
The synchronism control function for paralleling two lines is available via an external module. The module can be used with the Ekip Touch and Hi-Touch trip units in the distribution version and in the version for protecting generators Ekip G already fitted by the manufacturer with the Ekip Measuring Pro Module.
The Ekip Synchrochek Module acquires on the one side the voltage between two phases of the line by means of an external single-phase voltage transformer and on the other side the three voltages of the line by means of the Ekip Measuring Pro Module. Also on this side, for voltages above 690V a three-phase VT needs to be provided.
The Ekip Synchrocheck Module can be fitted directly in the terminal box area of the fixed circuit-breaker or in the fixed part of the withdrawable circuit-breaker and occupies, as shown in Fig. 4-3.8, one of the two spaces available in E1.2 and 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 with the Ekip Supply Module, which supplies both the trip unit and the Synchrocheck Module. The voltages that can be used for the supply are 110 Vac/dc to 220 Vac/dc or 24Vdc to 48Vdc, depending on the version used. An output contact is available that is activated when synchronism is reached to enable the circuit-breaker to be closed directly through cabling with the closing core or to be inserted into the check logic of the generator, according to the diagram of Fig. 5-3.8.

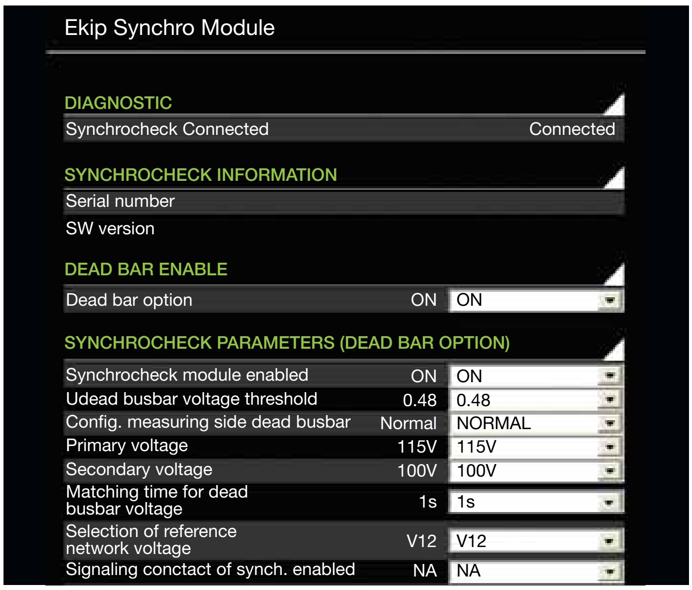
Figure 5-3.8



3.8.3 Range of possible settings

The operation of the synchronism module requires certain parameters to be set that are shown as in Fig. 6-3.8 and are set out in the following tables divided into “active busbar” or “dead busbar”.

Figure 6-3.8



Setting parameters for active busbar option			
1)	Syncrocheck Module enabled	YES/NO	
2)	ΔU voltage module difference threshold	setting (0.05... 0,2) x Un	step 0.001 x Un
3)	Ulive active busbar voltage threshold	setting (0.5...1.2) x Un	step 0.001 x Un
4)	Matching time for active busbar voltage	setting (0.1... 30)s	step 0.1s
5)	Δf frequencies difference threshold	setting (0.1...1)Hz	step 0.05Hz
6)	Δφ phases difference threshold	setting (5°...50°)	step 5°
7)	Primary voltage VT [V]	100, 115, 120, 190, 208, 220, 230, 240, 277, 347, 380, 400, 415,440, 480, 500, 550, 600, 660, 690, 910 950 1000	
8)	Secondary voltage VT [V]	100, 110, 115, 120	
9)	Enabling frequency check parameter	setting ON/OFF	
10)	Enabling phase check parameter	setting ON/OFF	
11)	Selection of reference network voltage	V12, V23, V31	
12)	Signalling contact of synchronism enabled	Normally open/closed NA/NC	

