protection and control
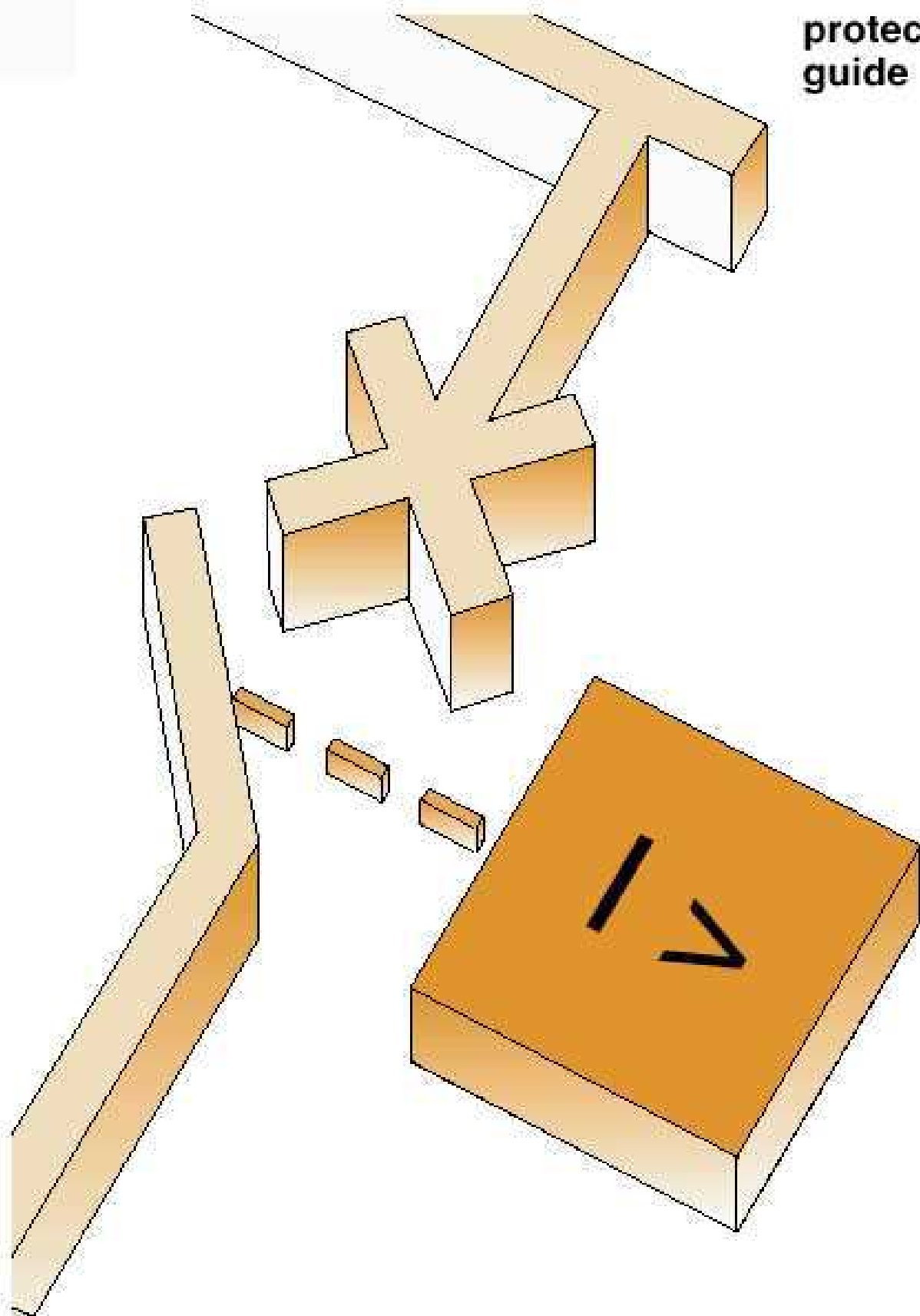
protection guide

Schneider Electric

presentation

contents

lexicon

Symbol	Description	Symbol	Description
I >	overcurrent protection	U <	undervoltage protection
I <—	directional overcurrent protection	> f >	over and underfrequency protection
I_N >	earth fault protection	U >	overvoltage protection
Ii >	negative sequence unbalance protection	P <—	real reverse power protection
⌐	thermal overload protection	Q <—	reactive reverse power protection
∆I	differential protection	U_N >	neutral voltage displacement protection
I/U >	voltage restrained overcurrent protection		Buchholz

generalities

Protection devices continuously monitor the electrical status of system units and cause them to be de-energized (e.g. tripped by a circuit breaker) when they are the site of a disturbance: short-circuit, insulation fault...

The objectives are:
■ to contribute to protecting people against electrical hazards,
■ to prevent equipment damage (the power produced by a three-phase short-circuit on a MV busbar can melt up to 50 kg of copper within 1 second, the temperature at the centre of the arc can exceed 10,000°C),
■ to limit thermal, dielectric and mechanical stress on equipment,
■ to maintain stability and service continuity in the system,
■ to protect adjacent installations (for example, by reducing induced voltage in adjacent circuits).

In order to attain these objectives, a protection system should have the following features:
■ speed,
■ discrimination,
■ reliability.

Protection, however, has its limits: faults have to actually occur in order for it to take effect. Protection cannot therefore prevent disturbances; it can only limit their duration. Furthermore, the choice of a protection system is often a technical and economic compromise between the availability and safety of the electrical power supply.

The choice of a protective device is not the result of isolated study, but rather one of the most important steps in the design of the electrical system.
Based on an analysis of the behaviour of electrical equipment (motors, transformers...) during faults and the phenomena produced, this guide is intended to facilitate your choice of the most suitable protective devices.
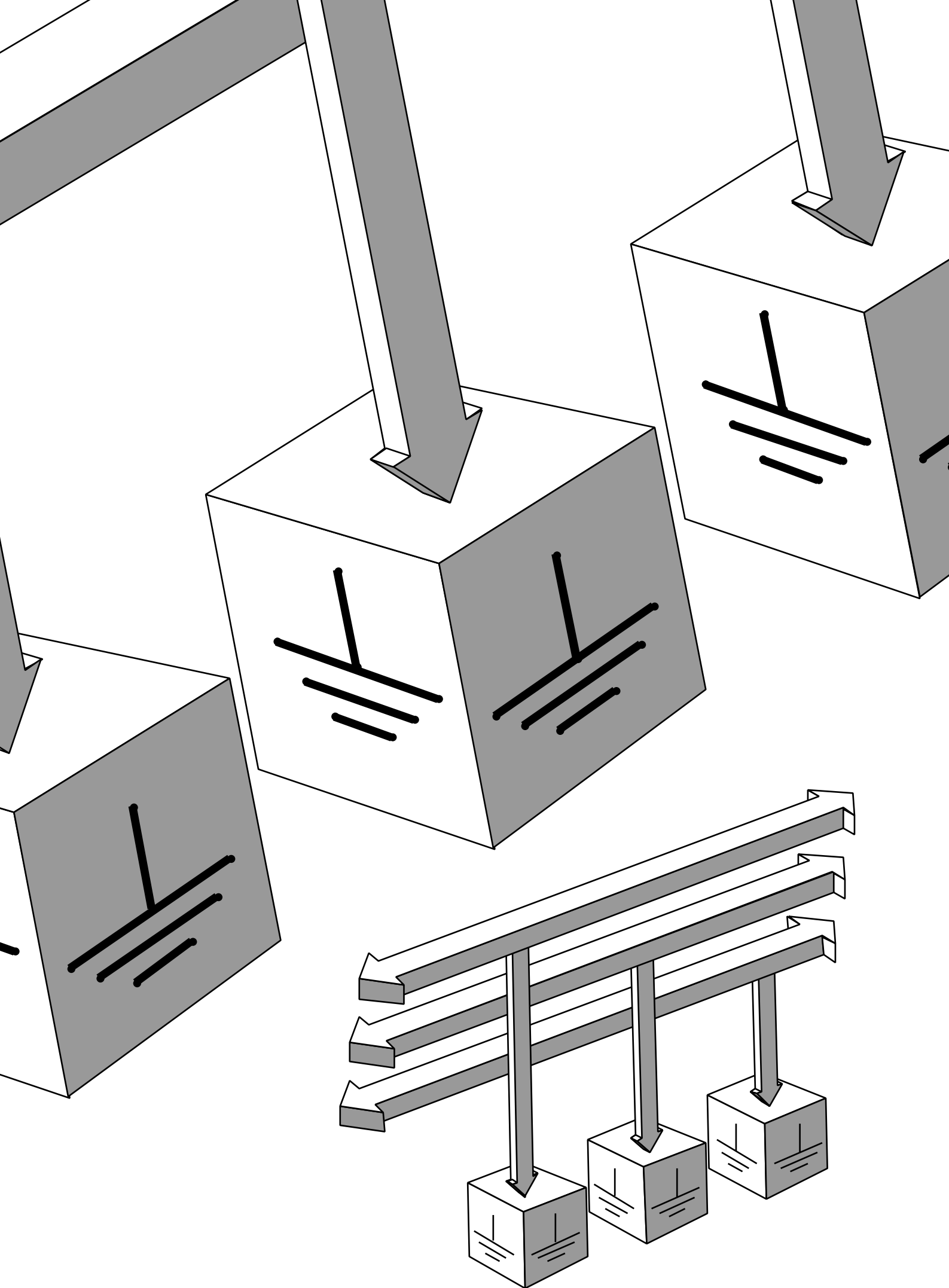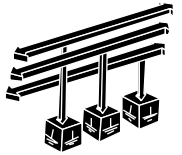
grounding systems

introduction

The choice of MV and HV grounding systems has long been a topic of heated controversy due to the impossibility of finding a single compromise for the various types of electrical systems. Experience acquired today enables a pertinent choice to be made according to the specific constraints of each system.

five grounding sytems

Neutral potential can be grounded using five methods that differ according to the kind (capacitive, resistive, inductive) and value (zero to infinity) of the Z_n impedance connection made between the neutral and earth:

■ $Z_n = \infty$ **ungrounded,** no deliberate connection,
■ Z_n is a **resistance** with a fairly high value,
■ Z_n is a **reactance** with a generally low value,
■ Z_n is a **reactance** designed to compensate for the system capacity,
■ $Z_n = 0$ - the neutral is directly **grounded.**

difficulties and selection criteria

The selection criteria involve many aspects:
■ technical characteristics (system function, overvoltage, fault current, etc...),
■ operation (service continuity, maintenance),
■ safety,
■ cost (investment and operating expenses),
■ local and national customs.

In particular, there are two major technical considerations which are, in fact, contradictory:

Reducing the level of overvoltage
Overvoltage is of several origins:
■ lightning overvoltage, which all overhead systems are exposed to, up to the user supply point,
■ internal system overvoltage caused by operations and certain critical situations (resonance),
■ overvoltage resulting from an earth fault itself and its clearance.

Reducing earth fault current (If).
Fault current that is too high produces a whole series of consequences:
■ damage caused by the arc at the fault point; particularly the melting of magnetic circuits in rotary machines,
■ thermal withstand of cable shields,
■ size and cost of earthing resistance,
■ induction into adjacent telecommunication systems,
■ danger for people created by raised frame potential.

Unfortunately, optimizing one of these requirements is automatically to the disadvantage of the other. Two typical grounding methods accentuate this contrast:
■ the ungrounded neutral system, which eliminates the flow of earth fault current through the neutral but causes the most overvoltage,
■ the directly grounded neutral system, which reduces overvoltage to a minimum, but causes high fault current.
An intermediate solution is therefore often chosen: the impedance grounded neutral system.

ungrounded
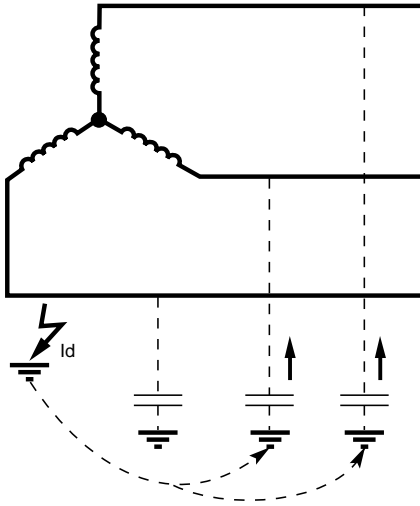
In this type of system, a phase-to-earth fault only produces a weak current through the phase-to-earth capacity of the fault-free phases.

It can be shown that $Id = 3\,C\omega V$

■ V being the simple voltage,
■ C the phase-to-earth capacity of a phase,
■ ω the frequency of the system ($\omega = 2\pi f$).

The Id current can remain for a long time, in principle, without causing any damage since it does not exceed a few amperes (approximately 2 A per km for a 6 kV single-pole cable, with a 150 mm^2 cross-section, PRC insulated, with a capacity of 0.63 µF/km). Action does not need to be taken to clear this 1st fault, making this solution advantageous in terms of maintaining service continuity. However, this brings about the following consquences:

■ if not cleared, the insulation fault must be signalled by a **permanent insulation monitor,**

■ subsequent fault tracking requires device made all the more complex by the fact that it is automatic, for quick identification of the faulty feeder, and also maintenance personnel qualified to operate it,

■ if the 1st fault is not cleared, a second fault occurring on another phase will cause a real two-phase short circuit through the earth, which will be cleared by the phase protections.

Advantage
The basic advantage is **service continuity** since the very weak fault current prevents automatic tripping.

Drawbacks
The **failure to eliminate overvoltage** through the earth can be a major handicap if overvoltage is high. Also, when one phase is earthed, the others are at delta voltage ($U = V.\sqrt{3}$) in relation to the earth increasing the probability of a 2nd fault. Insulation costs are therefore higher since the delta voltage may remain between the phase and earth for a long period as there is no automatic tripping. A maintenance department with the equipment to quickly track the 1st insulation fault is also required.

Applications
This solution is often used for industrial systems ($\leq$ 15 kV) requiring service continuity.
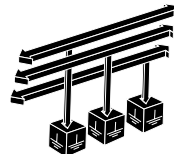
resistance grounding
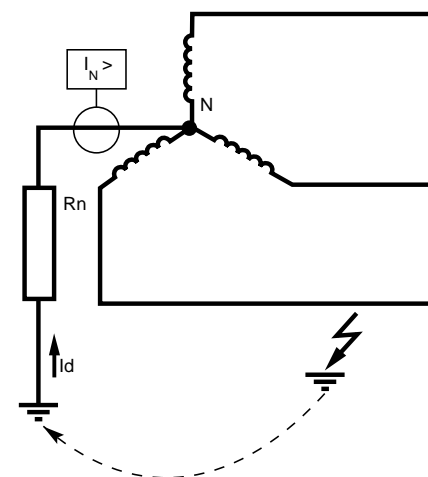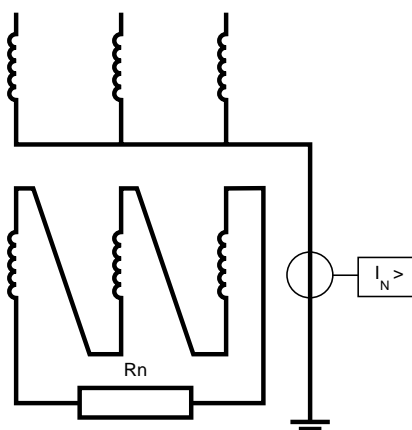
In this type of system, a resistive impedance limits earth fault current Id, while still allowing proper evacuation of overvoltage. Protections must however intervene automatically **to clear the first fault.** In systems that feed rotating machines, the resistance is calculated so as to obtain an Id current of 15 to 50 A.

This weak current must however be $Id \geq 2$ Ic (Ic : total capacitive current in the system) in order to reduce operation overvoltage and to enable simple detection.

Distribution systems use higher ratings (100 to 1000 A) that are easier to detect and allow evacuation of lightning overvoltage.

Advantages
This system is a good compromise between weak fault current and good overvoltage evacuation. The protection devices are fairly simple and discriminating and the current is limited.

Drawbacks
■ no service continuity; earth faults must be cleared as soon as they occur,
■ the higher the voltage and level of current limitation, the higher the cost of the earthing resistance.

Applications
Public and industrial MV distribution systems.

Earthing resistance
If the neutral is accessible (star-connected transformer), the earthing resistance is inserted between the neutral and earth. When the neutral is not accessible or when determined by the discrimination study, an artificial neutral point is established (zero sequence generator) using a coil or a special transformer with a very low zero sequence reactance.

Protections
The detection of weak fault current Id requires protections other than overcurrent phase relays.
These "**earth** fault" protections detect fault current:
■ directly in the neutral earthing connection ①,
■ or within the system by measuring the vectorial sum of the 3 currents using:
□ 3 CTs feeding the phase overcurrent protections ②,
□ a core balance CT - (accurate solution - to be used preferably) ③.
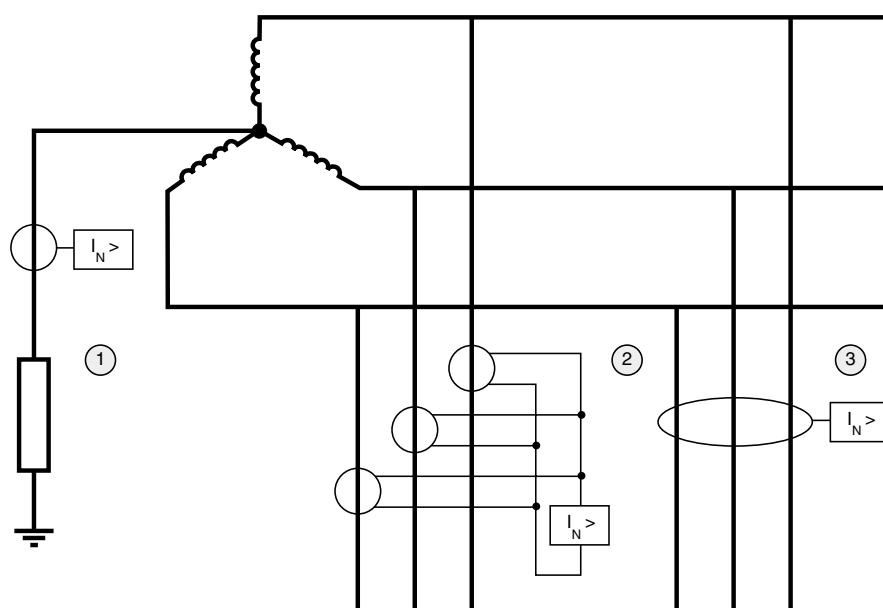
The relay is set according to the fault current Id that is calculated leaving out the zero sequence impedance of the source and of the connection in relation to impedance R_n and taking the following 2 rules into account:
■ setting > 1.3 times system capacitive current downstream from the protection,
■ setting at approximately 20 % of maximum earth fault current.
Also, if 3 CTs are used for detection, the setting must not be less than 10% of the CT rating to take into consideration the uncertainty linked to:
□ assymmetry of transient currents,
□ differences in performance level.

accessible neutral

non accessible neutral

grounding systems (cont.)

reactance grounding

For system voltage above 40 kV,
it is preferable to use reactance rather
than a resistance because of the difficulties
arising from heat emission in the event of a
fault.

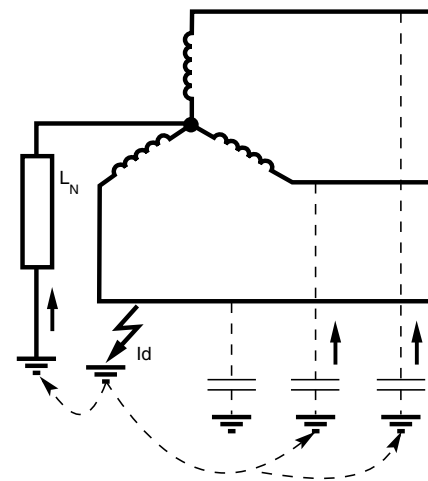## compensation reactance grounding

This system is used to compensate
for capacitive current in the system.
Fault current is the sum of the currents
which flow through the following circuits:
■ reactance grounding,
■ fault-free phase capacitance with respect
to earth.
The currents may compensate for each
other since:
■ one is inductive (in the grounding),
■ the other one is capacitive (in the fault-free
phase capacitances).
They are therefore opposite in phase.

Advantage
The system reduces fault current, even if
the phase-to-earth capacitance is high.

Drawback
The cost of reactance grounding may be
high due to the need to modify the reactance
value in order to adapt compensation.

Protection
Fault detection is based on the active
component of the residual current.
The fault causes residual currents to flow
throughout the system, but the faulty circuit
is the only one through which resistive
residual current flows.
In addition, the protective devices take into
account repetitive self-extinguishing faults
(recurring faults).

When the earthing reactance and system
capacitance are compensated ($3L_n Cw^2 =1$)
□ fault current is minimal,
□ it is resistive current,
□ faults are self-extinguishing.

The compensation reactance is called an
extinction coil or **Petersen coil**.

direct grounding

When the neutral is directly grounded without
any coupling impedance, fault current Id
between the phase and earth is practically a
phase-to-neutral short-circuit, with a high
value. This system, ideal for overvoltage
evacuation, involves all the drawbacks and
hazards of strong earth fault current. There is
no continuity of service, but there are no
specific protections: the **regular phase
overcurrent protections** clear the fault.

Applications
■ this type of system is not used in European
overhead or underground MV systems, but is
prevalent in North American distribution
systems. In these (overhead) systems, other
features come into play to justify the choice:
□ the existence of a distributed neutral
conductor,
□ 3 ph or 2 ph/N or ph/N distribution,
□ use of the neutral conductor as a protective
conductor with systematic earthing of each
electrical cable pole.

■ this type of system may be used when the
short-circuit power of the source is low.

short-circuit currents
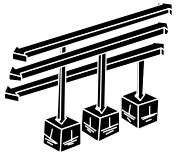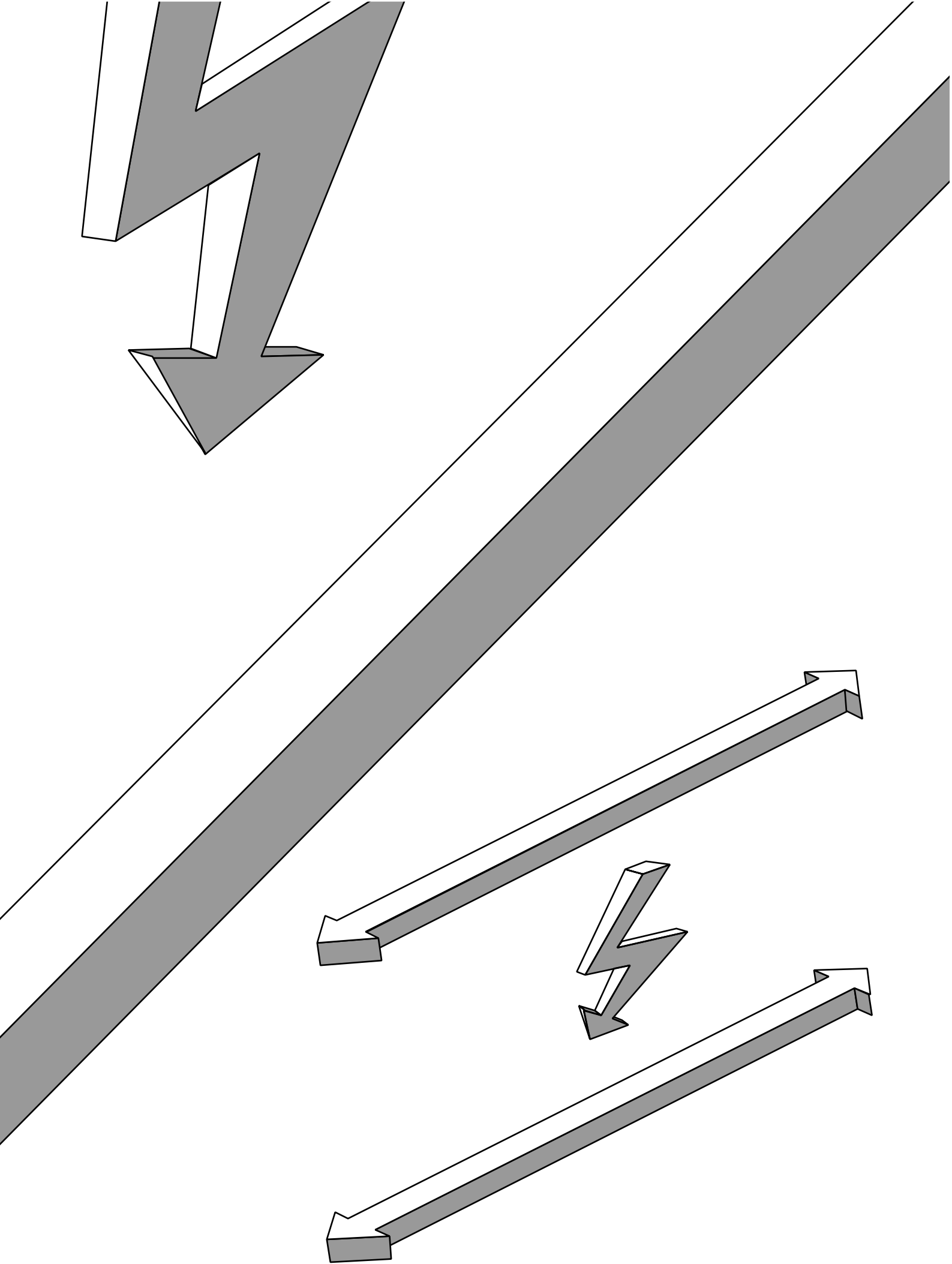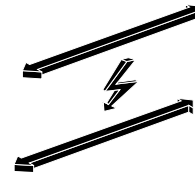
introduction

A short circuit is one of the major incidents affecting electrical systems.

The consequences are often serious, if not dramatic:
■ a short circuit disturbs the system environment around the fault point by causing a sudden **drop in voltage**,
■ it requires a part of the system (often a large part) to be **disconnected** through the operation of the protection devices,
■ all equipment and connections (cables, lines) subjected to a short circuit undergo strong **mechanical stress** (electrodynamic forces) which can cause breaks, and **thermal stress** which can melt conductors and destroy insulation,
■ at the fault point, there is often a **high power electrical arc,** causing very heavy damage that can quickly spread all around.

Although short circuits are less and less likely to occur in modern well-designed, well-operating installations, the serious consequences they can cause are an incentive to implement all possible means to swiftly detect and attenuate them.

The short circuit value at different points in the system is essential data in defining the cables, busbars and all breaking and protection devices as well as their settings.

definitions

Short-circuit current at a given point in the system is expressed as the **rms value Isc** (in kA) of its AC component.
The maximum **instantaneous value** that short-circuit current can reach is the **peak value Ip** of the first half cycle.
This peak value can be much higher than $\sqrt{2}.Isc$ because of the **damped DC component** that can be superimposed on the AC component. This random DC component depends on the instantaneous value of voltage at the start of the short-circuit and on the system characteristics.

Short-circuit power is defined by the formula $Ssc = \sqrt{3}\, Un \cdot Isc$ (in MVA).
This theoretical value has no physical reality; it is a **practical conventional value** comparable to an apparent power rating.
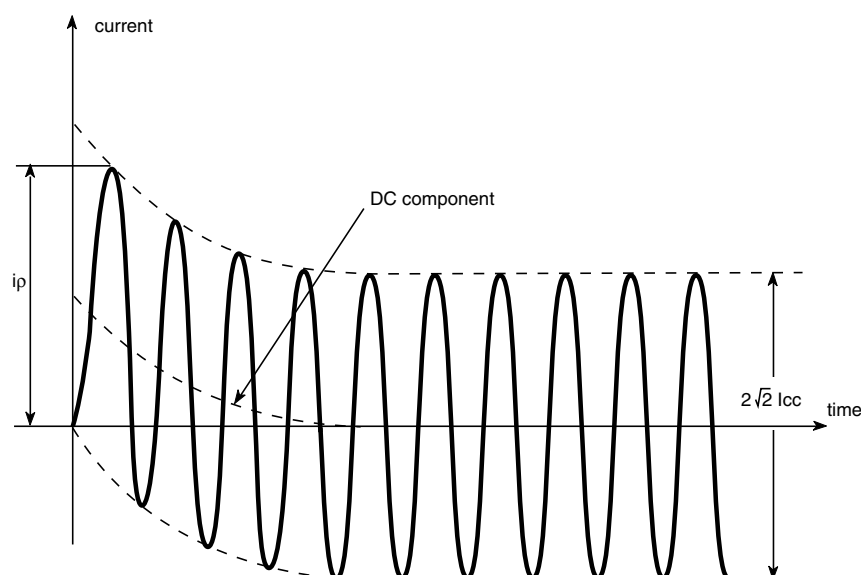
short-circuit currents (cont.)

phase-to-phase short-circuit

The Isc value of three-phase short circuit current at a point F within the system is:

$$Isc = \frac{U}{\sqrt{3}\ Zsc}$$

in which U refers to the phase-to-phase voltage at point F before the fault occurs and Zcc is the equivalent upstream system impedance as seen from the fault point.

■ in theory, this is a simple calculation; in practice, it is complicated due to the difficulty of calculating Zsc, an impedance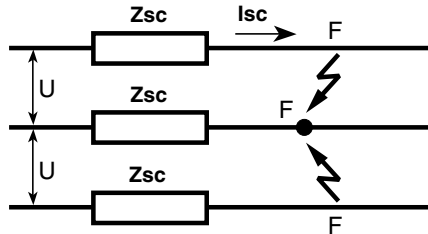 equivalent to all the unitary impedances of series- and parallel-connnected units located upstream from the fault. These impedances are themselves the quadratic sum of reactances and resistances.

$$Zsc = \sqrt{R^2 + X^2}$$

Calculations can be made much simpler by knowing the short-circuit power Ssc at the point that joins the distribution system.

Knowing Ssc at this point, the equivalent Za impedance upstream from this point can be calculated using the formula:

$$Za = \frac{U^2}{Ssc}\ ,\ Isc = \frac{U}{\sqrt{3}\ Za}$$

There may not be a single source of voltage, but rather several sources in parallel, in particular, synchronous and asynchronous motors, reacting like generators upon the occurrence of short circuits.
Three-phase short circuit current is generally the strongest current that can flow in the system.
Two-phase short circuit current is always weaker (by a ratio of $\sqrt{3}/2$, i.e. approximately 87%).

$$\text{2-phase } Isc = \frac{U}{2\ Zsc}$$

phase-to-earth short circuit current (single-phase)
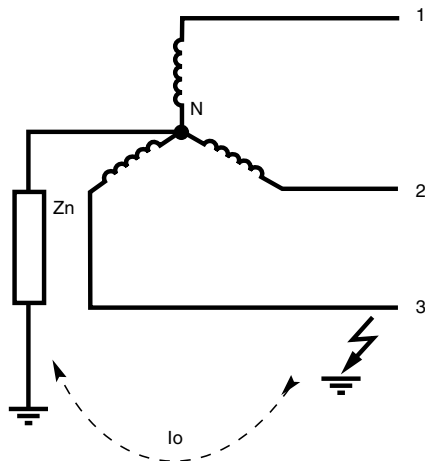
The value of this current depends on Z_n impedance between the neutral and earth. This impedance can be virtually nil if the neutral is directly grounded (in series with the earthing connection resistance) or, on the contrary, almost infinite if the neutral is ungrounded (in parallel with the system's phase to earth capacitance).
Calculation of this unbalanced short-circuit current requires the use of the symmetrical components method.
This method replaces the real system by superimposing 3 systems:
positive Z_1 , negative Z_2 , zero sequence Z_0
The value of the phase-to-earth fault current Io is:

$$I_0 = \frac{U\ \sqrt{3}}{Z_1 + Z_2 + Z_0 + 3\ Z_n}$$

This calculation is required for systems in which the neutral is earthed by a Z_n impedance. It is used to determine the setting of the "earth fault" protection devices which are to intervene to break the earth fault current.
In practice :

$$I_0 \simeq \frac{U}{\sqrt{3}\ Z_n}$$
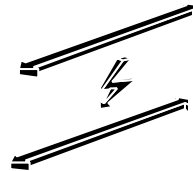
short circuit currents at generator terminals

It is more complicated to calculate short-circuit current at a synchronous generator's terminals than at the terminals of a transformer connected to the system. This is because the internal impedance of the machine cannot be considered constant after the start of the fault. It increases progressively and the current becomes weaker, passing through three characteristic stages:

■ **subtransient**: (approx. 0.01 to 0.1 sec). Short-circuit current (rms value of the AC component) is high: 5 to 10 times permanent rated current.

■ **transient**: (between 0.1 and 1 sec). Short-circuit current drops to between 2 and 6 times rated current.

■ **continuous:** Short-circuit current drops to between 0.5 and 2 times rated current.

The given values depend on the power rating of the machine, its excitation mode and, for continuous current, on the value of the exciting current, therefore on the machine's load at the time of the fault. Also, the zero sequence impedance of the AC generators is generally 2 to 3 times lower than their positive sequence impedance. Phase-to-earth short circuit-current is therefore stronger than three-phase current. By way of comparison, the three-phase short-circuit current at a transformer's terminals ranges between 6 and 20 times rated current depending on the power rating.

It can be concluded that short-circuits at generator terminals are difficult to assess, and that their low, decreasing value makes protection setting difficult.

3 short circuit currents at generator terminal
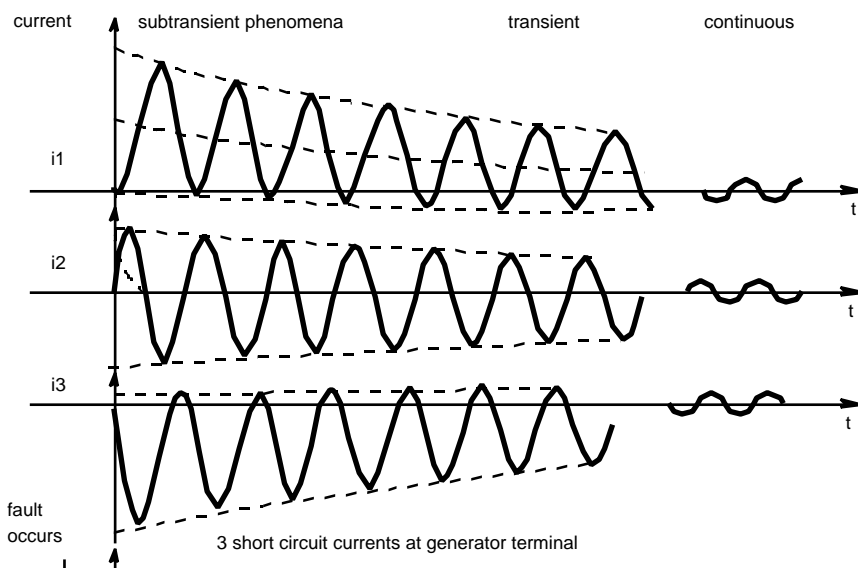
calculation of short-circuit currents

The rules for calculating short-circuit currents in industrial installations are presented in IEC standard 909 issued in 1988.

The calculation of short-circuit currents at various points in a system can quickly turn into an arduous task when the installation is a complicated one. The use of specialized software enables these calculations to be performed faster.

short-circuit currents (cont.)

equipment behaviour during short-circuits

There are 2 types of system equipment, the type that intervenes and the type that does not intervene at the time of a fault.

Passive equipment
This category comprises all equipment which, due to its function, must have the capacity to transport both normal current and short-circuit current without damage.

This equipment includes cables, lines, busbars, disconnecting switches, switches, transformers, series reactances and capacitors, instrument transformers.
For this equipment, the capacity to withstand a short-circuit without damage is defined in terms of:
■ electrodynamic withstand (expressed in peak kA), characterizing mechanical resistance to electrodynamic stress.
■ thermal withstand (expressed in rms kA for 1 to 5 seconds) characterizing maximum admitted overheating.

Active equipment
This category comprises the equipment designed to clear short circuit currents: circuit breakers and fuses.
This property is expressed by the **breaking capacity** and if required, by the **making capacity** upon occurrence of a fault.

■ **breaking capacity**
This basic characteristic of a switching device is the **maximum current** (in rms kA) **it is capable of breaking** in the specific conditions defined by the standards, it generally refers to the **rms value of the AC component** of the short circuit current; sometimes, for certain switchgear, the rms value of the sum of the 2 components is specified: AC and DC; it is then "unbalanced current".
The breaking capacity requires other data such as:
□ voltage,
□ R/X ratio of broken circuit,
□ system natural frequency,
□ number of breaks at maximum current, for example the cycle: B - M/B - M/B
(B = breaking; M = making),
□ status of the device after test.
The breaking capacity appears to be a fairly complicated characteristic to define: it therefore comes as no surprise that the same device can be assigned different breaking capacities depending on the standard by which it is defined.

■ **making capacity upon occurrence of a short-circuit**
In general, this characteristic is implicitly defined by the breaking capacity: a device should have the capacity to "make" upon the occurrence of a short-circuit that it has the capacity to break.
Sometimes making capacity needs to be higher, for example for AC generator circuit breakers.
The making capacity is defined **at peak kA** since the 1st asymmetric peak is the most restrictive one from an electrodynamic point of view.

■ **short-circuit current presumed to be "broken"**
Some devices have the capacity to limit the current they are going to break.
Their breaking capacity is defined as the **maximum current presumed to be broken** that would develop in the case of a full short circuit at the upstream terminals of the device.
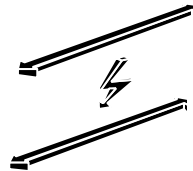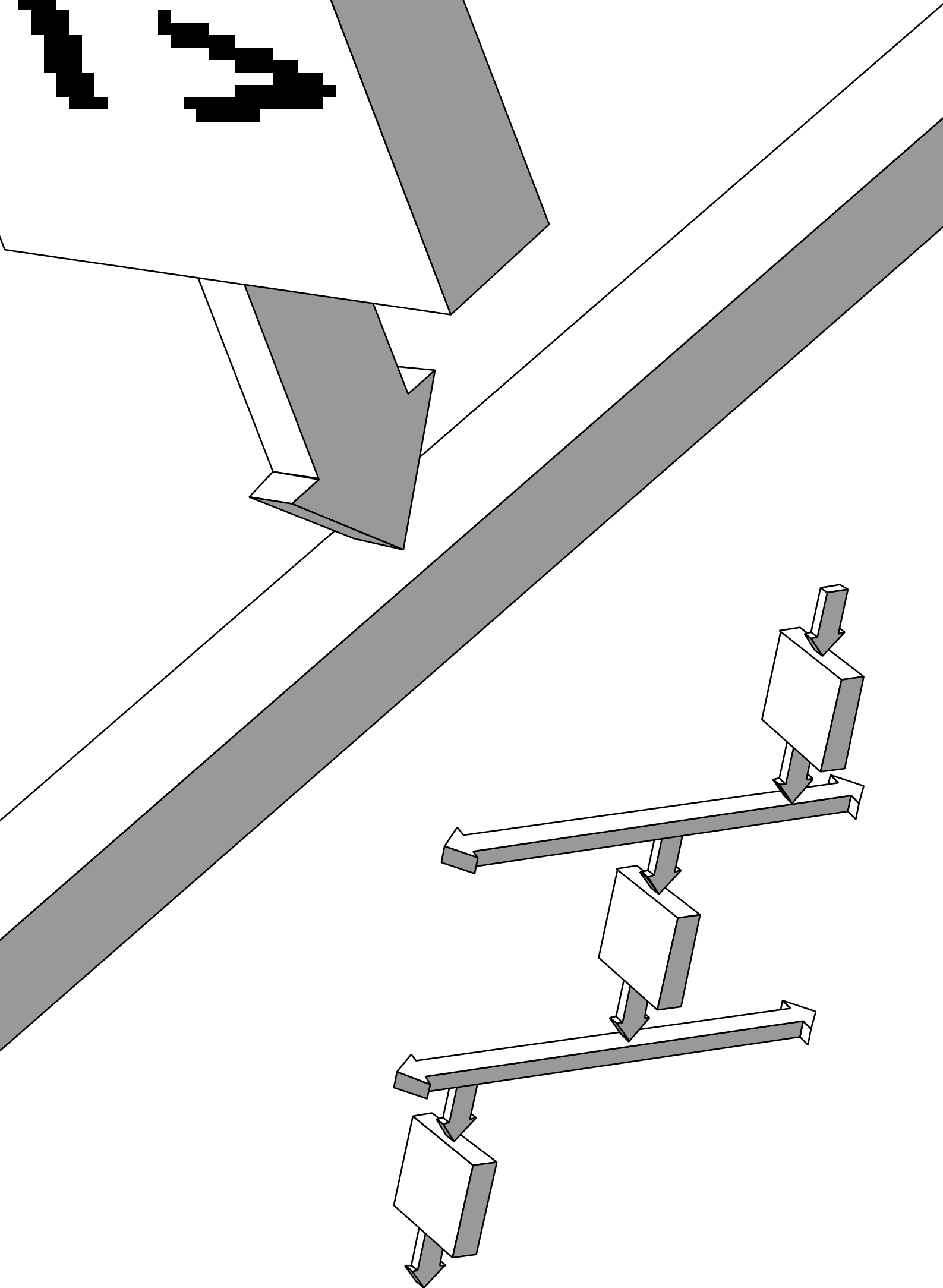
discrimination
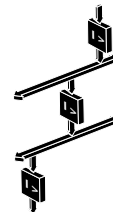
introduction

Protections comprise a coherent whole in relation to the structure of the system and its grounding. They should be looked upon as a system based on the principle of discrimination which consists of isolating as quickly as possible the part of the system affected by the fault and only that part, leaving all the fault-free parts of the system energized.

Various means can be implemented to ensure proper discrimination in electrical system protection:
■ current discrimination,
■ time discrimination,
■ discrimination by data exchange, referred to as logic discrimination,
■ discrimination by the use of directional protection devices,
■ discrimination by the use of differential protection devices.

current discrimination
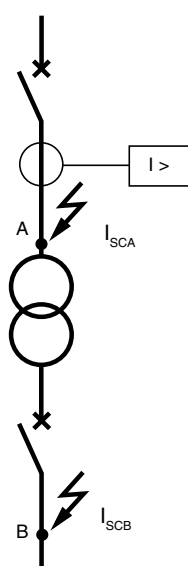
(fig.1)

example of current discrimination

Current discrimination is based on the fact that within a system, the further the fault is from the source, the weaker the fault current.
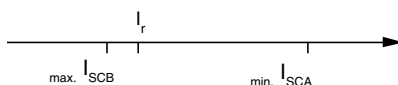
Current-based protection is installed at the starting point of each section: its setting is set at a value lower than the minimum value of short-circuit current caused by a fault in the monitored section, and higher than the maximum value of the current caused by a fault located downstream (beyond the monitored area). Set in this way, each protection device operates only for faults located immediately downstream from it, and is not sensitive to faults beyond.

In practice, it is difficult to define the settings for two cascading protection devices (and still ensure good discrimination) when there is no notable decrease in current between two adjacent areas (medium voltage system). However, for sections of lines separated by a transformer, this system can be used advantageously as it is simple, economical and quick (tripping with no delay).
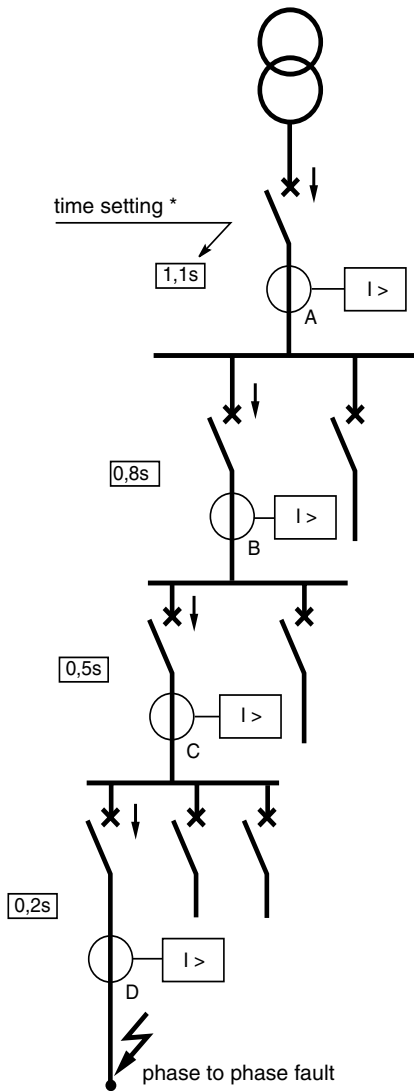
An example of the application is shown (fig.1).

$I_{SCA} > I_r \geq I_{SCB}$

I_{SCB} image at the transformer primary of the maximum short-circuit current on the secondary.

discrimination (cont.)

time discrimination

time setting *

1,1s

I >

A

0,8s

I >

B

0,5s

I >

C

0,2s

I >

D

phase to phase fault

(*)
$I_{RA} \geq I_{RB} \geq I_{RC} \geq I_{RD}$

I_R: setting of overcurrent protection

Time discrimination consists of setting different time delays for the current-based protection devices distributed throughout the system. **The closer the relay is to the source, the longer the time delay.**
The fault shown in the diagram opposite is detected by all the protections (at A, B, C, and D). The time-delayed protection at D closes its contacts more quickly than the one installed at C, which is in turn faster to react than the one at B, etc.
Once circuit breaker D has been tripped and the fault current has been cleared, protections A, B and C, which are no longer required, return to the stand-by position.

The difference in operation times Δt between two successive protections is the discrimination interval. It takes into account:
■ circuit breaker breaking time Tc,
■ time delay tolerances dt,
■ time for the protection to return to stand-by: tr

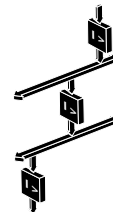Δt should therefore correspond to the relation:
Δt ≥ Tc + tr + 2dt.
Considering present switchgear and relay performances, Δt is assigned a value of 0.3 sec.
This discrimination system has two advantages:
■ it provides its own back-up (granted, by eliminating a fault-free part of the installation),
■ it is simple.
However, when there are a large number of cascading relays, since the protection located the furthest upstream has the longest time delay, the fault clearing time is prohibitive and incompatible with equipment short-circuit current withstand and external operating necessities (connection of a distributor to electrical system, for example).
This principle is used in radial networks.

application of time discrimination
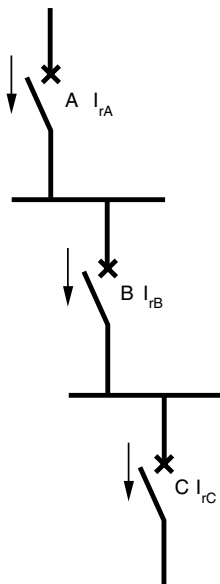
The time delays set for time discrimination are activated when the current exceeds the relay settings.
The settings must be coherent.

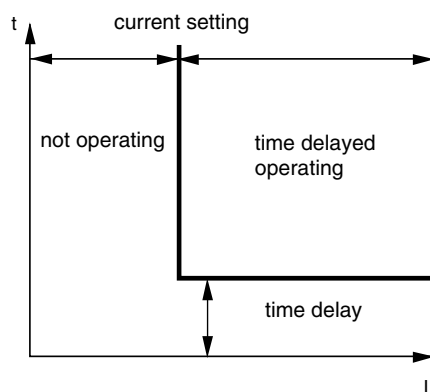There are 2 types of time-delayed current-based relays:
■ definite time relays,
the time delay is **constant** regardless of the current, provided it is higher than the setting.
$I_{rA} > I_{rB} > I_{rC.}$, $t_A > t_B > t_{C.}$

(fig.1)
definite time tripping curve
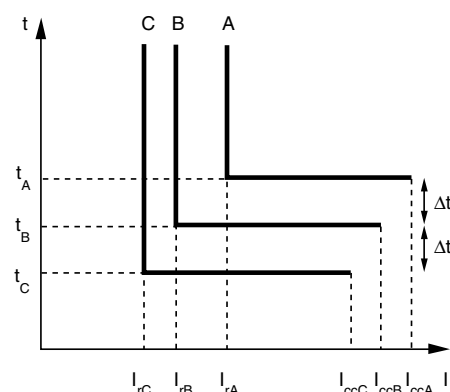
■ IDMT relays (fig. 2),
the stronger the current, the shorter the time delay. If the settings are set to In, overload protection is ensured at the same time as short-circuit protection and setting coherency is guaranteed.
$I_{nA} > I_{nB} > I_{nC}$
$I_{rA} = I_{nA}$ $I_{rB} = I_{nB}$ $I_{rC} = I_{nC}$
The time delays are set for the discrimination interval Δt of the maximum current detected by the upstream protection relay.
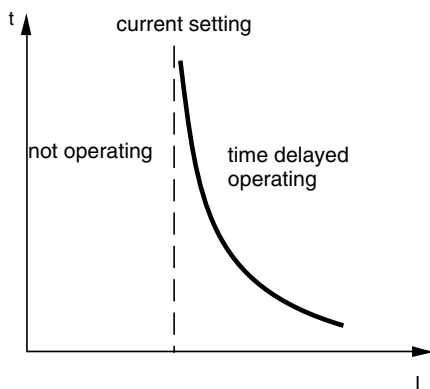
(fig.2)
IDMT tripping curve

discrimination (cont.)

logic selectivity

This principle is used when **short fault clearing time is required.**

Theexchange of logic data between successive protection devices **eliminates the need for discrimination intervals**.

In a radial system, the protections located upstream from the fault point are activated; those downstream are not. The fault point and the circuit breaker to be controlled can therefore be located without any ambiguity. Each protection activated by a fault sends:
■ a blocking input to the upstream stage (order to increase the upstream relay time delay),
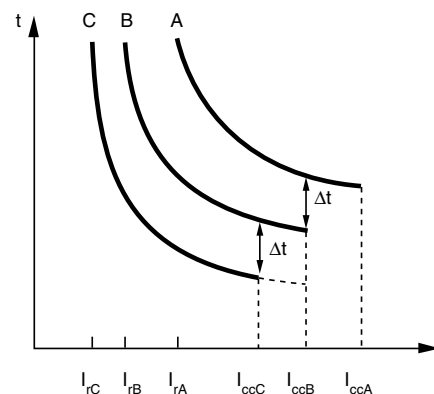■ a tripping order to the related circuit breaker unless it has already received a blocking input from the downstream stage. Time-delayed tripping is provided for as back-up.

Advantage
Tripping time is no longer related to the location of the fault within the discrimination chain.

I >

I >
R

← blocking input

I >
R

I >
R

phase-to-phase fault

logic selectivity system
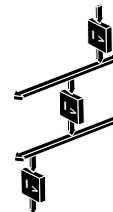
directional discrimination

In a looped system, in which faults are fed from both ends, it is necessary to use a protection system that is sensitive to the direction of the flow of fault current in order to locate and clear it.

Example of the use of directional protections:

D1 and D2 are equipped with instantaneous directional protections; H1 and H2 are equipped with time-delayed overcurrent protections.

In the event of a fault at point ①, only the protections on D1 (directional), H1 and H2 detect the fault. The protection on D2 does not detect it (because of the direction of its detection system). D1 breaks. The H2 protection de-energizes and H1 breaks.
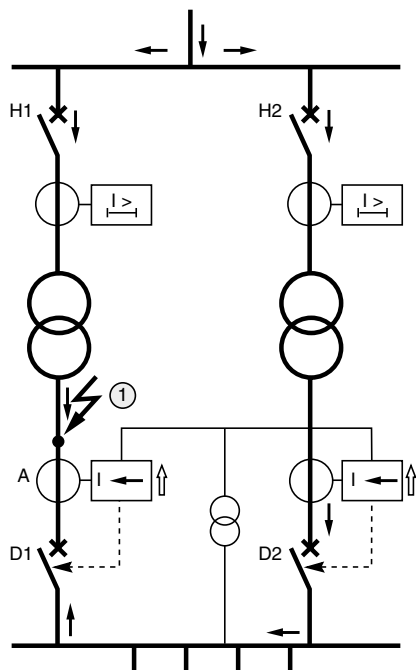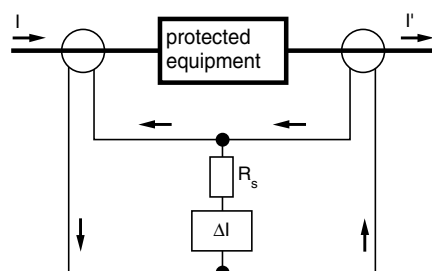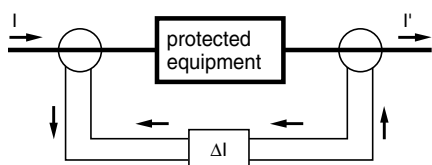
$t_{H1} = t_{H2}$

$t_{D1} = t_{D2}$

$t_H = t_D + \Delta t$

⇑ way of detection

example of use of directional protections

sélectivité par protection différentielle

These protections compare the current at the ends of the monitored section of the system. Any difference in amplitude and phase between the currents indicates the presence of a fault. This is a self-disciminating protection system as it only reacts to faults within the area it covers and is insensitive to any faults outside this area.

The protected equipment can be: a motor, an AC generator, a transformer, or a connection (cable or line).
This protection is used to :
■ detect fault currents lower than rated current
■ trip instantaneously since discimination is based on detection and not on time delays.

high impedance differential protection diagram

percentage-based differential protection diagram

There are two main principles:
The high impedance protective device is series-connected with a stabilization resistor [1] in the differential circuit.

The percentage-based differential protective device is connected separately to the I and I' current circuits.
The difference between these currents I - I' is determined in the protective device and the protection stability [1] is obtained by a restraint related to the measurement of let-through current $\dfrac{I + I'}{2}$.

[1] The stability of the differential protective device is its capacity to remain dropped out when there are no faults within the zone being protected, even if a differential current is detected:
□ transformer magnetizing current,
□ line capacitive current,
□ error current due to saturation of the current sensors.

electrical system protection
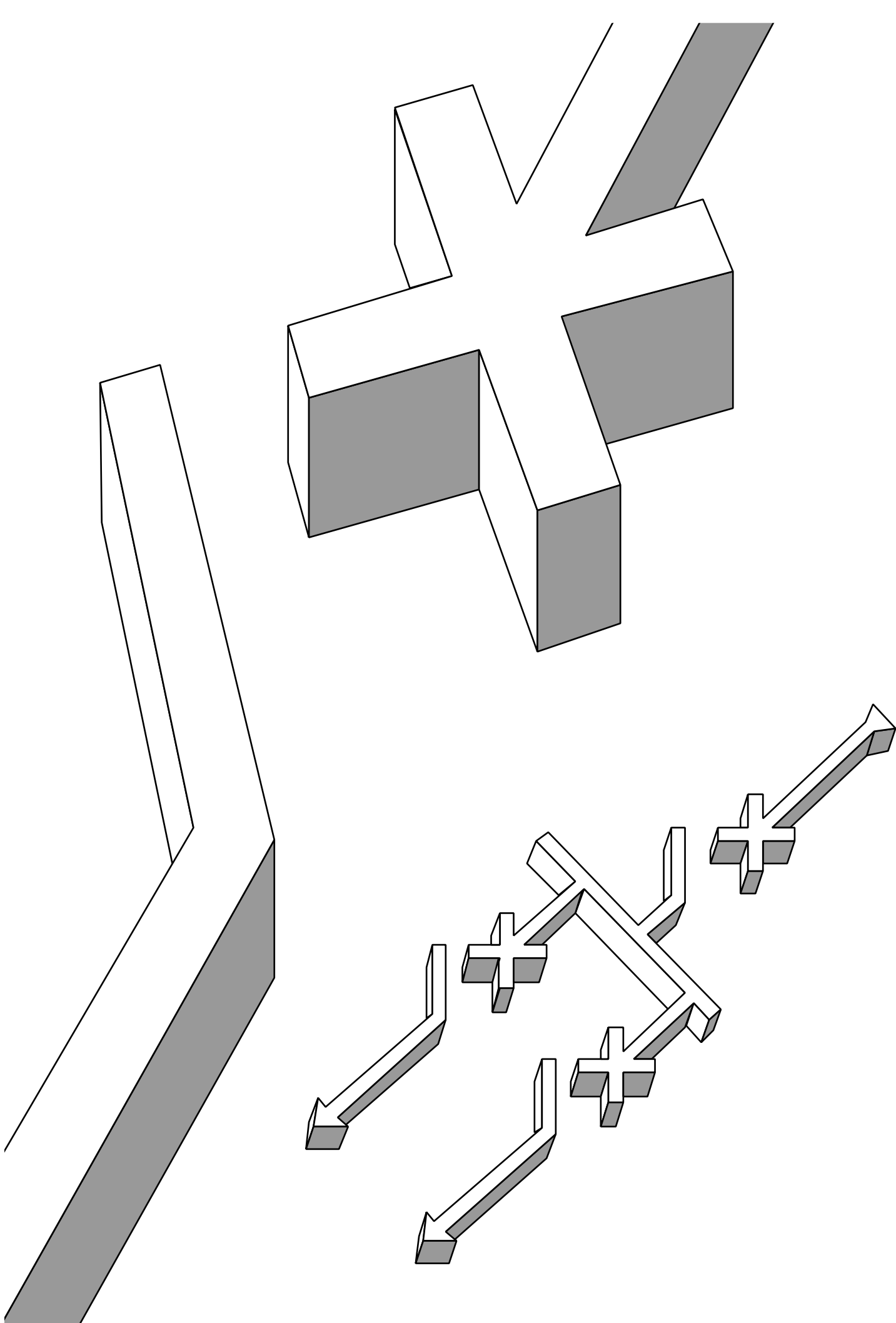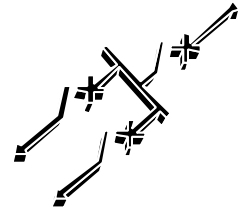
introduction

Electrical system protection should:
■ detect faults,
■ cut off of the faulty parts of the electrical system, keeping the fault-free parts in operation.

Protection systems are chosen according to the electrical system configuration (parallel operation of AC generators or transformers, loop or radial system, grounding system…).

Protection against each of the following types of faults is to be considered:
■ phase-to-phase faults,
■ earth faults (protections related to electrical system grounding).
This will be done by successively examining the following cases:
■ a single incoming line,
■ two incoming lines,
■ a busbar,
■ a loop.

electrical system protection (cont.)

electrical system with a single incoming line

(fig. 1)

phase-to-phase faults (fig. 1)

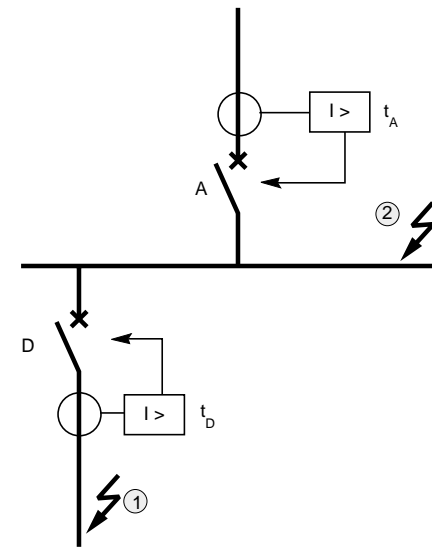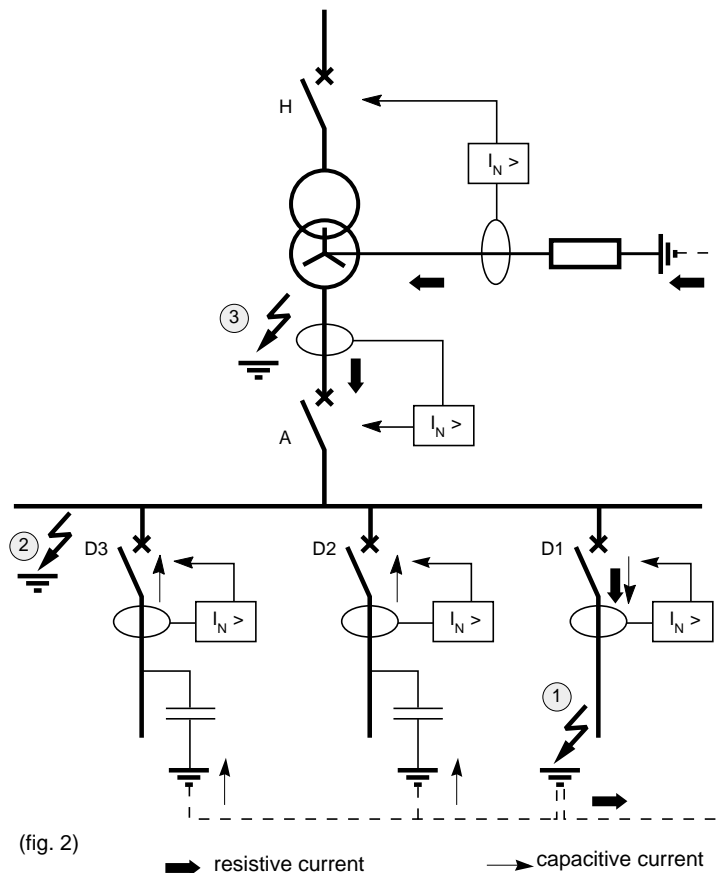The protection device at D detects faults ① on the outgoing lines and is tripped following a time delay t_D.
The protection device at A detects the faults ② on the busbars and is tripped following a time delay tA. It also acts as back-up in the event of a malfunction of protection D.
Choose : IrA ≥ IrD and tA ≥ t_D +Δt
Δt : discriminator interval
(generally 0,3 s).

phase-to-earth faults

Grounding by resistance on transformer (fig.2)

Outgoing lines, the incoming line and the grounding connection are equipped with earth fault protection devices.

These devices are necessarily different from multiphase fault protections as the fault currents are in a different range.

Outgoing line protections are set selectively in relation to the incoming line protection, which is itself set selectively in relation to the protection equipping the grounding connection (respecting discrimination intervals).

The fault current is fed back by the capacitances of the fault-free outgoing lines and the grounding resistance. All the fault-free outgoing line sensors detect capacitive current.

So as to prevent inadvertent tripping, the protection device on each outgoing line is set at a setting higher than the outgoing line's own capacitive current.
■ fault at ① : the D1 circuit breaker trips, actuated by the protection device linked to it,
■ fault at ② : the A circuit breaker trips, actuated by the incoming line protection device,
■ fault at ③ : the protection device located on the neutral grounding connection causes circuit breaker H to trip at the transformer primary.

(fig. 2)

➡ resistive current   → capacitive current
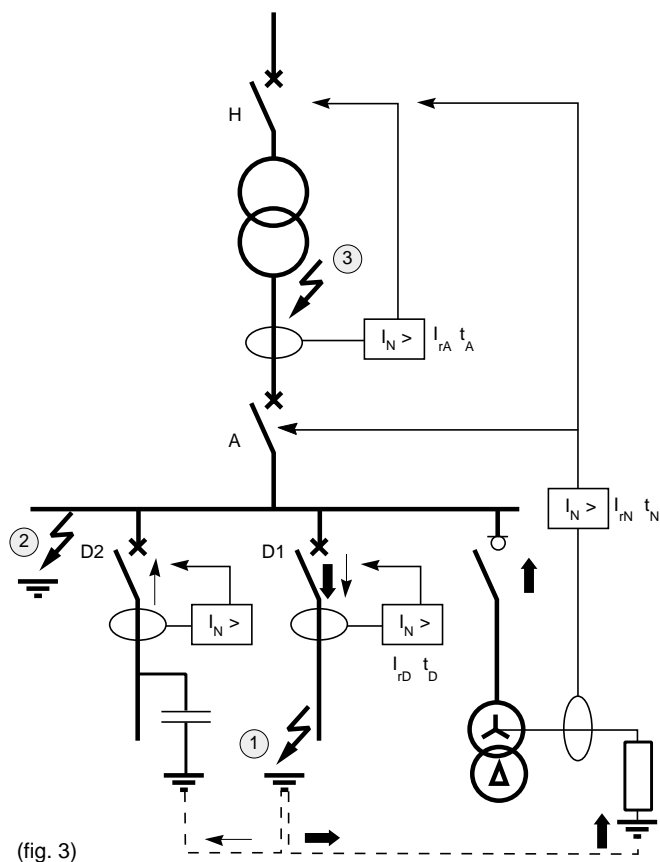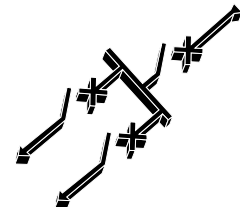
Grounding by resistance on the busbar (fig.3)

The outgoing and ingoing line protections are selectively set in relation to the protection equipping the grounding impedance. As in the previous case, the protection on each outgoing line is set at a setting higher than the outgoing line's own capacitive current.

In the event of a fault on outgoing line ① only the D1 outgoing line circuit breaker trips.

In the event of fault on the busbar ② , only the protection equipping the grounding connection detects the fault. It causes tripping by circuit breaker A.

In the event of fault on the transformer secondary ③ , the incoming line protection detects the fault. It causes tripping by circuit breaker H.

Note: when circuit breaker A is open, the transformer secondary is ungrounded.

(fig. 3)
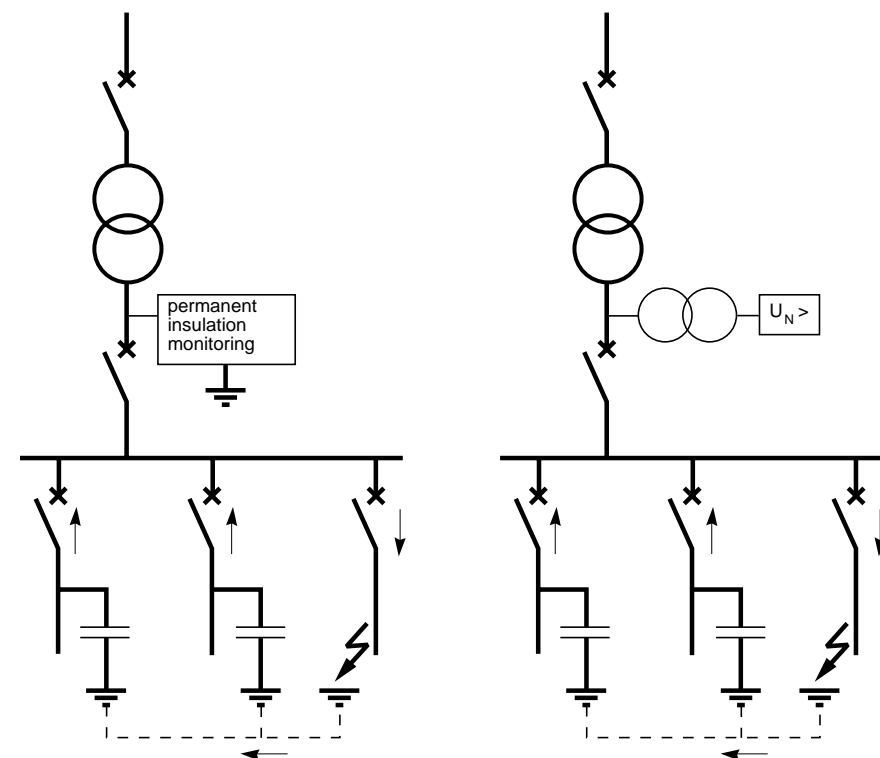
Ungrounded neutral (fig.4).

A fault, regardless of its location, produces current which is fed back by the capacitance of the fault-free outgoing lines.

in industrial system, this current is generally weak (a few amperes), allowing operations to carry on while the fault is being tracked. The fault is detected by a permanent insulation monitor (Vigilhom) or a neutral voltage displacement protection device. In the case of a system with high total capacitve current (tens of amperes), added measures are required to quickly clear the fault.

Directional earth protection can be used to selectively trip the faulty outgoing line.

(fig. 4)

system with two incoming lines
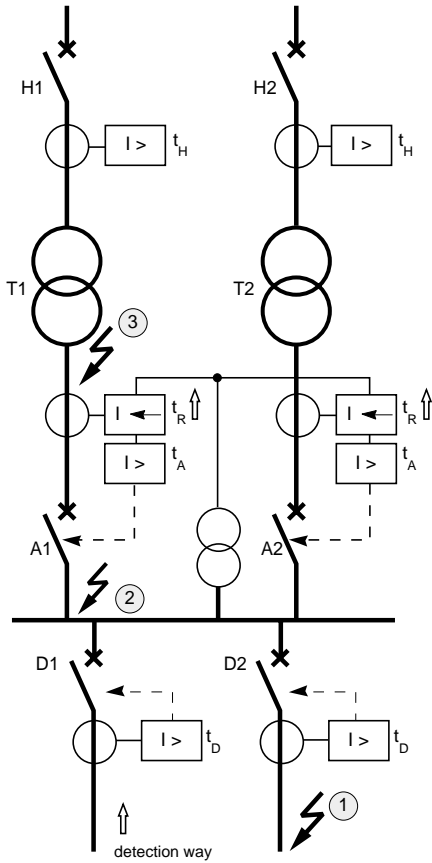
(fig. 1)

phase-to-phase faults (fig.1)

System with two transformer incomers or with two incoming lines

The outgoing lines are equipped with phase overcurrent protections with a time delay of t_D. The two incoming lines A1 and A2 are equipped with phase overcurrent protections selectively set with the outgoing lines, i.e. at a value of
$t_A \geq t_D + \Delta t$.

They are also equipped with directional protection devices with time delays set at
$t_R < t_A - \Delta t$.

Therefore, a fault at ① is cleared by the opening of D2 with a time delay of t_D.

A fault at ② is cleared by the opening of A1 and A2 with a time delay of t_A (the directional protections do not detect the fault).

A fault at ③ is detected by the A1 directional protection which opens at time t_R, allowing continued operation of the fault-free part of the system. The fault at ③ however is still fed by T1. At time
$t_H \geq t_A + \Delta t$, H1 is actuated by the phase overcurrent protection with which it is equipped.

phase-to-earth faults (fig. 2)

System with two transformer incomers

Grounding by resistance on the transformers. The outgoing lines are equipped with earth fault protection devices set at a setting higher than the corresponding capacitive current with a time delay of t_D.

The incomers (A1 and A2) are equipped with directional protections with a time delay of t_R.

The grounding connections are equipped with earth fault protections, the setting of which is higher than the settings of the incomer and outgoing line protections with a time delay of $t_N \geq t_D + \Delta t$.

Therefore, a fault at ① is cleared by the opening of D1.

A fault at ② is cleared by the opening of A1, A2, H1 and H2, triggered by the protections located on the grounding connections of the 2 transformers.

A fault at ③ is detected by the A1 directional earth fault protection which opens at time t_R, allowing continued operation of the fault-free part of the system.

However, fault ③ is still fed up to time t_N, the moment at which the protection located on the corresponding transformer's grounding connection triggers the opening of the H1 circuit breaker.
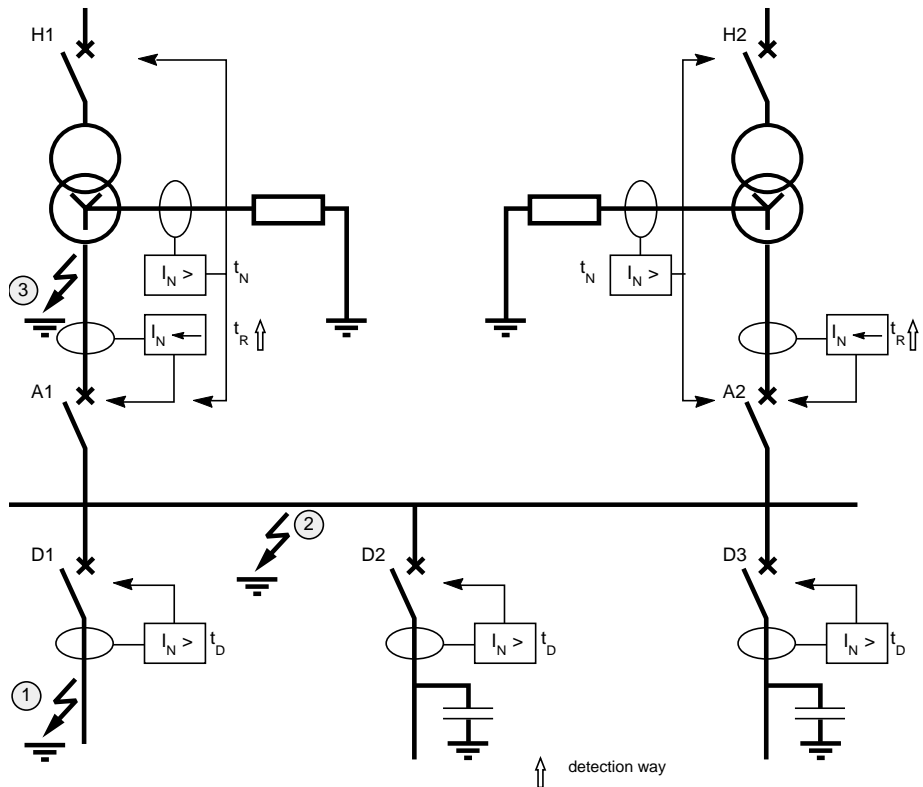
(fig. 2)
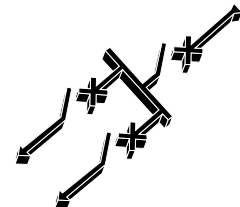
busbars
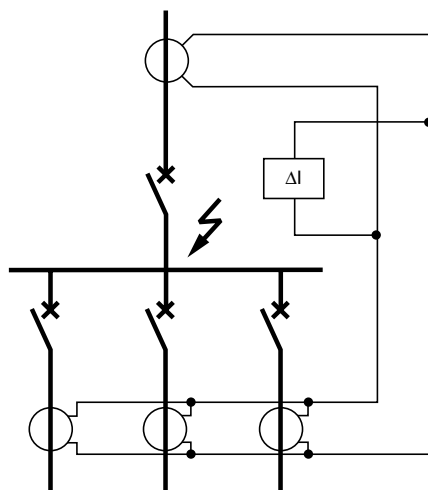
In addition to the protections described earlier, a busbar can be equipped with a specific protection device, referred to as high impedance differential protection, the aim of which is to be sensitive, quick and selective.

The differential protection (fig.1) takes the vectorial sum per phase of currents entering and leaving the busbar; whenever this sum is not equal to zero, it trips the busbar power supply circuit breakers.

Logic discrimination (fig.2) applied to overcurrent protections provides a simple, simple solution for busbar protection .
A fault at ① is detected by the D1 protection which transmits a blocking input to the A protection.
The D1 protection is tripped 0.6 sec. later

A fault at ② is detected only by the A protection which is tripped 0.1 sec. later.

(fig. 3)

(fig. 4)

electrical system protection (cont.)
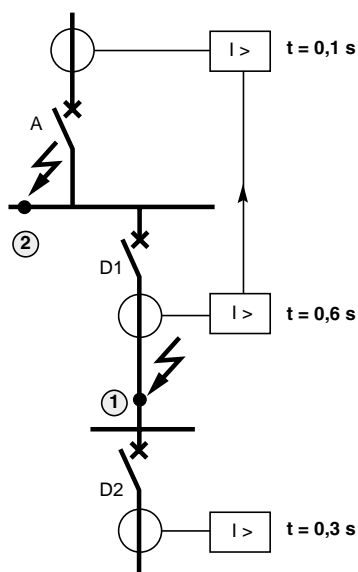
open loop
closed loop
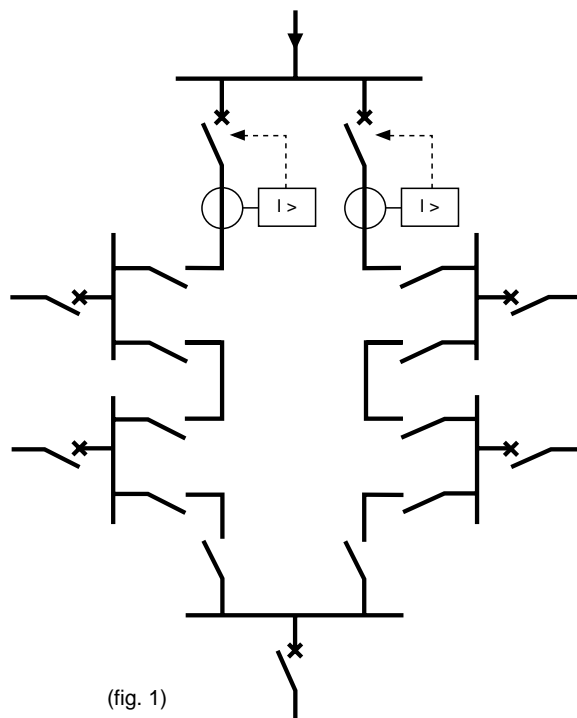
(fig. 1)

In a distribution system comprising substations fed in a loop, protection can be at the head of the loop or by sections:

Protection at the head of the loop (fig. 1)

The loop is always open.

The circuit breaker at the head of each loop is equipped with an overcurrent protection device.
A fault in a cable joining up 2 substations causes the opening of one of the two circuit breakers at the head, depending on the position of the loop opening.
Protection is often completed by an automation system which:
■ clears the fault with the power off by opening the devices located at the ends of the cable involved, after localisation of the faulty cable (by cable fault detector),
■ close the incomer circuit breaker that tripped,
■ closes the device which ensured the normal opening of the loop.
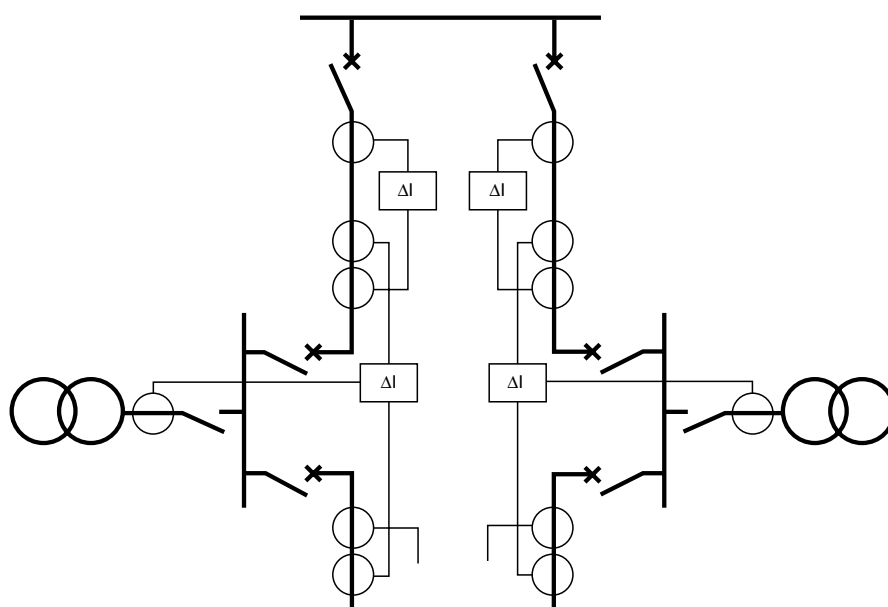
Loop section protection

Each end of the cable is equipped with a circuit breaker, with severall protection solutions.

■ **differential protection solution** (fig. 2): each cable is equipped with a differential line protection device and each substation is equipped with a busbar differential protection device. This type of protection is very quick but expensive. Also, if the neutral is resistance grounded, the sensitivity of the differential protections must cover phase-to-earth faults.
This solution may be used in bolh open and closed loops.

(fig. 2)
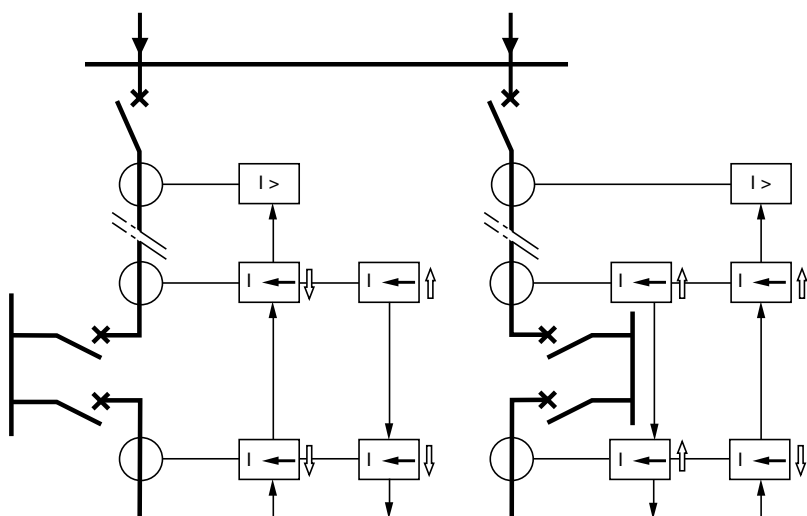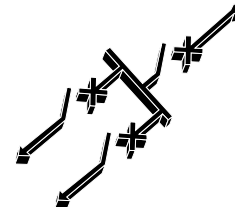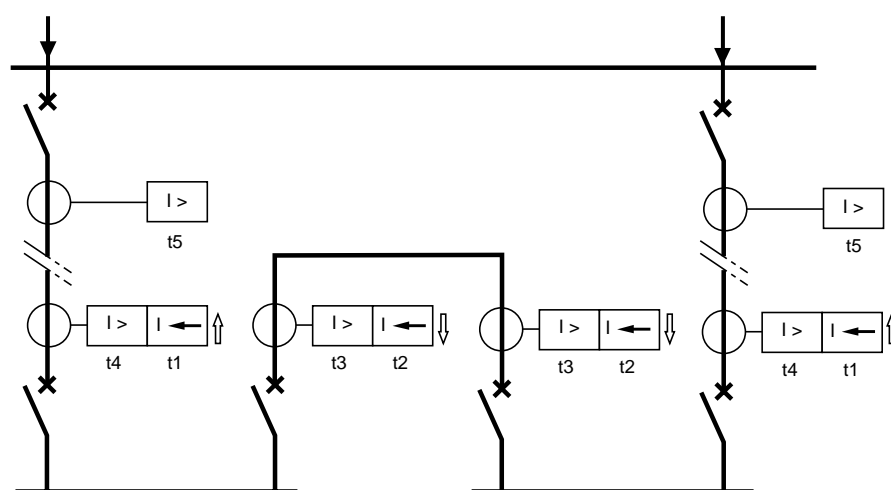
(fig. 3)

time gap between t1, t2,… t3 is ∆t discrimination interval ⇧ detection way

(fig. 4)

Loop section protection (cont.)

Overcurrent protection and directional logic discrimination (fig. 3)
The circuit breakers in the loop are fitted with overcurrent protection and directional protection devices. The principle of logic discrimination is also used to clear faults as quickly as possible.
A fault in the loop activates:
■ all the protection devices when the loop is closed,
■ all the protection devices upstream from the fault when the loop is open. Each protection device sends a blocking input to one of the devices adjacent to it within the loop, according to the data transmitted by the directional protection device.
Protection devices that do not receive a blocking input trip within a minimum amount of time regardless of the fault's position in the loop:
■ the fault is cleared by two circuit breakers, one on either side of the fault if the loop is closed, and all the switchboards remain energized,
■ the fault is cleared by the upstream circuit breaker if the loop is open. This solution is a full one since it protects the cables and switchboards. It is quick, discriminating and includes back-up protection.

Overcurrent and directional overcurrent protection (fig. 4)
In the case of a loop limited to two substations, time discrimination can be used with overcurrent and directional overcurrent protection devices as shown in the diagram. A higher number of substations results in prohibitive time delays.
The time gap between delays t1, t2… t5 is the discrimination interval ∆t.

Long distance protection
This solution is only useful for very long connections (several kilometers long). It is costly and very seldom used, in medium voltage.

transformer protection
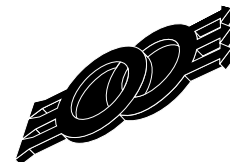
introduction

The transformer is a particularly important system component.
It requires effective protection against all faults liable to damage it, whether of internal or external origin.
The choice of a protection system is often based on technical and cost considerations related to the power rating.

types of faults

The main faults affecting transformers are:
■ overloads,
■ short-circuits,
■ frame faults

An **overload** can result from an increase in the number of loads being fed simultaneously or from an increase in the power absorbed by one or more loads.
It results in an overcurrrent of long duration causing a rise in temperature that is detrimental to the preservation of insulation and to the service life of the transformer.

Short circuits can be inside or outside the transformer:
■ internal: faults occurring between winding conductors with different phases or faults in the same winding. The fault arc damages the transformer winding and can cause fire. In oil transformers, the arc causes the emission of decomposition gas. If the fault is a weak one, there is a slight gas emission and the accumulation of gas can become dangerous. A violent short circuit can cause major damage that can destroy the winding and also the tank frame by the spread of burning oil.

■ external: phase-to-phase faults in the downstream connections. The downstream short circuit current produces electrodynamic forces In the transformer that are liable to affect the windings mechanically and then develop in the form of internal faults.

A **frame fault** is an internal fault. It can occur between the winding and the tank frame or between the winding and the magnetic core. It causes gas emission in oil transformers. Like internal short circuits, it can cause transformer damage and fire.

The amplitude of the fault current depends on the upstream and downstream grounding systems, and also on the position of the fault within the winding.

■ in star connections (fig.1), the frame current varies between 0 and the maximum value depending on whether the fault is at the neutral or phase end of the winding.

■ in delta connections (fig.2), the frame current varies between 50 and 100% of the maximum value depending on whether the fault is in the middle or at the end of the winding.
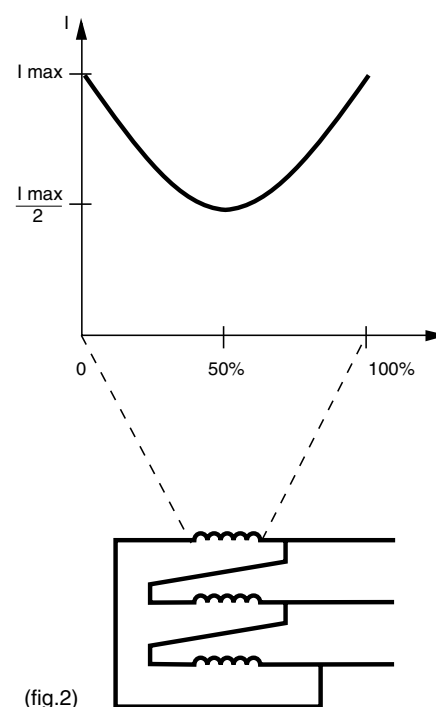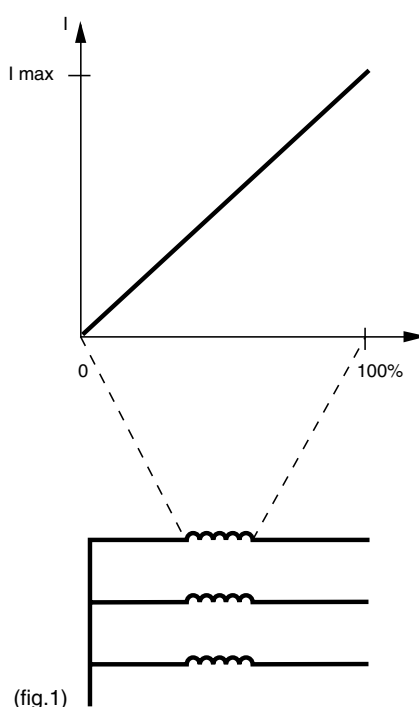
fault current according to the winding fault position

protection devices

Overloads

Overcurrent of long duration is generally detected by a direct time or IDMT delayed overcurrent protection which is discriminating with respect to secondary protection.

Thermal overload protection is used to monitor the temperature rise: overheating is determined by simulation of heat release as a function of the current and temperature lag of the transformer.
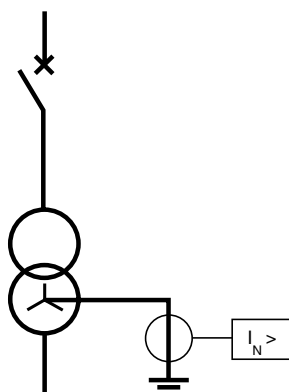
Short-circuits

For oil transformers:
■ a Buchholz relay or DGPT gas pressure temperature detector that is sensitive to gas release or oil movement is used, causing respectively a short-circuit between turns of the same phase and a violent phase-to-phase short-circuit.
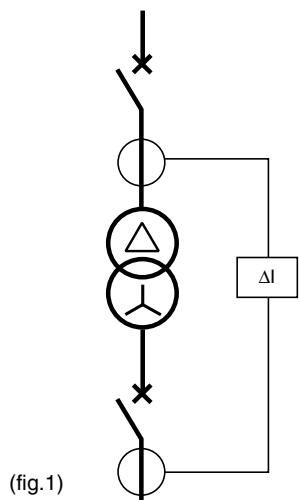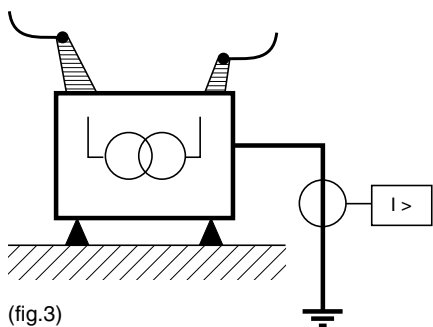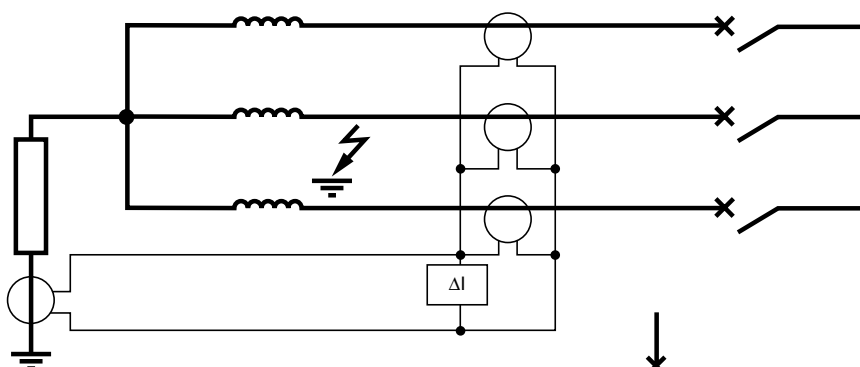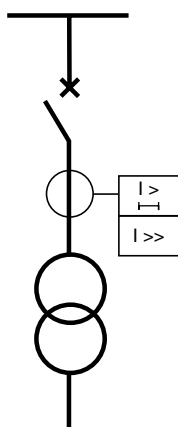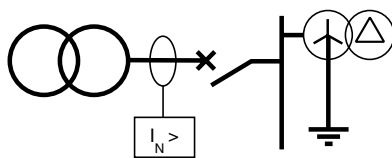■ differential transformer protection (fig.1) ensures rapid protection against phase-to-phase faults. It is sensitive to fault currents in the range of 0.5 In and is used for important transformers.
■ an instantaneous overcurrent protection (fig.2) device linked to the circuit breaker located at the transformer primary ensures protection against violent short circuits. The current setting is set at a value higher than the current due to a short circuit on the secondary, thus ensuring current discrimination.
■ for low power transformers, a fuse is used for overcurrent protection.

Tank frame faults
■ tank frame protection (fig.3):
This instantaneous overcurrent protection device installed on the transformer frame earthing connection constitutes a simple, efficient solution for internal winding-to-frame faults (provided its setting is suitable with grounding system used) the transformer tank has to be insulated from the ground.

This form of protection is discriminating, being sensitive only to transformer frame faults.

Another solution consists of using earth fault protection:
■ earth protection located on the upstream system for frame faults affecting the transformer primary.
■ earth fault protection located on the incoming line of the board being fed, if the neutral of the downstream system is earthed on the busbars (fig.4).
These protections are discriminating: they are only sensitive to phase-to-earth faults located in the transformer or on the upstream and downstream connections.
■ restricted earth protection if the neutral of the downstream system is earthed at the transformer (fig.5). This is a high impedance differential protection system which detects the difference in residual currents measured at the grounding point and at the three-phase transformer outlet.
■ neutral earth protection if the downstream system is earthed at the transformer (fig.6).

(fig.1)

(fig.2)

(fig.3)

(fig.4)

(fig.5)

(fig.6)
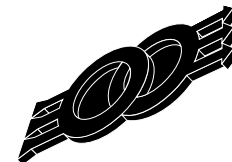
examples of transformer protection
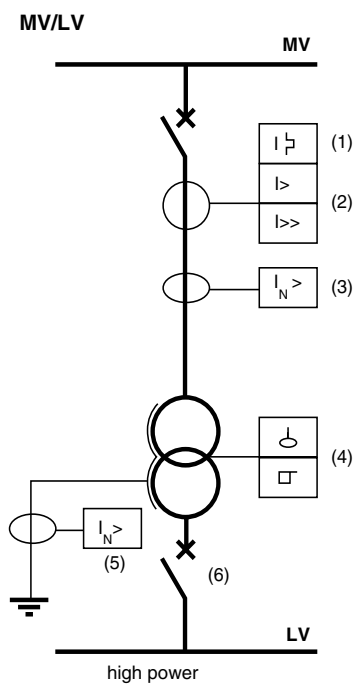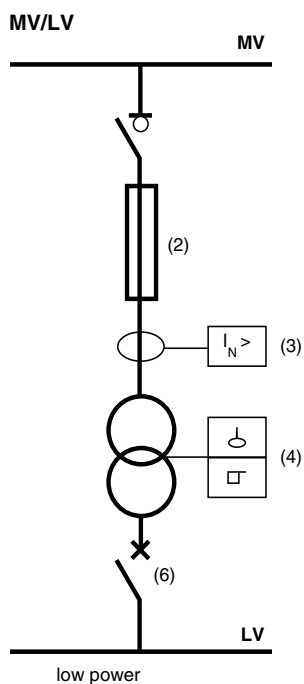
MV/LV

MV

(2)

$I_N >$ (3)

(4)

(6)

LV

low power

MV/LV

MV

$I \overline{}$ (1)

$I>$
$I>>$ (2)

$I_N >$ (3)

(4)

$I_N >$ (5)

(6)

LV

high power

(1) Thermal overload
(2) Fuse or 2-setting overcurrent
(3) Earth fault
(4) Buchholz or DGPT
(5) Tank earth leakage
(6) LV circuit breaker
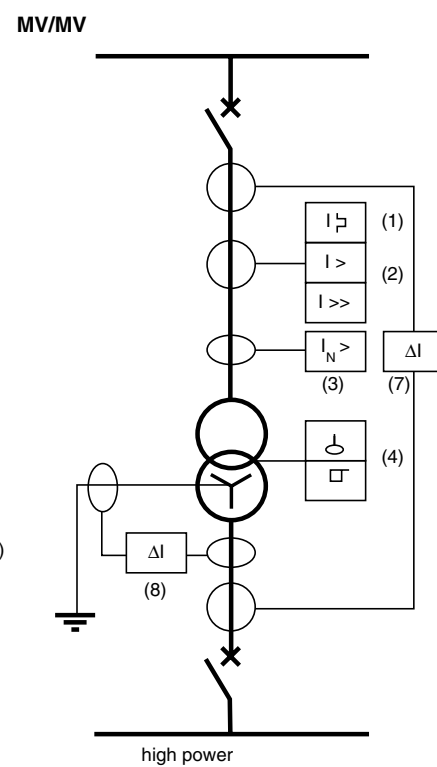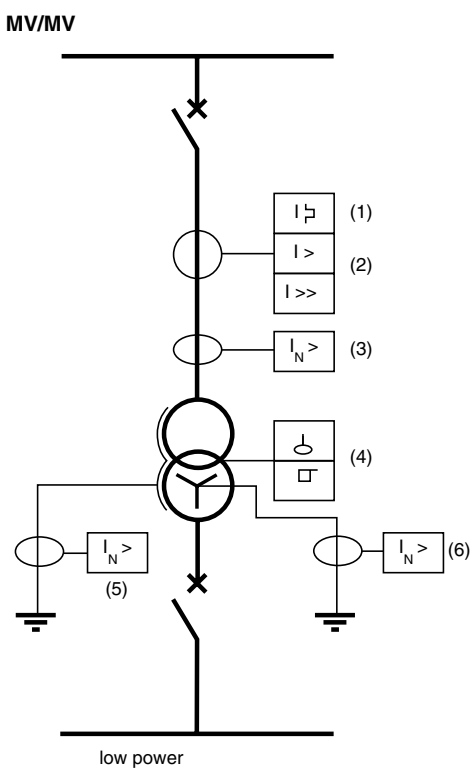
MV/MV

$I \overline{}$ (1)

$I >$
$I >>$ (2)

$I_N >$ (3)

(4)

$I_N >$ (5)

$I_N >$ (6)

low power

MV/MV

$I \overline{}$ (1)

$I >$
$I >>$ (2)

$I_N >$ (3)

ΔI (7)

(4)

ΔI (8)

high power

(1) Thermal overload
(2) Fuse or 2-setting overcurrent
(3) Earth fault
(4) Buchholz or DGPT
(5) Tank earth leakage
(6) Neutral earth protection
(7) Transformer differential
(8) Restricted earth fault protection

transformer protection (cont.)

setting information

type of fault	settings
overload	■ LV circuit breaker: In (for MV/LV transformer)
	■ thermal overload: time constant in the 10' range
short circuit	■ fuse: rating > 1.3 In, ■ direct time overcurrent lower setting < 6 In; time delay ≥ 0.3 s (selective with downstream), upper setting > downstream Isc instantaneous, ■ IDMT overcurrent IDMT lower setting (selective with downstream), high setting > downstream Isc, instantaneous, ■ differential transformer, 25% to 50% of In.
earth fault	■ tank earth leakage setting > 20 A 100 ms time delay, ■ earth fault current setting ≤ 20 % of maximum earth fault and ≥ 10% of CT rating if fed by 3 CTs, time delay 0.1 s if grounded within the system, time delay according to discrimination if grounded in the transformer, ■ restricted earth fault protection setting approximately 10% of In when the 3 CT integrator assembly is used, ■ neutral earth protection setting approximately 10% of maximum earth fault current.

motor protection
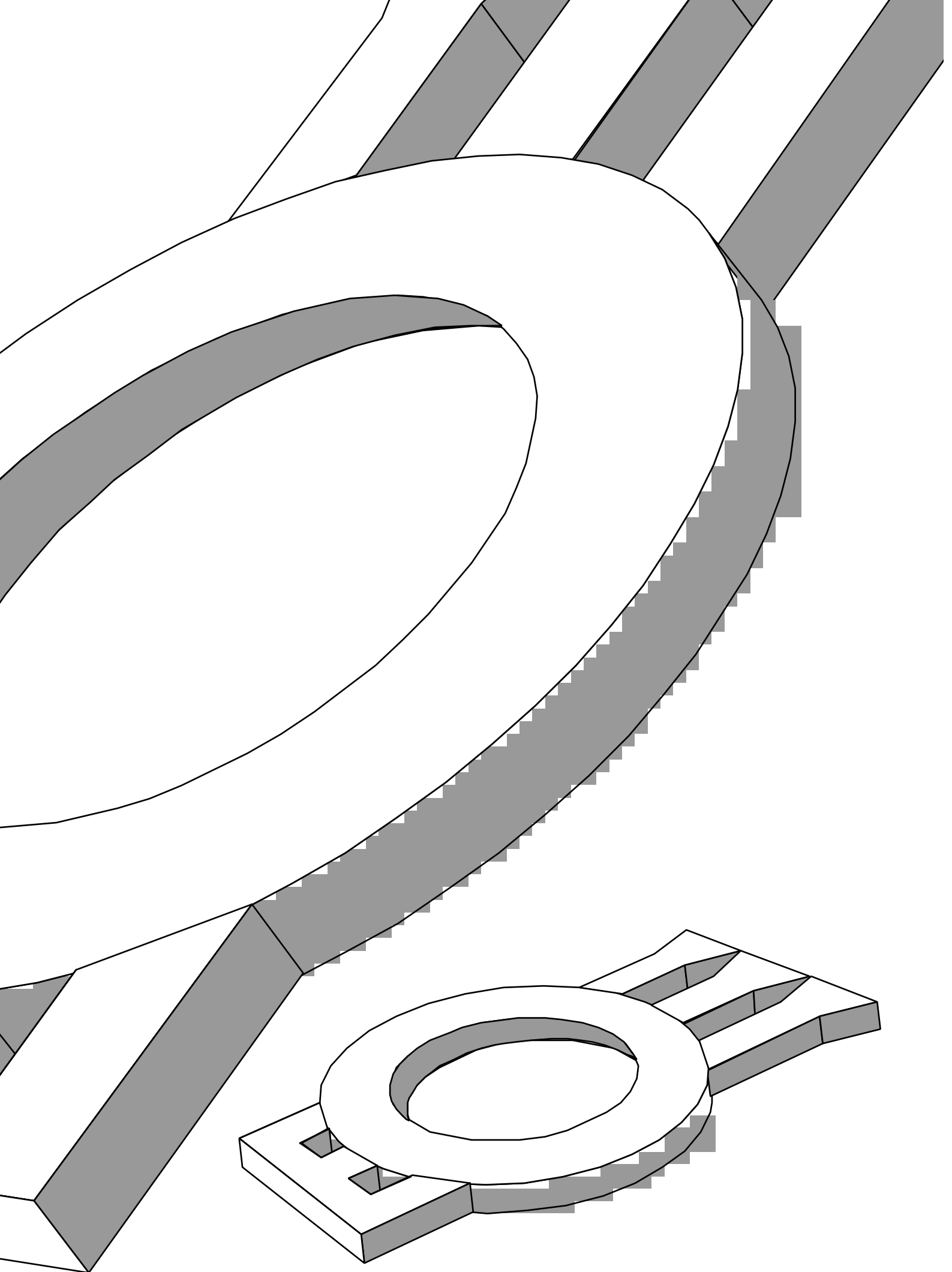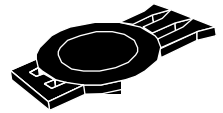
introduction

The motor constitutes an interface between the electrical and mechanical fields.
It is found in an environment linked to the driven load, from which it is inseparable.