Setting parameters for dead busbar option			
1)	Syncrocheck Module enabled	YES/NO	
4)	Matching time for dead busbar	setting (0.1... 30)s	step 0.1s
7)	Primary voltage VT [V]	100, 115, 120, 190, 208, 220, 230, 240, 277, 347, 380, 400, 415,440, 480, 500, 550, 600, 660, 690, 910 950 1000	
8)	Secondary voltage VT [V]	100, 110, 115, 120	
11)	Selection of reference network voltage	V12, V23, V31	
12)	Signalling contact of synchronism enabled	Normally open/closed NA/NC	
13)	U dead busbar voltage threshold	setting (0.05...1.2) x Vn	step 0.001 x Vn
14)	Enabling working mode on dead busbar	YES/NO	
15)	Configuring measuring side for dead busbar	normal or reverse	

NOTE: the number reference has been given to facilitate reading; it does not appear in the protection.

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

Un is the rated voltage of the trip unit that can be set on the display. Naturally, this value will coincide with the primary voltage of the VT, because the two systems that will connect together will have the same rated voltage.

A short explanation of the different protection-setting parameters follows

Parameter 1) Enables synchronism control module;

Parameter 2) Relates to the permitted difference between the voltage module selected as a reference for the two systems;

Parameter 3) Relates, in standard mode, to the voltage value of the system to which the connection will be made, which must be greater than the value set for the relative set time. Condition for checking stability in the voltage of the active system.

Parameter 4) Relates to the residential time of the check voltage set on the active busbar (3) and passive busbar (14);

Parameter 5) Relates to the permitted difference between voltage frequency selected as a reference for the two systems;

Parameter 6) Relates to the permitted difference between the phase of the voltage selected as a reference for the two systems;

Parameter 7) Relates to the setting of the primary voltage of the external VT on the synchronism module side;

Parameter 8) Relates to the setting 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;
The OFF setting of the frequency parameter cuts out the phase parameter, whatever selection has been made. In this way, the synchronism check is run only on voltage.
Setting ON for the frequency and phase parameter enables the synchronism check by monitoring the three voltage module, frequency and phase parameters;
Setting ON for the frequency parameter and OFF for the phase parameter enables the synchronism check by monitoring the voltage module, frequency parameters.

Parameter 11) Relates to the selection of the reference network voltage on the generator side (voltage sockets). Enables one of the network voltages V12 V23 V31 to be set as the voltage to be taken as a reference for how the VT was connected on the network side;

Parameter 12) Relates to the contact position for signalling the condition that is suitable for parallelism. It can be set as normally open NO (closes for suitable condition) or normally closed NC (opens for 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 set value for considering the busbar to be non active;

Parameter 14) Relates to the module's working mode: choose "YES" to enable "dead busbar" working mode; choose "NO" to enable standard "active busbar" working mode;

Parameter 15) Relates to dead busbar and refers to how the trip unit is inserted in relation to the active and to the non-active side.