Furthermore, the motor can be subjected to inner mechanical stress due to its moving parts.

A single faulty motor may cause disturbance in a complete production process.

Modern motors have optimized characteristics which make them inappropriate for operation other than according to their rated characteristics.

The motor is therefore a relatively fragile electrical load that needs to be carefully protected.

types of faults

Motors are affected by:
■ faults related to the driven load
■ power supply faults
■ internal motor faults

Faults related to the driven load
■ overloads. Since the power called upon is greater than rated power, there is overcurrent in the motor and an increase in losses, causing a rise in temperature.

■ too long, too frequent start-ups. Motor start-up creates substantial overcurrents which are only admissible since they are of short duration. If start-ups are too frequent or too long due to an insufficient gap between motor torque and load torque, the overheating that is inevitably produced becomes prohibitive.

■ jamming. This refers to a sudden stop in rotation for any reason related to the driven mechanism. The motor absorbs the start-up current and stays jammed at zero speed. There is no more ventilation and overheating very quickly occurs.

■ pump de-energizing. This causes motor idling which has no direct harmful effect. However, the pump itself quickly becomes damaged.

■ reverse power. This type of fault occurs due to a voltage drop when a synchronous motor driven by the inertia of the load sends power back into the network. In particular, should the normal network power supply be released, the synchronous motor can maintain the voltage in an undesirable fashion and feed the other loads which are connected in parallel.

Power supply faults
■ drop in voltage. This reduces motor torque and speed: the slow-down causes increased current and losses. Abnormal overheating therefore occurs.
■ unbalance. 3-phase power supply can be unbalanced because:
□ the power source (transformer or AC generator) does not provide symmetrical 3-phase voltage,
□ all the other consumers together do not constitute a symmetrical load, unbalancing the power supply network,
□ the motor is fed on two phases due to fuse melting.
Power supply unbalance produces reverse currrent causing very high losses and therefore quick rotor overheating.

Internal motor faults
■ phase-to-phase short-circuits: these can vary in strength depending on the position of the fault within the coil; they cause serious damage.

■ frame faults: fault current amplitude depends on the power supply network grounding system and on the fault's position within the coil. Phase-to-phase short-circuits and frame faults require motor rewinding, and frame faults can produce irreparable damage to the magnetic circuit.

■ loss of synchronism. This fault involves synchronous motors losing their synchronism due to field loss: motor operation is asynchronous but the rotor undergoes considerable overheating since it is not designed for this.

motor protection (cont.)

motor protection devices
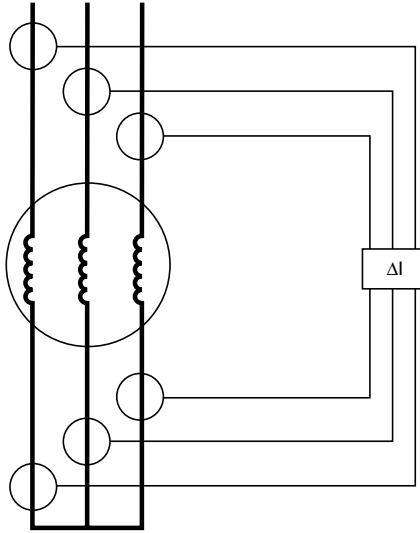
(fig.1)
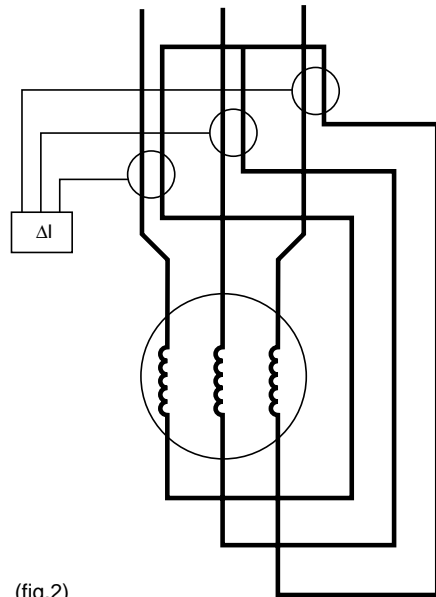
(fig.2)

Overloads
Overloads are monitored:
■ either by IDMT overcurrent protection,
■ or by thermal overload protection.
Thermal overload involves overheating due to current.
■ or by a temperature probe.

Excessive starting time and locked rotor
The same function ensures both protections. This involves an instantaneous current relay set at a value lower than the start-up current, which is validated after a time delay beginning when the motor is turned on; this time delay is set at a value greater than or equal to the normal duration of start-up.

Starts per hour
The corresponding protection is sensitive to the number of starts taking place within a given interval of time or to the time between starts.

Pump de-energizing
Is detected by a direct time undercurrent protection device which is reset when the current is nil (when the motor stops).

Reverse power
Is detected by a directional real power protection device.

Drops in voltage
Are monitored by a time-delayed undervoltage protection device. The voltage setting and time delay are set for discrimination with the system's short-circuit protection devices and to tolerate normal voltage drops, for example during motor starts. This type of protection is often shared by several motors in the same switchboard.

Unbalance
Protection is ensured by IDMT or direct time negative sequence unbalance detection.

Phase-to-phase short circuits
Are detected by a time-delayed overcurrent protection device. The current setting is set higher than or equal to the start-up current and the time delay is very short; its purpose is to make the protection insensitive to the first peaks of making current.

When the corresponding breaking device is a contactor, it is associated with fuses which ensure short-circuit protection.

For large motors, a high impedance or percentage-based differential protection system is used (fig. 1).

Through appropriate adaptation of the connections on the neutral side and by the use of summing current transformers, a simple overcurrent protection device ensures sensitive, stable detection of internal faults (fig.2).

Frame faults
This type of protection depends on the grounding system. Higher sensitivity is sought so as to limit damage to the magnetic circuit.

Field loss
(for synchronous motors). It is detected by a time-delayed max. reactive power protection device.

examples of protection
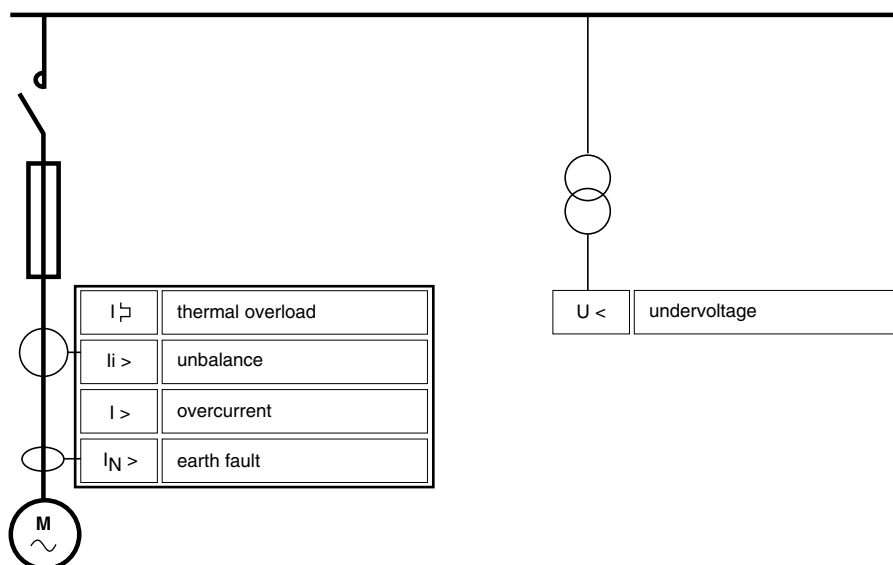
Contactor-controlled or circuit breaker-controlled asynchronous motor

Additional protection according to the type of load:
■ excessive starting time + locked rotor
■ starts per hour
■ undercurrent

I ⊐	thermal overload
Ii >	unbalance
I >	overcurrent
I_N >	earth fault

U <	undervoltage
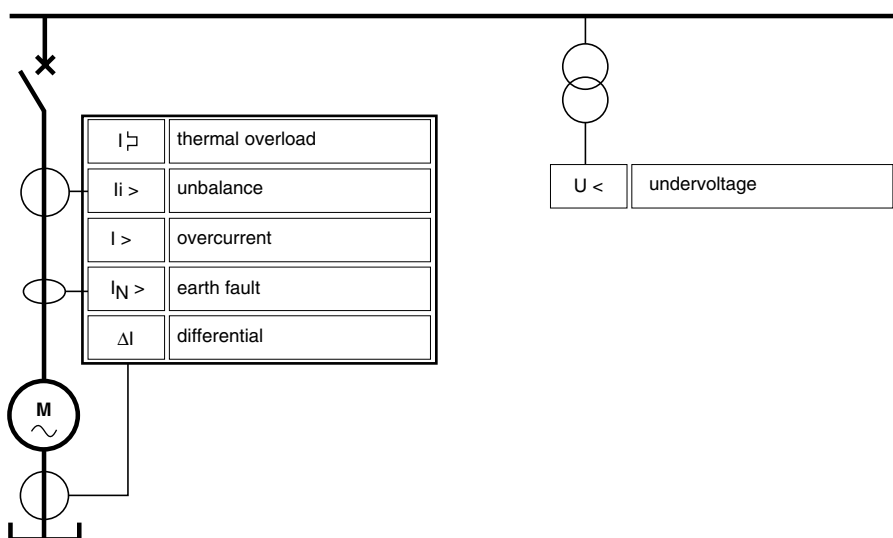
High power asynchronous motor

Additional protections according to the type of load:
■ excessive starting time + locked rotor
■ starts per hour
■ undercurrent

I ⊐	thermal overload
Ii >	unbalance
I >	overcurrent
I_N >	earth fault
ΔI	differential

U <	undervoltage
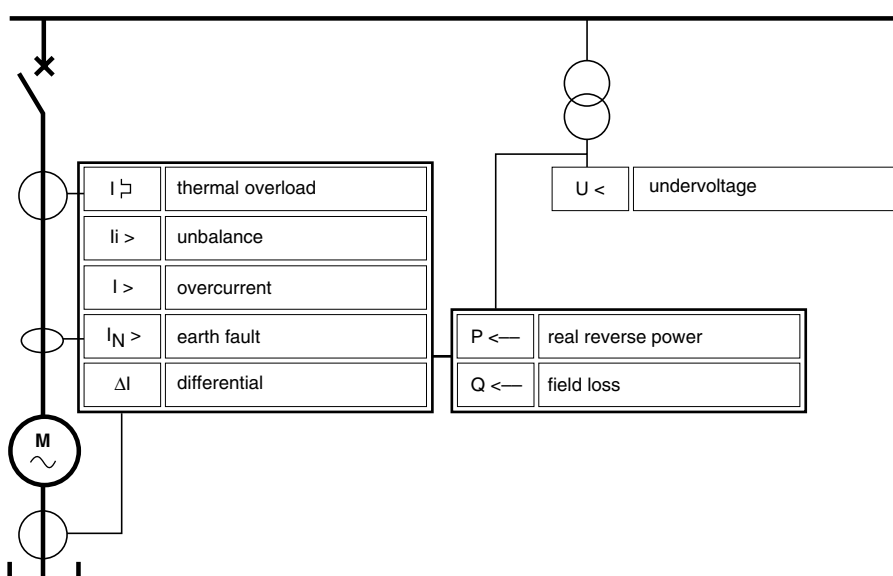
High power synchronous motor

Additional protection according to the type of load:
■ excessive starting time + locked rotor
■ starts per hour
■ undercurrent

I ⊐	thermal overload
Ii >	unbalance
I >	overcurrent
I_N >	earth fault
ΔI	differential

U <	undervoltage
P <—	real reverse power
Q <—	field loss

motor protection (cont.)

setting information

type of fault	settings
overloads	■ thermal overload parameters should be adapted to fit the characteristics of the motor (time constant in the 10' range), ■ IDMT overcurrent relay setting should allow starting.
breaking unbalance and phase reversal	■ negative sequence unbalance setting between 0.3 and 0.4 In, time delay: approximately 0.6 sec. If the system can function with almost continuous unbalance, an IDMT characteristic is used: setting allowing 0.3 In during starting without tripping
short circuits	■ fuse rating > 1.3 In, allowing starting, ■ direct time overcurrent setting ≥ 1.2 start-up current, time delay approximately 0.1 sec. differential: setting 10% to 20% of In
stator frame	■ resistance grounding The lowest setting compatible with the protected outgoing line's capacitive current is selected, setting between 10 and 20% of maximum earth fault current, time delay: 0.1 sec. approximately.
excessive starting time locked rotor	■ setting approximately 2.5 In, time delay 1.1 x starting time.
drop in voltage	■ setting between 0.75 and 0.8 Un, time delay: approximately 1 sec.
real reverse power	■ approximate settings setting 5% of Pn time delay 1 sec.
field loss	■ approximate settings setting 30% of Sn time delay 1 sec.

AC generator protection
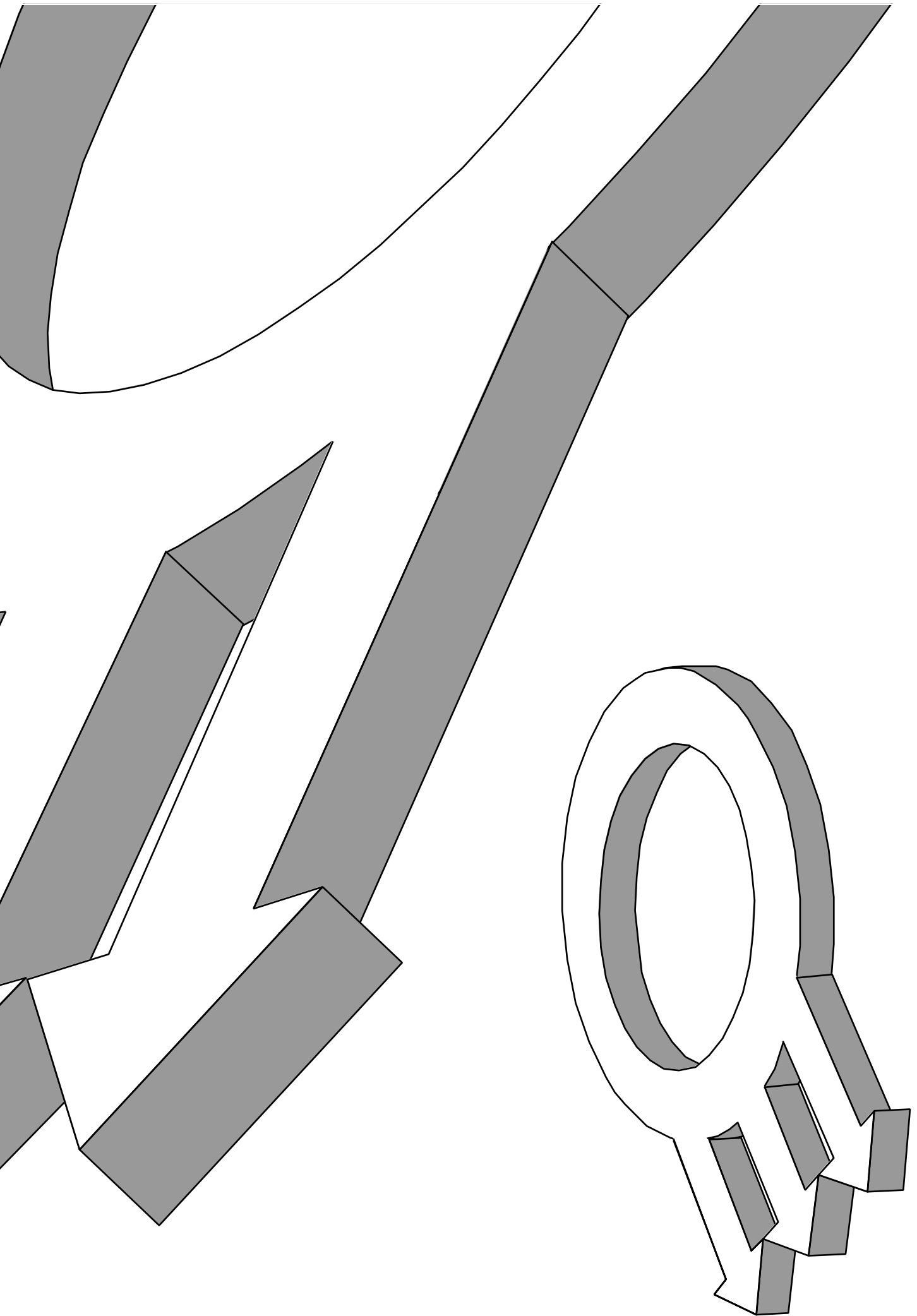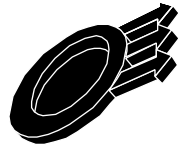
introduction

AC generator operation can be altered by both faults within the machine and by disturbances occurring in the electrical system to which it is connected.
An AC generator protection system therefore has a dual objective: protecting the machine and protecting the system.

types of faults

Faults such as overloads, unbalance and internal phase-to-phase faults are the same type for AC generators as for motors.

However, there are other types of faults that are characteristic of AC generators.
When **a short circuit occurs** in a an electrical system close to an AC generator, the fault current looks like that shown in figure 1.

The maximum short-circuit current value should be calculated taking into account the machine's substransient impedance X"d .
The value of the current detected by a protection device, which is very slightly time-delayed (by about 100 milliseconds), should be calculated taking into account the machine's transient impedance X'd.
The value of steady state short-circuit current should be calculated taking into account the synchronous impedance X.
This current is weak, generally less than the AC generator's rated current.

Internal phase-to-frame fault
This is the same type of fault as for motors and its effects depend on the grounding systems adopted. A particularity in relation to motors, however, lies in the fact that AC generators can operate decoupled from the electrical system during the start-up and shutdown periods, and also when operating for testing or on stand-by. The grounding system may differ depending on whether the AC generator is coupled or decoupled and the protection devices should be suitable for both cases.

Field loss
When an AC generator previously coupled with a system loses its field, it becomes desynchronized from the system. It then operates asynchronously, overspeeding slightly, and it absorbs reactive power.

Motor-like operation
When an AC generator is driven like a motor by the electrical power system to which it is connected and it applies mechanical energy to the shaft, this can cause wear and damage to the driving machine.

Voltage and frequency variations
Voltage and frequency variations during steady state operating are due to the malfunction of the related regulators. These variations create the following problems:
■ too high a frequency causes abnormal motor overheating,
■ too low a frequency causes motor power loss,
■ variations in frequency cause variations in motor speed which can bring about mechanical damage,
■ too high a voltage puts stress on all parts of the network,
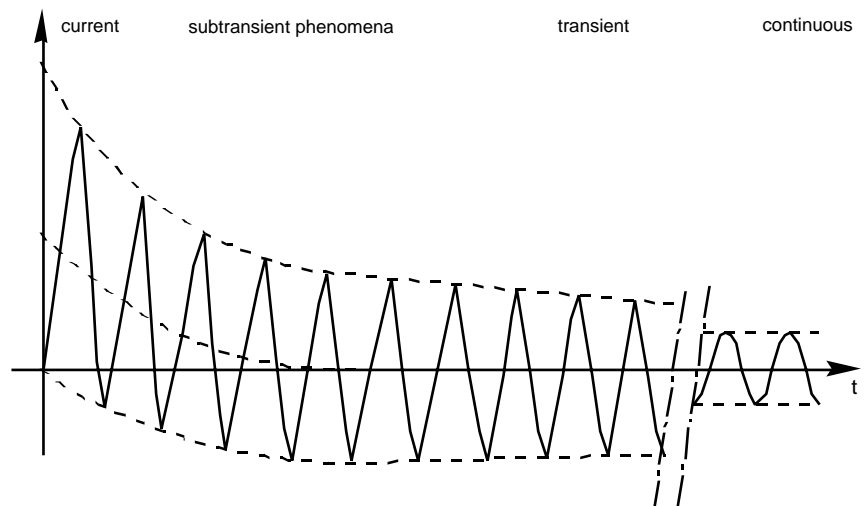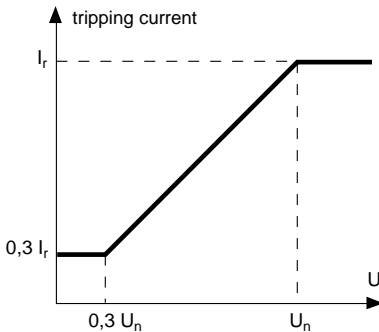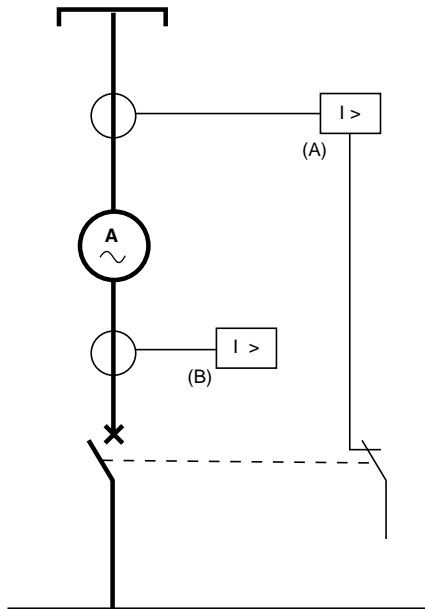■ too low a voltage causes torque loss and an increase in current and motor overheating.

fig.1

AC generator protection (cont.)

protection devices

(fig.2)

I_r : setting current

(fig.3)

AC generator connected to other power sources

Overloads
The overload protection devices for AC generators are the same as for motors:
■ IDMT overcurrent,
■ thermal overload,
■ temperature probe.

Unbalance
Protection, like for motors, is ensured by IDMT or direct time negative sequence detection.

External phase-to-phase short-circuits
As the value of short-circuit current decreases over time to within the range of rated current, if not weaker, in steady state operation, a simple current detection device can be insufficient.
This type of fault is effectively detected by a voltage restrained overcurrent detection device, the setting of which increases with the voltage (fig.2). Operation is delayed.

Internal phase-to-phase short circuits
■ high impedance or percentage-based differential protection provides a sensitive, quick solution.

■ In certain cases, especially for an AC generator with a low power rating compared to the system to which it is connected , the following combination can be used for internal phase-to-phase short-circuit protection (fig.3):

□ instantaneous overcurrent protection (A), validated when the AC generator circuit breaker is opened, with current sensors located on the neutral side, with a setting lower than rated current,

□ instantaneous overcurrent protection (B), with current sensors located on the circuit breaker side, with a setting higher than AC

generator short-circuit current.

Stator frame fault
■ if the neutral is grounded at the AC generator neutral point, earth fault or restricted earth fault protection is used.

■ if the neutral is grounded within the system rather than at the AC generator neutral point, stator frame faults are detected by:

□ earth fault protection on the AC generator circuit breaker when the AC generator is coupled to the electrical system,
□ by an insulation monitoring device for ungrounded systems when the AC generator is uncoupled from the system.

■ If the neutral is ungrounded, protection against frame faults is ensured by an insulation monitoring device. This device operates either by detecting residual voltage or by injecting DC current between the neutral and earth.

If this device exists in the system, it monitors the AC generator when it is coupled, but a special AC generator device, validated by the circuit breaker being in the open position, is needed to monitor insulation when the AC generator is uncoupled.

Rotor frame faults
When the exciting current circuit is accessible, frame faults are monitored by a permanent insulation monitor (Vigilohm).

Field loss
This type of fault is detected either by measuring the reactive power absorbed or by monitoring the excitation circuit if accessible, or else by measuring the impedance at the AC generator terminals.

Motor-like operation
This is detected by a relay that senses the real power absorbed by the AC generator.

Voltage and frequency variations
These are monitored respectively by an overvoltage-undervoltage protection device and an underfrequency device.
These protection devices are time-delayed since the phenomena do not require instantaneous action and because the electrical system protections and voltage and speed controller must be allowed time to react.
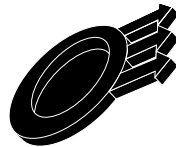
examples of applications

Low power AC generator, uncoupled

$I_N >$	earth fault
$I \, \Box$	thermal overload
$I_i >$	negative sequence unbalance
$\dfrac{I}{U} >$	voltage restrained overcurrent

Medium power AC generators

$I_N >$	earth fault
$I \, \Box$	thermal overload
$I_i >$	negative sequence unbalance
$\dfrac{I}{U} >$	voltage restrained overcurrent
$P \longleftarrow$	real reverse power
$Q \longleftarrow$	reactive reverse power
$> U >$	over and undervoltage
$> f >$	over and underfrequency

ΔI | differential

AC generator protection (cont.)
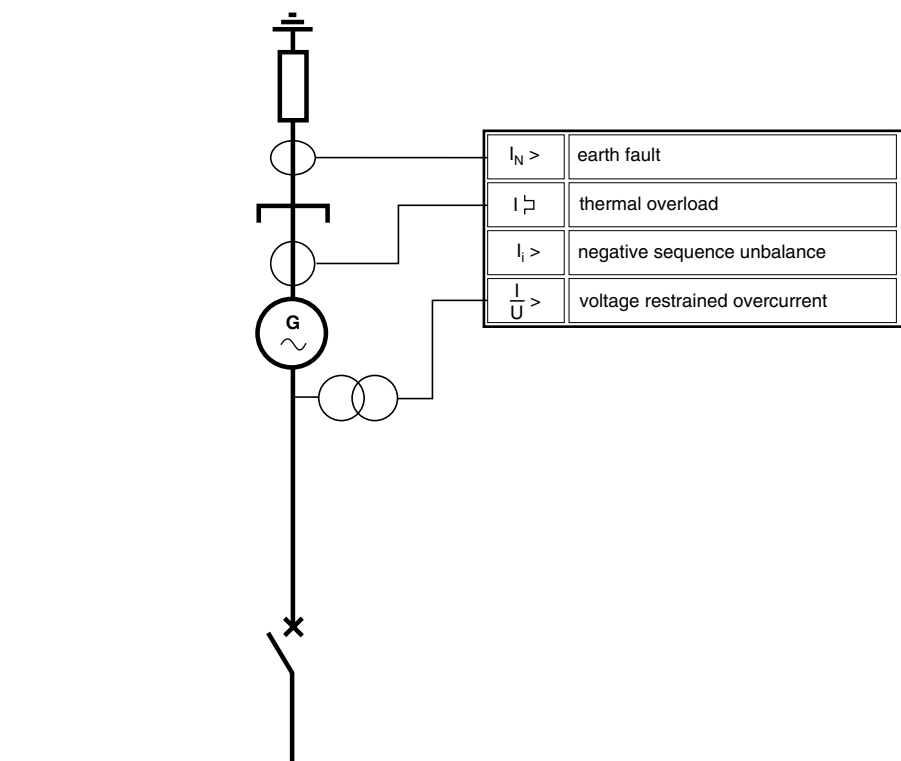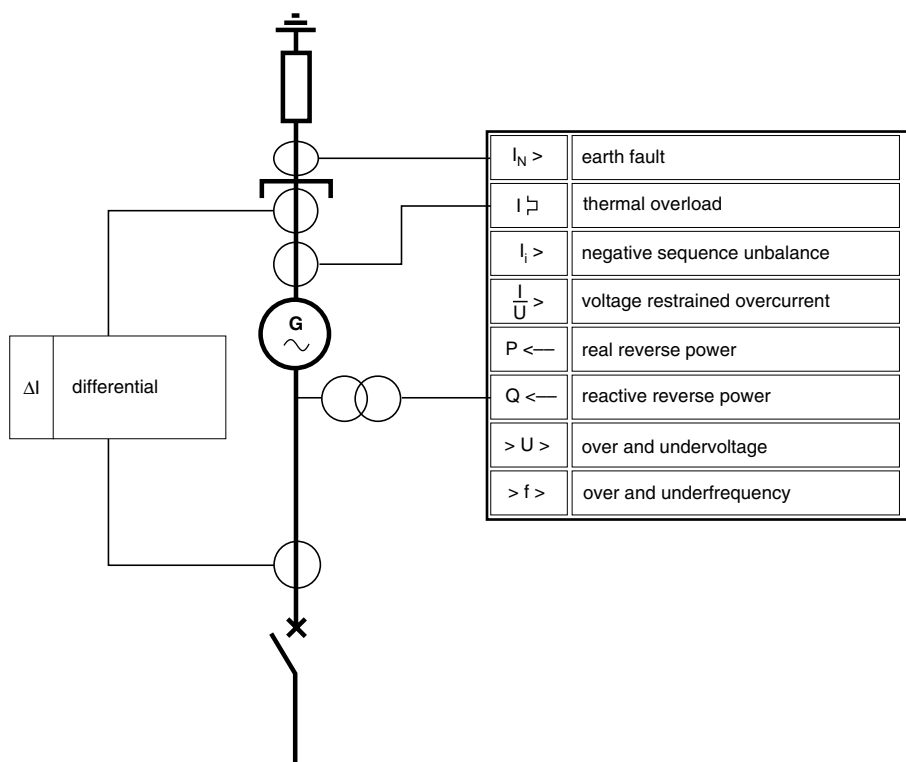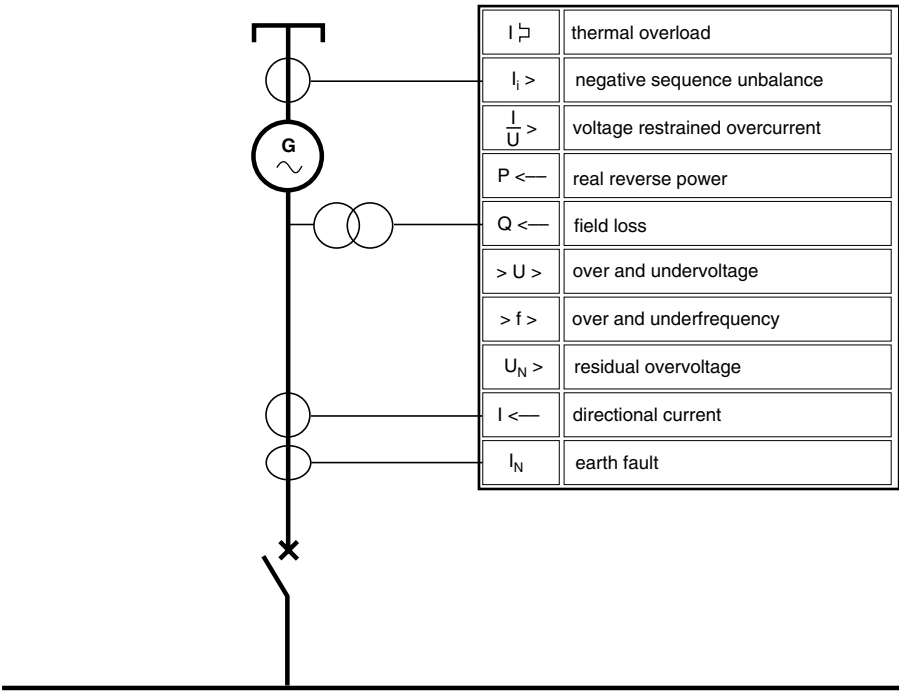
examples of applications

**Medium power AC generator
(grounded in electrical system)**

I $\sqsubset$	thermal overload
I$_i$ >	negative sequence unbalance
$\frac{I}{U}$ >	voltage restrained overcurrent
P <—	real reverse power
Q <—	field loss
> U >	over and undervoltage
> f >	over and underfrequency
U$_N$ >	residual overvoltage
I <—	directional current
I$_N$	earth fault

Medium power block generator

$\sqsubset$	thermal overload
Ii >	negative sequence unbalance
$\frac{I}{U}$ >	voltage restrained overcurrent
P <—	real reverse power
Q <—	field loss
U$_N$ >	residual overvoltage
> U >	over and undervoltage
> f >	over and underfrequency
I$_N$ >	earth fault

ΔI	differential

setting information

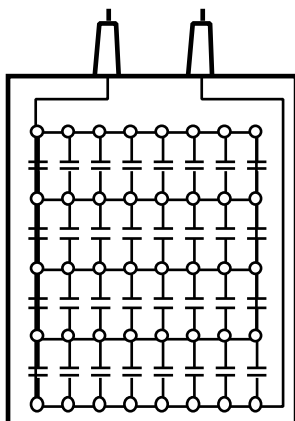| type of fault	settings
overloads	■ thermal overload to be adapted to rated characteristics (time constants in the 10' range)).
unbalance	■ max. neg. phase sequence component to be adapted to characteristics (if lack of data, setting 15% of In, IDMT).
external short-circuit	■ voltage restrained overcurrent setting 1.2 to 2 times In, time delay according to discrimination.
internal short-circuit	■ high impedance differential threshold approximately 10% of In.
frame faults	■ neutral grounded in electrical system earth fault, setting 10% to 20% of maximum earth fault current, time delay: instantaneous or 0.1 sec. ■ neutral grounded at AC generator neutral point earth fault setting approximately 10% In time delay according to discrimination ■ ungrounded residual overvoltage setting approximately 30% of Vn
field loss	■ reactive reverse power setting 30% of Sn, time delay of a few seconds.
motor operation	■ directional real power setting 1 to 20% of Pn, time delay ≥ 1 sec.
voltage variation	■ over and undervoltage 0.8 Un < U < 1.1 Un, time delay: approximately a second.
speed variation	■ over and underfrequency 0.95 fn < f < 1.05 fn, time delay: a few seconds.

capacitor protection
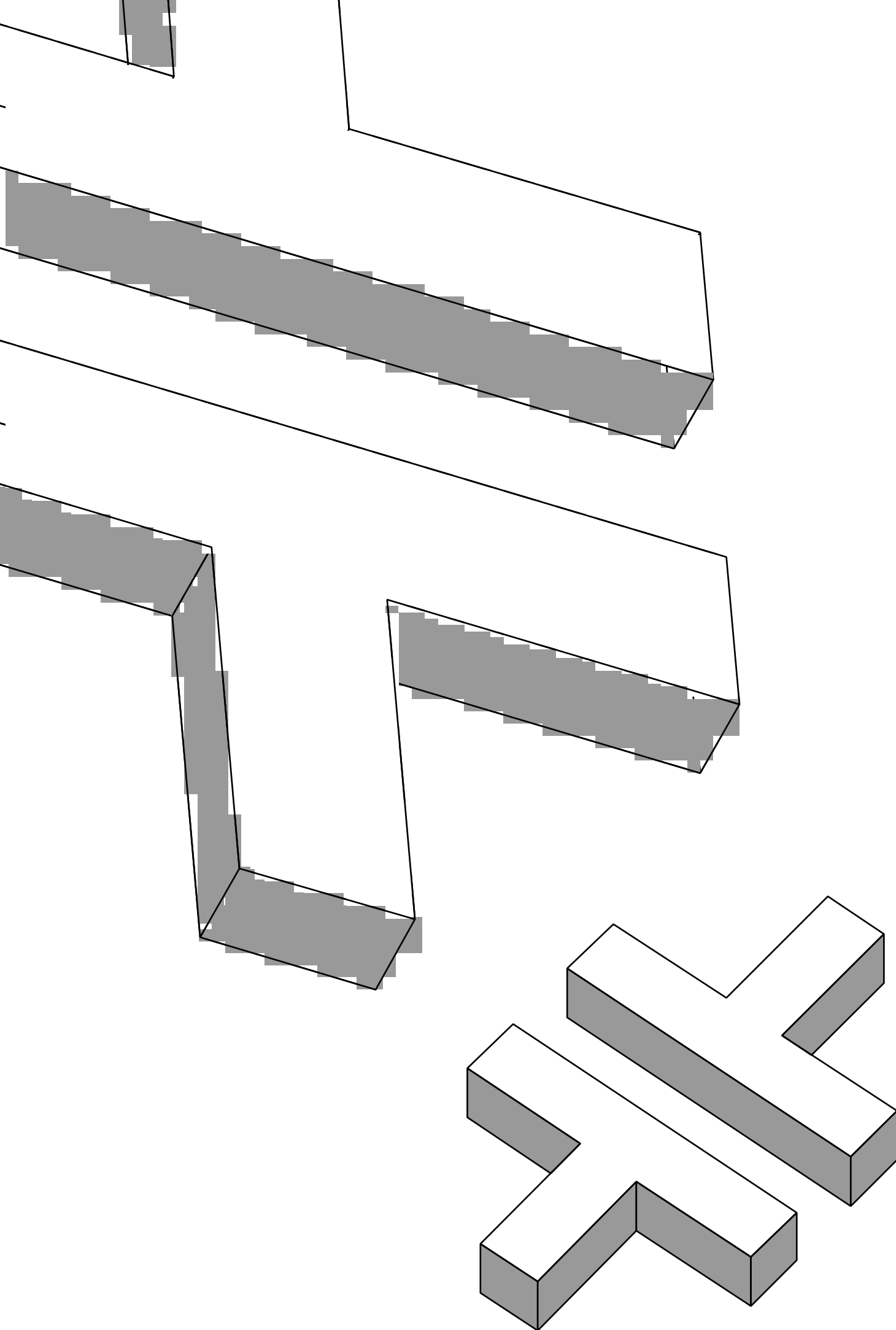
introduction

Capacitor banks are used to compensate for reactive energy absorbed by electrical system loads, and sometimes to make up filters to reduce harmonic voltage.
Their role is to improve the quality of the electrical system.
They may be connected in star, delta and double star arrangements, depending on the level of voltage and the system load.

A capacitor comes in the form of a case with insulating terminals on top. It comprises individual capacitances which have limited maximum permissible voltages (e.g. 2250 V) and are series-mounted in groups to obtain the required voltage withstand and parallel-mounted to obtained the desired power rating.

There are two types of capacitors:
■ those with no internal protection,
■ those with internal protection:
a fuse is combined with each individual capacitance.

types of faults
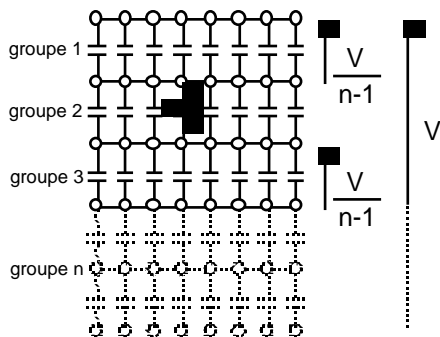
The main faults which are liable to affect capacitor banks are:
■ overload,
■ short-circuit,
■ frame fault,
■ capacitor component short-circuit.

An **overload** is due to temporary or continuous overcurrent:
■ continuous overcurrent linked to:
□ raising of the power supply voltage,
□ the flow of harmonic current due to the presence of non-linear loads such as static converters (rectifiers, variable speed drives), arc furnaces, etc.,
■ temporary overcurrent linked to the energizing of a capacitor bank step.
Overloads result in overheating which has an adverse effect on dielectric withstand and leads to premature capacitor aging.

A **short-circuit** is an internal or external fault between live conductors, phase-to-phase or phase-to-neutral depending on whether the capacitors are delta or star-connected. The appearance of gas in the gas-tight chamber of the capacitor creates overpressure which may lead to the opening of the case and leakage of the dielectric.

A **frame fault** is an internal fault between a live capacitor component and the frame created by the metal chamber.
Similar to internal short-circuits, the appearance of gas in the gas-tight chamber of the capacitor creates overpressure which may lead to the opening of the case and leakage of the dielectric.

A **capacitor component short-circuit** is due to the flashover of an individual capacitance.
■ with no internal protection: the parallel-wired individual capacitances are shunted by the faulty unit:
□ the capacitor impedance is modified
□ the applied voltage is distributed to one less group in the series
□ each group is submitted to greater stress, which may result in further, cascading flashovers, up to a full short-circuit.

■ with internal protection: the melting of the related internal fuse eliminates the faulty individual capacitance:
□ the capacitor remains fault-free,
□ its impedance is modified accordingly.

(fig.1)

capacitor protection (cont.)

protection devices

Capacitors should not be energized unless they have been discharged. Re-energizing must be time-delayed in order to avoid transient overvoltage. A 10-minute time delay allows sufficient natural discharging. Fast discharging reactors may be used to reduce discharging time.

Overloads
■ Overcurrent of long duration due to the raising of the power supply voltage may be avoided by overvoltage protection that monitors the electrical system voltage. This type of protection may be assigned to the capacitor itself, but it is generally a type of overall electrical system protection. Given that the capacitor can generally accommodate a voltage of 110% of its rated voltage for 12 hours a day, this type of protection is not always necessary.
■ Overcurrent of long duration due to the flow of harmonic current is detected by an overload protection of one the following types:
□ thermal overload
□ time-delayed overcurrent,
provided it takes harmonic frequencies into account.
■ The amplitude of overcurrent of short duration due to the energizing of capacitor bank steps is limited by series-mounting impulse reactors with each step.

Short circuits
Short-circuits are detected by a time-delayed overcurrent protection device. Current and time delay settings make it possible to operate with the maximum permissible load current and to close and switch steps.

Frame faults
Protection depends on the grounding system. If the neutral is grounded, a time-delayed earth fault protection device is used.

Capacitor component short-circuits
Detection is based on the change in impedance created
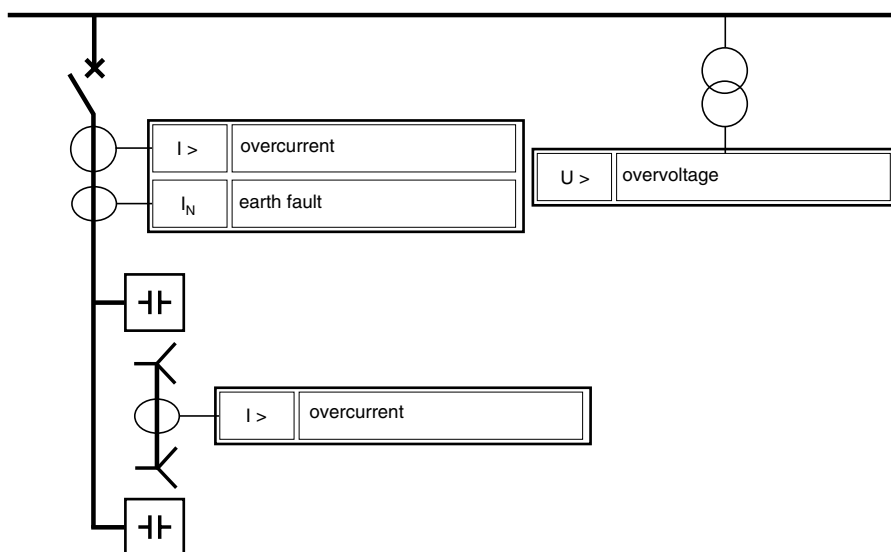■ by the short-circuiting of the component for capacitors with no internal protection
■ by the elimination of the faulty individual capacitance for capacitors with internal fuses.
When the capacitor bank is double star-connected, the unbalance created by the change in impedance in one of the stars causes current to flow in the connection between the netural points. This unbalance is detected by a sensitive overcurrent protection device.
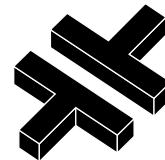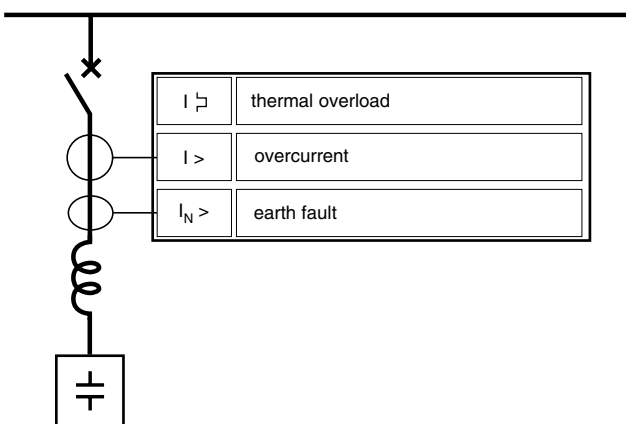
examples of capacitor bank protection

**Double star connected capacitor bank for reactive power compensation**

I >	overcurrent
I$_N$	earth fault

U >	overvoltage

I >	overcurrent

Filter

I $\dashv$	thermal overload
I >	overcurrent
I$_N$ >	earth fault

capacitor protection (cont.)

setting information

type of fault	setting
overload	■ overvoltage setting ≤ 110 % Vn ■ thermal overload setting ≤ 1.3 In or overcurrent setting ≤ 1.3 In direct time or IDMT time delay 10 sec
short-circuit	■ overcurrent direct time setting approximately 10 In time delay approximately 0.1 sec
frame fault	■ earth fault direct time setting ≤ 20 % maximum earth fault current and ≥ 10 % CT rating if suppied by 3 CTs time delay approximately 0.1 sec
capacitor component **short circuit**	■ overcurrent direct time setting < 1 ampere time delay approximately 1 sec

sensors
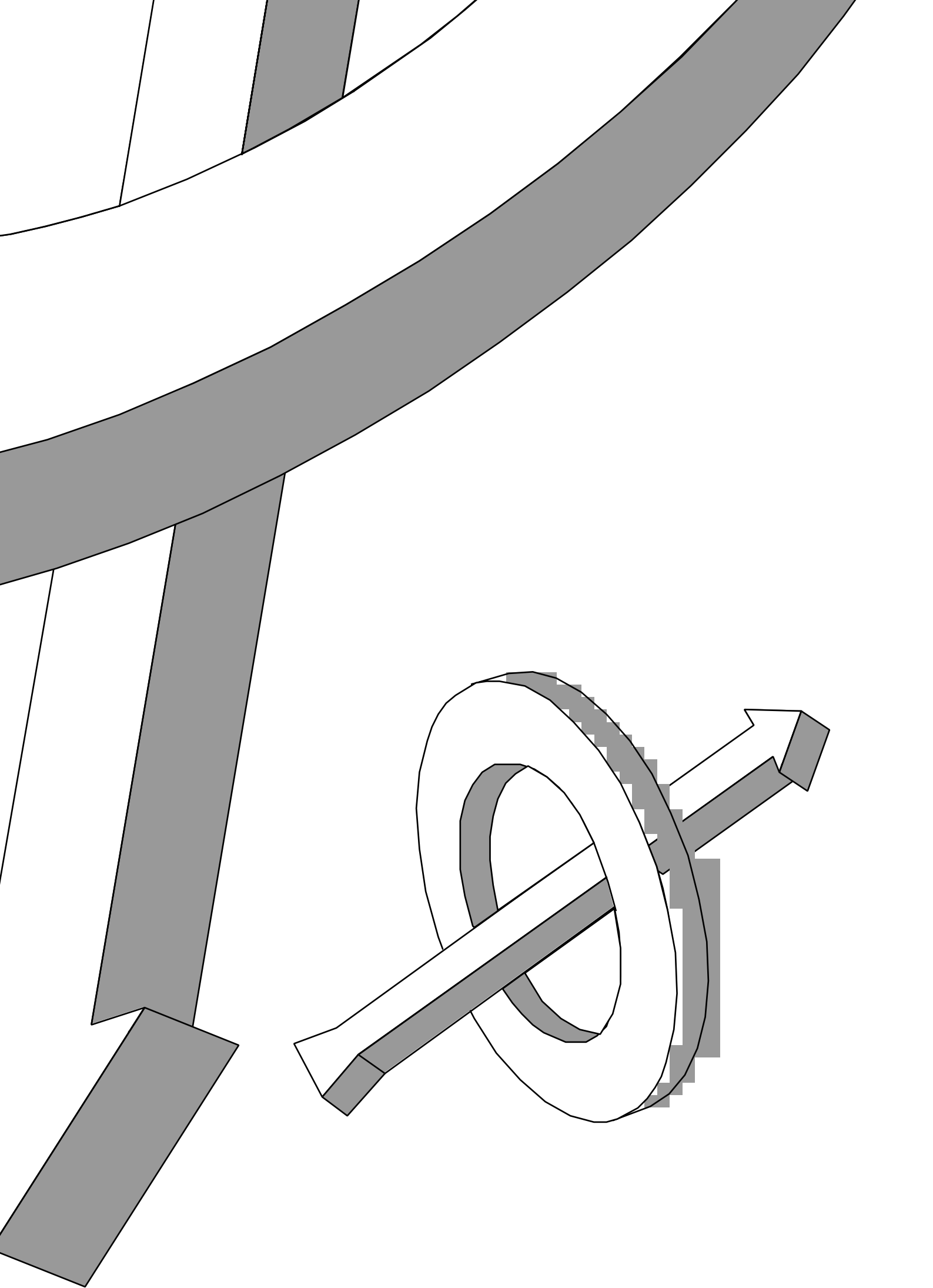
introduction

Protection or measuring devices require data on the electrical rating of the equipment to be protected.

For technical, economic and safety reasons, this data cannot be obtained directly from the high voltage equipment power supply; the following intermediary devices are needed:
■ voltage transformers (VT),
■ current transformer (CT),
■ core balance CTs to measure earth fault current.

These devices fulfill the following functions:
■ reduction of the value to be measured (e.g.1500/5 A),
■ galvanic isolation,
■ providing the power required for data processing and for protection operation itself.

current transformers (CTs)

P1 ● ↓ I1

S1 → I2

S2

P2 ●
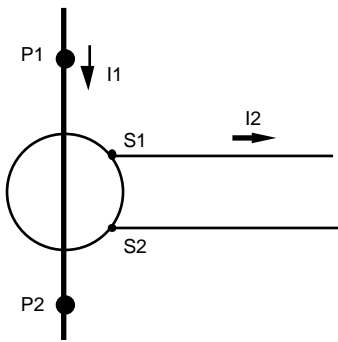
The CTs are characterized by the following values (according to IEC 185 standards)*.

CT voltage
This is the operating voltage applied to the CT primary. Note that the primary is at the HV potential level and that one of the secondary terminals is generally earthed.

As for other equipment, the following is also defined :
■ maximum1 min. withstand voltage at standard frequency
■ maximum impulse withstand voltage.

e.g. for 24 kV rated voltage, the CT must withstand 50 kV voltage for 1 min at 50 Hz and 125 kV impulse voltage .

Rated transformation ratio
It is usually given as the transformation ratio between primary and secondary current I1/I2. Secondary current is generally 5 A or 1 A.

Accuracy level
It is defined by the composite error for the accuracy limit current.
e.g. 5P10 means 5% error for 10 In
10P15 means 10% error for 15 In

5P and 10P are the standard **accuracy classes.**
5 In, 10 In, 15 In, 20 In are the standard **accuracy limit currents**.

The accuracy limit factor is the ratio between the accuracy limit current and the rated current .
Class X is another way of specifying CT characteristics based on "knee-point voltage" (fig.1, CT response in saturated state).

Accuracy level power
Secondary power at rated current for which the accuracy level is guaranteed. Expressed in VA, it indicates the power that the secondary can deliver for its rated current, while respecting the rated accuracy class. It represents the total consumption of the secondary circuit, i.e. the power consumed by all the connected devices as well as the connecting wires.

If a CT is loaded at a power rating lower than its accuracy level power, its actual accuracy level is higher than the rated accuracy level. Likewise, a CT that is loaded too much loses accuracy.

Admissible short time current
Expressed in rms kA, the maximum current admissible for 1 second (I_{th}) (the secondary being short-circuited) represents CT thermal overcurrent withstand. The CT must have the capacity to withstand short-circuit current for the time required to clear it. If the clearing time t is other than 1 sec., the current the CT can withstand is $I_{th} / \sqrt{t}$.
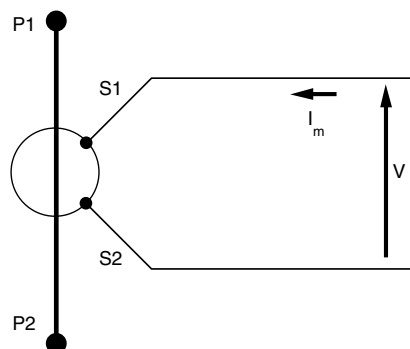
Electrodynamic withstand expressed in peak kA is at least equal to 2.5 x I_{th}

Normal values of rated currents:
■ at the primary (in A)
10 - 12.5 - 15 - 20 - 25 - 30 - 40 - 50 - 60 - 75 and multiples or decimal submultiples.

* Also to be taken into account are elements related to the type of assembly, characteristics of the site (e.g. temperature), system frequency, etc...

CT response in saturated state

When subjected to very strong current, the CT becomes saturated, i.e. the secondary current is no longer proportional to the primary current.
The current error which corresponds to the magnetization current becomes very high.

Knee-point voltage (fig.1)
This is the point on the current transformer magnetization curve at which a 10% increase in voltage V requires a 50% increase in magnetization current I_m.
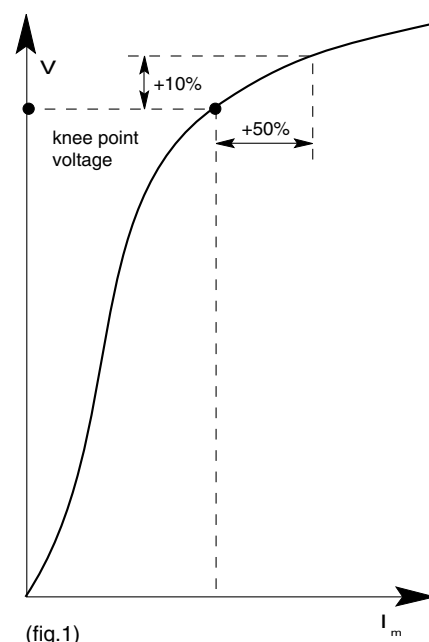
(fig.1)

conclusion on CTs sending current into an overcurrent type protection device

For direct time overcurrent protections, if twice the setting current does does cause saturation, operation is ensured no matter how strong the fault.
For IDMT overcurrent protections, saturation must not be reached for current values in the working part of the operation curve (a maximum of 20 times the setting current).

specific "wide band" current sensors

These sensors, most often without magnetic circuits and therefore **not subject to saturation**. Linked to an electronic device, their **response is linear**.
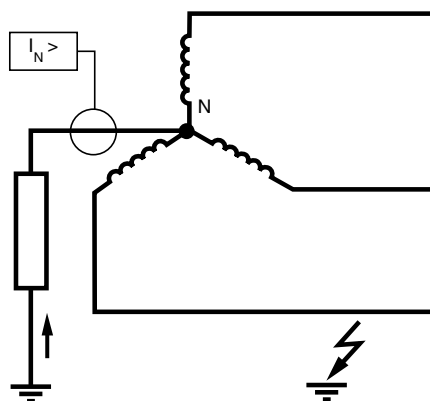
These CTs are used and supplied with the digital technology protection units. They only require knowledge of the primary rated current.
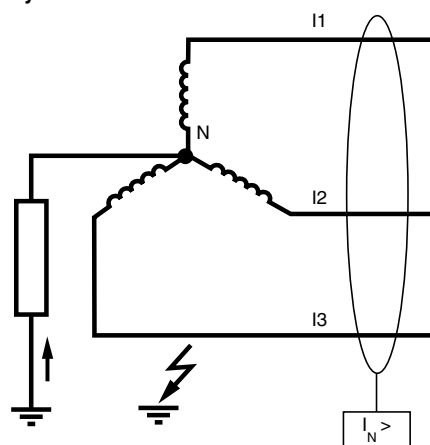
earth fault protection sensors

Earth fault current can be detected in several ways.

CT mounted on neutral point

(fig.1)

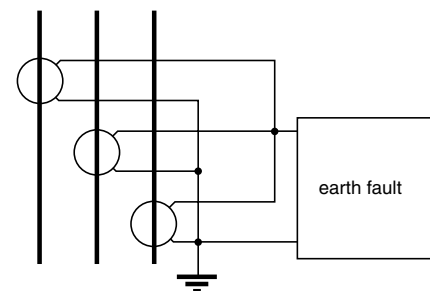**Differential measurement by core balance CT**

(fig.2)

3 CT summing integrator assembly (fig.3)
This assembly is only used if it is impossible to use core balance CTs.
Because of the CT summing error, the minimum setting for residual current is approximately 10% of In.

(fig.3)

differential protection sensors

The CTs should be specified according to the operating principle of the protection system; refer to the instruction manual of the system being used.


protected zone

differential protection

sensors (cont.)
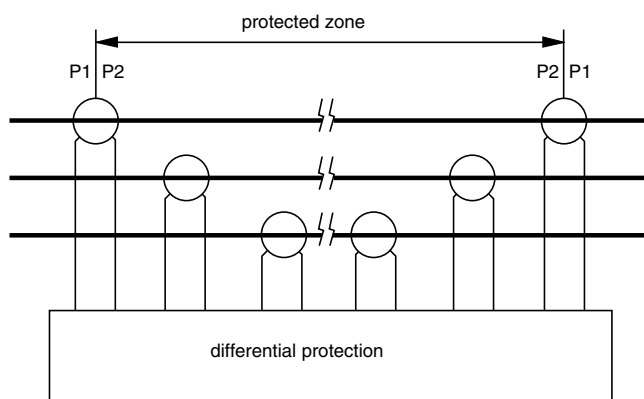
voltage transformers

Voltage transformers have the following characteristics (IEC186) [1]
- electrical system frequency generally 50 or 60Hz,
- system's highest primary voltage (secondary voltage is standardized 100, $100/\sqrt{3}$, 110, $110/\sqrt{3}$ Volts),
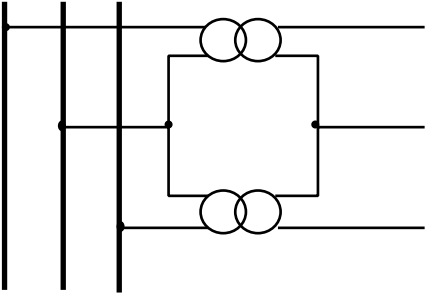- rated voltage factor
- VA power rating and accuracy class

3-transformer assembly (requires 1 insulated high voltage terminal per transformer)
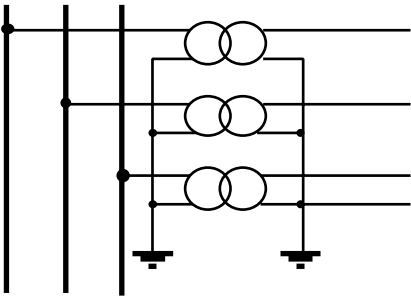
voltage ratio:

$$\frac{Un/\sqrt{3}}{100/\sqrt{3}}$$

2 transformer assembly ("V" assembly) (requires 2 insulated high voltage terminals per transformer)
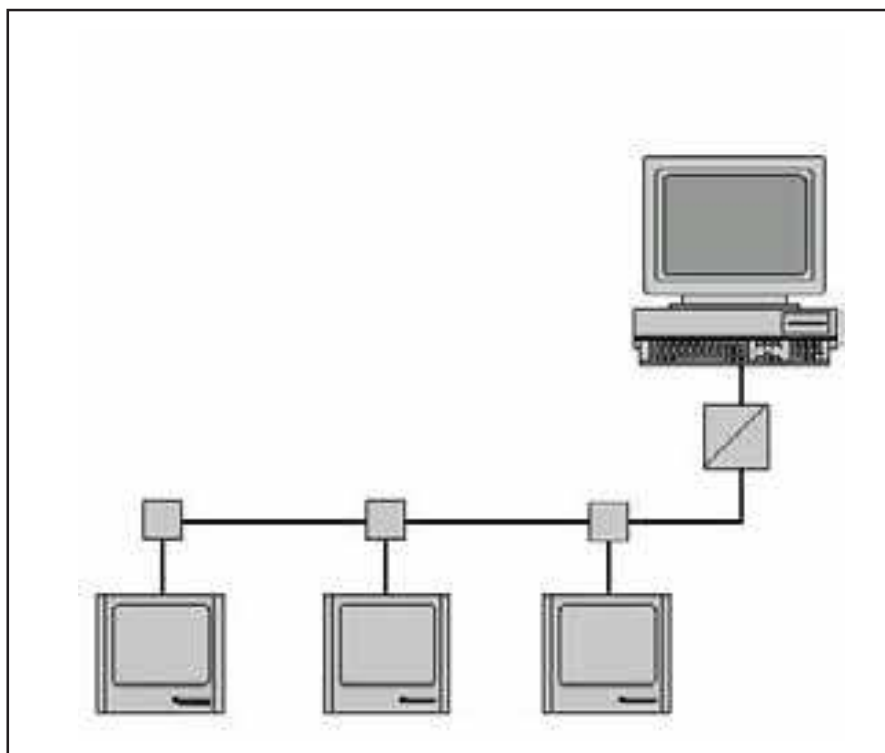
voltage ratio:

$$\frac{Un}{100}$$

In ungrounded systems, all neutral phase VTs must be loaded enough to prevent the risk of ferromagnetic resonance.

[1] also to be taken into account are elements related to the type of assembly, characteristics of the site (e.g. temperature...) etc...

Protection
and control

RS 485 - Modbus network connection accessories instruction manual

Merlin Gerin
Modicon
Square D
Telemecanique

Schneider Electric

Contents

RS 485 network

Presentation

The Modbus communication network may be used to connect equipment to a central monitoring and control system on a local network in half duplex, master-slave mode.

The communication network is a LAN (Local Area Network). Transmission is of the serial type and all the stations are connected in parallel to a 2-wire / (4-wire) bus. The physical layer is of the RS 485 type in compliance with the EIA RS 485 standard.

The RS 485 communication bus operates according to the principle of differential line voltage.

There are 2 main wiring principles for this type of network:
■ 2-wire topology,
■ 4-wire topology.

2-wire bus topology

Two-wire cabling of the communication network makes it possible to use a single shielded pair, which means simple cabling.

Each item of equipment connected to the network includes a transmitter and a receiver that are connected to the same cable.

Since communication is half duplex, alternating and two-way, messages are conveyed in both directions on the same line from the master to the slaves and vice versa.

Communication takes place alternately, with the transmitters taking turns on the line.

The master can be any station.

Connection of the stations (2-wire)
The network comprises a single cable (a shielded, twisted pair). The various stations in the network are connected by linking both of the following:
■ all the outputs marked + (TD+, RD+) to the network + wire (marked L+),
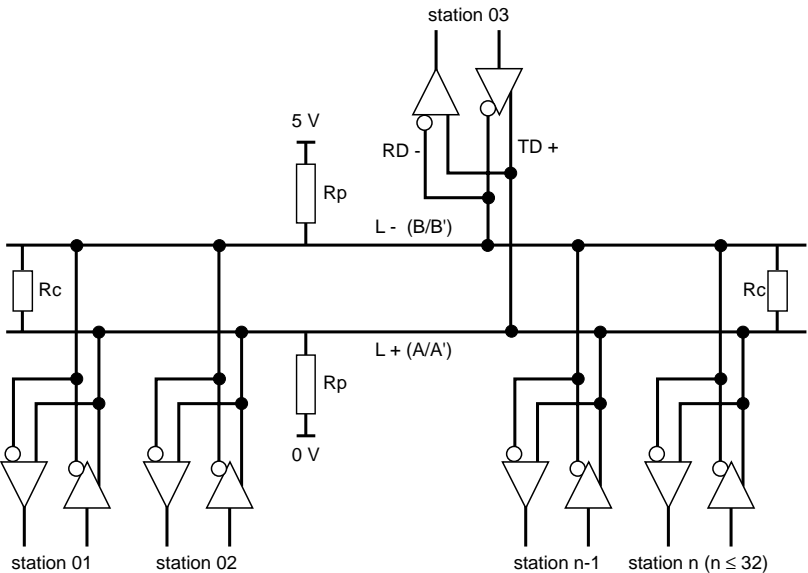■ all the outputs marked - (TD-, RD-) to the network - wire (marked L-).

General characteristics

type of transmission	asynchronous serial
rate	300, 600, 1200, 2400, 4800, 9600, 19200, 38400 bauds [1]
data formats	1 start, 8 bits, no parity, 1 stop 1 start, 8 bits, even parity, 1 stop 1 start, 8 bits, odd parity, 1 stop
RS 485 electrical interface	complies with EIA RS 485 standard
maximum distance	1300 m
branch distance	less than 3 m
maximum number of stations on a line	32

[1] 300, 600 bauds not available with ACE 909-2.
300, 600, 1200, 2400 not available with Sepam 1000+.

General architecture of an RS 485 network

transmitters

receivers

Impedance matching
Two 150 Ω resistors (Rc) are required at each end to match line impedance. Each item of equipment, as well as each connector, connection box and interface, contains a 150 Ω resistor which can be used for this purpose.
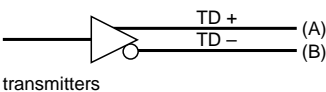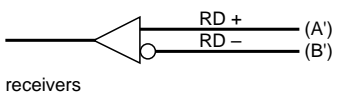
Polarization
Polarization creates a continuous flow of current through the network, putting all the receivers in deactivated status until a transmitter is validated.
The network is polarized by connecting the (L+) line to the 0 V and the (L-) line to the 5 V via two 470 Ω polarization resistors (RP).
The network should only be polarized in one location on the line to avoid random transmission.
It is recommended that the master's power supplies and resistors be used.
The ACE 909-2 and ACE 919 converters provide this polarization.
Some Schneider equipment offers also this possibility.

Please note
Some equipment items do not comply with the RS 485 standard with respect to polarities as well as polarization and line impedance matching.
When a mixture of equipment is being connected, make sure to check these points.

4-wire bus topology

For 4-wire connection of the communication network, 2 shielded pairs are used.

With 4-wire connection, the "master station" is defined and then the two communication lines, a master to slaves "transmission" line and a slaves to master "receiving" line. Communication is alternating half duplex. Requests are sent from the master to the salves on the transmission line. Replies are sent from the slaves to the master on the receiving line.

Connection of stations (4-wire)
The different network are stations are connection by linking:
■ master station
□ RD+ inputs to the L+ "transmission" line,
RD- inputs to the L- "transmission" line,
□ TD+ outputs to the L+ "receiving" line,
TD- outputs to the L- "receiving" line.

The connection of the master station is the opposite to that of the other stations:
■ master station
□ RD+ input to the L+ "receiving" line,
RD- input to the L- "receiving" line,
□ TD+ output to the L+ "transmission" line,
TD- output to the L- "transmission" line.
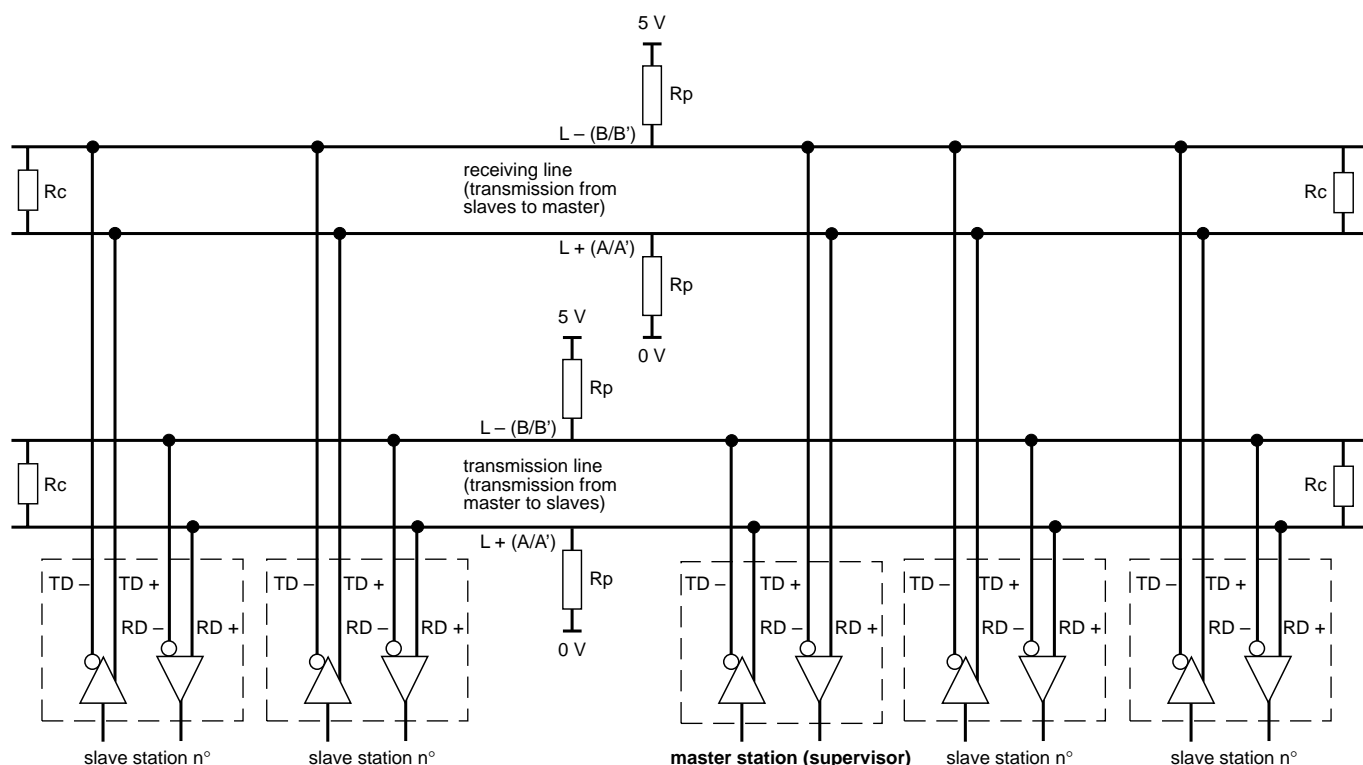
RC = load resistor (150 ohms),
Rp = polarization resistor (470 ohms)

Impedance matching
Four 150 Ohm resistors (Rc) are mandatory, one at each end, for impedance matching of both the transmission and receiving lines.

Polarization
(see 2-wire topology)
It is necessary to polarize both the transmission and receiving lines.
ACE 909-2 and ACE 919 converters are only used with the 2-wire topology.

Communication interfaces

Schneider's experience in the industrial world has shown that more than 50% of communication problems are linked to the commissioning of the network.

This manual describes the accessories available and the different connection schemes that may be used for equipment fitted with a Modbus RS 485 physical link.

These accessories may be used to:
■ facilitate commissioning,
■ reduce risks linked to the environment (EMC),
■ reduce incorrect wiring (faulty welding...).

Merlin Gerin equipment items which use the same type of RS 485 interface, connected to 9-pin Sub-D connectors, are identified in the connection schemes by the symbol ▇MERLIN GERIN .

Example of equipment concerned:

Sepam 2000
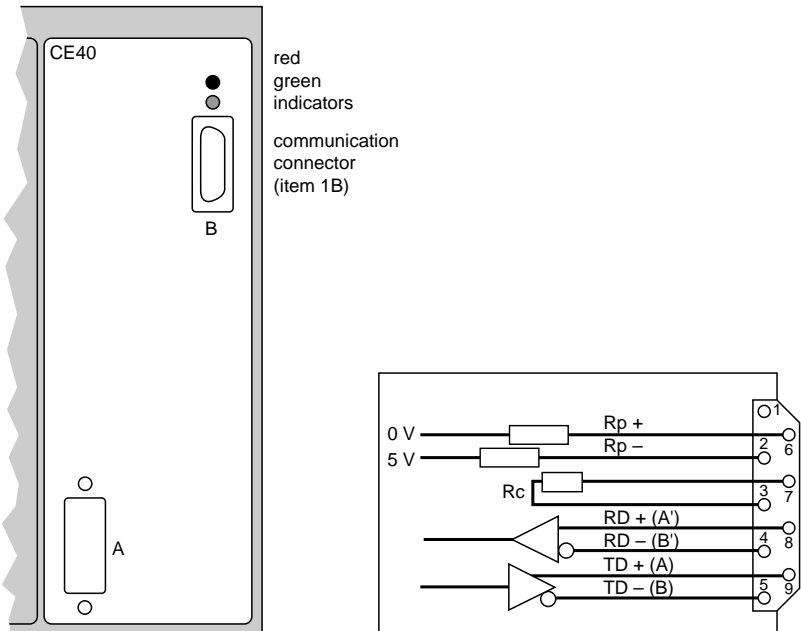
| You wish to connect an equipment item			to a network:		
			recommended module		
function	**type**	**example**	2-wire network	powered 2-wire network	4-wire network
Modbus slave equipment	Sepam 1000 +			ACE 949 and CCA 612 cable	
	powered 2-wire RS 485		CCA 609 and CCA 602 cable	CCA 629 and CCA 602 cable	
	not-powered 2-wire RS 485		CCA 609 and CCA 602 cable	CCA 629 and CCA 602 cable	
	4-wire RS 485	Sepam 2000 DC 150 Vigilohm system			CCA 609 and CCA 602 cable
Modbus master equipment	RS 232		ACE 909-2	ACE 909-2	
	2-wire RS 485		CCA 609 and master cable		
	2-wire RS 485		ACE 919	ACE 919	
	4-wire RS 485		CCA 609 and master cable		CCA 609 and master cable
repeater	2-wire RS 485 / 2-wire RS 485		ACE 919	ACE 919	

Sepam 1000+ communication interface module ACE 949

The network cable connections are made to terminals Ⓐ and Ⓑ situated on the module.

The power supply for the RS 485 communication interfaces (ACE 949 opposite, items V- and V+) is provided via the network cable by a single accessory, ACE 909-2 (or ACE 919) which may be used to connect up to 20 units.

The distributed power supply network is wired using a shielded cable that comprises 2 twisted pairs.

Each module is equipped with a 3 meter long **CCA 612** prefabricated cable connected to the Ⓒ output of Sepam 1000+.
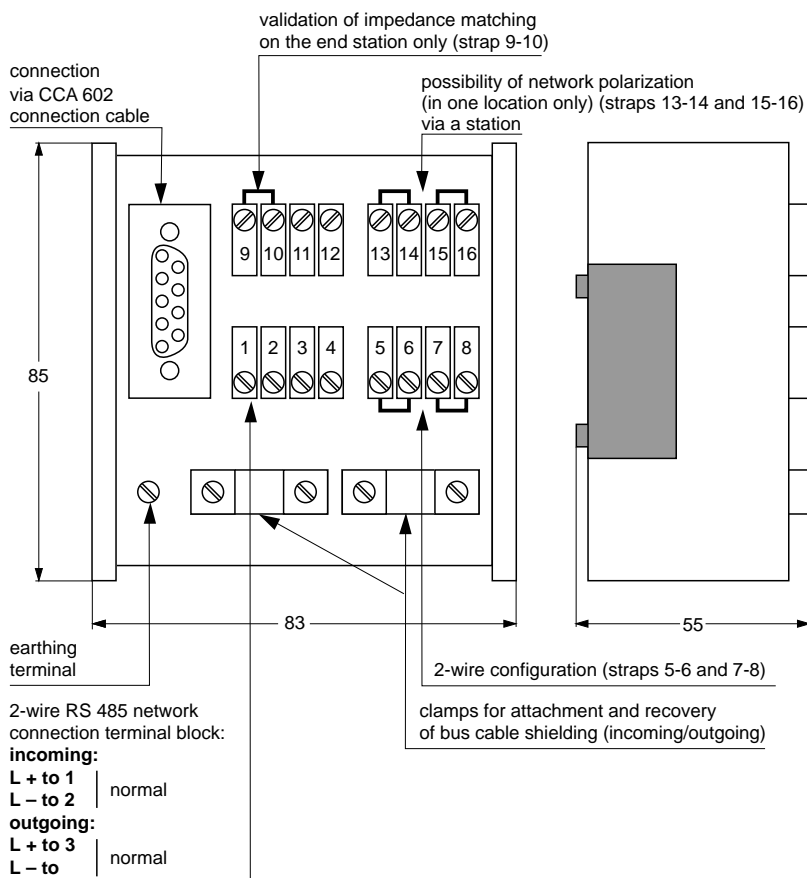

green indicator line activity

Accessories
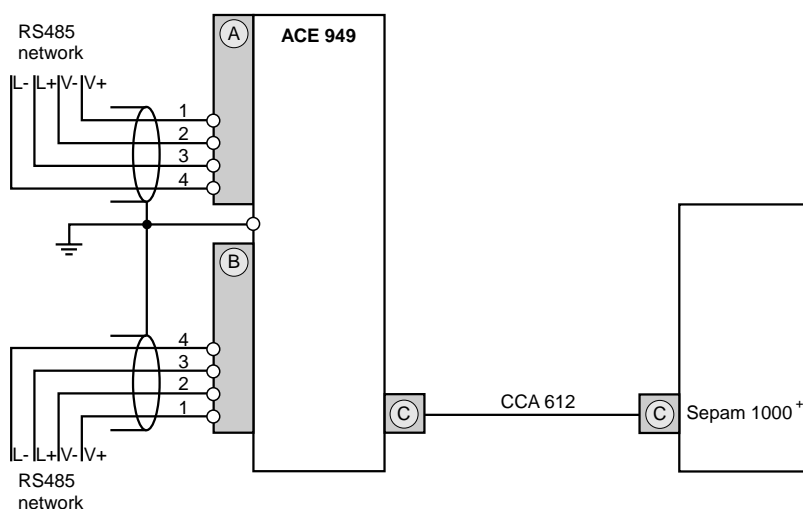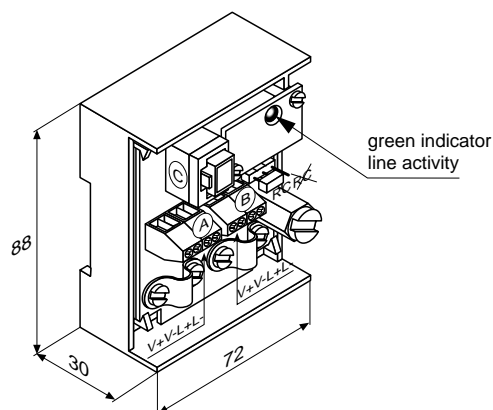
CCA 609 connection box

Each equipment item may be connected to the network cable via a CCA 609 connection box mounted on a DIN rail (symmetrical or asymmetrical). The connection box can be used to tap onto the communication cable.

The CCA 609 box is used for 4-wire topologies and/or in the case of polarization by a Sepam. It is replaced in other cases by the CCA 629 box.

With this type of connection, it is possible to remove a station from the network without leaving any connectors "loose" It also facilitates the connection of new stations at a later date.

■ Mounting on symmetrical or asymmetrical DIN rail,
■ Dimensions: 83 mm (L) x 85 mm (H) " 110 m (D) with CCA 602 connected,
■ Weight: 120 g.

connection via CCA 602 connection cable

validation of impedance matching on the end station only (strap 9-10)

possibility of network polarization (in one location only) (straps 13-14 and 15-16) via a station

85

83

55

earthing terminal

2-wire configuration (straps 5-6 and 7-8)

2-wire RS 485 network connection terminal block:
incoming:
L + to 1
L – to 2 │ normal
outgoing:
L + to 3
L – to │ normal

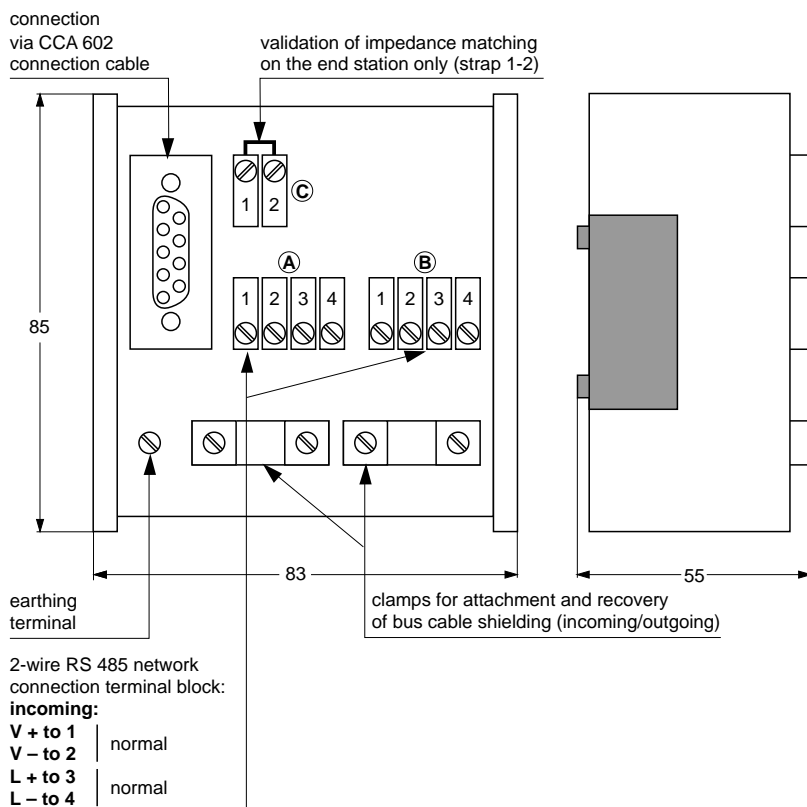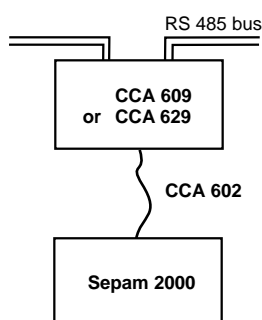clamps for attachment and recovery of bus cable shielding (incoming/outgoing)

CCA 629 connection box 2 wire

Each equipment item may be connected to the network cable via a CCA 629 connection box mounted on a DIN rail (symmetrical or asymmetrical). The connection box can be used to tap onto the communication cable and provides continuity of the distributed power supply.

This box is connected to 2-wire RS 485 networks only.

With this type of connection, it is possible to remove a station from the network without leaving any connectors "loose" It also facilitates the connection of new stations at a later date.

■ Mounting on symmetrical or asymmetrical DIN rail,
■ Dimensions: 83 mm (L) x 85 mm (H) x 110 m (D) with CCA 602 connected,
■ Weight: 120 g.

RS 485 bus

CCA 609
or CCA 629

CCA 602

Sepam 2000

connection via CCA 602 connection cable

validation of impedance matching on the end station only (strap 1-2)

85

83

55

earthing terminal

clamps for attachment and recovery of bus cable shielding (incoming/outgoing)

2-wire RS 485 network connection terminal block:
incoming:
V + to 1
V – to 2 │ normal
L + to 3
L – to 4 │ normal

CCA 600-2
9-pin connectors

The CCA 600-2 accessory may be used to produce cables long enough for customized cabling systems:
■ connection of station to CCA 609,
■ connection of CCA 609 to ACE 909,
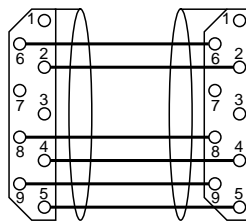■ supplied with the ACE 909-2 / ACE 919.
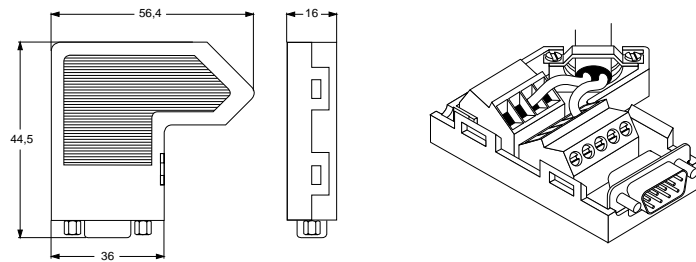
CCA 602 cable

The CCA 602 "cable" accessory is used to create branches of the RS 485 network from the CCA 609 connection box to each equipment item.

It may also be used to connect the ACE 909 converter (master / central computer link).

This accessory comprises a 3-meter cable with a 9-pin sub-D connector with metallic cover at either end.
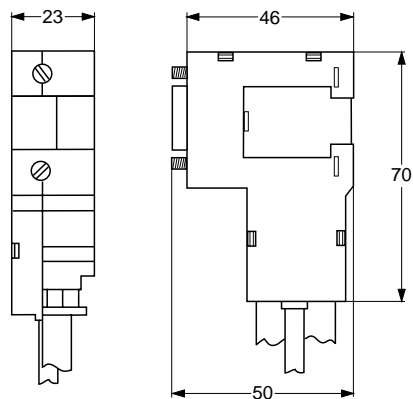
CCA 619 connector 2 wire
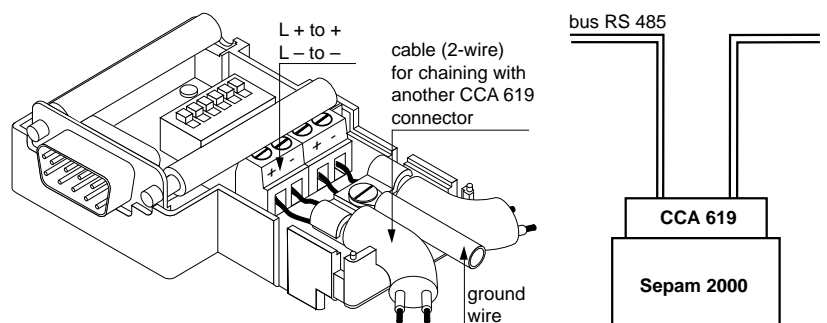## (CCA 629 alternative solution)

Presentation
Each equipment item may be connected directly to the 2-wire RS 485 communication network only, using the CCA 619 connector.
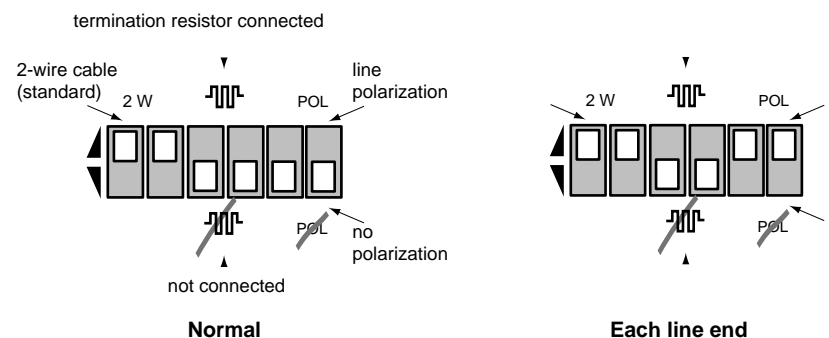■ dimensions: see diagram,
■ weight: 120 g.

Connection of the CCA 619 connector

L + to +
L – to –

cable (2-wire) for chaining with another CCA 619 connector

ground wire

bus RS 485

CCA 619

Sepam 2000

Setting of the configuration microswitches

termination resistor connected

2-wire cable (standard)

line polarization

no polarization

not connected

Normal

Each line end

Converters

ACE 909-2 RS 485 / RS 232 converter

Presentation
The ACE 909 converter may only be used for 2-wire mode operation.

Without requiring any flow control signals, after the parameters are set, the ACE 909-2 performs conversion, polarization and automatic dispatching of Modbus frames between the master and the stations by two-way alternating transmission (half-duplex with single pair).
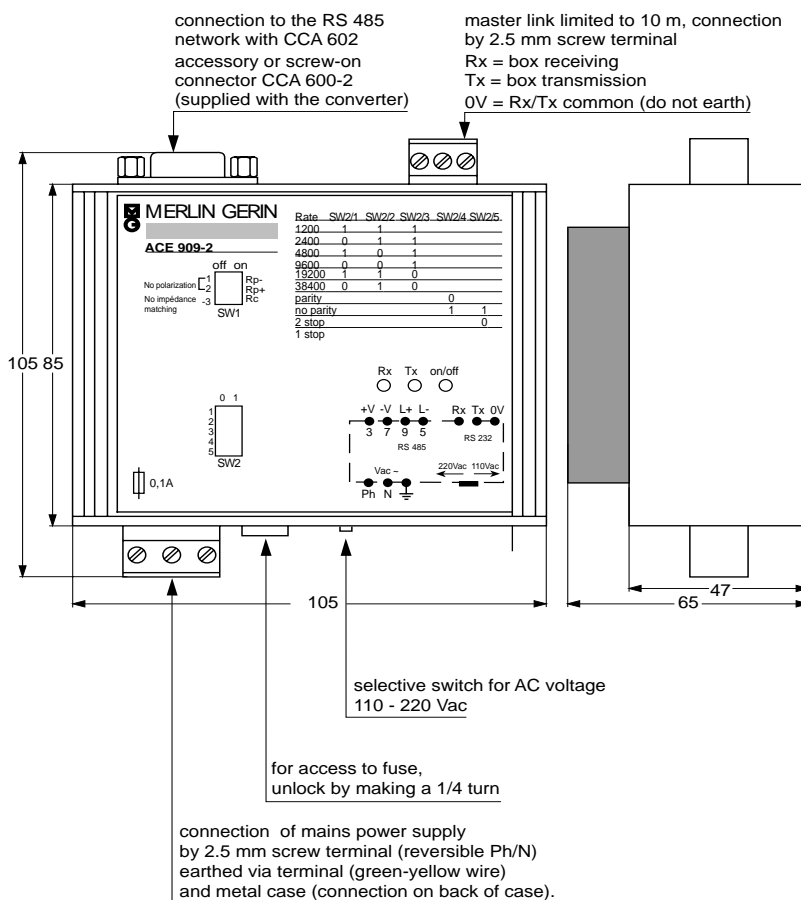
The ACE 909-2 converter also provides a 12 V supply for the distributed power supply of the Sepam 1000[+] ACE 949 interfaces.

At the time of cabling, it is necessary to ensure that the L+ and L- lines are independent or insulated. The setting of the communication parameters should be the same as the setting of the Sepam 1000[+]s and the master communication.

Data displayed on the front of the device
■ On/Off: On (lit) / Off (extinguished),
■ Tx, Rx display of RS 232 transmission and receiving line activity.

Connection

connection to the RS 485 network with CCA 602 accessory or screw-on connector CCA 600-2 (supplied with the converter)

master link limited to 10 m, connection by 2.5 mm screw terminal
Rx = box receiving
Tx = box transmission
0V = Rx/Tx common (do not earth)

Rate	SW2/1	SW2/2	SW2/3	SW2/4	SW2/5
1200	1	1	1		
2400	0	1	1		
4800	1	0	1		
9600	0	0	1		
19200	1	1	0		
38400	0	1	0		
parity				0	
no parity				1	1
2 stop					0
1 stop					

selective switch for AC voltage 110 - 220 Vac

for access to fuse, unlock by making a 1/4 turn

connection of mains power supply by 2.5 mm screw terminal (reversible Ph/N) earthed via terminal (green-yellow wire) and metal case (connection on back of case).

Weight: 460 g
DIN rail mounting

Commissioning

Parameter setting of supply voltage
The 110 Vac/220 Vac supply voltage is changed using a switch which may be accessed on the bottom of the box (fuse end).

Please note:
This operation must be performed before energizing the converter.

Parameter setting of transmission via SW2
Used to set the rate and format of asynchronous transmission.

To change the parameter setting, the box must be de-energized (reset) in order for the new values to be processed.

Parameter setting of line resistors via SW1
The SW1 microswitches are used to activate (or deactivate) the RS 485 network polarization and line impedance matching resistors.

Box configuration when delivered
■ mains power supply 220 Vac.
■ 9600 baud rate, 8-bit format, with parity, 1 stop bit,
■ polarization and line impedance matching resistors activated,

speed	SW2 / 1	SW2 / 2	SW2 / 3
1200	1	1	1
2400	0	1	1
4800	1	0	1
9600	0	0	1
19200	1	1	0
38400	0	1	0
strap	**position**	**function**	
SW2 / 4	0	with parity	
	1	without parity	
SW2 / 5	0	2 stop	
	1	1 stop	

strap	position	function
SW1 / 1	ON	polarization at 0 V via Rp - 470 Ω
SW1 / 2	ON	polarization at 5 V via Rp + 470 Ω
SW1 / 3	ON	150 Ω impedance matching resistor at end of RS 485 bus

Electrical characteristics
■ mains power supply:
110 Vac / 220 Vac, ±10%, 47 to 63 Hz,
■ protection by 0.1 A time-delayed fuse (5 mm x 20 mm),
■ galvanic isolation 2000+ V rms, 50 Hz, 1 mn between:
□ mains input and interface internal power supply outputs,
□ mains input and mechanical frame,
■ galvanic isolation 1000 V rms, 50 Hz, 1 mn between RS 232 and RS 485 interfaces,
■ transmission delay < 100 ns.

Mechanical characteristics
■ mounting on symmetrical/asymmetrical DIN rail,
■ dimensions: 105 mm (L) x 85 mm (H) x 47 mm (D),
■ weight: 460 g,
■ ambient operating temperature: -5 °C to +55 °C.

electromagnetic compatibility	
CEI 60255-5, 1.2 impulse wave / 50 microseconds	1 kV differential mode 3 kV common mode
IEC 60255-22-1, 1 MHz damped oscill. wave	0.5 kV differential mode 1 kV common mode
IEC 60255-22-4, 5 ns fast transients	4 kV with capacitive coupling in common mode 2 kV with direct coupling in common mode 1 kV with direct coupling in differential mode

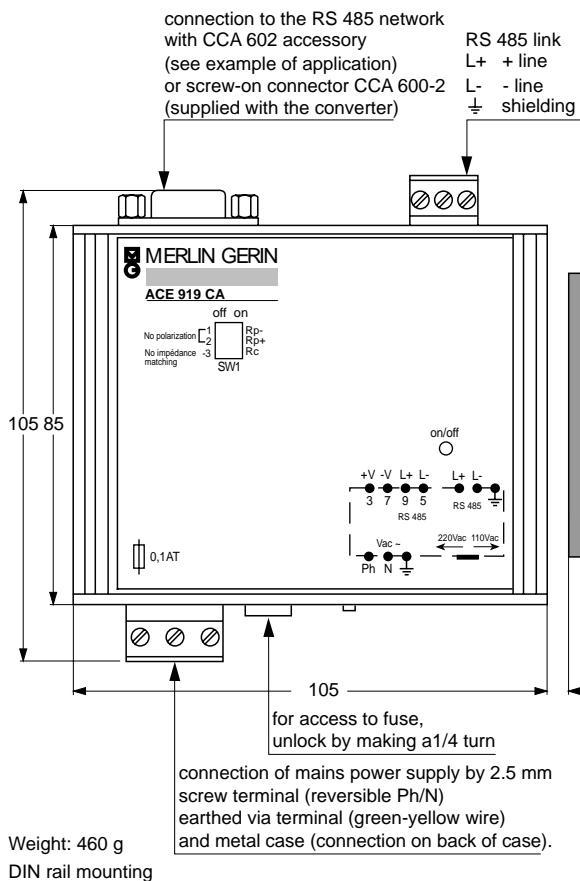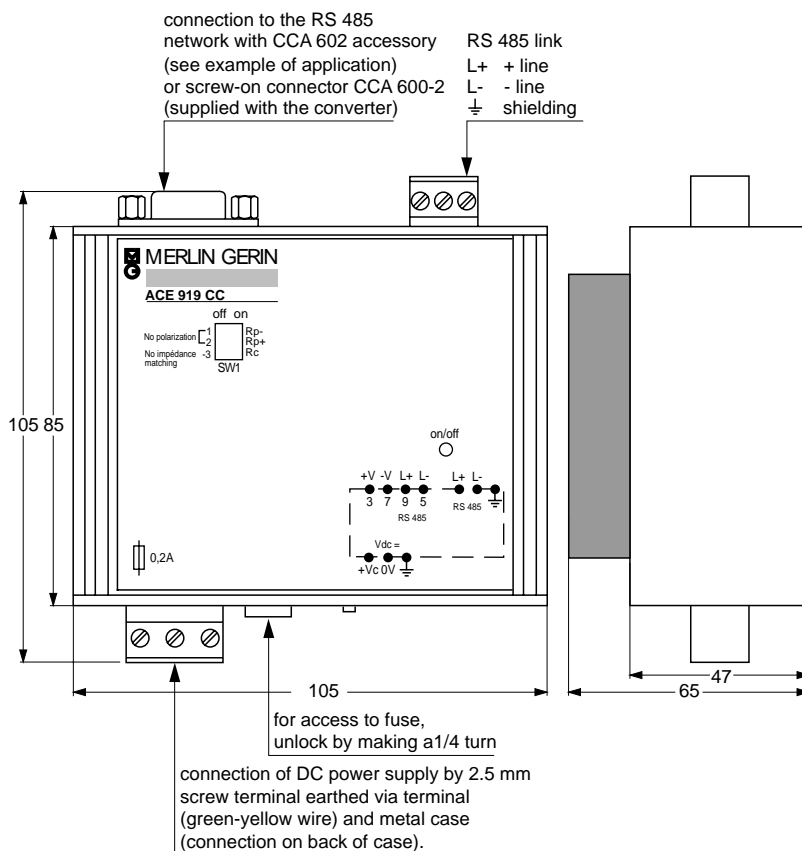## ACE 919 RS 485 / RS 485 converter

Presentation
The ACE 919 converter is used to connect a master / central computer equipped with an RS 485 type serial port as a standard feature to the stations cabled in an RS 485 bus type network, and to adapt the system for operation in 2-wire mode.

Without requiring any flow control signals, the ACE 919 converter performs network polarization. The ACE 919 converter also provides a 12 V supply for the distributed power supply of the Sepam 1000+ ACE 949 interfaces.

Data displayed on the front of the device
■ On/Off: On (lit) / Off (extinguished).