3.8.4 Setting example

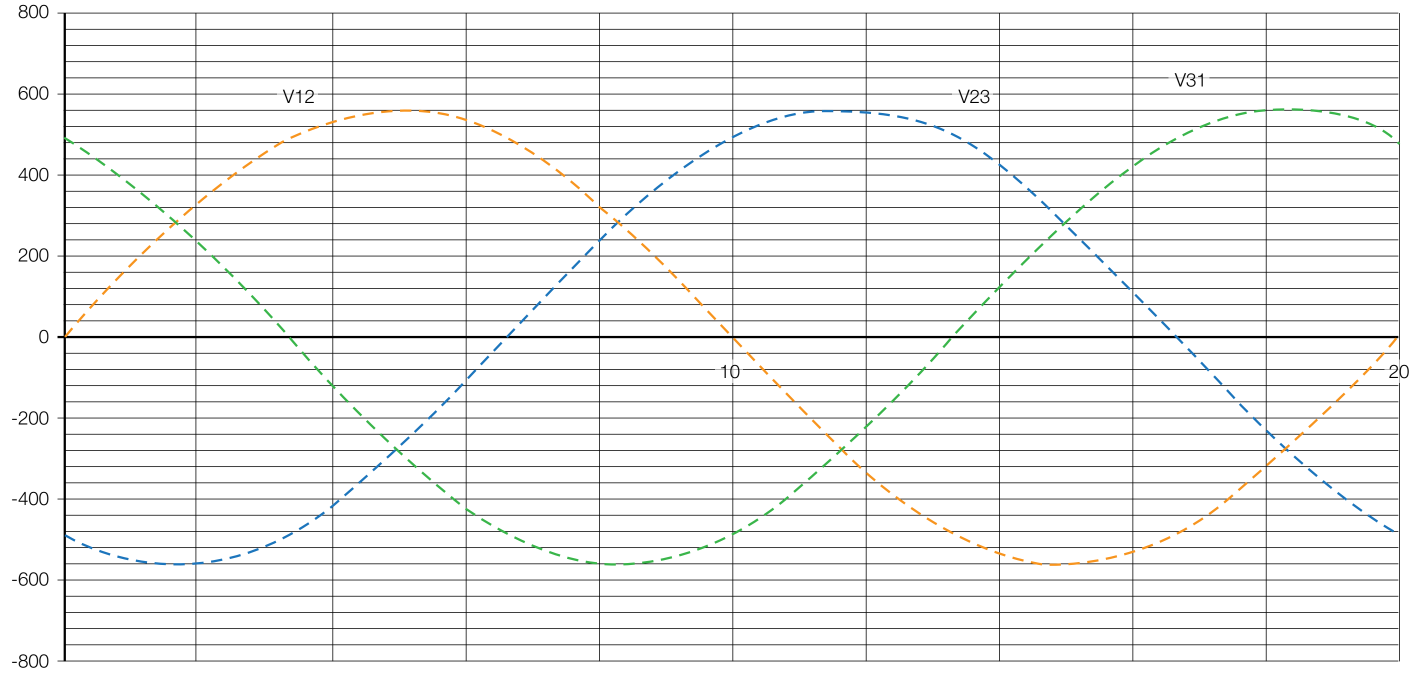
The example considers a plant portion characterised by:

- active busbar with three voltages having the following parameters and shown in Fig. 7-3.8
  network voltage V12: module V=400V; phase angle φ_{12}=0
  network voltage V23: module V=400V; phase angle φ_{23}=120°
  network voltage V31: module V=400V; phase angle φ_{31}=240°
  voltage frequency f=50Hz
- generator that has to be connected in parallel to the busbar.

The protection runs internal checks on the set values of the parameters "threshold Δf" and "threshold Δf", making possible only values that enable synchronism to be obtained that persists for at least 100ms, which is considered to be the minimum time required for the parallel circuit-breaker to close.

In a first approximation the evaluation of the parameters Δf and Δφ that are consistent and accepted by the protection

Figura 7-3.8



can be evaluated with reference to the following formula:
360° x Δf x t ≤ 2 x Δφ°.

The following parameters can thus be set because they fulfil the 100ms condition:

2) Voltages module difference ΔV threshold:	4%
5) Frequencies difference Δf threshold:	0.2Hz
6) Phases difference Δφ threshold:	5°

and determine synchronism that lasts about 139ms.

It is assumed that the actuation logic that closes the parallel-connection circuit-breaker requires a total of 180ms. The Δf or Δφ settings must therefore be modified to obtain synchronism that lasts longer than the closing time of the circuit-breaker.
If the set parameter Δf=0.2Hz has to be confirmed and a time of 0.18s is considered, the new Δφ to be set must be greater than 6.48°.
If the set parameter Δφ=5° has to be confirmed and a time of 0.18s is considered, the new Δf to be set must be less than 0.154Hz.