Connection

connection to the RS 485
network with CCA 602 accessory
(see example of application)
or screw-on connector CCA 600-2
(supplied with the converter)

RS 485 link
L+ + line
L- - line
⊥ shielding

MERLIN GERIN
ACE 919 CC

off on
No polarization 1
                 2   Rp-
No impédance   3   Rp+
matching   SW1 Rc

on/off ○

+V -V L+ L-   L+ L-
3   7   9   5   RS 485   ⊥
        RS 485

0,2A

Vdc =
+Vc 0V ⊥

105 85

105

for access to fuse,
unlock by making a1/4 turn

connection of DC power supply by 2.5 mm
screw terminal earthed via terminal
(green-yellow wire) and metal case
(connection on back of case).

47
65

Weight: 460 g
DIN rail mounting

connection to the RS 485 network
with CCA 602 accessory
(see example of application)
or screw-on connector CCA 600-2
(supplied with the converter)

RS 485 link
L+ + line
L- - line
⊥ shielding

MERLIN GERIN
ACE 919 CA

off on
No polarization 1
                 2   Rp-
No impédance   3   Rp+
matching   SW1 Rc

on/off ○

+V -V L+ L-   L+ L-
3   7   9   5   RS 485   ⊥
        RS 485

0,1AT

Vac ~   220Vac 110Vac
Ph N ⊥

105 85

105

for access to fuse,
unlock by making a1/4 turn

connection of mains power supply by 2.5 mm
screw terminal (reversible Ph/N)
earthed via terminal (green-yellow wire)
and metal case (connection on back of case).

47
65

Weight: 460 g
DIN rail mounting

Commissioning

AC or DC power supply
ACE 919   DC   24-48 Vdc,
ACE 919   AC   110-220 Vac.

Parameter setting of supply voltage
For ACE 919 CA the 110 Vac/220 Vac supply voltage
is changed using a switch which may be accessed
on the bottom of the box (fuse end).

Please note:
This operation must be performed before energizing
the converter.

Parameter setting of line resistors via SW1
The SW1 microswitches are used to activate
(or deactivate) the RS 485 network polarization
and line impedance matching resistors.

Box configuration when delivered
■ mains power supply 220 Vac or 48 Vdc.
■ 9600 baud rate, 8-bit format, with parity, 1 stop bit,

strap	position	function
SW1 / 1	ON	polarization at 0V via Rp - 470 Ω
SW1 / 2	ON	polarization at 5V via Rp + 470 Ω
SW1 / 3	ON	150 Ω impedance matching resistor at end of RS 485 bus

Electrical characteristics
■ mains power supply:
110 Vac / 220 Vac $\pm$ 10%, 47 to 63 Hz,
■ protection by 0.1 A time-delayed fuse
(5 mm x 20 mm),
■ galvanic isolation 2000+ V rms, 50 Hz,
1 mn between:
□ mains input and interface internal power supply
outputs,
□ mains input and mechanical frame,

DC power supply
■ 24 / 48 Vdc $\pm$ 20%

Mechanical characteristics
■ mounting on symmetrical/asymmetrical DIN rail,
■ dimensions: 105 mm (L) x 85 mm (H) x 47 mm (D),
■ weight: about 400 g,
■ ambient operating temperature: -5 °C to +55 °C.

electromagnetic compatibility	
IEC 60255-5, 1.2 impulse wave / 50 microseconds	1 kV differential mode 3 kV common mode
IEC 60255-22-1, 1 MHz damped oscill. wave	0.5 kV differential mode 1 kV common mode
IEC 60255-22-4, 5 ns fast transients	4 kV with capacitive coupling in common mode 2 kV with direct coupling in common mode 1 kV with direct coupling in differential mode

Wiring and commissioning

RS 485 network cable

The characteristics of the cable recommended for connecting the CCA… type connection boxes or ACE type RS 485 interfaces are as follows:
■ twisted pair with tinned copper braid shielding, coverage: > 65%,
■ characteristic impedance: 120 Ω,
■ gauge: AWG 24,
■ resistance per unit length: < 100 Ω / km,
■ capacitance between conductors: < 60 pF / m,
■ conductor and shielding: < 100 pF / m.

The total network cable length should not be greater than **1300 meters** except limitation due to distributed power supply.

Examples of compatible cables:
■ supplier: BELDEN, reference: 9841 (1 pair) or 9842 (2 pairs),
■ supplier: FILOTEX, reference: FMA-2PS.

Wiring precautions

For the sake of both the safety of people and efficient combating against the effects of interference, the cabling of systems which comprise digital links must comply with a set of basic rules aimed at establishing an equipotential-bonded, meshed and earthed network.

Special care must be taken when making connections between buildings with earthing that is not interconnected.
For details and useful recommendations, please refer to the Telemecanique document TSX DG GND F entitled "Grounding cabling guide".

All the accessories make it possible to ensure the continuity of the cable shielding and regular grounding.

It is therefore necessary to ensure that:
■ the 2 connectors at the ends of the CCA 602 branching cable are plugged in correctly and locked by the 2 screws specially provided,
■ the clamps are tightened onto the metallic shielding braid on each CCA 609, CCA 619, CCA 629 and ACE 949 connection box,
■ each CCA connection box is grounded (earthed) by a 2.5 mm² diameter green-yellow wire or a short braid (< 10 cm) via the terminal specially provided,
■ the metal case of the ACE 909 or ACE 919 converter is grounded (earthed) by a green-yellow mains power supply connector wire and an eye lug on the back of the case.

Connection of "master" station

ACE 909-2 or ACE 919 converters

In the wiring examples shown, the master is situated at the end of the network, which is generally the case.

With a master situated in the middle of the network, it is necessary to remove the impedance matching resistors from the master stations and install them at the end of the line.

Modicon BM 85 in RS 485

BM85	R/D	A	3	to L+
	R/T	B	2	to L-
	Gnd		1	
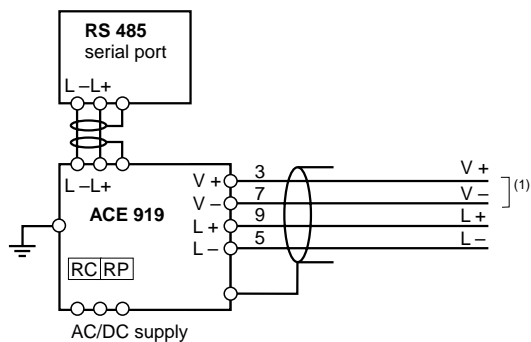
Modicon BM 85 in RS 2432

BM85	RxD	2	to Tx	4-6 strap
	TxD	3	to Rx	7-8
	GND	5	to 0V	
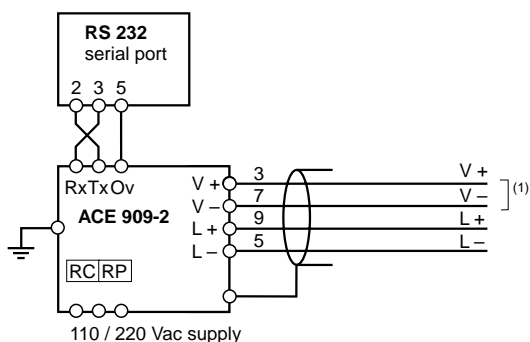
APPLICOM board in RS 485

BX4010	RC	4	to L+
	T-	3	to L+
	T+	2	to L-
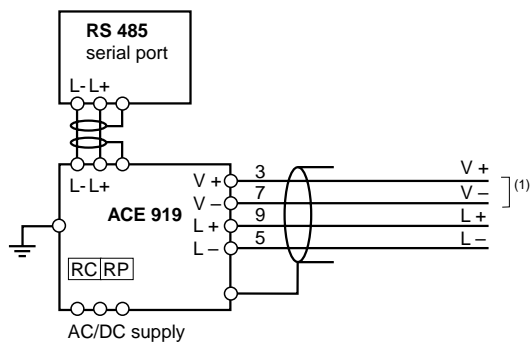
RC impedance matching resistor to be installed if at end of line
RP polarization of deactivated line

(1) distributed power supply output to be used for the connection of Sepam 1000+.

Connection of "slave" stations 2 wire RS 485

Master station in RS 232
with ACE 909-2

CCA 629 and CCA 629

MERLIN GERIN

CCA 602 | CCA 602 | CCA 602

RS 232
serial port
2 3 5

RxTxOv
V + 3
V − 7
L + 9
L − 5
ACE 909-2

RC RP

110 / 220 Vac supply

1 2 | CCA 629 | 4 3 2 1
1 2 3 4

1 2 | CCA 629 | 4 3 2 81
1 2 3 4

(1)
1 2 | CCA 629 | 4 3 2 1
1 2 3 4

L + / L −

(1) strap 1-2 impedance
matching resistor at end of line

CCA 609 and CCA 602

MERLIN GERIN

CCA 602 | CCA 602 | CCA 602

RS 232
serial port
2 3 5

RxTxOv
V + 3
V − 7
L + 9
L − 5
ACE 909-2

RC RP

110 / 220 Vac supply

9 10 11 12   13 14 15 16 | CCA 609
1 2 3 4   5 6 7 8

(1) 2-wire configuration strap 5-6 and 7-8

(2) strap 9-10 impedance
matching resistor at end of line

CCA 619

RS 232
serial port
2 3 5

RxTxOv
V + 3
V − 7
L + 9
L − 5
ACE 909-2

RC RP

110 / 220 Vac supply

MERLIN GERIN

CCA 619 | CCA 619 | CCA 619 | CCA 619
+ − + − | + − + − | + − + − | + − + −

L + / L −

2 W   POL

2 W   POL

Master station in RS 232
with ACE 909

CCA 602 and CCA 629

assembly to be installed for EMC
protection of master
(CCA 609 or CCA 629) interface

(1) strap 1-2 impedance
matching resistor at end of line

CCA 602 and CCA 609

assembly to be installed
for EMC protection of master
(CCA 609 or CCA 629)
interface

(1) 2-wire configuration strap 5-6 and 7-8

(2) strap 9-10 impedance
matching resistor at end of line

CCA 619

assembly to be installed for EMC
protection of master
(CCA 609 or CCA 629) interface

Connection of "slave" stations 2 wire RS 485 (cont'd)

Master station in RS 485 without converter

CCA 602 and CCA 629

assembly to be installed for EMC protection of master (CCA 609 or CCA 629) interface

(1) strap 9-10 impedance matching resistor at end of line

CCA 602 and CCA 609

assembly to be installed for EMC protection of master (CCA 609 or CCA 629) interface

(1) 2-wire configuration strap 5-6 and 7-8

(2) strap 9-10 impedance matching resistor at end of line

CCA 619

assembly to be installed for EMC protection of master (CCA 609 or CCA 629) interface

Connection of "slave" stations Sepam 1000+
2 wire RS 485

**Sepam 1000+ needs distributed power supply
for ACE 949 interface**

Master station in RS 232
with ACE 909-2

RC impedance matching resistor to be installed if at end of line

RP polarization of deactivated line
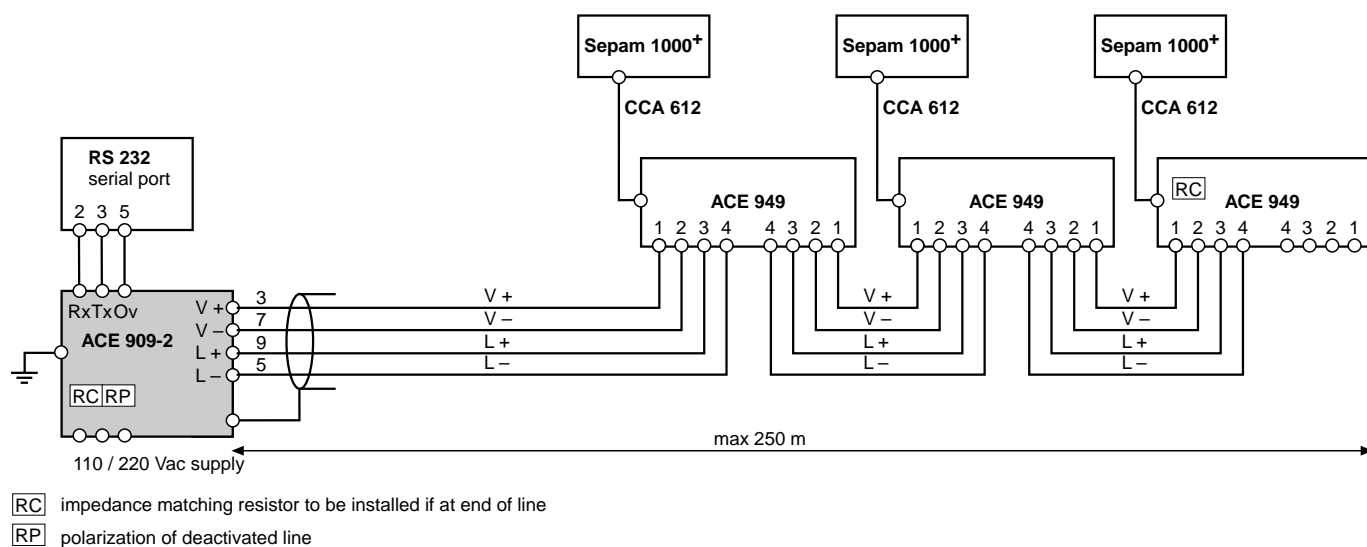
Master station in RS 485
with ACE 919

RC impedance matching resistor to be installed if at end of line

RP polarization of deactivated line
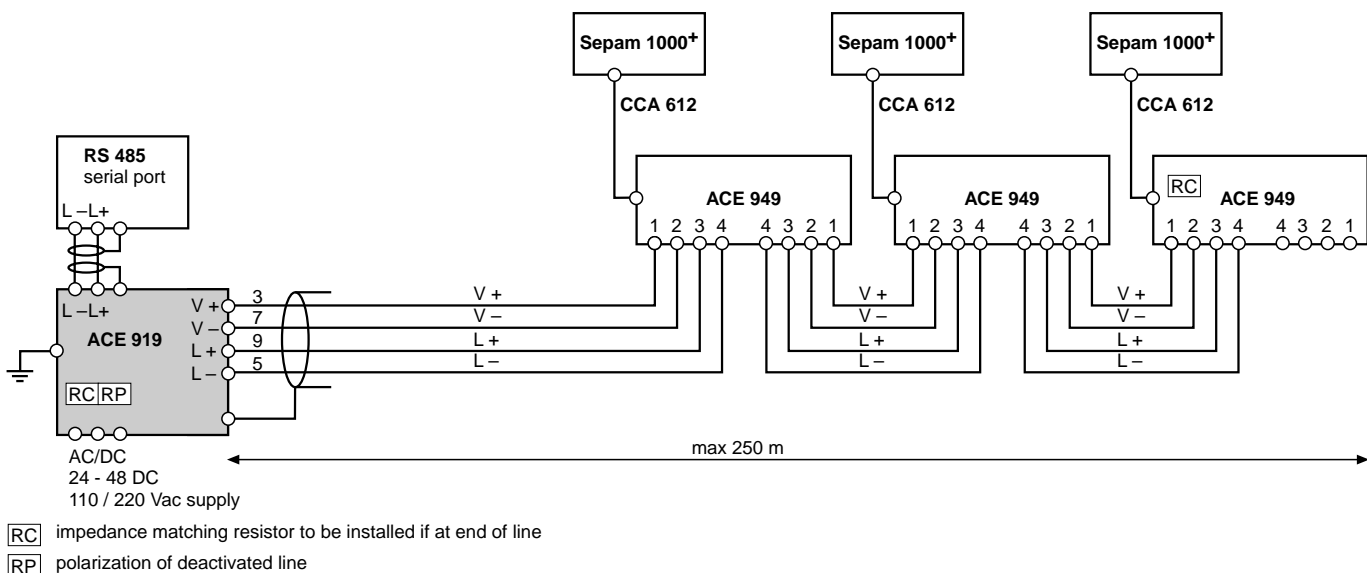
Connection of "slave" stations 2 wire RS 485
with Sepam 1000⁺

**Sepam 1000⁺ needs distributed power supply
for ACE 949 interface**

Master station in RS 232
with ACE 909-2

Extension of an existing network with CCA 629
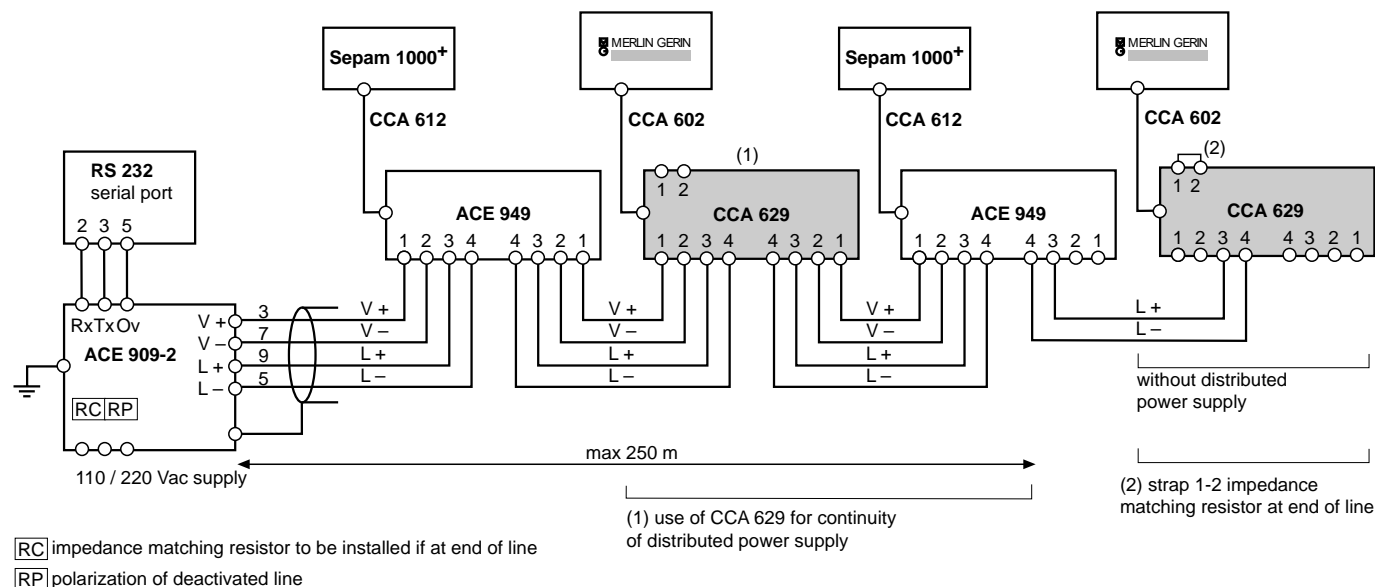
max 250 m

(1) use of CCA 629 for continuity
of distributed power supply

without distributed
power supply

(2) strap 1-2 impedance
matching resistor at end of line

110 / 220 Vac supply

RC impedance matching resistor to be installed if at end of line

RP polarization of deactivated line

Extension of an existing network with CCA 609

max 250 m

(1) use of CCA 629 for continuity
of distributed power supply

without distributed
power supply

(2) strap 9-10 impedance
matching resistor at end of line
(3) strap 5-6 and 7-8
for 2-wire RS 485

110 / 220 Vac supply
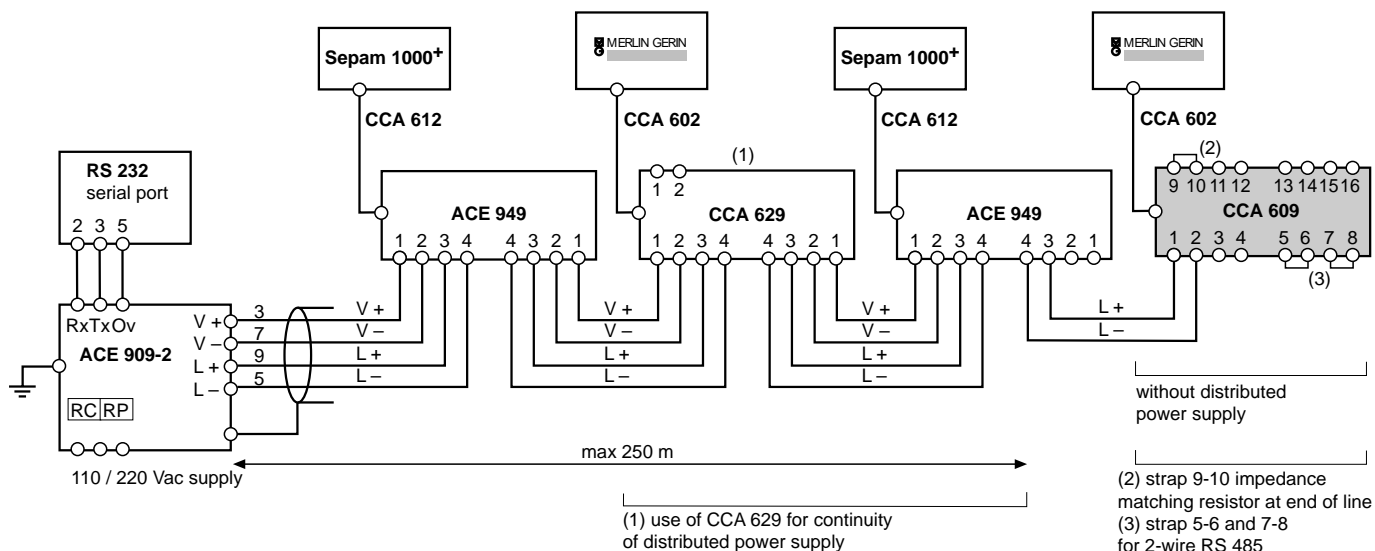
RC impedance matching resistor to be installed if at end of line

RP polarization of deactivated line

Master station in RS 232 with ACE 919

Extension of an existing network with CCA 629

without distributed power supply

(2) strap 1-2 impedance matching resistor at end of line

(1) use of CCA 629 for continuity of distributed power supply

max 250 m

RC impedance matching resistor to be installed if at end of line

RP polarization of deactivated line

Extension of an existing network with CCA 609

without distributed power supply

(2) strap 9-10 impedance matching resistor at end of line

(3) strap 5-6 and 7-8 for 2-wire RS 485

(1) use of CCA 629 for continuity of distributed power supply

max 250 m

RC résistance d'adaptation en extrémité de ligne

RP polarisation de la ligne au repos

Connection of "slave" stations
4 wire RS 485

Master station at one end of line

polarization of lines,
load resistors at end of lines,
transmission (optional), receiving
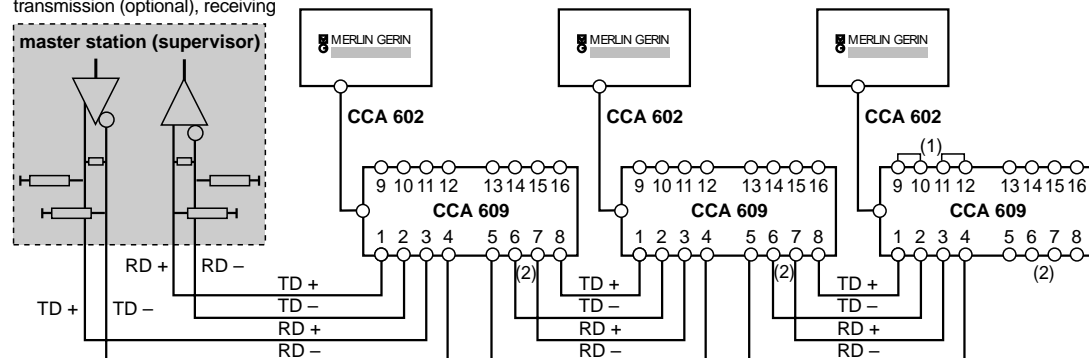
(1) strap 9-10 and 11-12 impedance matching resistor at end of both lines
(2) removal of strap 5-6 and 7-8 in 2-wire mode

Master station at the middle of line

polarization of lines,
transmission (optional),
receiving

TD +	8
TD −	4
RD +	9
RD −	5

(*) pins on CCA 609 9-pin
Sub-D connector
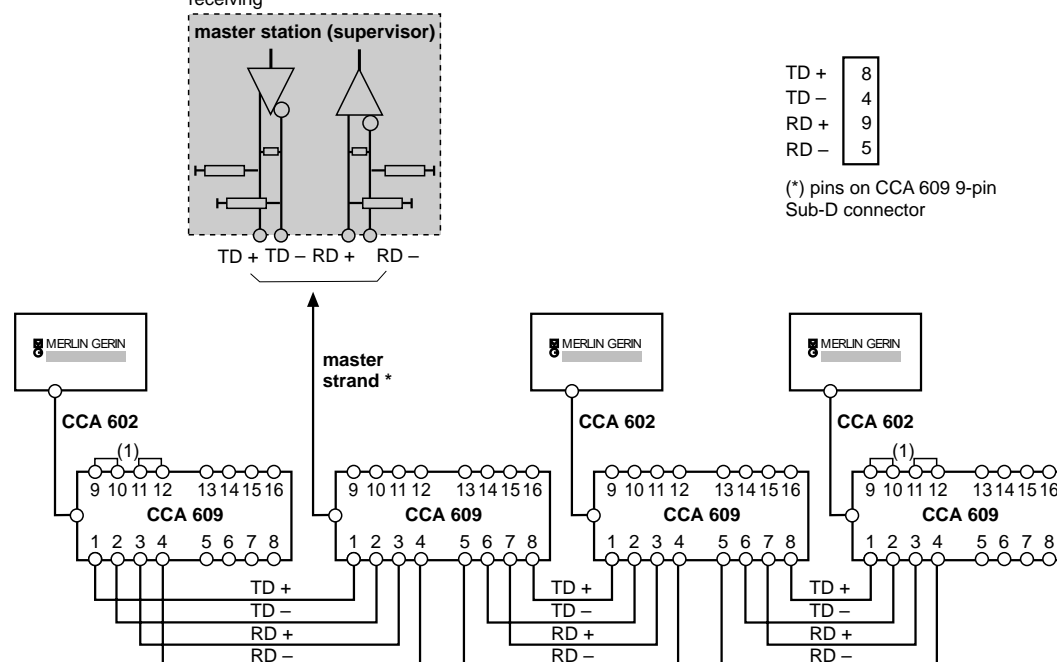
(1) strap 9-10 and 11-12 impedance matching resistor at end of both lines

Extension of the RS 485 network with ACE 919
in case of distributed power supply
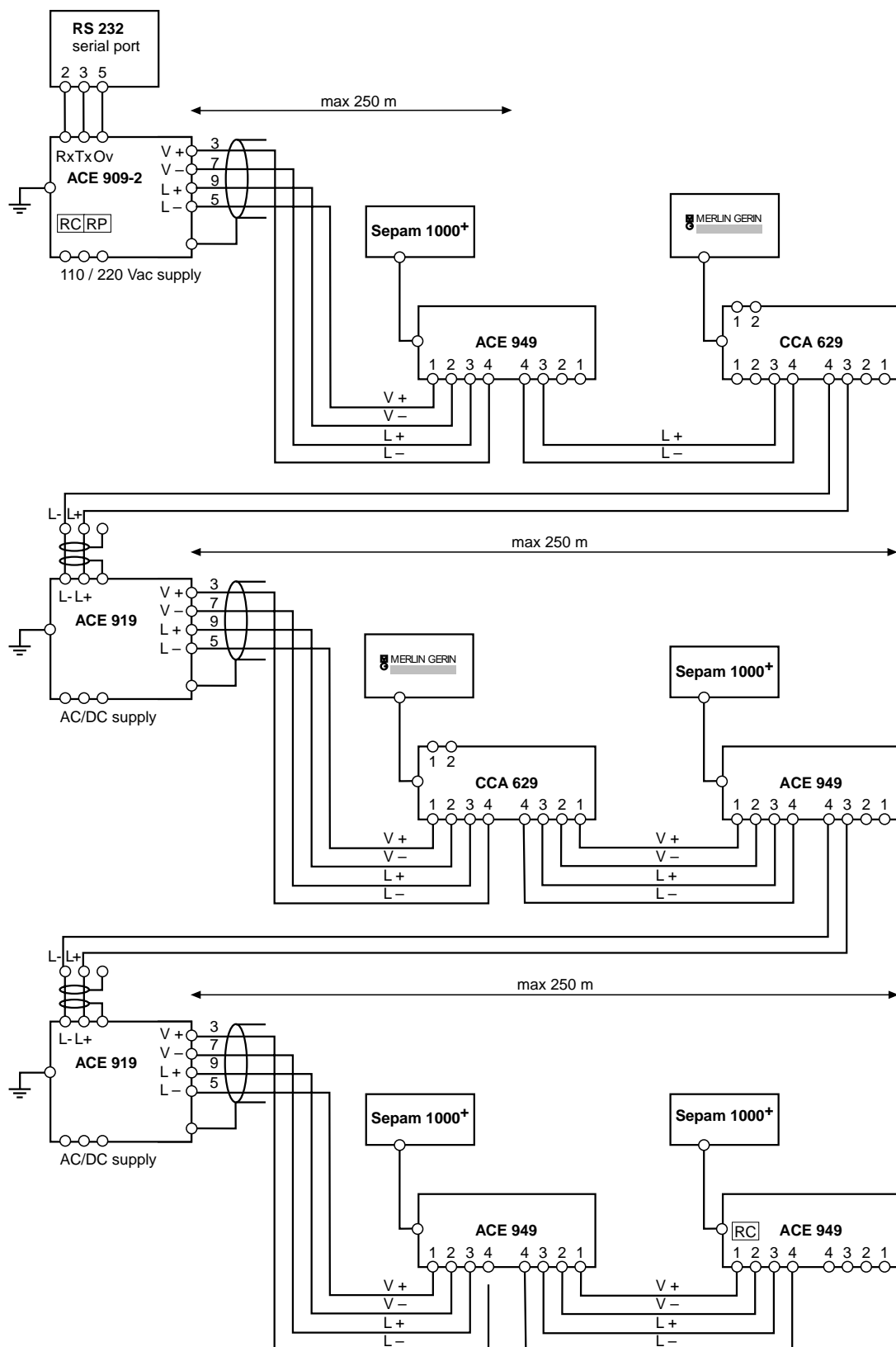
RC RC load impedance matching resistor to be installed if at end or beginning of line
RP RP polarization of deactivated line

Setting of communication parameters

Before Modbus communication equipment is put into service, parameters need to be set.

selection	
transmission rate adjustable from 300 to 38,400 bauds	on converters on equipment
slave n° assigned adjustable from 1 to 255	to equipment
parity: no parity, even parity, odd parity	on converters on equipment
line polarization	1 location only (master)
line impedance matching	at end of line on converters on equipment

Troubleshooting

Operating problems

In case of problems, it is advisable to connect the devices to the RS 485 network one by one.

The green lamp indicates that there is traffic on the line.

Make sure that the master sends frames to the equipment concerned
and to the RS 232 – RS 485 / RS 485 – RS 485 converter, if there is one.

Points to be checked
Check:
■ the wiring to the CCA 612 connectors, the CCA 602 branching cables
and the RS 485 network cable,
■ the wiring of the ACE convecters,
■ the wiring to each ECA 609 / CCA 629 / CCA 619 connection box,
■ the wiring of the ACE 949 interface,
■ the distributed voltage V+, V- (12 V),
■ the polarization is in one location only,
■ the impedance matching is set up at the ends and only at the ends
of the RS 485 network,
■ the cable used is the one advised,
■ the ACE converters used are correctly connected and parameterized,
■ the L+ or L- lines are not earthed,
■ the earthing of all the cable shielding,
■ the earthing of all the converters, interfaces and connection boxes.

Use an oscilloscope to check the forum of the signals:
■ transmit voltage
□ level 0   +1.5 V   to   +5 V
□ level 1   -1.5 V   to   -5 V
■ reception voltage threshold
□ level 0   > +0.2 V
□ level 1   < -0.2 V

Protection
and control

Sepam range
Sepam 2000
Sepam 1000
Diagnosis guide

Merlin Gerin
Modicon
Square D
Telemecanique

Schneider Electric

Sepam 2000 diagnosis guide

Contents

■ the **symptoms** column describes the fault observed, together with the possible consequences.
■ the **possible causes** column describes what could have caused the fault.
■ the **remedies** column describes the tests to be performed or operations to be carried out to correct the situation (they are not necessarily given opposite the causes discussed).

All indicators off

Symptoms	Possibles causes	Remedies
■ all the indicators and the display unit are off, ■ the TSM 2001 terminal is not communicating, the screen is blank.	■ the Sepam 2000 is not being supplied with power, ■ the device has been switched on rapidly several times in a row, causing internal tripping of the CE40 power supply.	■ check the voltage on the power supply connector, ■ disconnect the power supply for a few minutes, ■ if the fault persists, change the Sepam 2000 power supply board. The CE40 board is fitted with an internal fuse; never replace it (since other power supply components are damaged when the fuse blows).

"maintenance" message and red indicator on

Symptoms	Possible causes	Remedies
■ Sepam displays the **maintenance** message, ■ the red ⬦ indicator is on, ■ the TSM 2001 pocket terminal is not operational, ■ the Sepam 2000 is not working; the watchdog has dropped out.	**The parameters have been altered.** There may be several causes for the alteration: ■ the memory cartridge has been inadvertently plugged in or pulled with the power on. ■ Sepam 2000 self-testing has detected an internal fault which prevents it fromcarrying out its functions.	■ replace the customer cartridge by the TSM 2005 final testing cartridge and read the internal fault using the TSM 2001 (see TSM 2005 manual, chapter on reading internal faults). **without the TSM 2005** ■ to locate the fault, replace the cartridge by another one (made for use in the same model). If the fault disappears, it came from the cartridge: reprogram it with **LOGIPAM** using the **reprogram settings** option, ■ if necessary, replace the faulty cartridge, ■ if the fault persists, replace the power supply card, ■ if the fault persists, replace Sepam 2000.

> Before re-energizing the Sepam, check the complete parameter setting of the Sepam:
> ■ status,
> ■ protection settings,
> ■ control logic parameters: bistables, time delays...

"maintenance" message and red indicator off

Symptoms	Possible causes	Remedies
■ Sepam displays the **maintenance** message, ■ the red ⬦ indicator is off, ■ the TSM 2001 pocket terminal is operational, ■ Sepam 2000 is working, ■ the **maintenance** message disappears when a key on the front of the device is pressed, but comes back again after a few seconds.	■ the microswitches are in a prohibited setting, ■ Sepam 2000 internal self-testing has detected an internal fault which does not prevent Sepam 2000 from momentarily performing its functions.	■ check the setting of the microswitches on the ECM (or ECA) and 3U+Vo boards (**installation** manual), ■ for S25 and S35 Sepam, an error code can be read with the pocket terminal in the **About Sepam** menu, SFT 2800 heading; it appears in line 4 of the screen, on the right : □ code 0400: change the ECM (ECA) board (slot 2), □ code 1000: change the 3U+Vo board, □ code 0800: change the additional ECM (ECA) board (slot 3), □ codes 2000, 8000: change the RTD boards, □ other codes or if the fault persists: replace Sepam 2000. **With TSM 2005** ■ replace the customer cartridge by the TSM 2005 final testing cartridge and read the internal fault using the TSM 2001 (see TSM 2005 manual, chapter on reading internal faults).

Sepam 2000 diagnosis guide

"CARTRIDGE" message

Symptoms	Possible causes	Remedies
■ Sepam displays the **cartridge** message, ■ the red ⚲ indicator is on. ■ the TSM 2001 pocket terminal is not working, ■ Sepam 2000 is not working; the watchdog relay has dropped out.	■ the cartridge does not match the Sepam model, ■ boards needed for Sepam 2000 operation are missing, ■ the boards have been switched around, ■ 2 different ECM boards are pluged in Sepam.	■ ensure that the cartridge has not been mixed up with another Sepam 2000 cartridge, ■ check the number of ESTOR I/O boards. It should be greater than or equal to the number of boards needed for the control logic program, ■ check that the cartridge is installed in the correct model of Sepam: the Sepam model in which the cartridge should be inserted appears in line 1 of the label on the front of the cartridge. **Example** : a cartridge labeled **S25 LX M01** should be inserted in a model **2025 LX** Sepam, ■ the Sepam model appears in the label stuck to its side. Check that the boards present in the rear compartment of that model comply with the **board position table** in the appendix, ■ check that ECM boards have the same sérial number (03143179 or 3122288). **With TSM 2005** ■ replace the customer cartridge by the TSM 2005 final testing cartridge and read the internal fault using the TSM 2001 (see TSM 2005 manual, chapter on reading internal faults).

"M.CARTRIDGE" message and red indicator on

Symptoms	Possible causes	Remedies
■ Sepam displays the **M.CARTRIDGE** message, ■ the red ⚲ indicator is off, ■ the TSM 2001 pocket terminal is not working, ■ the Sepam 2000 is not working; the watchdog has dropped out.	■ cartridge memory fault, with possible altered parameters.	■ replace the cartridge. Before re-energizing the Sepam, check the complete parameter setting of the Sepam: ■ status, ■ protection settings, ■ control logic parameters: bistables, time delays...

"M.CARTRIDGE" message and red indicator off

Symptoms	Possible causes	Remedies
■ Sepam displays the **M.CARTRIDGE** message, ■ the red ⚲ indicator is off, ■ the TSM 2001 pocket terminal is working, ■ the Sepam 2000 is working, ■ the **M.CARTRIDGE** message disappears when a key on the front of the device is pressed, but comes backagain after a few seconds.	■ incorrect status setting, ■ the maximum number of cartridge memory entries has been reached	■ check whether the **STATUS** menu parameters are blinking. Blinking parameters should be reprogrammed, ■ for S25 and S35 Sepam, an error code is read using the pocket terminal in the **About Sepam** menu, item SFT 2800; it appears in line 4 of the screen, on the right: ▫ code 0040 : replace the cartridge.

Everything off except for green and red indicators

Symptoms	Possibles causes	Remedies
■ the green **on** indicator is on, ■ the red ↘ inidicator is off, ■ the TSM 2001 pocket terminal is not communicating, its screen is blank, ■ the 3 indicators **I on, O off, trip** and the display unit are off, ■ the blinking cursor is displayed on the TSM 2001 pocket terminal but the terminal is not working.	■ the cartridge is missing, ■ there may be a programming fault in the cartridge, ■ the control logic part is not programmed, ■ power supply board fault.	■ check for the cartridge behind the shutter, ■ replace the cartridge by a cartridge that is presumed to be a good one (intended for the same model of Sepam 2000). If the fault disappears, the fault came from the cartridge: replace or reprogram it, ■ if the fault persists, change the Sepam 2000 power supply board, ■ if the fault persists, change Sepam 2000.

Display of dashs

Symptoms	Possible causes	Remedies
■ a line of dashs is displayed: **--------------,** ■ this message may appear in normal operating conditions.	■ pressing a key on the front which is not used (e.g. V/Hz key on a Sepam which does not contain voltage measurement functions), ■ pressing the **alarm** key (to display the stored messages) when no messages have been stored, ■ when stored messages are being read (after the user has pressed the **alarm** key), the dashs appear to indicate the end of the list of messages (they appear after the oldest message).	■ none. This is not a fault.

The TSM 2001 display is blank

Symptoms	Possible causes	Remedies
■ the TSM 2001 pocket terminal screen is dark, or blank except for the blinking cursor, ■ the green **on** indicator is on, ■ lthe red ↘ indicator is off, ■ the Sepam 2000 display unit is working and the keys on the front are operational.	■ the TSM 2001 pocket terminal display unit contrast adjustment has been modified, ■ the pocket terminal is out of order.	■ turn the dial on the right-hand side of the TSM 2001 pocket terminal, ■ test the pocket terminal on another Sepam 2000 to determine whether the fault comes from the terminal or Sepam 2000. If the fault is located in Sepam 2000, replace it.

Sepam 2000 diagnosis guide (cont'd)

The current measurements are false

Symptoms	Possible causes	Remedies
■ the difference between the expected measurement and the measurement indicated by Sepam 2000 may be between 10% and 500%, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ the microswitches on the back of the ECM (or ECA) board are not set correctly, ■ one of the parameters in the **status** menu is not set correctly.	■ check the setting of the microswitches on the ECM (or ECA) board; refer to **installation** manual, ■ check that the In setting (**status** menu, **phase CT** heading) matches the rating of the CTs or CSP sensors being used; refer to **use/commissioning** manual, ■ check that the network frequency has been selected correctly (50 or 60 Hz, **status** menu). **With TSM 2005** ■ use the TSM 2005 to test the ECM or ECA current boards (see TSM 2005 manual, chapter on testing ECM or ECA boards).

The residual current measurement is false

Symptoms	Possible causes	Remedies
■ reading < 50% of injected current.	■the core balance CT is not compatible.	■ replace the core balance CT by a CSH, ■ check that the core balance CT is wired to the core balance CT input and not to the CT input.

I2 current measurement does not appear

Symptoms	Possible causes	Remedies
■ the I2 measurement is missing. It does not appear on the display or on the TSM 2001 pocket terminal, ■ the phase 1 and 3 currents are correct.	■ the number of phase CTs selected in the **status** menu is 2 instead of 3. If this is the case, Sepam is unaware of the presence of the phase 2 CT.	■ check the number of CTs indicated in the **status** menu, phase CT heading. Set it to 3.

One of the 3 phase current measurements is zero

Symptoms	Possible causes	Remedies
■ one of the measurements indicates a value of zero or close to zero, ■ the other 2 phase current measurements are working normally. The indications are the same on the display and on the TSM 2001 pocket terminal, ■ the green **on** indicator is on ■ the red ↘ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ there are only 2 CTs in the cubicle, ■ one CT is not wired, ■ the ECM (or ECA) current input board is faulty, ■ the current measured is less than 1.5% of In.	■ Sepam connected to a 1A/5A CT: ensure that there is current in the CT secondary circuit which reaches the CCA 660 or CCA 650 connector, ■ replace the ECM board, ■ Sepam connected to a CSP sensor: momentarily reverse the connections (BNC connector) on the ECA board: if the fault disappears, the problem is an external one; if the fault persists, replace the ECA board. **With TSM 2005** ■ use the TSM 2005 to test the ECM or ECA current boards (see TSM 2005 manual, chapter on testing ECM or ECA boards).

The voltage measurements are false

Symptoms	Possible causes	Remedies
■ the difference between the expected measurement and the measurement indicated by Sepam 2000 may be between 10% and 500%, ■ the protections do not trip at the expected setting, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ the microswitches on the back of the 3U+Vo board are not set correctly, ■ one of the parameters in the **status** menu is not set correctly.	■ check the setting of the microswitches on the 3U+Vo board; refer to **installation** manual, ■ check that the Unp and Uns settings (**status** menu, **phase VT** heading) match the VTs being used; refer to **use/ commissioning** manual, ■ check that the network frequency has been selected correctly (50 or 60 Hz, **status** menu). **With TSM 2005** ■ use the TSM 2005 to test the 3U+Vo boards (see TSM 2005 manual, chapter on testing 3U+Vo boards).

One or two phase voltage measurements do not appear

Symptoms	Possible causes	Remedies
■ the U13 (and U32) measurement is missing. It does not appear on the display or on the TSM 2001 pocket terminal, ■ the other voltages are correct.	■ the phase VTs selected in the **status** menu are U21(and U32). If this is the case, Sepam is unaware of the presence of the other VTs.	■ check the number of VTs indicated in the **status** menu, phase VT heading. Set it to 3.

A voltage measurement is zero

Symptoms	Possible causes	Remedies
■ one of the phase-to-phase voltage measurements indicates a value of zero or close to zero. The indications are the same on the display and on the TSM 2001 pocket terminal, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ there are only one or two VTs in the cubicle, ■ the 3U+Vo voltage input board is faulty, ■ the voltage measured is less than 1.5% of Un.	■ ensure that the wiring to Sepam 2000 is correct, ■ replace the 3u+Vo board. **With TSM 2005** ■ use the TSM 2005 to test the 3U+Vo voltage boards (see TSM 2005 manual, chapter on testing 3U+Vo voltage boards).

Sepam 2000 diagnosis guide (cont'd)

The power measurements and accumulated energy readings are false

Symptoms	Possible causes	Remedies
■ the power indicated may be totally false or almost zero, ■ the power factor indicated may be a deviant value, ■ otherwise, the current and voltage measurements are correct.	■ inversion of CT wiring to Sepam 2000 current inputs if the frequency is correct, ■ inversion of VT cabling to Sepam voltage inputs if the frequency is displayed by dashs.	■ check the wiring. Comply with the given order of phases.

The current measurement is zero and the accumulated energy increments

Symptoms	Possible causes	Remedies
■ the accumulated energy increments for a displayed current of zero.	■ the load is low and the current is less than 1.5% of In (e.g. no-load transformer).	■ normal operation.

The frequency measurement is not displayed or is given as dashs

Symptoms	Possible causes	Remedies
■ no display of frequency measurement, ■ otherwise, the current and voltage measurements are correct, ■ the power indicated and the power factor are correct.	■ inversion of VT wiring to Sepam 2000 voltage inputs, ■ direction of phase rotation is incorrect, ■ the frequency is not measured if voltage U21 < 40%, ■ the frequency is outside the tolerance range 45 < F < 55 for 50 Hz 55 < F < 65 for 60 Hz.	■ check the wiring. Comply with the given order of phases.

A protection does not trip at the expected set point

Symptoms	Possible causes	Remedies
■ one or more protections do not trip at the expected set points.	■ the causes may be same as when the current or voltage measurements are false; microswitches or **status** parameter set incorrectly, ■ a protection set point is outside the range accepted by Sepam 2000 after a modification of In, Ib, Unp or Uns, ■ the control logic omits the protection (see control logic operation further on), ■ the protection is set to 999.	■ check the setting of the microswitches on the 3U+Vo and the ECM (or ECA) boards; refer to **installation** manual, ■ check that the frequency, Unp and Uns settings (**status** menu, **phase VT** heading) match the VTs being used; refer to **use/commissioning** manual, ■ check that the In setting (**status** menu, **CT ratio**) matches the rating of the CTs or CSP sensors used. See user **commissioning manual**; ■ using the TSM 2001 pocket terminal, review the list of protections (**protections** menu) and check that none of them is blinking. If that is the case, reset it. Generally speaking, it is recommended to set all the parameters in the **status** menu **before** setting the protections, ■ check the control logic.

"connector" message

Symptoms	Possible causes	Remedies
■ the display unit indicates **connector,** ■ pressing key **A** (for example) makes the message disappear momentarily, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ detection of unplugged connector.	■ check that all connectors are plugged into rear of device, ■ check that the detection of plugged connectors bridge (marked DPC) is present on terminals 5 and 6 of the 6-pin connectors; terminals 7 and 8 on the 8-pin connectors and terminals 20 and 21 on the 21-pin connectors. N.B. The BNC, power supply and communication connectors are not equipped with the plugged connector detection system.

A logic input generates a fault in cabling outside Sepam

Symptoms	Possible causes	Remedies
■ the logic input is working normally but it creates interference in the outside circuit (e.g. monitoring of tripping circuit continuity), ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ wiring error on the connector of the related board, ■ the ESB or ESTOR board is faulty.	■ check wiring, ■ replace the faulty ESB or ESTOR board.

Sepam 2000 diagnosis guide (cont'd)

The standard control logic does not operate as expected

Symptoms	Possible causes	Remedies
■ the standard control logic does not operate as expected, ■ case in which Sepam 2000 is equipped with standard control logic. The standard control logic is recognized by the presence of the **CAT** label which is read on the TSM 2001 pocket terminal, in the **About Sepam** menu, **program logic** heading, ■ the green **on** indicator is on, ■ the red ⬧ indicator is off, ■ the display unit is lit up, ■ the TSM 2001 pocket terminal is working normally.	■ the control logic time delays are not set correctly, ■ the Kp parameters, set via the pocket terminal, are not set correctly. They mainly define the control logic operating modes according to the type of switchgear, ■ fault in wiring outside Sepam 2000, ■ ESB or ESTOR board faulty.	■ if Sepam 2000 is equipped with the standard control logic, refer to the **use/commissioning** manual. Check: ▫ control logic time delay settings, ▫ Kp parameters (control logic contacts set with the TSM 2001 pocket terminal). ■ control logic with undervoltage release: check the open order input **I13** wiring (normally set to 1), ■ generator control logic: check the emergency shutdown input **I22** wiring (normally set to 1). **With TSM 2005** ■ use the TSM 2005 to test the ESB or ESTOR logic input/output boards (see TSM 2005 manual, chapter on testing ESB and ESTOR boards). **Without TSM 2005** ■ in case of doubt regarding the operation of a logic input, check that there is voltage on the input, and set it to 1; to do so check the input status (1 or 0) using the TSM 2001 pocket terminal (**program logic** menu, **logic input** heading). In the event of a discrepancy, change the faulty board, ■ when in doubt regarding the operation of a relay output, check that the relay is activated when Sepam sets the output to 1; to do so check the input status (1 or 0) using the TSM 2001 pocket terminal (**program logic** menu, **logic input** heading). In the event of a discrepancy, change the faulty board.

Control logic does not operate as expected

Symptoms	Possible causes	Remedies
■ the control logic does not operate as expected, ■ case in which Sepam 2000 is equipped with customized control logic, ■ the green **on** indicator is on, ■ the red ⬧ indicator is off, ■ the display unit is lit up, ■ lthe TSM 2001 pocket terminal is working normally.	■ error in the control logic program, ■ time delays or Kp internal bits incorrectly set, ■ defect in cabling outside Sepam 2000, ■ faulty ESB or ESTOR board.	■ if there is no **CAT** label, it is essential to obtain the customized control logic program in order analyze it and detect the source of the fault, ■ when in doubt regarding the operation of logic outputs, refer to the paragraph above.