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

14) Enabling working mode on non-active busbar:	"NO" setting to enable "active busbar" mode and set up the protection controlling two active busbars.
3) Active busbar voltage threshold:	setting 99% of Un.
4) Matching time for active busbar voltage:	setting 10s; these settings are tailored to plant requirements and ensure that the active network voltage has a suitable and stable value.
11) Selecting reference network V:	V12 The selected voltage is taken as a reference for the synchronism check.
9) Enabling frequency check parameter:	setting ON.
10) Enabling phase check parameter:	setting ON; the settings enable the synchronism on the three voltage, phase and frequency parameters to be checked in response to the check mode hypothesised in this example.
12) Signalling contact of synchronism enabling:	setting NA; Ithe plant control logic requires synchronism suitability to be signalled by the closure of the dedicated contact. NA status is thus set.
7) Primary voltage of the external VT	on the basis of the network voltage indicated in the initial data, the value 400V is set.
8) Secondary voltage of the external VT	on the basis of the secondary voltage of the selected VT (hp 100V), the value 100V is set in the trip unit.

Generator synchronisation is carried out by the operator or is performed by the system control logic, which, for example, acts on the exciter to control the voltage amplitude or on the first motor for phase and frequency checks.

When the three generator voltages, in particular, the voltage set as a reference, take on lower voltage, frequency and phase values than the set parameters with respect to the corresponding network voltage, the synchronism control module supplies its consent.

This signal can be integrated into the control logic to enable the generator's circuit-breaker to be closed by the parallel connection. Fig. 8-3.8 shows the typical shape of the two sinusoidal voltages with differences in the module, in the phase and in the frequency.

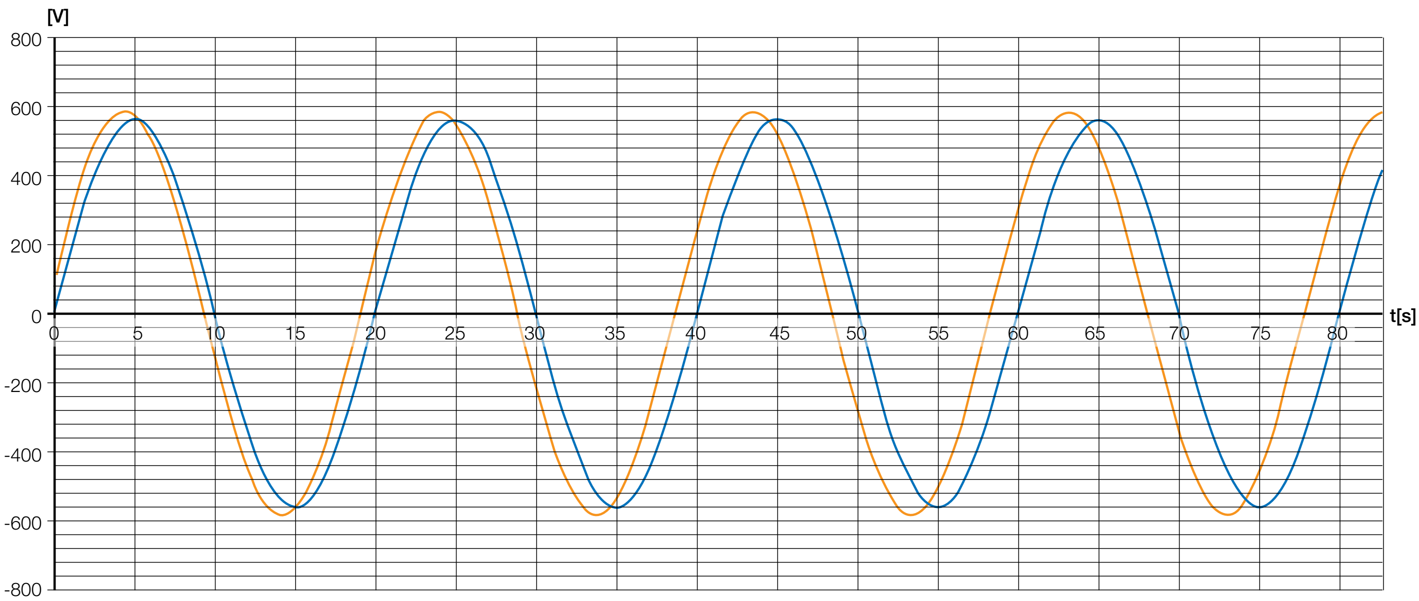
3.9 Protection against overload and short circuit

These protection functions are the traditional current functions that are normally available in the electronic protection trip units that are fitted in ABB SACE Emax 2 air circuit-breakers and they are commonly used for normal plant applications. Their use for protection purposes and their control in terms of setting need to be calculated and depend on the particular generator protection requirements.