The red communication indicator stays on

Symptoms	Possible causes	Remedies
■ the red communication indicator is on, ■ this indicator (communication watchdog) is located on the back of Sepam 2000, near the communication inlet, on the CE40 power supply board. It is normal for it to light up for a few seconds when the power is switched on. When the device is operating normally, it should be off, ■ this indicator may light up even if the remote monitoring and control system is not operating or is not connected.	■ Sepam 2000 communication coupler blockage, ■ communication coupler failure.	■ change the communication kit (2 boards).

The green Jbus indicator does not blink

Symptoms	Possible causes	Remedies
■ the green communication indicator does not blink, ■ the green indicator is located on the back of Sepam 2000, near the communication inlet, on the CE40 power supply board. If the remote monitoring and control system is connected, the indicator should blink to indicate that there is electrical activity in the line. If it does not blink, it means that the Sepam communication input is **electrically deactivated**, ■ the red coupler indicator is off, ■ the rest of Sepam 2000 is working normally.	■ the remote monitoring and control system is not in service or is not sending messages throught the line, ■ the line is cut, ■ the L+ and L- network wires are reversed, ■ polarization or impedance matching of the RS 485 line are incorrect.	■ refer to Jbus communication documents and check the following: ❑ check the direction of line cabling to terminals 1 to 4 of all the CCA609 units in the network, ❑ check that the line has been polarized. This should be at one point only. ❑ check that line impedance has been matched at both ends. **With TSM 2005** ■ use the TSM 2005 and a PC to test the communication system (refer to communication kit manual.

Sepam 2000 diagnosis guide (cont'd)

The Jbus communication CPT2 diagnosis counter increments

Symptoms	Possible causes	Remedies
■ the CPT2 counter increments, ■ the counter is accessed via the TSM 2001 pocket terminal, **status** menu, **communication** heading. It counts the errors in the communication frames. When the device is operating normally, it should not increment, ■ the green coupler indicator is blinking (so the line is not cut). The red coupler indicator is off, ■ the rest of Sepam 2000 is working normally.	■ one of the communication parameters has not been set correctly: rate or parity, ■ impedance matching and/or communication network polarization are incorrect, ■ there is noise on the line **N.B.** The frames which contain errors are detected by Sepam 2000 which does not process them. Overall Sepam/remote monitoring and control system operation is not generally affected and the number of frames with errors remains limited (a few).	■ use the TSM 2001 pocket terminal to set the communication rate and parity in accordance with the remote monitoring and control system (**status** menu, **communication** heading), ■ if this is not sufficient, check polarization and line impedance matching (see **Jbus communication** manual), ■ check that the CCA 609 clamps are tightened onto the cable shielding and not onto the insulating material. The clamps earth the cable shielding, ■ check the earthing of the CCA 609 (green-yellow wire), ■ check that the CCA 602 cable connecting Sepam and the CCA 609 unit is plugged in and locked at both ends. It contributes to shielding continuity, ■ check that the communication network does not cross through zones with high levels of electrical pollution. **With TSM 2005** ■ use the TSM 2005 and a PC to test the communication system (refer to communication KIT manual).

The JBUS communication CPT9 diagnosis counter does not increment

Symptoms	Possible causes	Remedies
■ the CPT9 counter does not increment, ■ the counter is accessed via the TSM 2001 pocket terminal, **status** menu, **communication** heading. It counts the errors in the communication frames. When the device is operating normally, it should not increment, ■ the green coupler indicator is blinking (so the line is not cut). The red coupler indicator is off, ■ the rest of Sepam 2000 is working normally.	■ the remote monitoring and control system never addresses this Sepam, ■ one of the communication parameters is not set correctly: rate, slave number or parity, ■ communication network impedance matching or polarization is incorrect.	■ use the TSM 2001 pocket terminal to set the communication speed, salve number and parity in accordance with the remote monitoring and control system (**status** menu, **communication** heading), ■ if this is not suficient, check polarization and impedance matching (see **Jbus communication** manual).

Sepam 2000 appendix

Table of rear compartment board positions

■ The table below indicates the position of the boards in the rear compartment according to the different Sepam 2000 models.
■ If the board poisitions are not complied with, Sepam 2000 will not start up and will display **maintenance** or **cartridge**.

slot	8	7	6	5	4	3	2	1
S26 or S25 models								
LS			ESTOR[2]	ESTOR	ESB	SONDE	ECM[1]	CE40
LT			ESTOR[2][4]	ESTOR[4]	ESB	3U+Vo	ECM[1]	CE40
LX			ESTOR[2][4]	ESTOR[4]	ESB	nothing	ECM[1]	CE40
XT			ESTOR[2]	ESTOR	ESB	3U+Vo	nothing	CE40
S36 or S35 models								
KR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	nothing	ECM	ECM[1]	CE40
KZ	SONDE	ESTOR[2]	ESTOR	ESB	nothing	ECM	ECM[1]	CE40
YR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	nothing	nothing	ECM[1]	CE40
ZR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	nothing	SONDE	ECM[1]	CE40
LR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	3U+Vo	ECM	ECM[1]	CE40
LS	SONDE	ESTOR[2]	ESTOR	ESB	3U+Vo	ECM	ECM[1]	CE40
SR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	3U+Vo	SONDE	ECM[1]	CE40
SS	SONDE	ESTOR[2]	ESTOR	ESB	3U+Vo	SONDE	ECM[1]	CE40
XR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	3U+Vo	nothing	ECM[1]	CE40
TR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	3U+Vo	3U+Vo	ECM[1]	CE40
CR	ESTOR[3]	ESTOR[2]	ESTOR	ESB	nothing	ECMD	ECMD	CE40
CC[5]	ESTOR[3]	ESTOR[2]	ESTOR	ESB	ECMD	ECMD	ECMD	CE40
TS[5]	SONDE	ESTOR[2]	ESTOR	ESB	3U+Vo	3U+Vo	ECM[1]	CE40

Notes
[1] or ECA for CSP sensor,
[2] the ESTOR 2 board may be installed, depending on the application,
[3] option for the ESTOR board,
[4] For SX1 and SX2 applications the ESTOR boards are not installed in Sepam,
[5] available with S36 only.

Functions of rear compartment boards

■ **CE40**
Power supply: 3 versions available: 24/30 VDC, 48/127 VDC and 220/250 VDC.
■ **INT RS 485** :
Communication interface. It is located behind the metal plate on the power supply board.
■ **ECM**
Current inputs for 1 A or 5 A seonsor and CSH core balance CT input for residual current measurement. Sepam TC type.
■ **ECA**
current inputs for CSP sensor or CSH core balance CT input for residual current measurement. This board in installed in place of the ECM board for Sepam 2000 CS type.

■ **3U+Vo**: voltage inputs and residual voltage input,
■ **SONDE**: 6 PT100 RTD inputs,
■ **ESB**: 2 logic inputs, 2 output relays and watchdog relay
3 versions available: 24/30 VDC, 48/127 VDC and 220/250 VDC,
■ **ESTOR**: 8 logic inputs and 4 output relays 3 versions available: 24/30 VDC, 48/127 VDC and 220/250 VDC.

Sepam 1000 diagnosis guide

All indicators off

Symptoms	Possible causes	Remedies
■ all the indicators and the display unit are off.	■ the Sepam 1000 is not being supplied with power.	■ check the voltage on the power supply connector, ■ if the fault persists, change the Sepam 1000 AS' power supply board. The AS' board is fitted with an internal fuse; never replace it (since other power supply components are damaged when the fuse blows).

Everything off except for green and red indicators

Symptoms	Possible causes	Remedies
■ the green **on** indicator is on, ■ the red ↘ indicator is on, ■ the **trip** indicator and display unit are off, ■ the watchdog has dropped out.	■ the self-tests have detected an internal fault, ■ power supply board fault.	■ change the Sepam AS' power supply board, ■ if the fault persists, replace the Sepam 1000.

display of the "check settings" message

Symptoms	Possible causes	Remedies
■ the display unit shows the message: **check settings,** ■ the values of some parameters are blinking, ■ the protections are working normally.	■ Sepam 1000 has detected a parameter setting faults (outside range, incompatible settings, set point modified after a change of In, etc.).	■ switch to parameter setting mode and change the settings of all the parameters which are blinking on the display unit.

The -, + and enter keys are disabled

Symptoms	Possible causes	Remedies
■ the **-**, **+** and **enter** keys are disabled.	■ Sepam is not in parameter setting mode.	■ switch to parameter setting mode by pressing for a second on the **P** key on the back of Sepam.

Display of the "fault" message

Symptoms	Possible causes	Remedies
■ internal fault.	■ internal fault.	■ replace Sepam.

The current measurements are false

Symptoms	Possible causes	Remedies
■ the difference between the expected measurement and the measurement indicated by Sepam 1000 may be between 10% and 500%, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is working.	■ the microswitches on the back of the EM (or EA) board are not set correctly, ■ one of the parameters in the **status** loop is not set correctly.	■ check the setting of the microswitches on the EM (or EA) board; refer to **installation** manual, ■ check that the In setting (**status** loop) matches the rating of the CTs or CSP sensors being used; refer to **use/ commissioning** manual, ■ check that the network frequency has been selected correctly (50 or 60 Hz, **status** loop).

One of the phase current measurements is zero

Symptoms	Possible causes	Remedies
■ a measurement indicates a value of zero or close to zero, ■ the 2 other phase current measurements are working normally, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is working.	■ there are only 2 CTs in the cubicle, ■ one CT is not wired, ■ the EM (or EA) current input board is faulty.	■ Sepam connected to a 1A/5A CT: ensure that there is current in the CT secondary circuit which reaches the CCA 660 or CCA 650 connector, ■ replace the EM board, ■ Sepam connected to a CSP sensor: momentarily reverse the connections (BNC connector) on the EA board: if the fault disappears, the problem is an external one; if the fault persists, replace the EA board.

The voltage measurements are false

Symptoms	Possible causes	Remedies
■ the difference between the expected measurement and the measurement indicated by Sepam 1000 may be between 10% and 500%, ■ the protections do not trip at the expected setting, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is working.	■ the microswitches on the back of the ET board are not set correctly, ■ one of the parameters in the **status** loop is not set correctly.	■ check the setting of the microswitches on the ET board; refer to **installation** manual, ■ check that the Unp and Uns settings (**status** loop) match the VTs being used; refer to **use/commissioning** manual, ■ check that the network frequency has been selected correctly (50 or 60 Hz, **status** loop).

The U32 and U13 phase voltage measurements do not appear

Symptoms	Possible causes	Remedies
■ the U32 and U13 measurements are missing, ■ the U21 voltage measurement is correct.	■ the **VT's** parameter in the **status** loop is set to U21, in which case Sepam is unaware of the value of the other voltage measurements.	■ check the **VT's** parameter (**status** loop). Set it to U21U32.

A voltage measurement channel indicates zero

Symptoms	Possible causes	Remedies
■ one of the phase-to-phase voltage measurements indicates a value of zero or close to zero, ■ the green **on** indicator is on, ■ the red ⬟ indicator is off, ■ the display unit is working.	■ there are only one or two VTs in the cubicle or not all the VTs are cabled, ■ the ET voltage input board is faulty.	■ ensure that the VT secondaries are wired to Sepam 1000, ■ replace the ET board.

A protection does not trip at the expected set point

Symptoms	Possible causes	Remedies
■ one or more protections do not trip at the expected set points.	■ the causes may be same as when the current or voltage measurements are false; microswitches or **status** parameter set incorrectly, ■ a protection set point is outside the range accepted by Sepam 1000 after a modification of In, Ib, Unp or Uns, ■ case of residual current protection: core balance CT connection error (2 A , 30 A rating or CT).	■ check the setting of the microswitches on the ET and the EM (or EA) boards; refer to **installation** manual, ■ check that the Unp and Uns settings (**status** loop) match the VTs being used, ■ check that the In setting (**status** loop) matches the rating of the CTs or CSP sensors being used; refer to **use/commissioning** manual, ■ check that the network frequency setting has been selected correctly (50 or 60 Hz, **status** loop), ■ review the list of parameters and check that none of them are blinking. If that is the case, set the parameters again. Generally speaking, it is recommended to set all the parameters in the **status** menu **before** setting the protections, ■ residual current: check the core balance CT connection. Check that the core balance CT is a CSH.

A protection does not trip

Symptoms	Possible causes	Remedies
■ a protection does not trip.	■ inhibition of the protection by a 999 type setting, ■ incorrect addressing of the protection output, ■ residual current protection: microswitches not set correctly.	■ check the set points, ■ check the output addressing. Make sure in particular that the ES1 board is included if relays AUX1, AUX3 and AUX4 are supposed to be used, ■ residual current protection: if the sum of the phase currents i used, check that the setting of the SW1 microswitches on the EM or EA board is as follows: ◨ **SW1.**

Sepam 1000 diagnosis guide (cont'd)

Acknowledgement is impossible

Symptoms	Possible causes	Remedies
■ the reset key is disabled, acknowledgement is impossible.	■ the fault at the origin of tripping is still present.	■ check for the presence of the fault (current, voltage, frequency): □ think of undervoltage protections which trip when there is zero voltage, □ also remember the thermal overload and starts per hour protections which remain in tripped status even when there is no current. In such cases, wait for the conditions which caused tripping to disappear.

Frequency measurement and functions do not work

Symptoms	Possible causes	Remedies
■ the frequency measurement is displaying hyphens, ■ the frequency protections do not trip.	■ incorrect wiring, ■ U21 or forward voltage too low.	■ check the wiring (direction of phase rotation), ■ check voltage amplitude: U21 voltage should be greater than 30% of Unp and forward voltage should be greater than 20% of Vnp.

The logic input does not work

Symptoms	Possible causes	Remedies
■ the logic input remains at zero, whether it is supplied with power or not, ■ the green **on** indicator is on, ■ the red ↘ indicator is off, ■ the display unit is working.	■ wiring error on the ES1 board connector, ■ ES1 board microswitch setting error, in the case of use with 24/30 VDC.	■ check the wiring and voltage on the input terminals, ■ if the input is used with 24/30 VDC, the microswitches on the ES1 board must be set as follows: ▦ **SW1,** ■ if the fault persists, replace the ES1 board.

Sepam 1000 appendix

Table of rear compartment board positions

■ the table below indicates the position of the boards in the rear compartment according to the different Sepam 1000 models.
■ failure to use the correct board positions is liable to damage Sepam 1000.

slot	3	2	1	0
S05 model				
LX 1 A / 5 A CT sensor		EM	AS'	ES1 (option)
LX CSP sensor		EA	AS'	ES1 (option)
TX		ET	AS'	ES1 (option)

Functions of rear compartment boards

■ **EM**: current inputs for 1 A or 5 A sensor and CSH core balance CT input for residual current measurement,
■ **EA**: current inputs for CSP sensor and CSH core balance CT input for residual current measurement,
■ **ET**: voltage inputs and residual voltage input,
■ **AS'**: power supply and 2 outputs 4 versions available:
□ 24/30 VDC,
□ 48/125 VDC,
□ 220/250 VDC and 100/127 VAC,
□ 220/240 VAC,
■ **ES1**: 1 logic input and 3 output relays and watchdog relays single multi-voltage version available.

TRANSFORMER PROTECTION

■ **Protection functions :**

- Main characteristics
- Protection by circuit breaker
- Logic discrimination

■ **Protection functions :**

- 49 : thermal overload
- 50/51 : phase overcurrent
- 50N/51N : earth fault protection
- 59N : neutral voltage displacement
- 67 : directional overcurrent
- 67N : directional earth fault
- 27 : undervoltage
- 27R : remanent undervoltage
- 59 : overvoltage
- 50/51 : tank earth leakage
- 64REF : restricted earth fault
- 87T : differential protection

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TRANSFORMER PROTECTION

■ **Main characteristics :**

- Transformer energizing inrush current :

Ie

$$\hat{i}_e\,(t) = \hat{I}_e\; e^{-\frac{t}{e}}$$

t
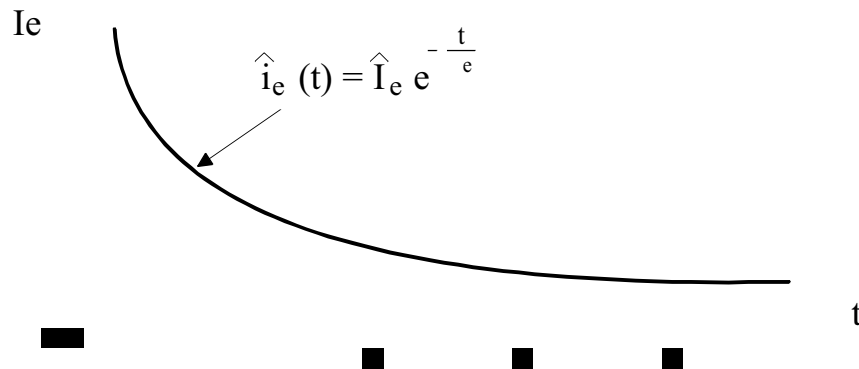
$\hat{i}_e(t)$: current peak value as a function of time

$\hat{I}_e$: value of maximum peak, i.e. the first peak

τ_e: damping time constant

- Inrush current at high voltage end of TRIHALtransformers:

Power in kVA	160	250	400	630	800	1000	1250	1600	2000
$ne = \dfrac{\hat{I}e}{In}$	10.5	10.5	10	10	10	10	10	10	9.5
te (s)	0.13	0.18	0.25	0.26	0.30	0.30	0.35	0.40	0.40

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TRANSFORMER PROTECTION

■ **Main characteristics (cont'd) :**

- Vector group :

Va

A
VA-VB
B

C

a

b

c

Dy11

VC

11

VB

Va

VA

VA-VB
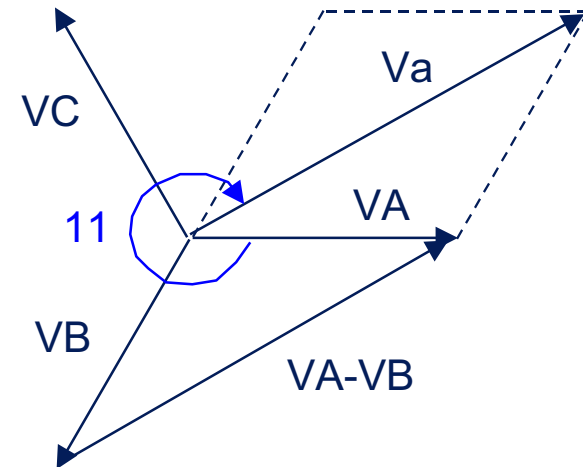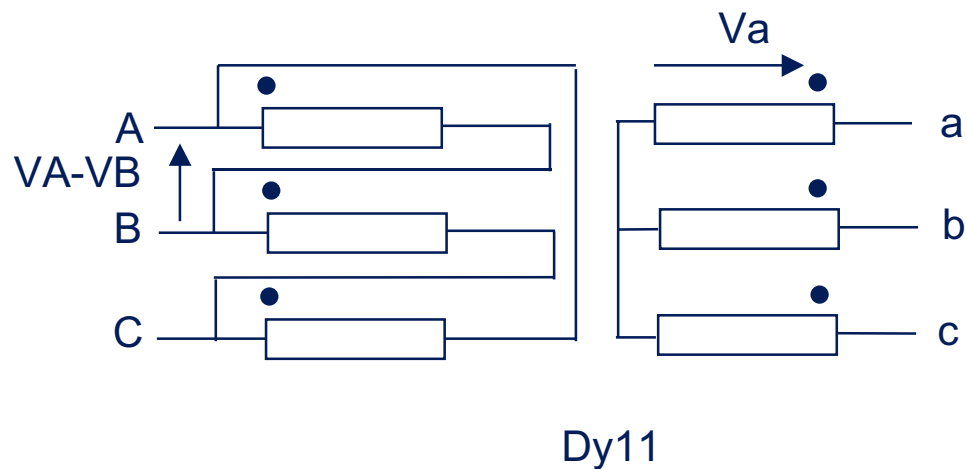
TRANSFORMER PROTECTION

■ **Main characteristics (cont'd) :**

• For earth fault :
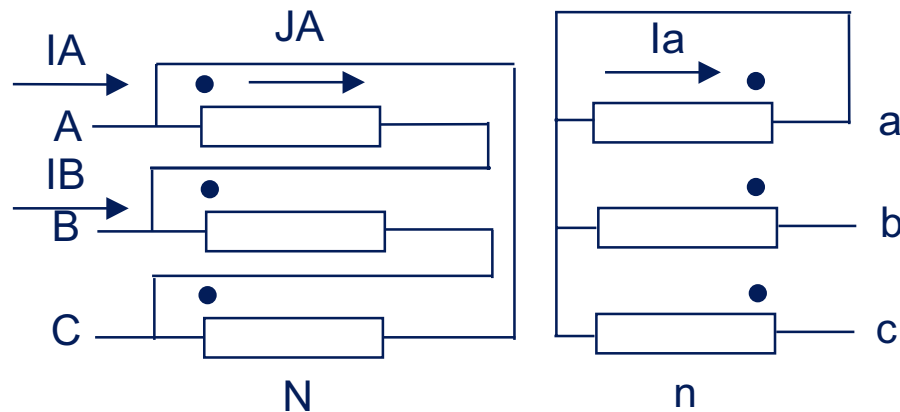
During the fault :

$n.Ia = N.JA$ and $IA = JA$

$Ia = Icc$ three - phase

IA = -IB = 0.58 . Icc three - phase / k

k : transformer ratio = 0.58 . N / n

TRANSFORMER PROTECTION

■ **Main characteristics (cont'd) :**

• For phase to phase fault :
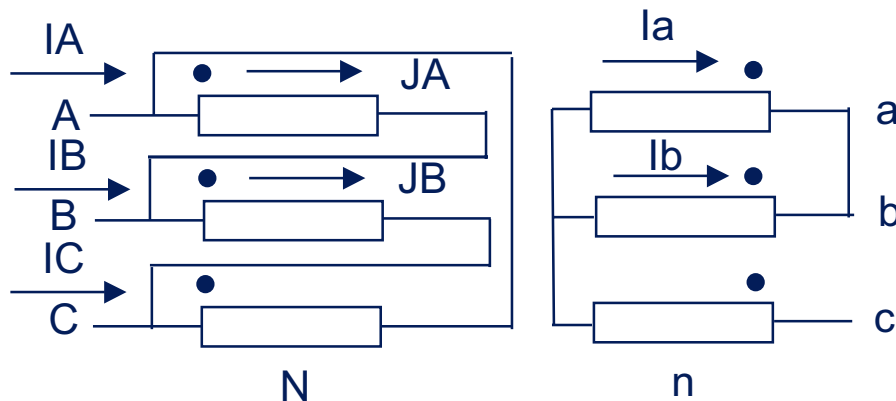
During the fault :

$n.Ia = N.JA = -n.Ib = -N.JB$

$Ia = 0.866\ Icc\ three - phase$

$IA = JA - JC$

IA = Ia.n/N = 0.5.Icc three - phase / k

$IB = JB - JA$

$IB = -Ia.n/N - Ia.n/N$

IB = -2.Ia.n/N = - Icc three - phase / k

$IC = JC - JB$

IC = Ia.n/N = 0.5.Icc three - phase / k

k : transformer ratio = 0.58 . N / n

TRANSFORMER PROTECTION

■ With DT curves
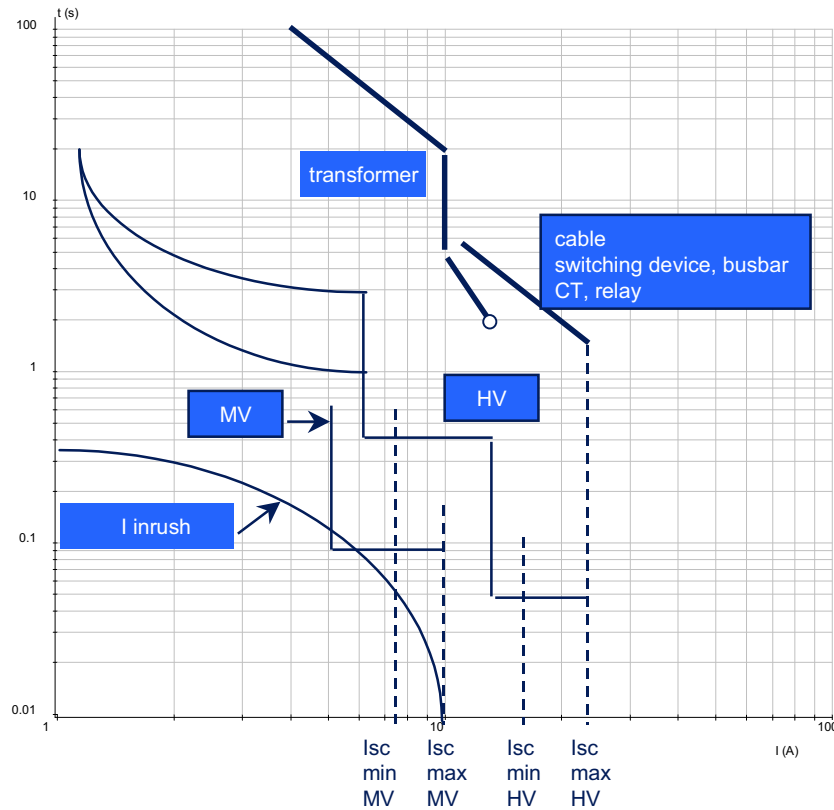
■ With IDMT curves
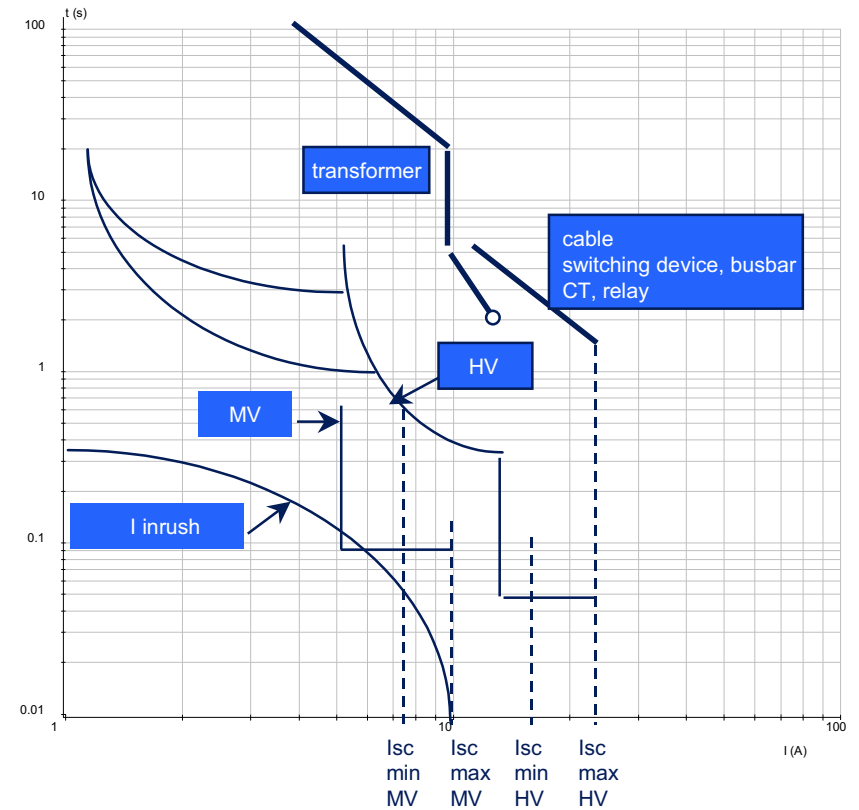
TRANSFORMER PROTECTION

■ I < switch breaking capacity
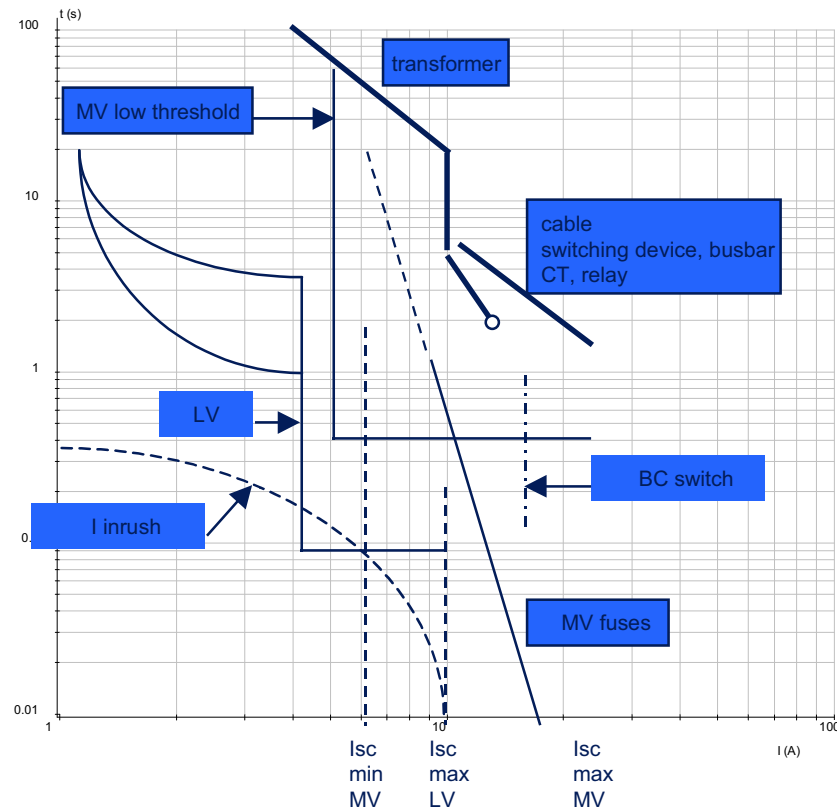
■ I > switch breaking capacity: BEWARE!
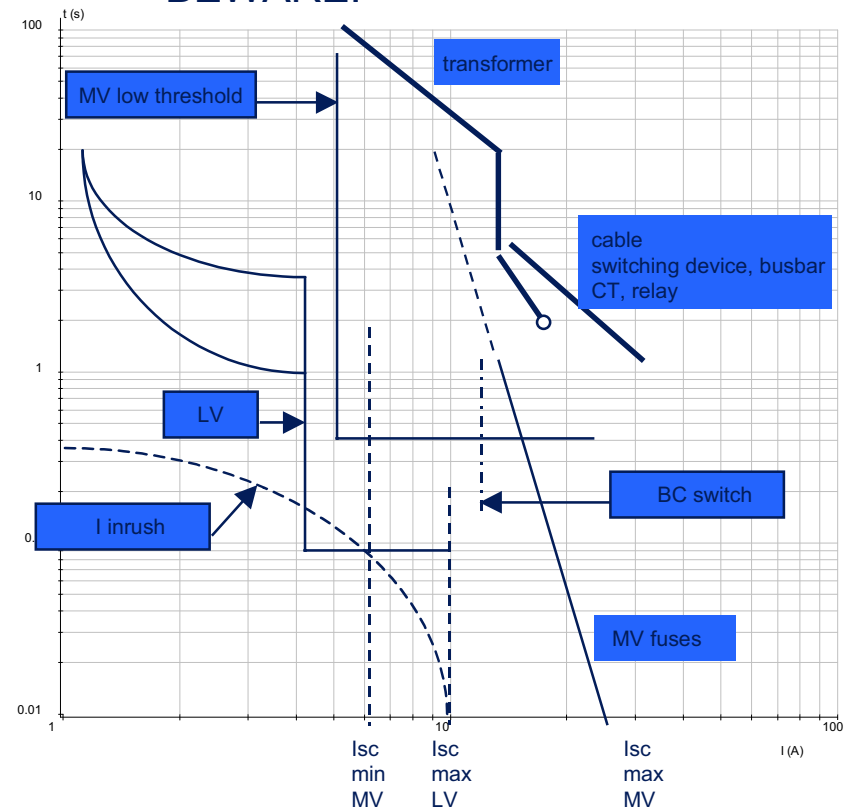
TRANSFORMER PROTECTION
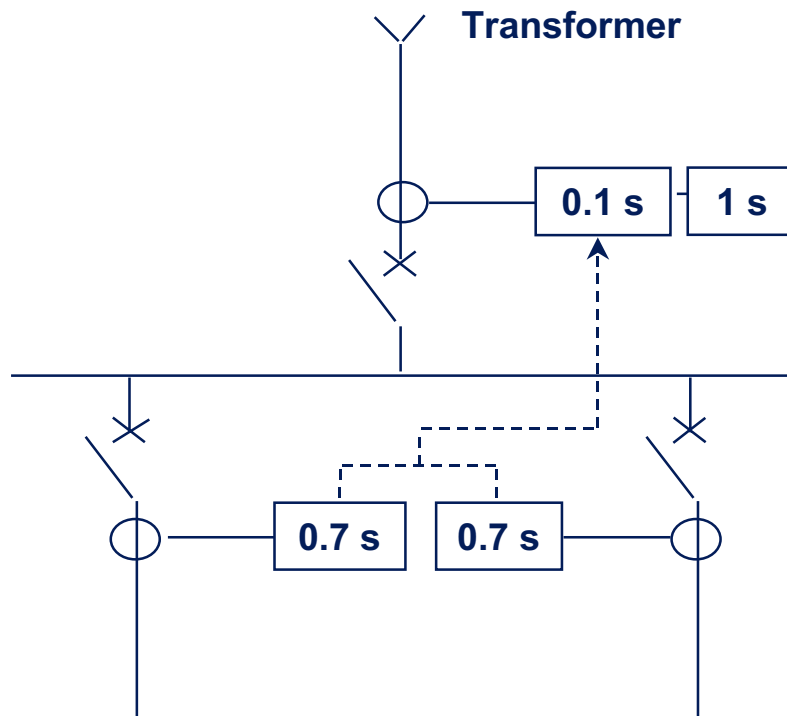
■ **Logic discrimination :**

Transformer

0.1 s — 1 s

0.7 s   0.7 s

Fault on busbar eliminated after 0.1 s without adding any other protection

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TRANSFORMER PROTECTION

■ **Logic discrimination :**

Inhibition of
BI transmision
if fault not cleared

Output O14 : BI transmision

Overcurrent (inst)

Earth fault (inst)

≥1

t   0

T3 = 0.2s

&

Overcurrent (time)

Earth fault (time)

≥1

≥1

tripping

Overcurrent (logic)

Earth fault (logic)

≥1

&

Input I12 : BI receipt

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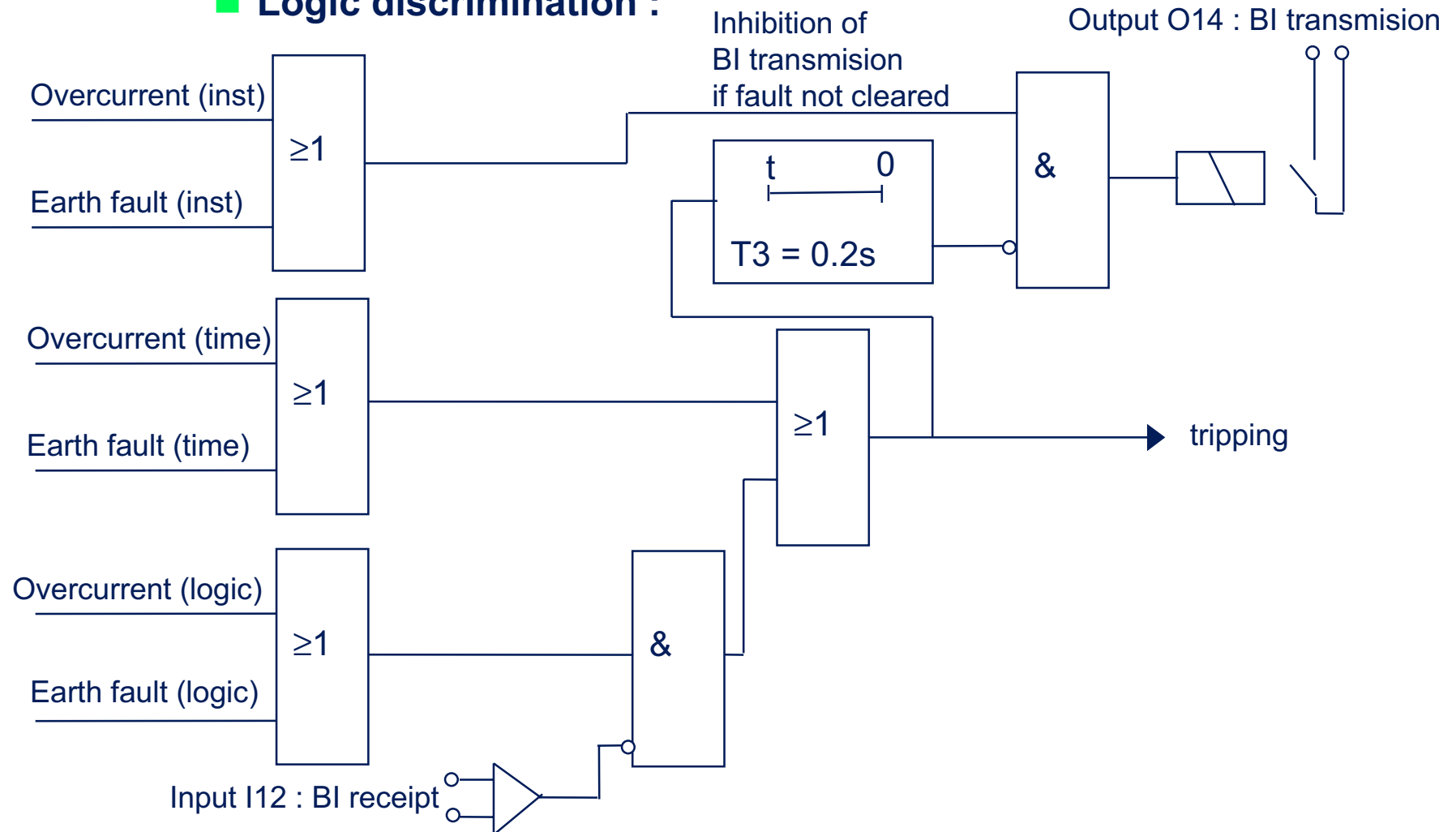
TRANSFORMER PROTECTION

■ **Overcurrent (50/51) :**

- 1st setting :   1.25 Iscmaxdown <=Is1<=0.8 Iscminup

    Time setting $\approx$ 0.1 s

- 2nd setting :   1.25 Isdown <=Is1<=0.8 Iscmindown

    Time setting $\approx$ Tdown + 0.3 s

- **Transient overreach = (Iso - Is1) / Is1**

    Iso = setting current, that is, r.m.s. value of steady state current required to operate the relay

    Is1 = steady state r.m.s. value of the fault current which when fully offset will just operate the relay

TRANSFORMER PROTECTION

■ **Overcurrent (50/51) :**

- Current shape in case of saturation of CT:

I ct

Peak value

Right value

Fundamental value

t

Low value of fundamental current ⇒ risk of no detection of the fault ⇒ measurement of peak value

TRANSFORMER PROTECTION

- **Overcurrent (50/51) :**
  - Current shape in case of no saturation of CT :

I ct

Peak value

Filtered peak value

t

Transient overreach can be very high if only the peak value is considered ⇒ peak value is filtered (no DC component)

TRANSFORMER PROTECTION

■ **Overcurrent (50/51) :**

  - Conclusion :

  - Filtered peak detection is used to ensure tripping in case of CT saturation
  - Efficace value avoids the risk of unexpected tripping

  SEPAM MIX THE TWO MEASUREMENTS TO GUARANTEE A GOOD TRANSIENT OVERREACH (LESS THAN 10% FOR ANY TIME CONSTANT)

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TRANSFORMER PROTECTION

■ **Earth fault (50N/51N) :**

Harmonic 2 restrain

An earth fault current (including harmonic 2) could appear
in case of CT saturation if earth fault is measured by means
of the sum of 3 TC.

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TRANSFORMER PROTECTION

■ **Thermal overload (49) :**

- Heat rise calculation :

$$T \times \frac{dE}{dT} + E = \left(\frac{Ieq}{Ib} \right)^2$$

$$Ieq^2 = I^2 + K \times Ii^2$$

- I is the greatest value of I1, I2, I3 (at 50 Hz) and I1rms
- Ii is the negative sequence current

$$E = \left[Eo - \left(\frac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\frac{Ieq}{Ib} \right)^2$$

- Eo : initial heat rise

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TRANSFORMER PROTECTION

■ **Thermal overload (49) (cont'd) :**

$$E = \left[Eo - \left(\frac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\frac{Ieq}{Ib} \right)^2$$

• **Operation**

TRANSFORMER PROTECTION

■ **Thermal overload (49) :**

$$t = T \times Log \dfrac{\left(\dfrac{I}{Ib}\right)^2}{\left(\dfrac{I}{Ib}\right)^2 - Es2}$$

$$t = T \times Log \dfrac{\left(\dfrac{I}{Ib}\right)^2 - 1}{\left(\dfrac{I}{Ib}\right)^2 - Es2}$$

Es2 = thermal setting point in %

T = heat rise time constant

Cold curve

Hot curve

t

100

10

1

0.1

Ieq/Ib

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TRANSFORMER PROTECTION

■ **Thermal overload (49) (cont'd) :**

- A transformer often has two operating modes (ONAN - ONAF)
- Two groups of parameters are available
- Switching from one mode to the other is controlled by a Sepam input
- Accounting for ambient temperature when the temperature measured exceeds 40°

TRANSFORMER PROTECTION

■ **Residual overvoltage (59N) :**

- For isolated neutral 59N protection is required to detect earth fault before closing the circuit breaker

- This function can be located elsewhere in the network (on busbar for example)

TRANSFORMER PROTECTION
Phase directional overcurrent (67) :
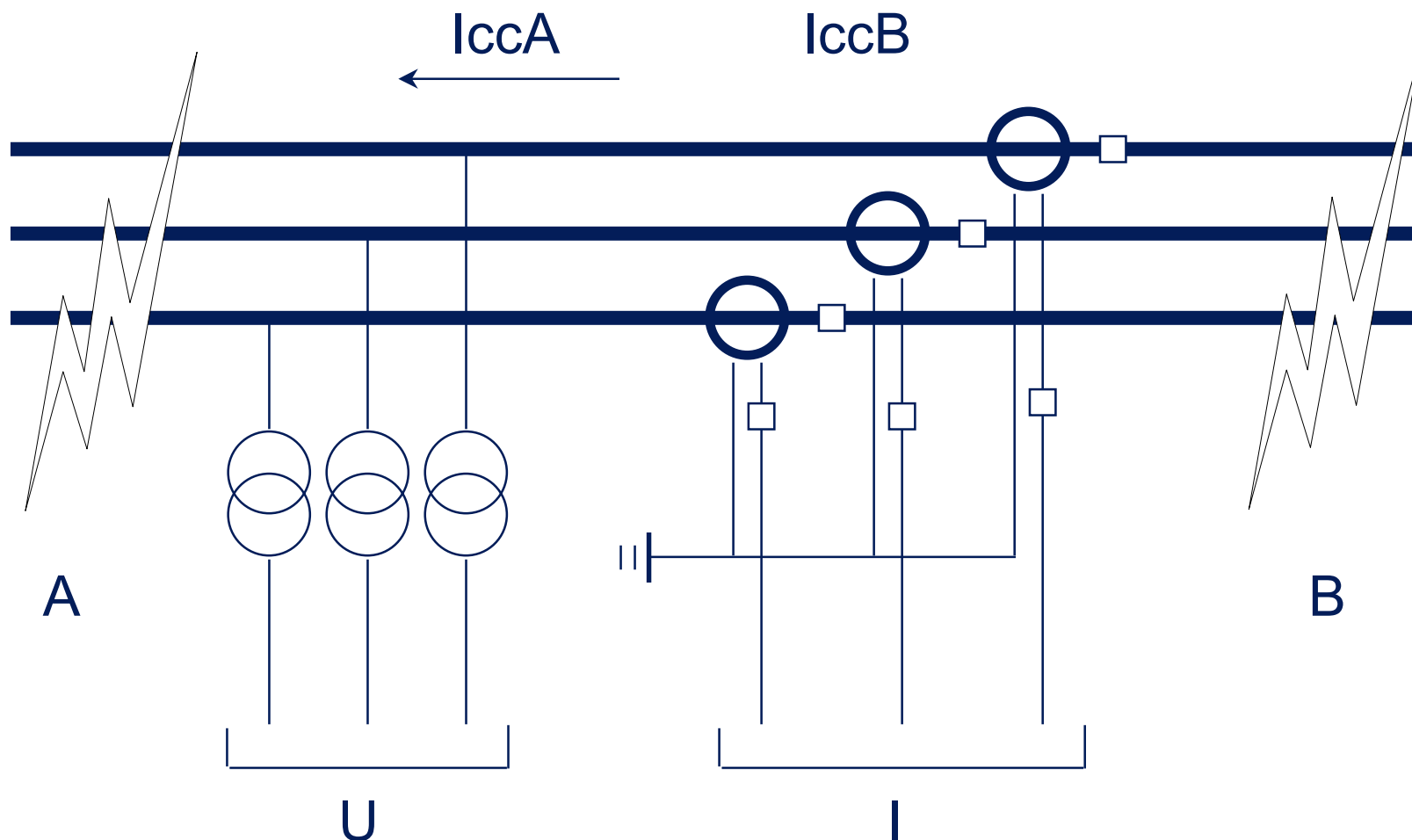
TRANSFORMER PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ Fault in A :

IsA

IccA

Relais

IccA

U13   I3   U21

I1

I2

U32
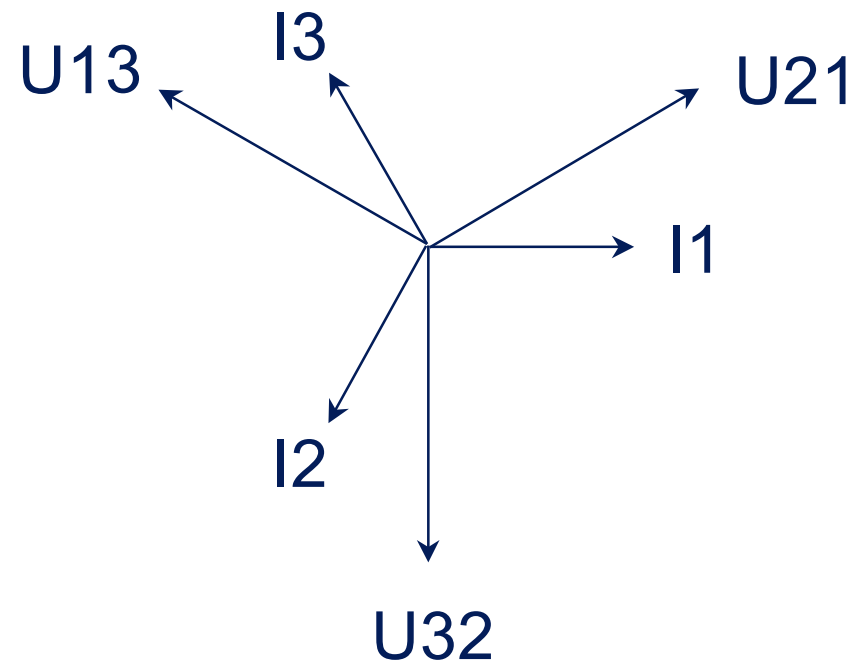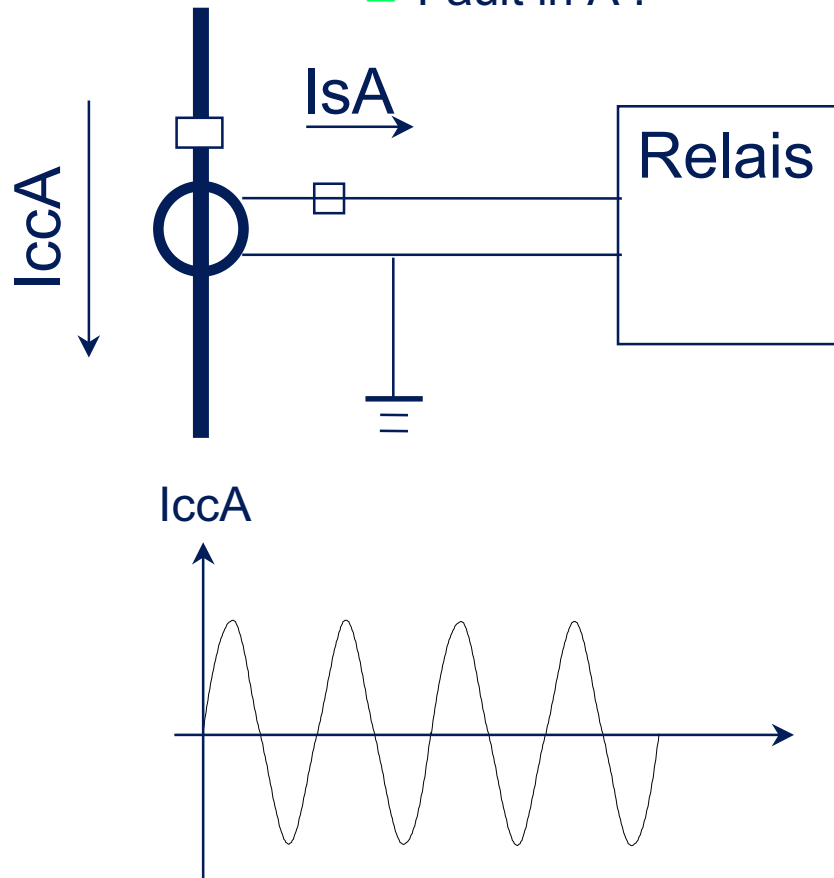
TRANSFORMER PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ Fault in B :

TRANSFORMER PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ Measurement of the phase shift angle between a reference voltage, called the polarization voltage, and a current makes it possible to determine the current direction