3.9.1 L Protection against overload (ANSI 49)

Overcurrents can cause overheating of the stator windings and must be eliminated before the temperature reaches critical levels for the machine.
Temperature rises above values that could be critical for the machine are avoided by monitoring the current that the generator has to supply in normal operating conditions. The protection can be provided by the traditional current protection function against overload L (ANSI 49 code) or for higher current values that therefore require shorter tripping times the function against delayed short circuit S (ANSI 51 code) could be used.
In principle, the prescriptions for the overload limits of the generator that are supplied as a typical time/current overload curve or by characteristic single current-proof points are gen-

Figure 8-3.8



erally indicated in the main national and international standards or in shipbuilding regulations.
As an example, we can quote the permitted characteristic for generators according to IEEE standards and which are characterised by the following points:

Stator current as % of machine's rated current	218	150	127	115
Ampacity time in seconds	10	30	60	120

A further limit point is specified in the main shipping registers and is characterised by:

Stator current as % of machine's rated current	300
Ampacity time in seconds	2

International standard IEC 60034-1 state that generators must be able to carry a current that is 1.5 times the rated current for at least 30 s. This prescription thus corresponds to a point of the overload curve permitted by IEEE.

3.9.2 Maximum time-delayed current protection S and instantaneous current protection I (ANSI 51 and 50)

Maximum instantaneous current protections (ANSI 50 code or protection I) or time-delayed protection (ANSI 51 code or protection S) are used as a protection against network short circuits. This condition is viewed by the generator as a large power and current request with consequent slowing down of the machine. In addition to the typical reduction of network voltage at the fault point, this would trigger an energisation 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 machine parameter X"d.
The main problem that arises therefrom is the deterioration of the stator and rotor windings because of the high overtemperatures that are generated by the currents and the problems linked to the machine's mechanical structure.
The functions against delayed or instantaneous short circuits can thus be used to disconnect the generator from the plant portion affected by the fault. They can be considered to be the main protections for small generators or as back-up protections for other protection functions for larger generators. In addition, the time-delayed protection 51 or S could be used as mentioned previously also as a protection against high overload currents that occur during normal operation and have to be interrupted relatively quickly in order to prevent the machine working beyond its thermal limits. In addition to normal protection S against delayed short circuits, it should be remembered that also directional current function D (ANSI 67) is available to which current direction is associated.

An IU protection is also available that protects from unbalance between the currents of the single phases protected by the circuit-breaker (ANSI 46).

3.9.3 Working modes and characteristics of the protections

The LSI current protections work on the basis of the RMS value of the currents of the three phases, and of neutral if it is present.
The protection L has curves complying with standard IEC 60947-2 with the thermal memory function, and with standard IEC 61255-3. Current threshold and trip delay can be set.
The protection S has a constant time or dependent time curves with I^2t constant and with thermal memory function. Current threshold and trip delay can be set. This protection can be disabled.
The protection I can be set only in current. Intentional delays cannot be set and it cannot be disabled.
When one of the currents exceeds the set current threshold, and this condition remains set for a period longer than the set delay, for the functions L and S, or instantaneously for the function I (i.e. with no intentional delay) the circuit-breaker is tripped.

3.9.4 Range of possible settings

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

Overload 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	Curve I^2t=cost
Time threshold	t1 = (3…144)s with I = 3xI1	Time step	1s	Curve 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	Threshold step	1s	Curve (k= 1…20 N= 1, 2, 4)

Short circuit delayed protection S			
First current threshold	I2 = (0.6…10) x In	Threshold step	0.1 x In
Time threshold Curve t=const (*)	t2 = (0.05…0.8)s	Time step	0.01s
Time threshold Curve I^2t=const	t2 = (0.05…0.8)s with I = 10xI1	Time step	0.01s
Second current threshold	I5 = (0.6…10) x In	Threshold step	0.1 x In
Time threshold Curve t=const	t5 = (0.05…0.8)s	Time step	0.01s

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

Short circuit instantaneous protection I			
Current threshold	I3 = (1.5…15) x In	Threshold step	0.1 x In
Time threshold	Instantaneous		

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

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 400V;
- rated current InG=1515A

characterised 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%
Subtransient reactance quadrature	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

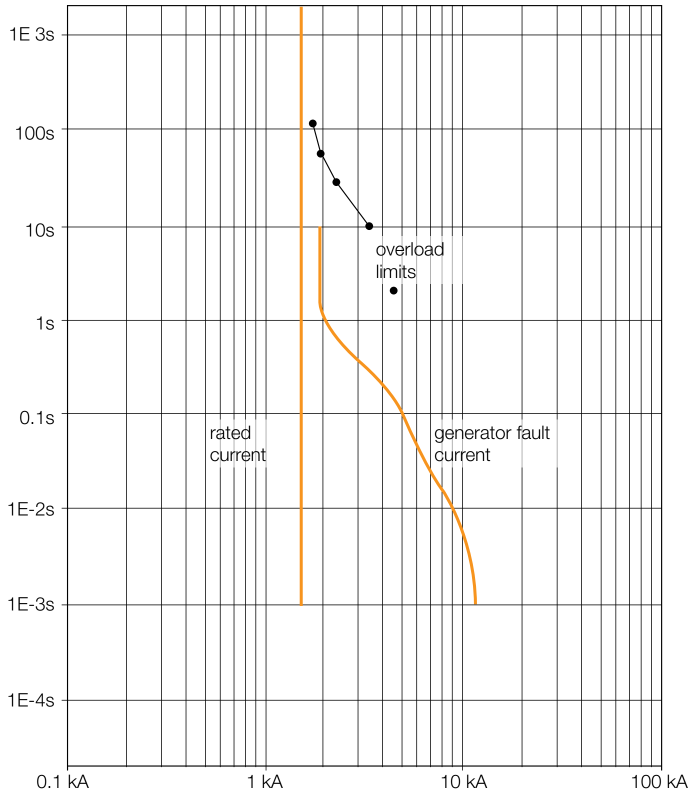
and by the following overload limits referring to the rated current and shown in Table 2-3.9.

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 reported on a time/current graph give rise to the curves shown on the graph in Fig. 1-3.9 that show the shape of the fault current and the generator's overload limits.

Figure 1-3.9



The aim of the example is to find settings for the generator circuit-breaker that are suitable for the LSI functions that enable a curve protection to be obtained that is suitable for the machine characteristics, paying attention, if possible, to create a possible selectivity condition in relation to the circuit-breaker of the users supplied.
With reference to the rated current of the generator (1515A), using a circuit-breaker with 2000A rated current is envisaged.
The chosen settings identify a trip curve of the circuit-breaker, as seen from the graph in Fig. 2-3.9.
The protection intercepts the machine's short circuit curve, detail in Fig. 4-3.9, by insulating the machine from the network fault or protecting the machine from critical overloads during normal operation, detail in Fig. 3-3.9, which would otherwise cause the thermal limits to be exceeded.

3. Protections of Ekip G trip unit

In the example, the following settings have been selected:

overload L or 49	I1=0.75xIn t1=3s
delayed short circuit S or 51	I2=2xIn constant time curve t2=0.10s
instantaneous short circuit I or 50	I3=OFF