■ In practice:
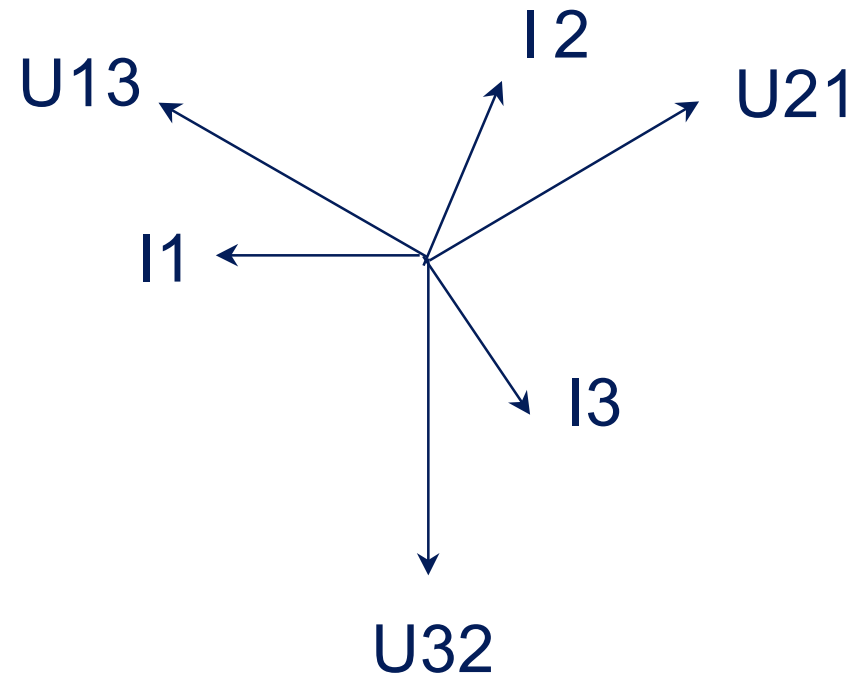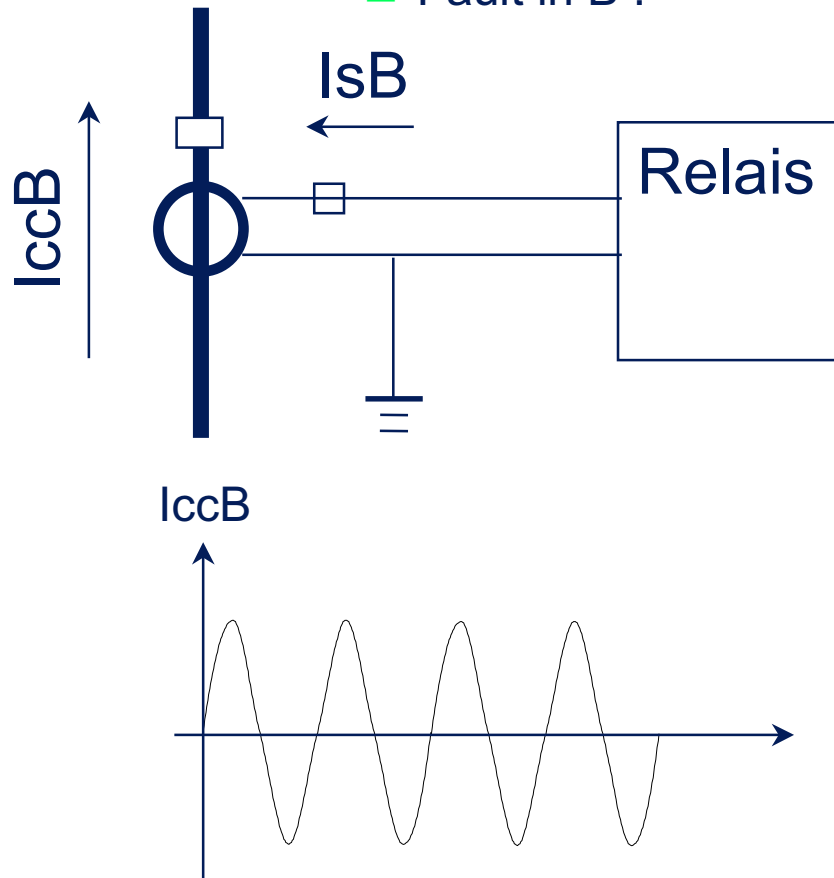
    • polarization by phase-to-phase voltage

    • measurement of $\varphi 1$= phase shift (U32,I1), $\varphi 2$= phase shift (U13,I2) and $\varphi 3$ = phase shift (U21,I3)

TRANSFORMER PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Conventions :**

I1

I1 in normal direction

$\varphi 1$

$\varphi 1$

U32

I1

I1 in inverse direction

■ $\varphi 1$ = phase shift (U32,I1)
varies according to the impedance of the circuit under consideration

■ Conventional current direction:
- • Normal direction = from busbar to cable
- • Inverse direction = from cable to busbar

■ Conventional CT wiring:
normal direction   inverse direction

I

I

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TRANSFORMER PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Characteristic angle θ :**

Normal zone

θ

U32

Inverse zone

■ Division of a current vectorial plane into 2 half-planes:

- normal zone
- inverse zone

■ Characteristic angle θ =
angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage

■ Setting values of θ :

- 30° if high reactance circuit (φ1minimum)
- 45° average case
- 60° if high resistance circuit (φ1 maximum)

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TRANSFORMER PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Principle :**

I1

$\varphi1$

$\theta=45°$

U32

Is

Phase overcurrent

Direction detection in normal direction

Directional protection function
tripping zone

■ Association of 2 functions:

- phase overcurrent protection
function
adjustable setting Is
Definite or IDMT time

- detection of the current direction
characteristic angle θ

■ Two-phase protection

- I1 and $\varphi1$ (phase shift U32,I1)

- I2 and $\varphi2$ (phase shift U13,I2)

- I3 and $\varphi3$ (phase shift U21,I3)

■ Protection operational if:
polarization voltage > 1.5%Un

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TRANSFORMER PROTECTION
Directional earth fault (67N) :

IscA

IscB

A

B

Vrsd

Irsd

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TRANSFORMER PROTECTION
Directional earth fault (67N) (cont'd):

φ0A

V2

Fault at A

N

V1

Vrsd

IrsdA

V3

Normal direction
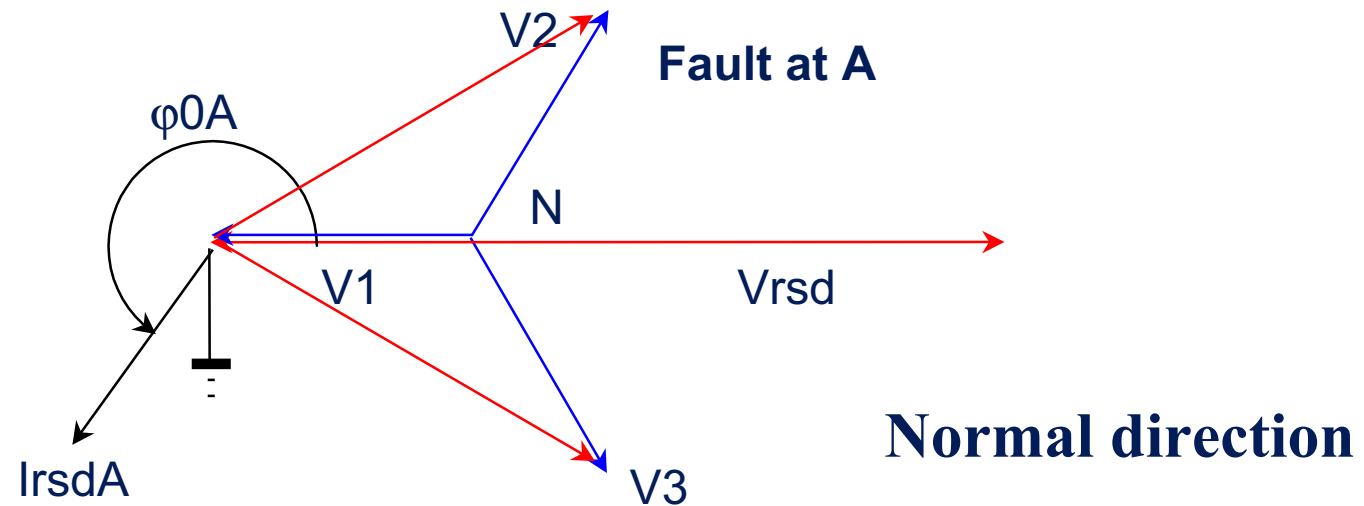
$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\,\vec{Z}_N \times \vec{I}_{rsd}$$

TRANSFORMER PROTECTION
Directional earth fault (67N) (cont'd):

IrsdB   V2   **Fault at B**

φ0B

N

V1   Vrsd

Reverse direction

V3

$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\,\vec{Z}_N \times \vec{I}_{rsd}$$

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TRANSFORMER PROTECTION
Directional earth fault (67N) (cont'd):

■ Measurement of the phase shift angle between the residual voltage - called the polarization voltage - and the earth fault current makes it possible to determine the direction

TRANSFORMER PROTECTION
Directional earth fault (67N) (cont'd):

Inverse zone

$\theta 0$

Vrsd

Normal zone

- Division of a current vectorial plane into 2 half-planes:
  - normal zone
  - inverse zone

- Characteristic angle $\theta 0$ =
  angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage

- Typical values of $\theta 0$:
  - 0° if N earthed by resistance
  - 15°, 30°, 45°, 60°: intermediate values
  - 90° if isolated neutral (Irsd=Icapa)
  - -45° if N earthed by reactance

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TRANSFORMER PROTECTION
Directional earth fault (67N) (cont'd):

inverse zone

$\theta 0 = 45°$

$\phi 0$ Is0

Vrsd

Ip

normal zone

Irsd

Earth fault
Direction detection in normal direction
Directional protection function
tripping zone

- Association of 2 functions:
  - earth fault protection function
    adjustable setting Is0
    Definite time
  - detection of the current direction
    characteristic angle $\theta 0$

- Plane single-pole protection
  - Ip : projection of Irsd on the
    characteristic line
  - $\phi 0$: phase shift (Vrsd,Irsd)

- Protection operational if:
  polarization voltage >= 2.6% Un

Schneider Electric

TRANSFORMER PROTECTION
Directional earth fault (67N) (cont'd):

COMPENSATED NEUTRAL SYSTEM :

■ Petersen coil + resistor:

- designed to compensate capacitive currents
  => Irsd is highly resistive

=> characteristic angle not adjustable: $\theta 0 = 0°$

- self-extinguishing earth fault
  => short, recurring faults

=> protection memory time adjustable

   Tmem ~ 250 ms

- in practice, the system is slightly dissymmetrical and the residual voltage is not zero when there is no fault

=> Vs0 setting adjustable

TRANSFORMER PROTECTION

■ **Tank earth leakage :**

- If the transformer is not protected by a restricted earth fault differential protection (64REF), and if the transformer tank is isolated from the earth, a tank earth leakage protection is required
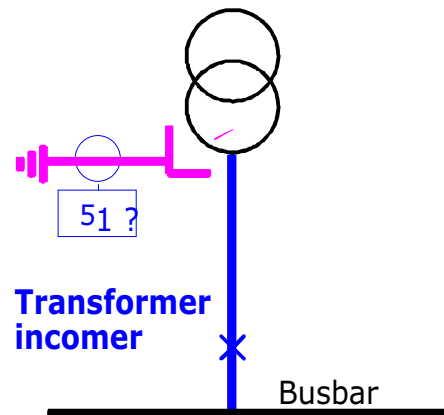
51 ?

Transformer incomer

Busbar

TRANSFORMER PROTECTION

■ **Restricted earth fault (64REF) :**

- If the protection 64 REF is required

- or if the transformer has a power rating of more or equal than 5 MVA the protection 64 REF is required on transformer incomer.

- It offers the advantage of having greater sensitivity than differential protection (5% of In)
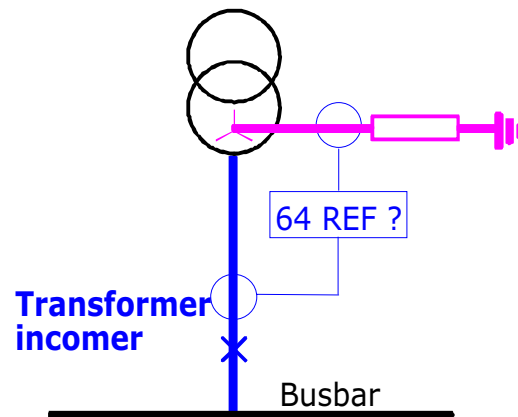
TRANSFORMER PROTECTION
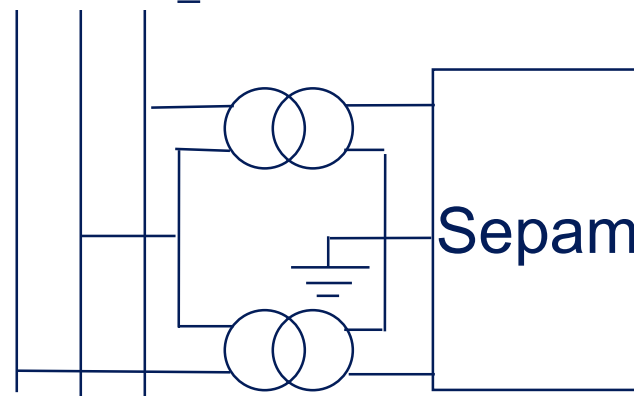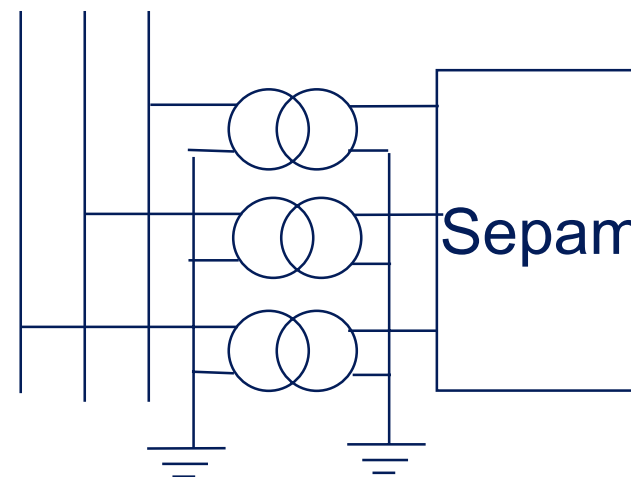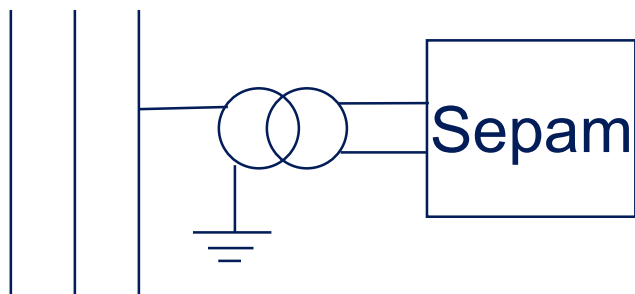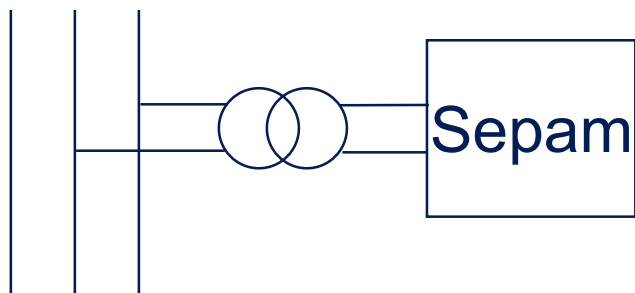
■ **Undervoltage (27) :**

TRANSFORMER PROTECTION

Undervoltage (27) : coordination with overcurrent protection

■ Undervoltage protection   ■ Overcurrent protection
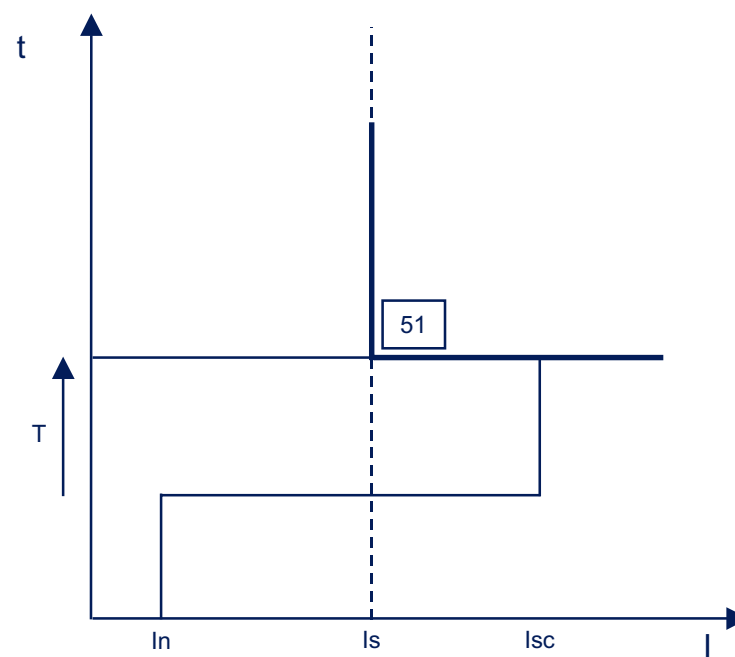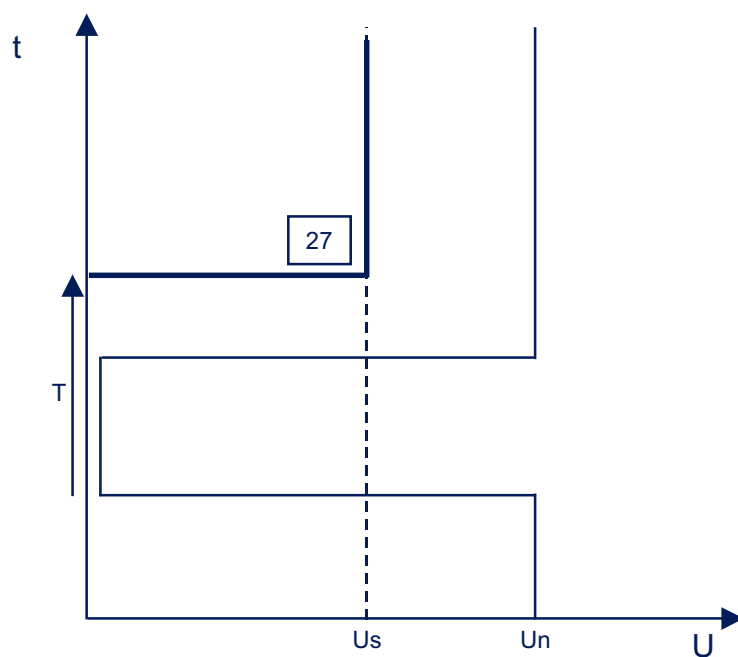
TRANSFORMER PROTECTION
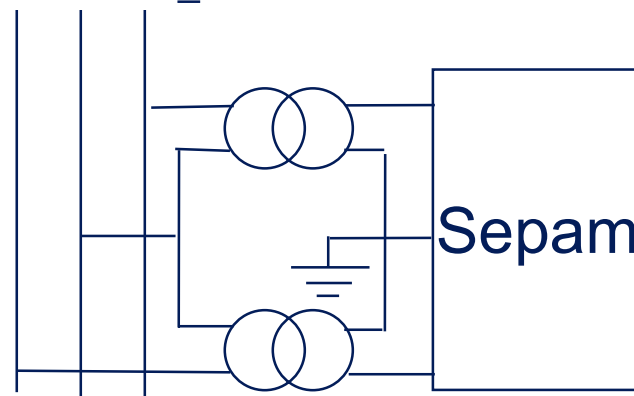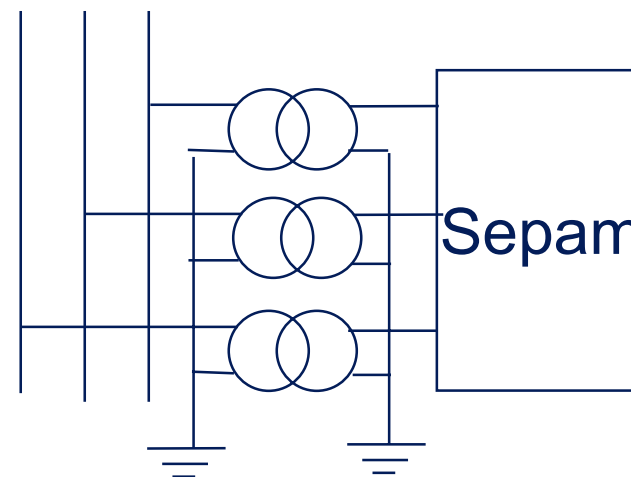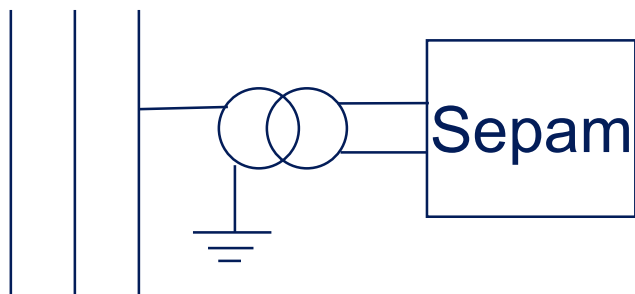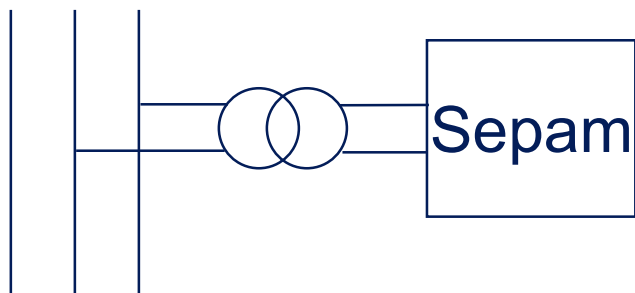
■ **Overvoltage (59) :**

TRANSFORMER PROTECTION

■ **Remanent undervoltage (27R) :**

- If the transformer supplies power to machines that should not be energized until the voltage, maintained by the machines after the opening of the circuit by an automatic changeover device, drops below a given value.

TRANSFORMER PROTECTION

■ **Differential protection (87T) :**

- Protection of HV/MV, MV/MV and MV/LV transformers

- Protection of 2-winding transformers

- Protection of 3-winding transformers

- Protection of auto-transformers

- Protection of generator-transformer units

TRANSFORMER PROTECTION
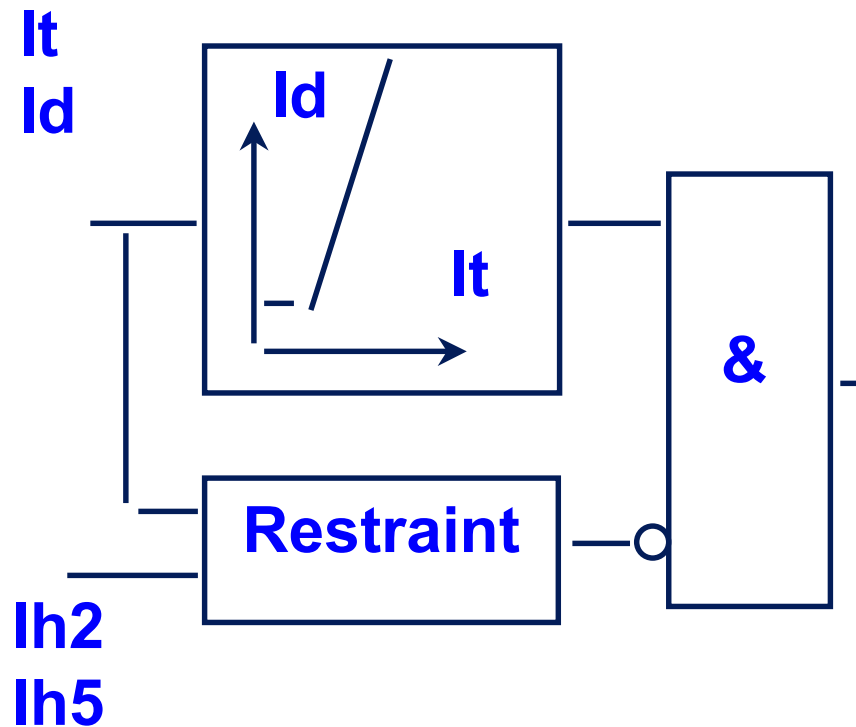
- Biased characteristic
  - Id/It adjustable between 15 and 50%

- 2nd harmonic restraint for :
  - a high stability on transformer inrush
  - a high stability on external fault
  - a secure tripping action on internal faults

- 5th harmonic restraint for :
  - a high stability during over-excitation of the transformer

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TRANSFORMER PROTECTION

Restraint function is performed by **neural network** :

- 4 inputs
- A multitude of thresholds, factory set
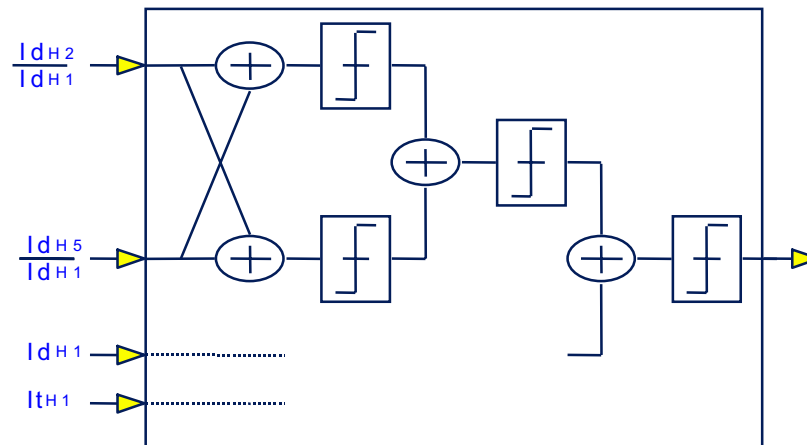
For the best compromise between sensitivity and stability

TRANSFORMER PROTECTION

Artificial neural network: What's the benefit ?

idh2

Disable trip

Enable trip

idh5
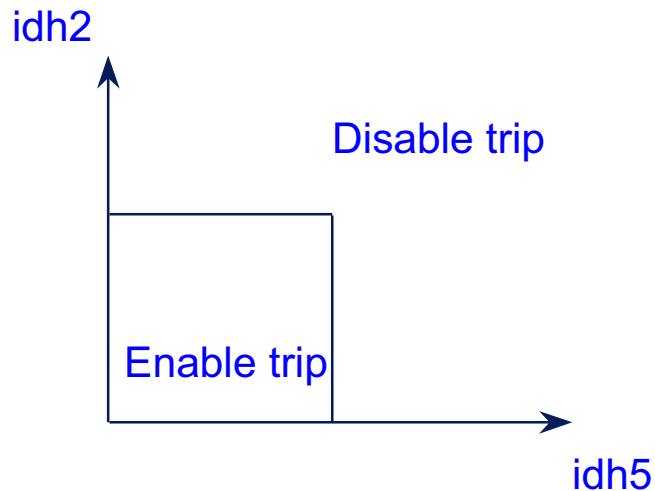
Classical harmonic restraint
regardless id and it

idh2

Disable trip

Enable trip

idh5
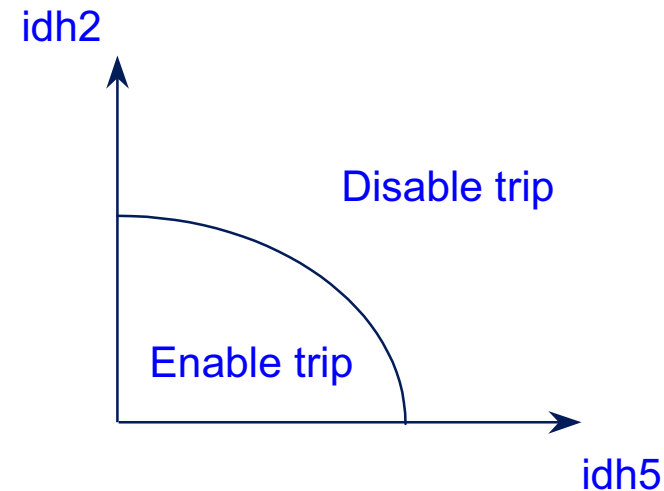
Neural network harmonic restraint
for one couple of id and it

■ Neural network adapt the harmonic restraint to the level of differential and
through current

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TRANSFORMER PROTECTION

S2000D is sensitive and stable in rated conditions ...

Id : differential current
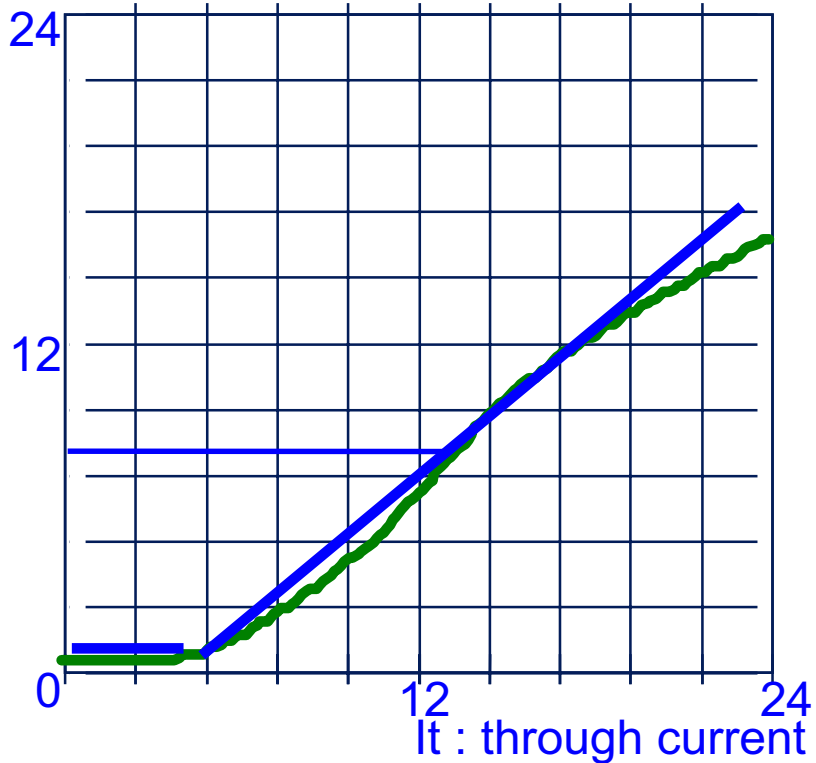
It : through current

- Comparison of the tripping characteristics of :
  - Sepam 2000 D, with neural network differential protection

  - Conventional differential protection

- For the same Id/It setting

- **In rated conditions : low 2nd and 5th harmonic ratios**

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TRANSFORMER PROTECTION

S2000D is sensitive and stable … during transformer inrush

Id : differential current
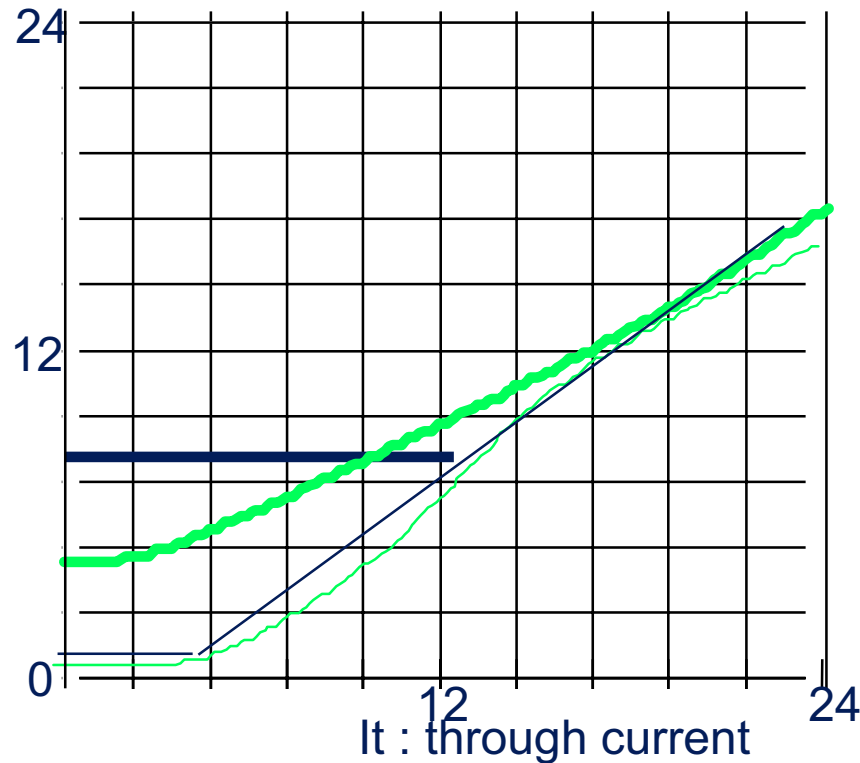
It : through current

- Comparison of the tripping characteristics of :

  Sepam 2000 D, with neural network differential protection

  Conventional differential protection

- For the same Id/It setting

- **On transformer inrush, with a 2nd harmonic ratio of 100%**

TRANSFORMER PROTECTION

Innovation to make easier customer's life: Only one setting

■ **For a conventional differential protection :**

???

Settings :

I-DIFF> (0.15 - 2.00)	2nd HARMON (on - off)
	2nd HARMON (10 -80%)
	CROSSB 2HM (0 - 1000 periods)
SLOPE 1 (0.10 - 0.50)	n. HARMON (5th 4th 3rd)
	n. HARMON (10 - 80%)
	CROSSB nHM (0 - 1000 periods)
	IDIFFmax n (0.5 - 20.0)
BASE PT 2 (0.0 - 10.0)	T-SAT-BLO (2 - 250 periods)
SLOPE 2 (0.25 - 0.95)	SAT-RESTR (5.00 - 15.00)
I-DIFF>> (0.15 - 2.00)	T-DELAY> (0.00 - 60.00s)
	T-DELAY>> (0.00 - 60.00s)
	T-RESET (0.00 - 60.00s)

■ **For Sepam 2000 D21/D22/D31 :**
   Slope of the percentage characteristic

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TRANSFORMER PROTECTION
Simplified choice of sensors

■ **For a conventional differential protection current sensors specified according to BS142, with :**

Vk = (Rtc + Rf). Isat,

et

$$Isat \geq (Id>>) . \frac{1}{1+e^{\frac{-0,5.T}{\tau}}} \left\{ \frac{\sqrt{3}}{2} + \omega\tau \left(1-e^{\frac{-1,7.T}{\tau}} \right) \right\}$$

■ **For Sepam 2000 D21/D22/D31 :**

5P20

No interposing CT's

BUSBAR PROTECTION

Merlin Gerin
Modicon
Square D
Telemecanique

Schneider Electric

BUSBAR PROTECTION

- Logic discrimination
- 87 : High impedance differential relay
- 87 : Percentage differential relay
- 81R : Rate Of Change Of Frequency
- 25 : Synchro-check
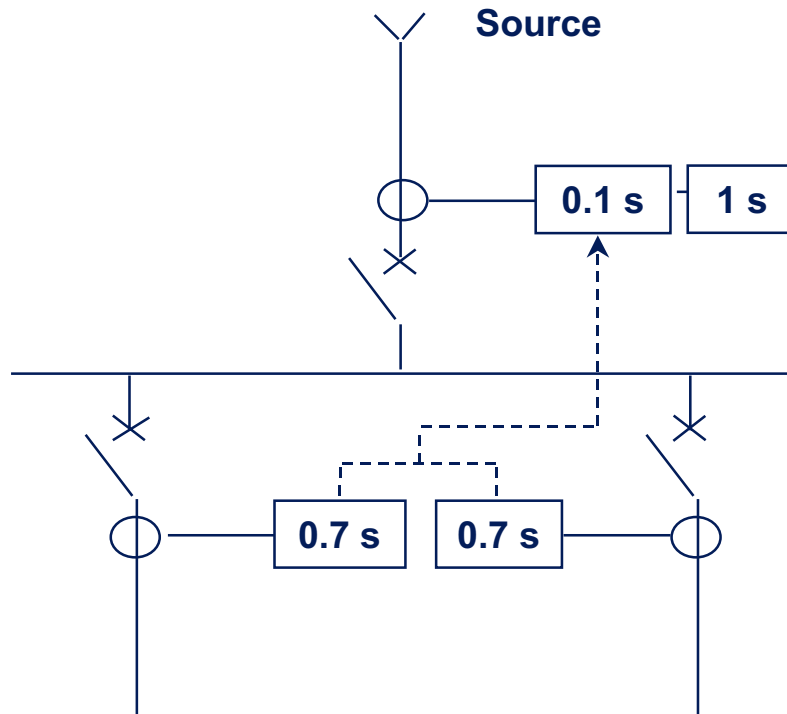
Schneider Electric

BUSBAR PROTECTION

■ **Logic discrimination :**

Source

| 0.1 s | 1 s |

Fault on busbar eliminated after 0.1 s without adding any other protection

| 0.7 s | 0.7 s |

BUSBAR PROTECTION

■ **Logic discrimination :**

BUSBAR PROTECTION

■ **High impedance differential protection (87) :**

Source

1 s

0.7 s

0.7 s

Differential relay

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BUSBAR PROTECTION

■ **High impedance differential protection (87) (cont'd) :**

3 incomers

7 feeders

No busbar coupling
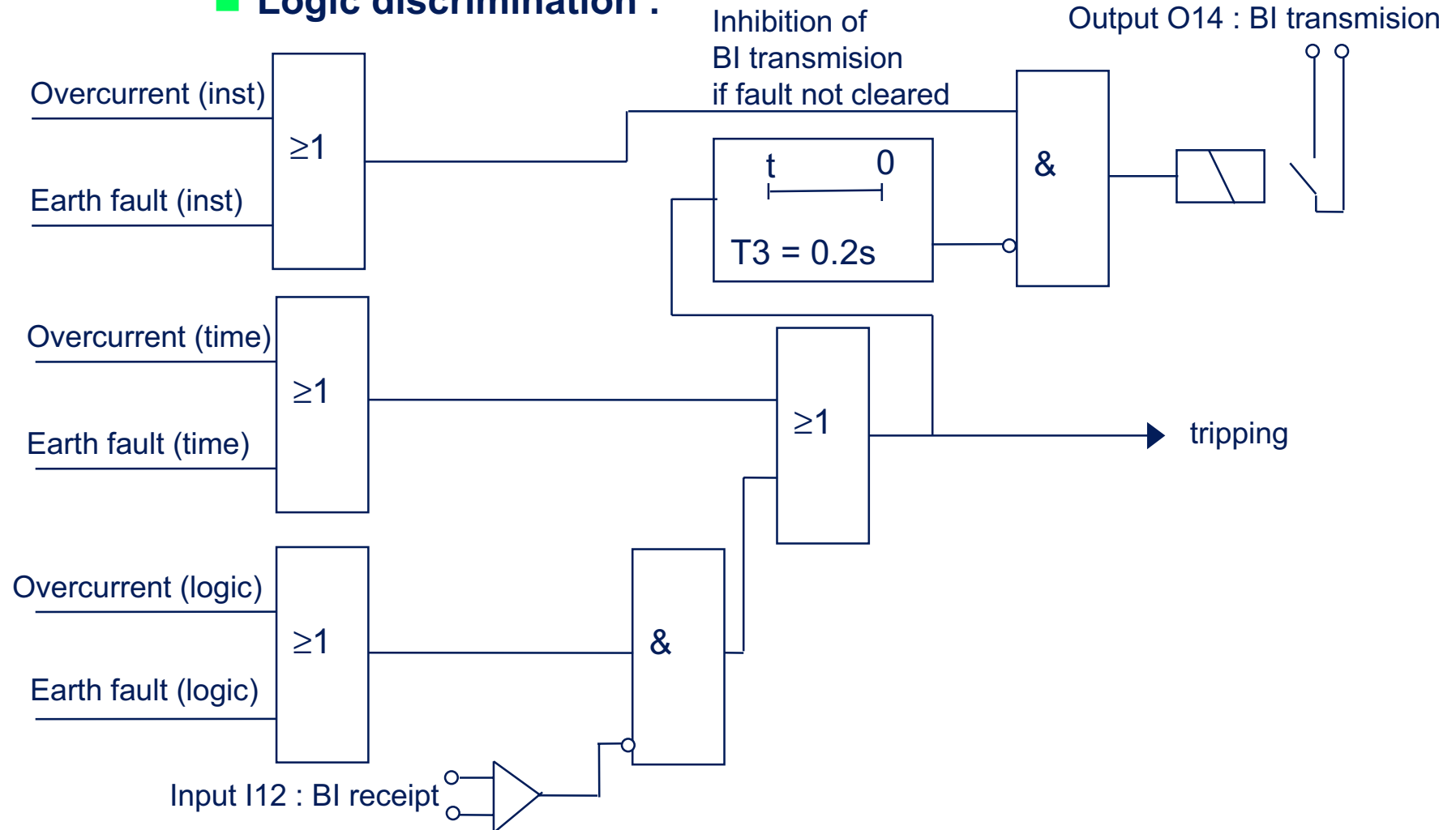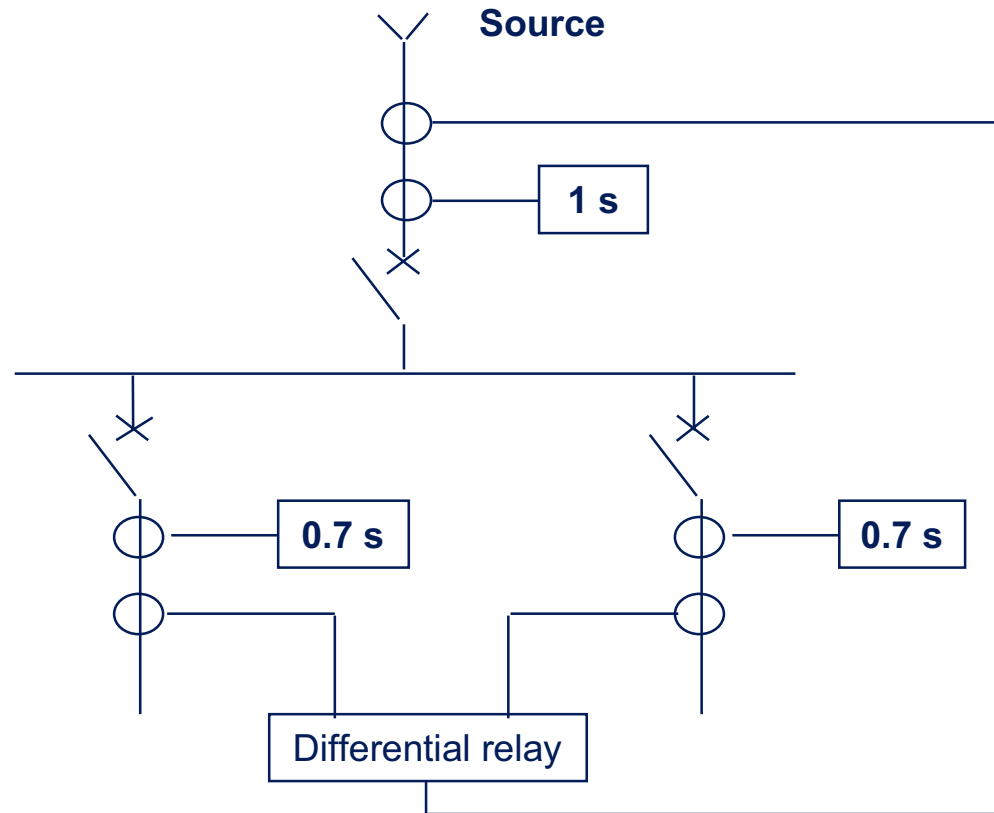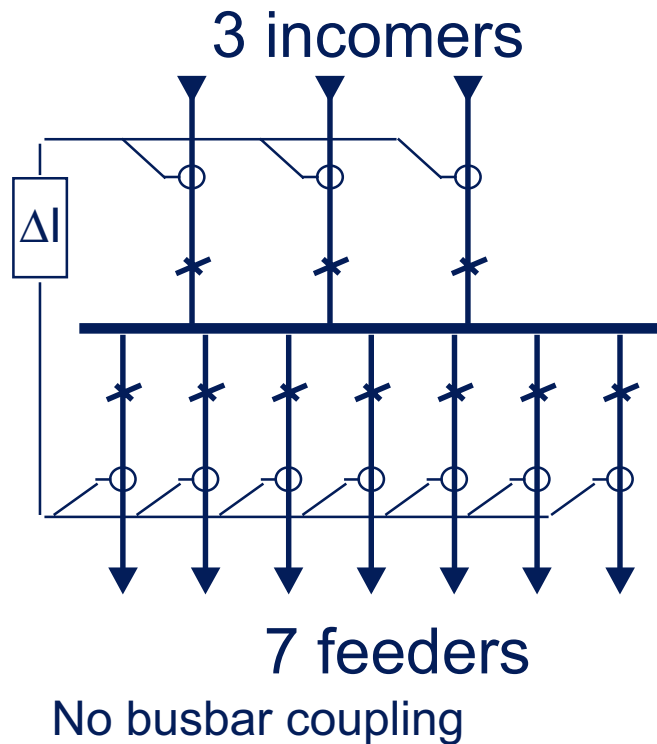
DATA

■ Max. 3-phase Isc = 30 kA

■ Sensors:

- 10 CTs in parallel per phase
- I_n/i_n: 2000 A / 5 A
- R_{CT} = 1.76 Ω
- i_μ = 20 mA for V=160 V
- Iscs = 30000x5/2000 = 75A

■ Wiring:

- L = 2x15 m max.
- S = 2.5 mm² Cu

■ Setting: I_s = 0.5I_n

■ Surge limiter: i_{RN} = 4 mA

BUSBAR PROTECTION

■ **High impedance differential protection (87) (cont'd) :**

■ Wiring resistance:

$$R_W = 0.0225 \times \frac{30}{2.5} = 0.27\Omega$$

■ CT knee-point voltage:

$$V_K \geq 2(R_{CT} + R_W)i_{scs}$$

$$V_K \geq 2 \times (1.76 + 0.27) \times 30000 \times \frac{5}{2000} = 304V$$

$$\Rightarrow \quad V_K = 320 \text{ V}$$

■ Stabilizing resistance:

$$(R_{CT} + R_W)\frac{i_{scs}}{i_s} < R_s \leq \frac{V_K}{2i_s}$$

$$(1.76 + 0.27) \times \frac{75}{0.5 \times 5} < R_s \leq \frac{320}{2 \times 0.5 \times 5}$$

$$61 < R_s \leq 64 \quad \Rightarrow \quad R_s = 64\Omega$$

■ Surge limiter:

$$V_{pk} = 2\sqrt{2V_K R_s i_{scs}}$$

$$V_{pk} = 2\sqrt{2 \times 320 \times 64 \times 75} = 3500V$$

$$V_{pk} > 3kV \quad \Rightarrow \quad \text{surge limiter required}$$

BUSBAR PROTECTION

■ **High impedance differential protection (87) (cont'd) :**

■ Number of limiter units:

$$N \geq \frac{i_{scs}}{40} = \frac{75}{40} = 1.9 \implies N = 2$$

■ Total limiter unit leakage current:

$$i_{RN} = 4N = 8 \; mA$$

■ Magnetizing current of a CT at $R_s.I_s$:

$$R_s.i_{set} = 64 \times 2.5 = 160 \, V$$

$$\implies i_\mu = 20 \, mA$$

■ Minimum primary current detected:

$$I_d = \frac{2000}{5}(i_{set} + 10 i_\mu + i_{RN})$$

$$I_d = \frac{2000}{5}(2.5 + 10 \times 0.02 + 0.008)$$

$$\implies I_d = 1083 A$$

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BUSBAR PROTECTION

■ **Percentage differential protection (87) :**

- Avantages :