Figure 2-3.9

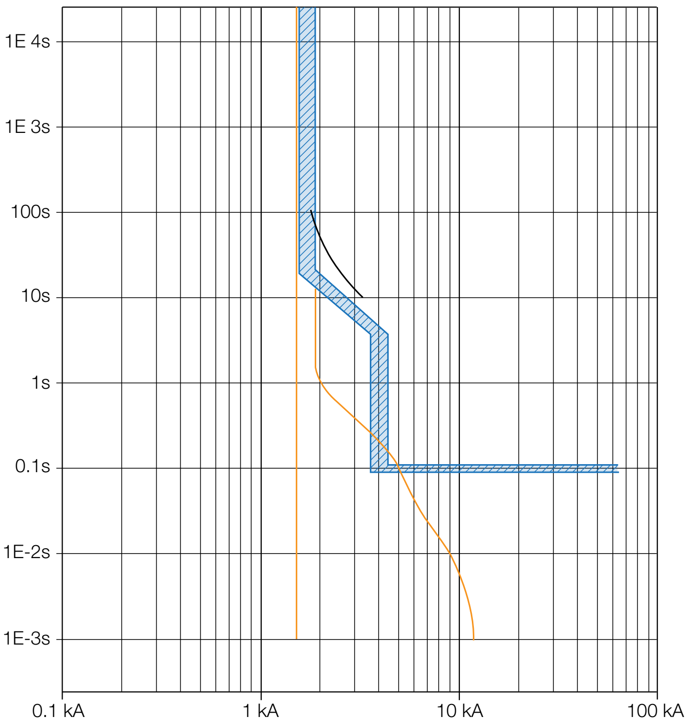


Figure 3-3.9

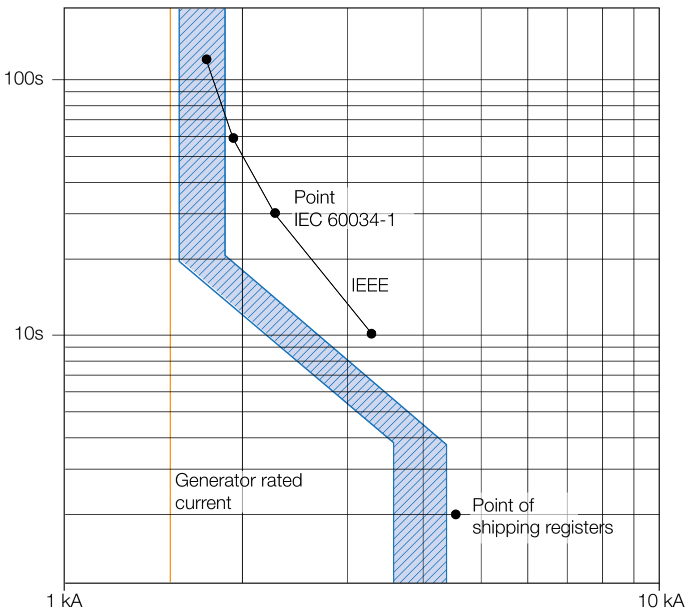
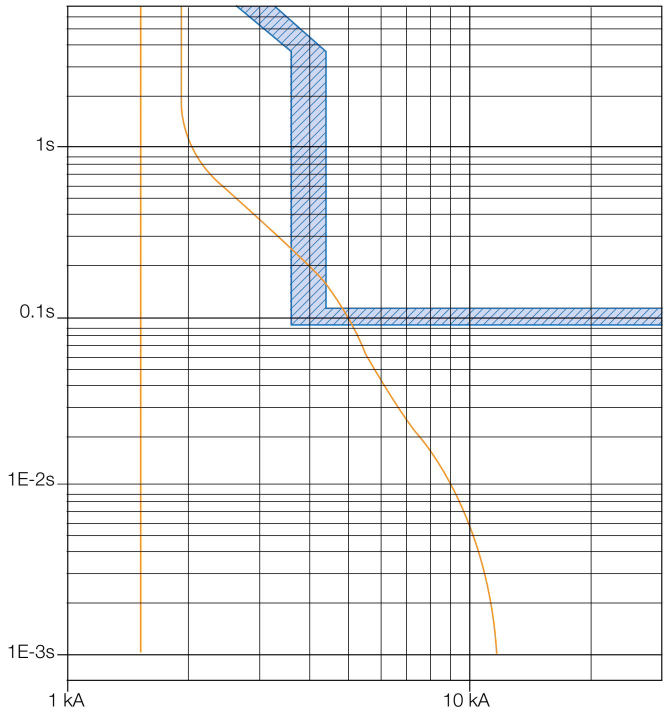


Figure 4-3.9



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