  – Low impedance differential protection

  – CT ratios can be different

  – Low cost solution

Sepam D31 can be use to protect a busbar

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BUSBAR PROTECTION

■ **Percentage differential protection (87) (cont'd) :**

• **1 incomer, 1 bus tie, several feeders**

Incomer

Bus tie

sepam
D31
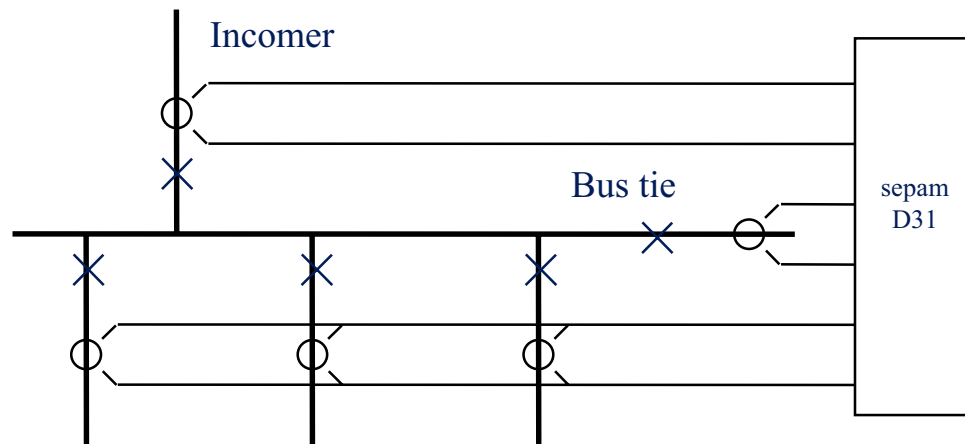
Feeders without generator

Same ratio for the three feeder CTs

$$2,5\frac{S}{\sqrt{3}.Un} \geq InCTs \geq 0,1\frac{S}{\sqrt{3}.Un}$$

$$S = \sqrt{3} \times Un \times Ids / 0.3$$

Un : Busbar rated voltage

Sizing of CTs :
IsatCTs $\geq$ 2.Isc
and   IsatCTs $\geq$ 20 InCTs

Isc : Maximum external short circuit current

InCTs : Rated current of CTs

Ids = 1.3 x maximum incomer (or feeder) rated current

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BUSBAR PROTECTION

■ **Percentage differential protection (87) (cont'd) :**

• **1 incomer, 2 feeders**

Incomer

sepam
D31

Feeders with or without generator
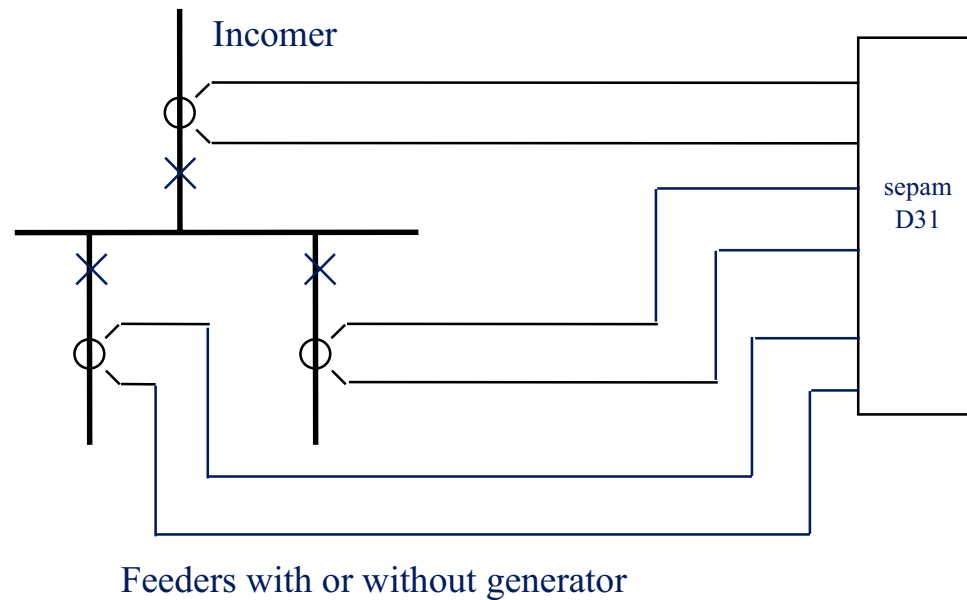
BUSBAR PROTECTION

■ **Percentage differential protection (87) (cont'd) :**

• **2 incomers, several feeders**

Incomer   Incomer

sepam
D31

Feeders without generator
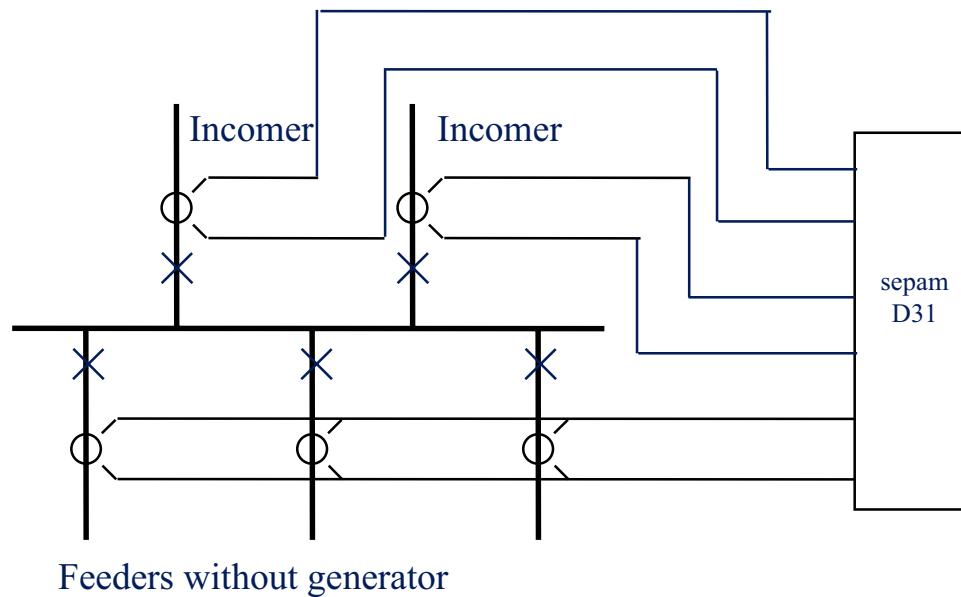
BUSBAR PROTECTION

■ **Percentage differential protection (87) (cont'd) :**

• **example :**

S = 31.5 MVA

In = 1730 A

Icc = 14 kA

2500/5

Bus tie 2500/5

sepam D31

2500/5

2500/5 2500/5 2500/5

M M

Icc = 4.8 kA (motor supply)

P = 12.5 MW cos Phi = 0.9 S = 14.2 MVA
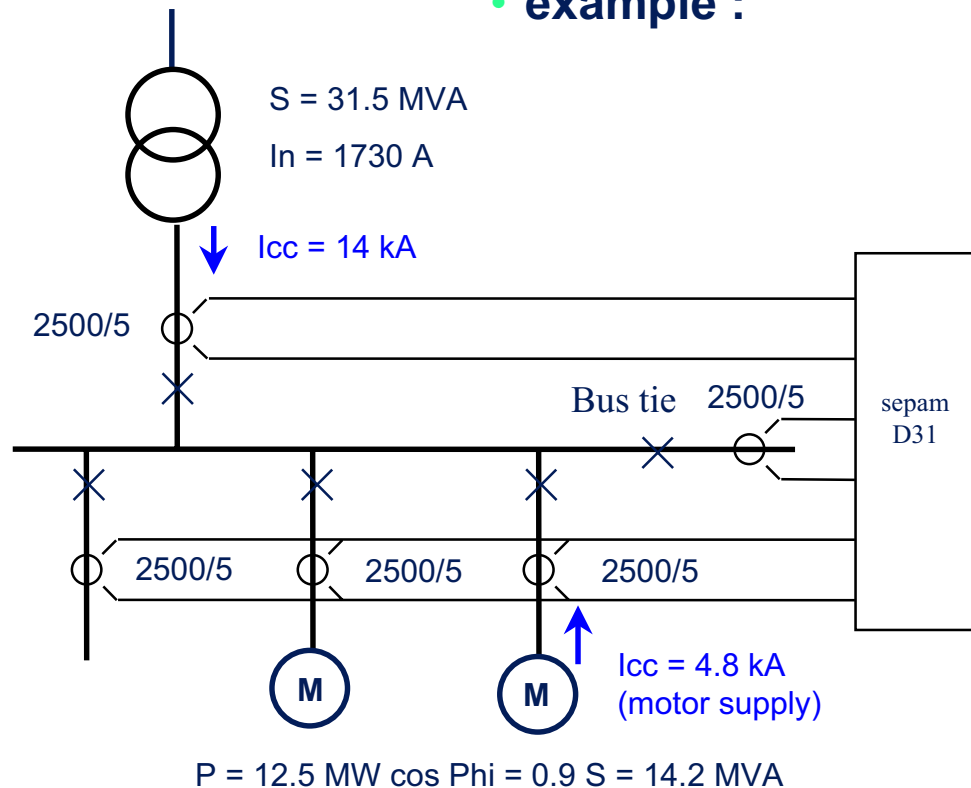
Setting of the relay :

In = In' = In" = 2500 A

Un = Un' = Un" = 10.5 kV

phase shift = 0

Sensitivity : Ids = 1.3 x 1730 = 2249 A

$$S = \frac{\sqrt{3} \times Un \times Ids}{0.3} = 136 MVA$$

Slope : Id/It = 15%

$$0.4 \leq \frac{S}{\sqrt{3} \times Un \times In} \leq 10$$

$$\frac{S}{\sqrt{3} \times Un \times In} = 2.99$$

Schneider Electric

BUSBAR PROTECTION

- **Rate Of Change Of Frequency protection (81R) :**
  - Loss of main application
  - Load shedding application
  - Complement to underfrequency (81L) and overfrequency (81H) protections
  - ROCOF measurement based on positive sequence voltage

Underfrequency protection (81L)

$$t2 = \frac{f - f\min}{df / dt} + timesetting$$

f

fmin

Time setting

t1   t2

t
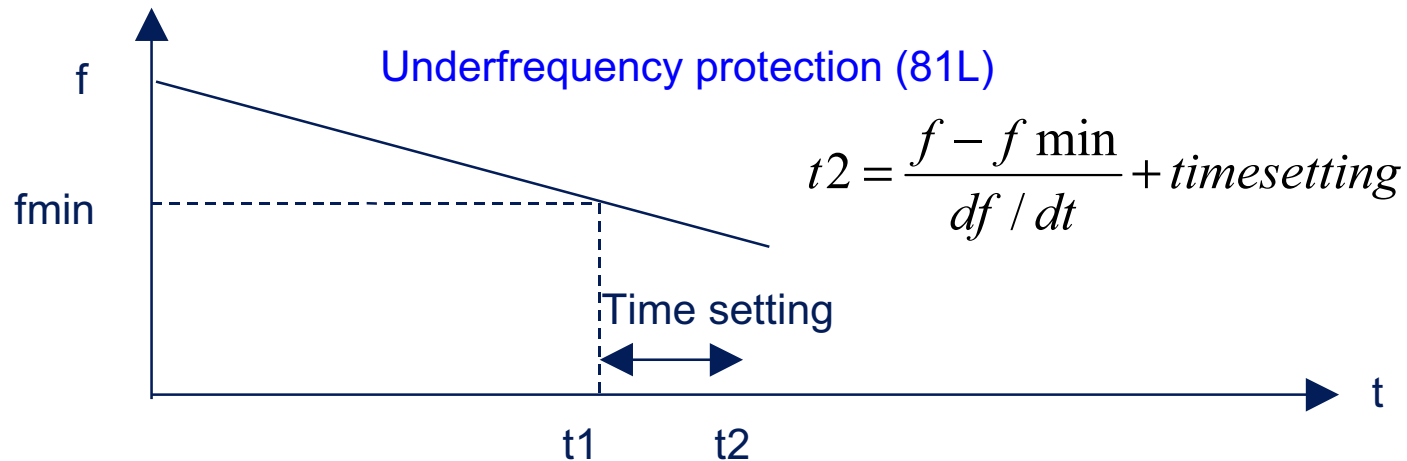
BUSBAR PROTECTION

■ **Rate Of Change Of Frequency protection (81R) (cont'd) :**
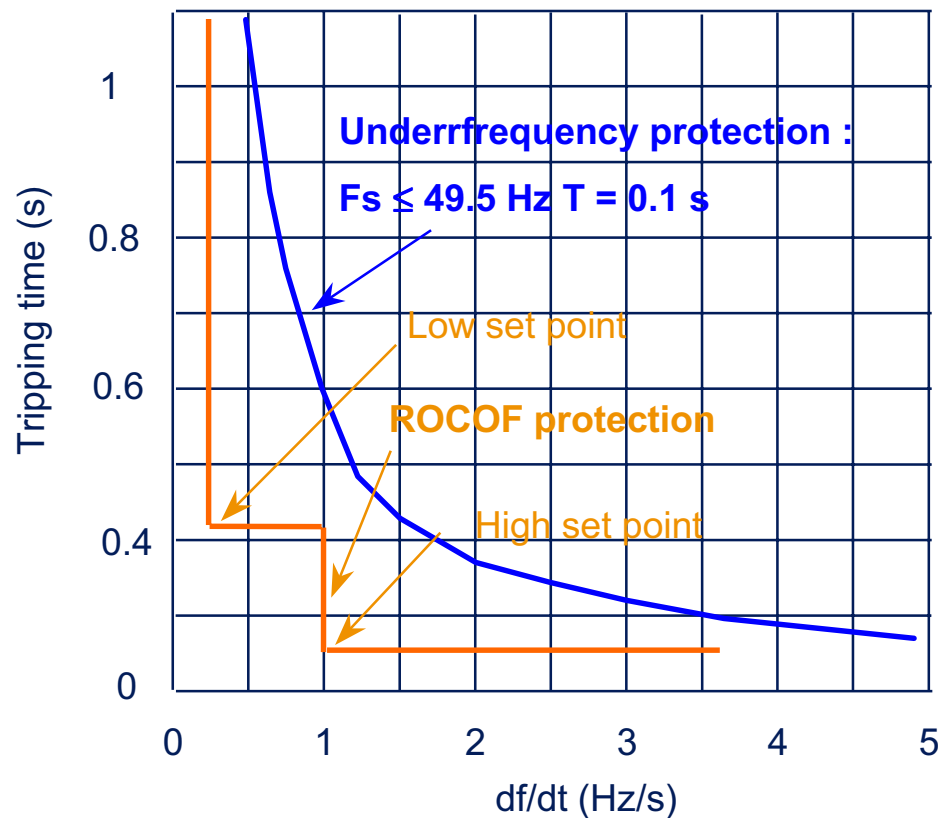
Low set point :

$$df / dt = \frac{\Delta P \times Fn}{2 \times Sn \times H}$$

$$H = \frac{J \times \omega^2}{2 \times Sn}$$

Sn : Rated power

Fn : Rated frequency

H : Inertia constant

J : Inertia moment

ω : machine speed (rd/s)

BUSBAR PROTECTION

- **Rate Of Change Of Frequency protection (81R) (cont'd) :**

  - Typical inertia constant value :

  $0.5 \leq H \leq 1.5$ for diesel and low rated generators (≤ 2 MVA)

  $2 \leq H \leq 5$ for gas turbine and medium rated generators (≤ 40 MVA)

  - Low set point :

    - $df/dt \approx 0.2$ Hz $T \approx 0.3 - 0.5$ s

    - Disturbances such as fault, load variation... causes frequency swing

  - High set point :

    - $df/dt \approx 1$ Hz $T \approx 0.15$ s

    - To provide faster tripping than the frequency protection

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BUSBAR PROTECTION

■ **Synchro-check (25) :**

- dUs set point : can depend on power transit
- dFs set point :depends only on accuracy
- dPhi set point :can depend on power transit
- Us high : to detect presence of voltage
- Us low : to detect absence of voltage
- Time Ta : to take into account of the circuit breaker closing time

BUSBAR PROTECTION
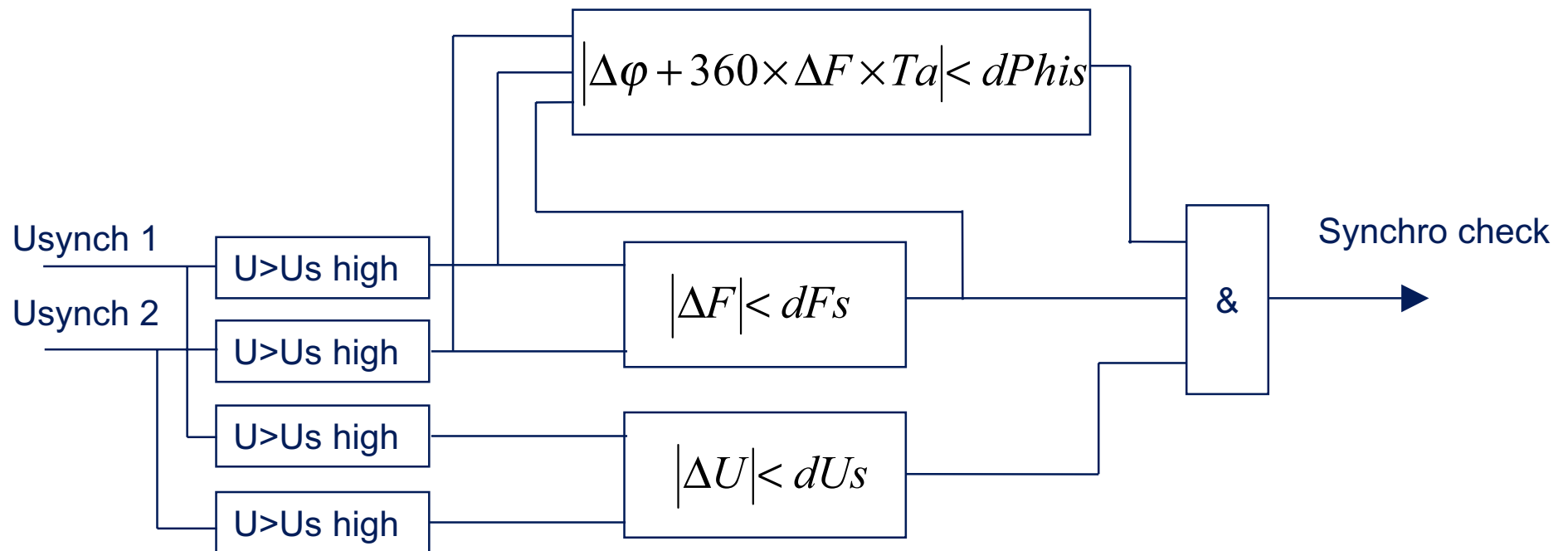
■ **Synchro-check (25) (cont'd) :**

BUSBAR PROTECTION
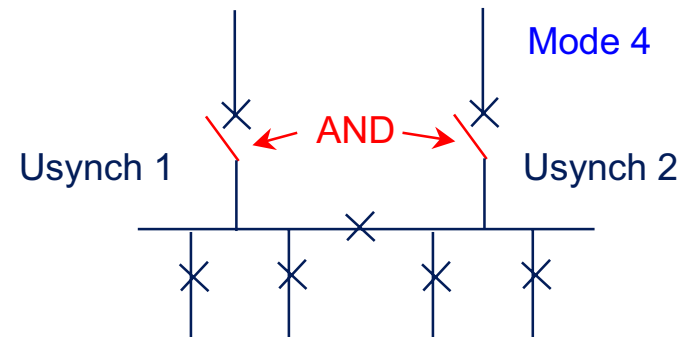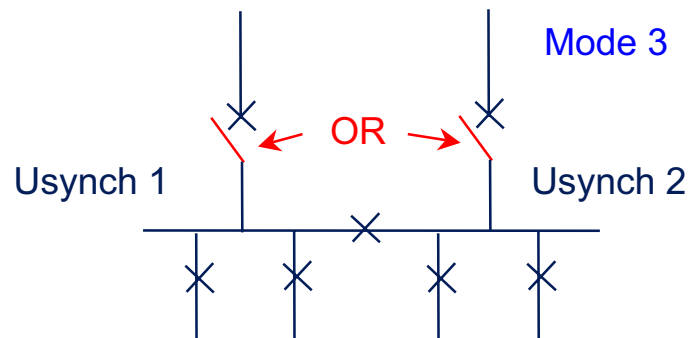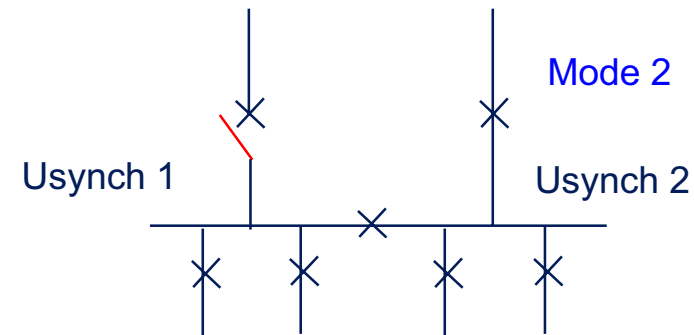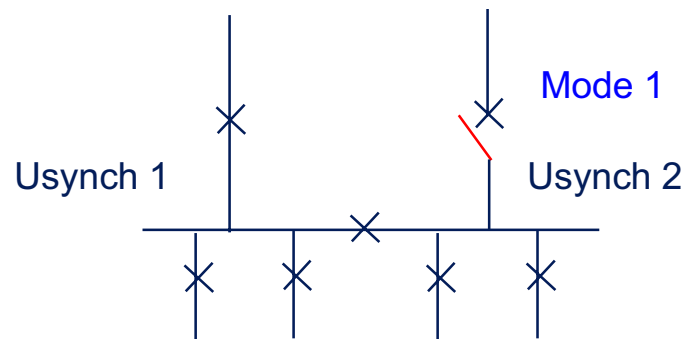
■ **Synchro-check (25) (cont'd) :**

- 4 operating modes :

Mode 1

Usynch 1   Usynch 2

Mode 2

Usynch 1   Usynch 2

Mode 3

Usynch 1   ← OR →   Usynch 2

Mode 4

Usynch 1   ← AND →   Usynch 2

SUBSTATION PROTECTION

SUBSTATION PROTECTION

- Logic discrimination
- 50:51 : Phase overcurrent
- 50N/51N : earth fault
- 46 : Negative sequence / unbalance
- 27 : Undervoltage
- 27R : Remanent undervoltage
- 59 : Overvoltage
- 59N : Residual overvoltage
- 67 : Phase directional overcurrent
- 67N : Directional earth fault
- 32P : Reverse real power
- 81R : Rate Of Change Of Frequency

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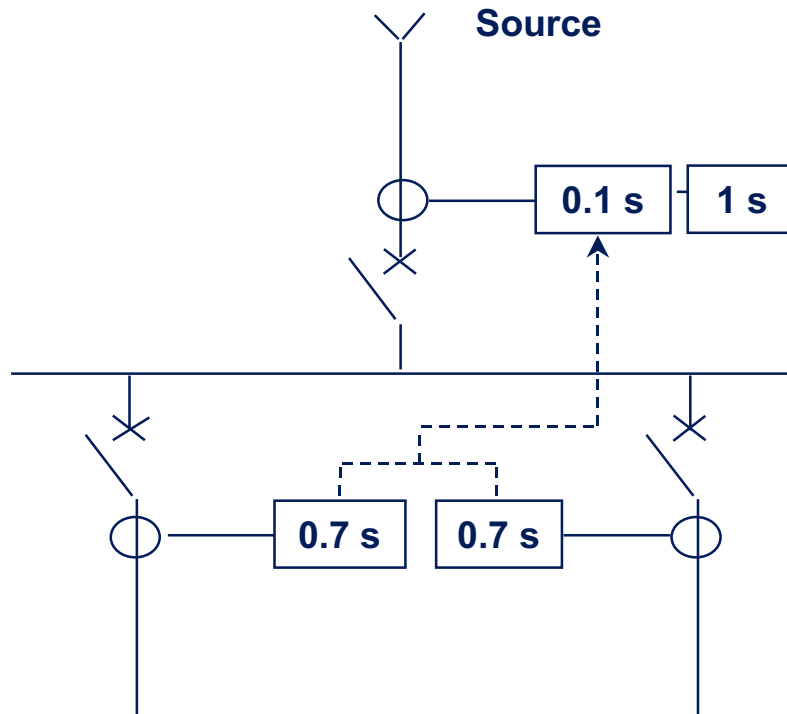
SUBSTATION PROTECTION

■ **Logic discrimination :**

Source

Fault on busbar eliminated after 0.1 s without adding any other protection

0.1 s — 1 s

0.7 s   0.7 s

SUBSTATION PROTECTION

■ **Logic discrimination :**

Overcurrent (inst)

Earth fault (inst)

≥1

Inhibition of
BI transmision
if fault not cleared

t   0

T3 = 0.2s

&

Output O14 : BI transmision

Overcurrent (time)

Earth fault (time)

≥1

≥1

tripping

Overcurrent (logic)

Earth fault (logic)

≥1

&

Input I12 : BI receipt
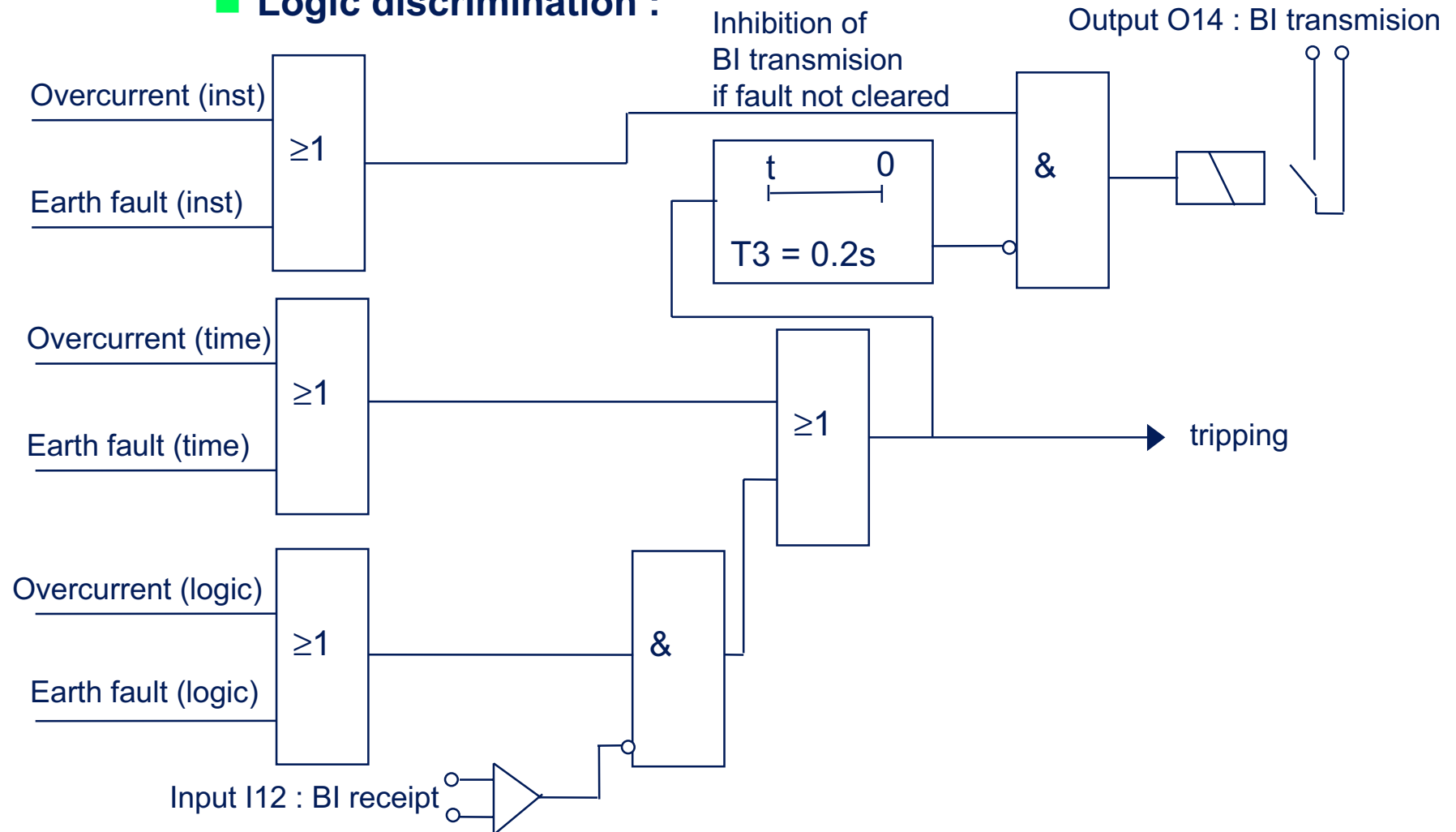
SUBSTATION PROTECTION

■ **Overcurrent (50/51) :**

• DT and IDMT curves

   Transient overreach = (Iso - Is1) / Is1

   Iso = setting current, that is, r.m.s. value of steady state current required to operate the relay

   Is1 = steady state r.m.s. value of the fault current which when fully offset will just operate the relay

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SUBSTATION PROTECTION

■ **Overcurrent (50/51) :**

- Current shape in case of saturation of CT:

I ct

Peak value

Right value

Fundamental
value

t

Low value of fundamental current ⇒ risk of no detection of
the fault ⇒ measurement of peak value

Schneider Electric

SUBSTATION PROTECTION

- **Overcurrent (50/51) :**
  - Current shape in case of no saturation of CT :

I ct

Peak value

Filtered peak value

t

Transient overreach can be very high if only the peak value is considered $\Rightarrow$ peak value is filtered (no DC component)

SUBSTATION PROTECTION

■ **Overcurrent (50/51) :**

- • Conclusion :

- • Filtered peak detection is used to ensure tripping in case of CT saturation
- • Efficace value avoids the risk of unexpected tripping

SEPAM MIX THE TWO MEASUREMENTS TO GUARANTEE A GOOD TRANSIENT OVERREACH (LESS THAN 10% FOR ANY TIME CONSTANT)

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SUBSTATION PROTECTION

■ **Earth fault (50N/51N) :**

Harmonic 2 restrain

An earth fault current (including harmonic 2) could appear
in case of CT saturation if earth fault is measured by means
of the sum of 3 TC.

SUBSTATION PROTECTION
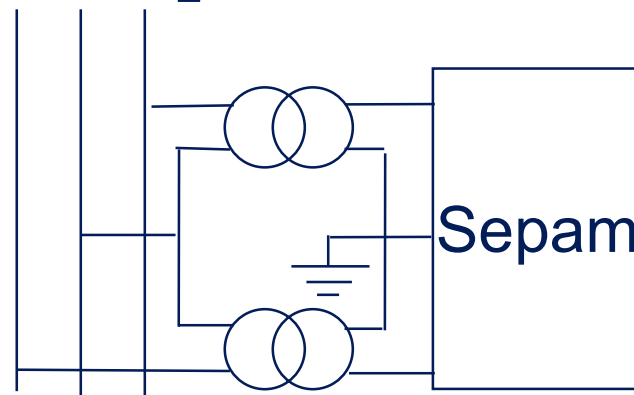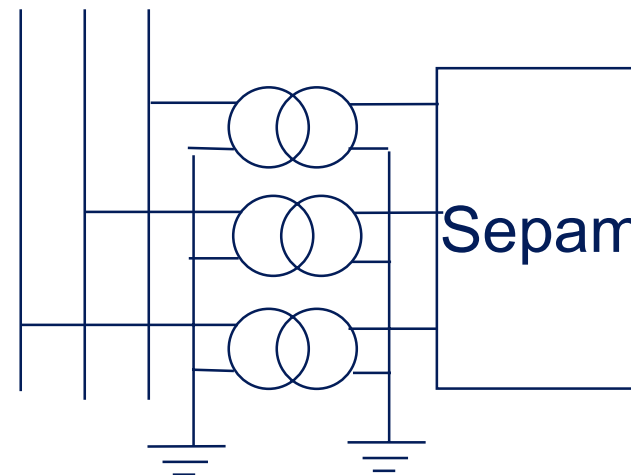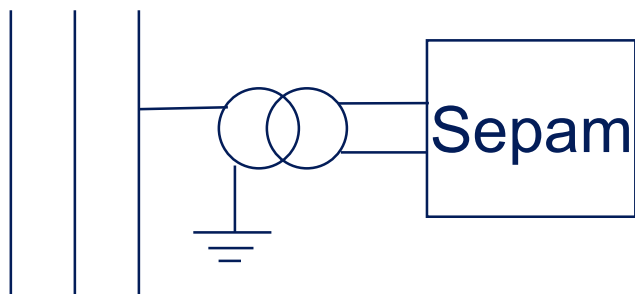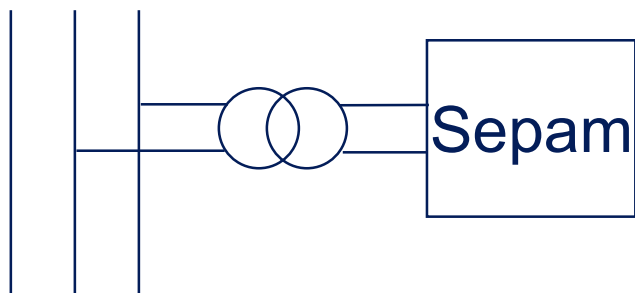
■ **Undervoltage (27) :**

SUBSTATION PROTECTION

Undervoltage (27) : coordination with overcurrent protection

■ Undervoltage protection

■ Overcurrent protection
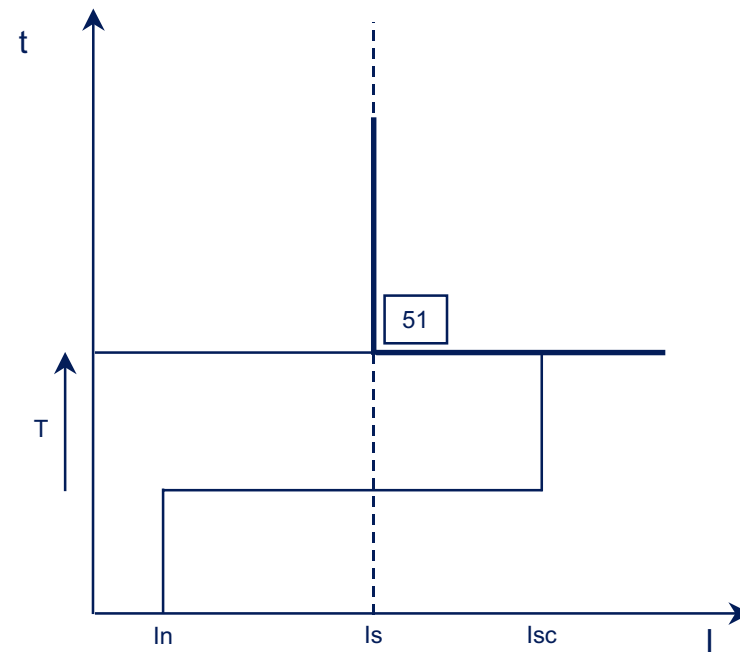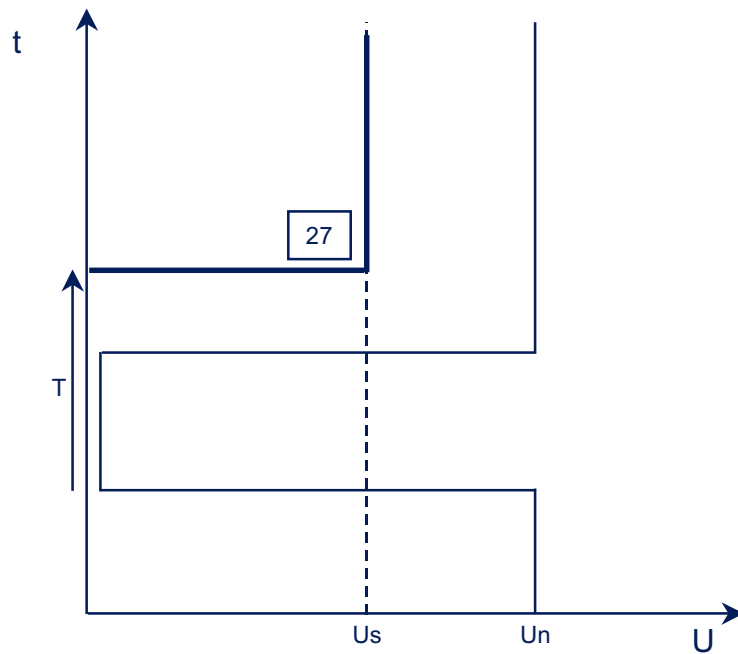
SUBSTATION PROTECTION

■ **Remanent undervoltage (27R) :**

- If the feeder supplies power to machines that should not be energized until the voltage, maintained by the machines after the opening of the circuit by an automatic changeover device, drops below a given value.

SUBSTATION PROTECTION

■ **Overvoltage (59) :**
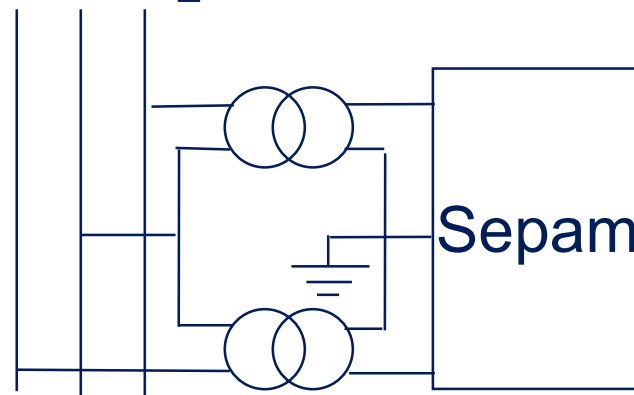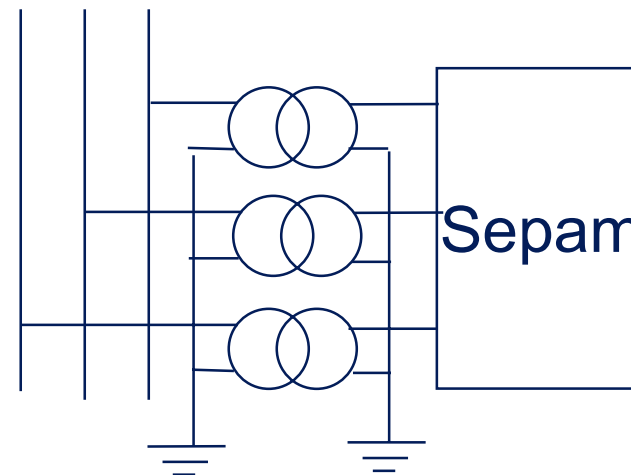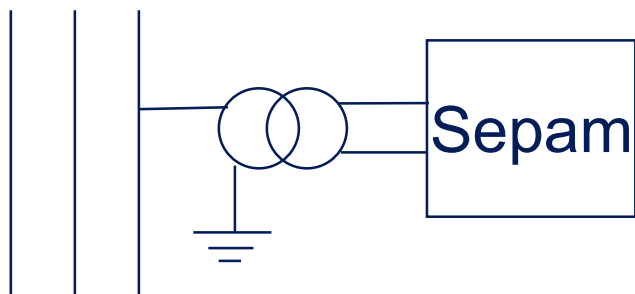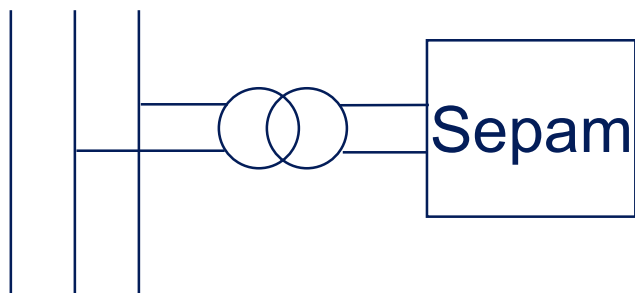
SUBSTATION PROTECTION

■ **Residual overvoltage (59N) :**

- • For isolated neutral 59N protection is required to detect earth fault before closing the circuit breaker

- • This function can be located elsewhere in the network (on busbar for example)

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SUBSTATION PROTECTION

■ **Phase directional overcurrent (67) :**

- Necessary to have horizontal discrimination in case of several power supplies operating in parallel
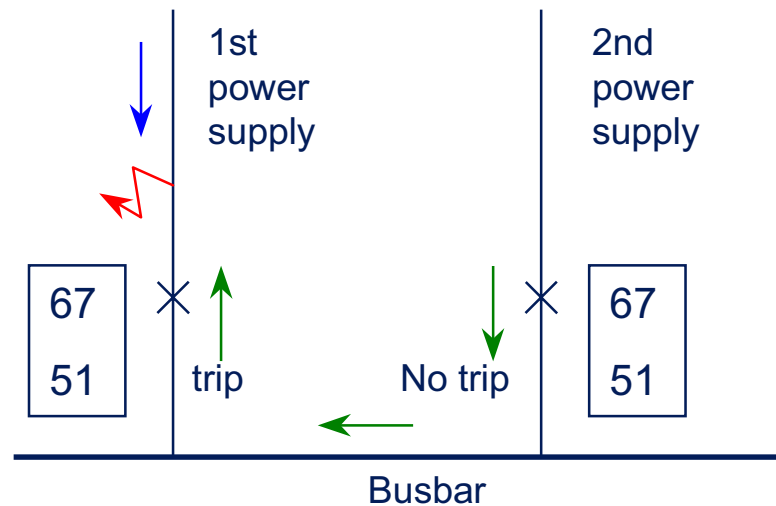
SUBSTATION PROTECTION
Phase directional overcurrent (67) :
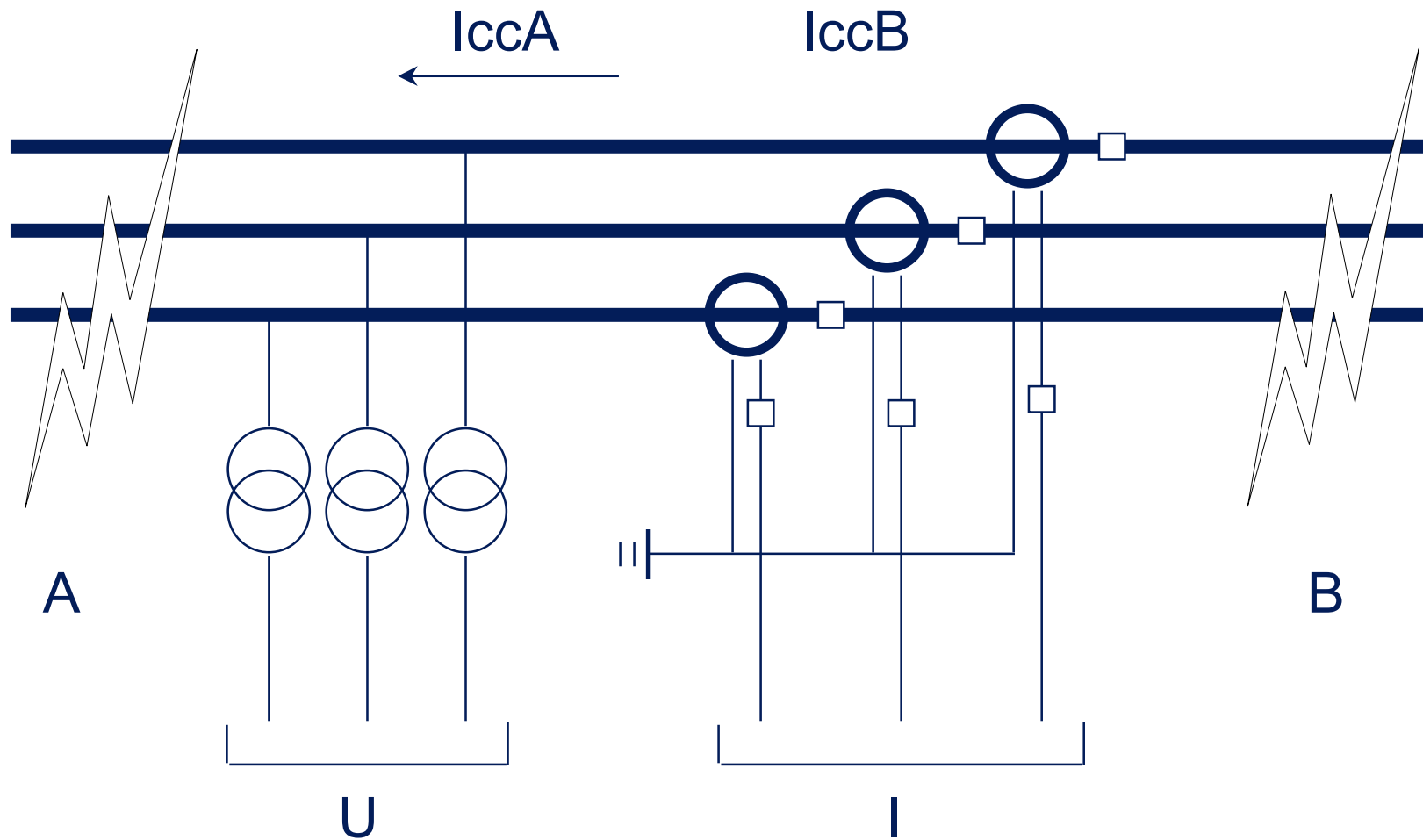
SUBSTATION PROTECTION
Phase directional overcurrent (cont'd) (67) :
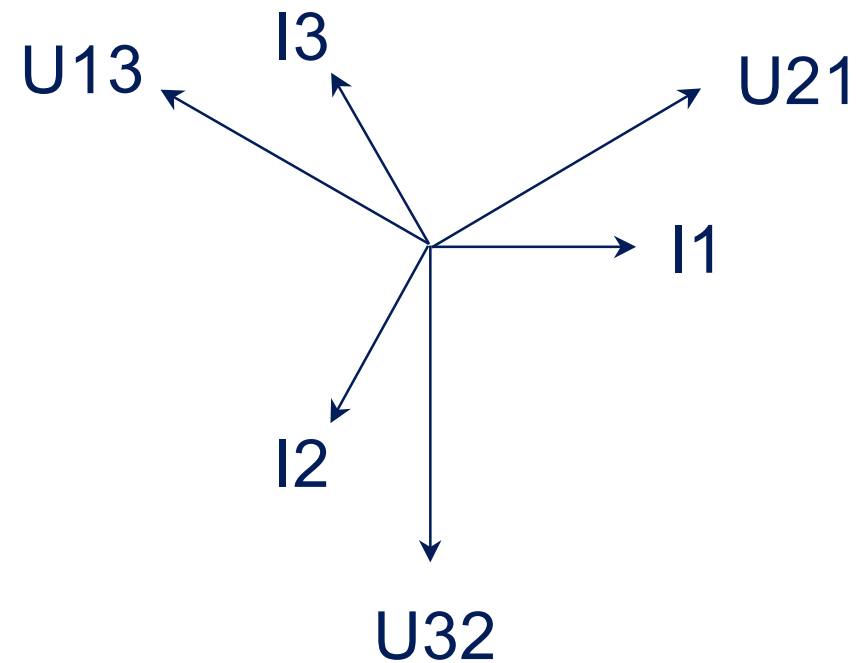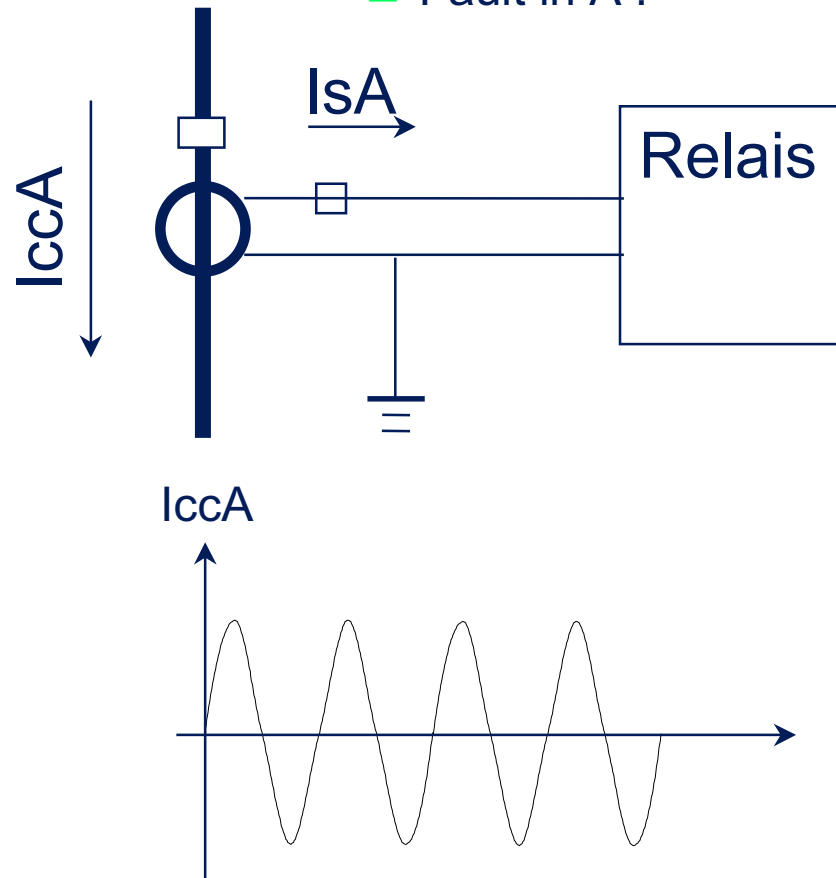
■ Fault in A :

SUBSTATION PROTECTION
Phase directional overcurrent (cont'd) (67) :
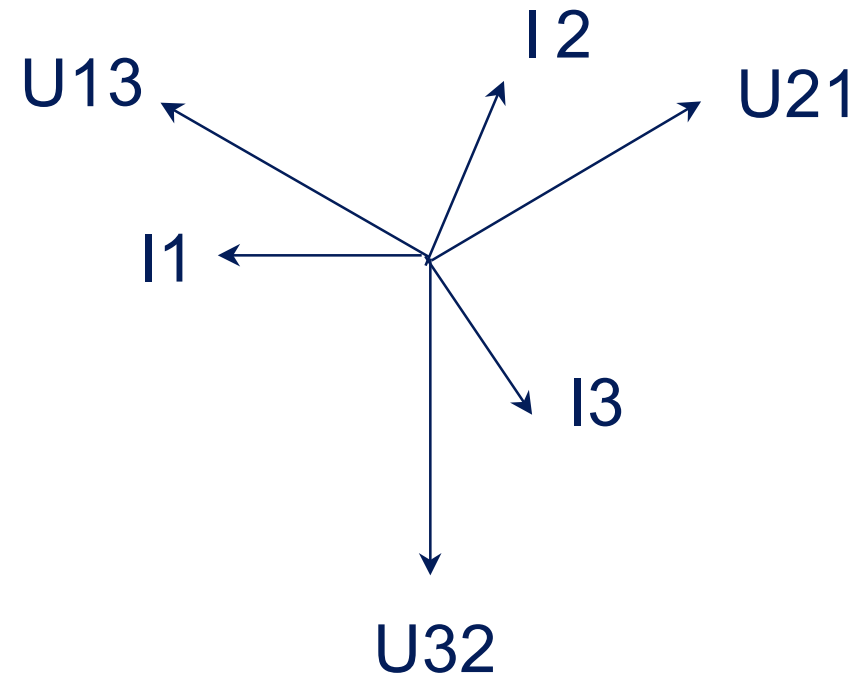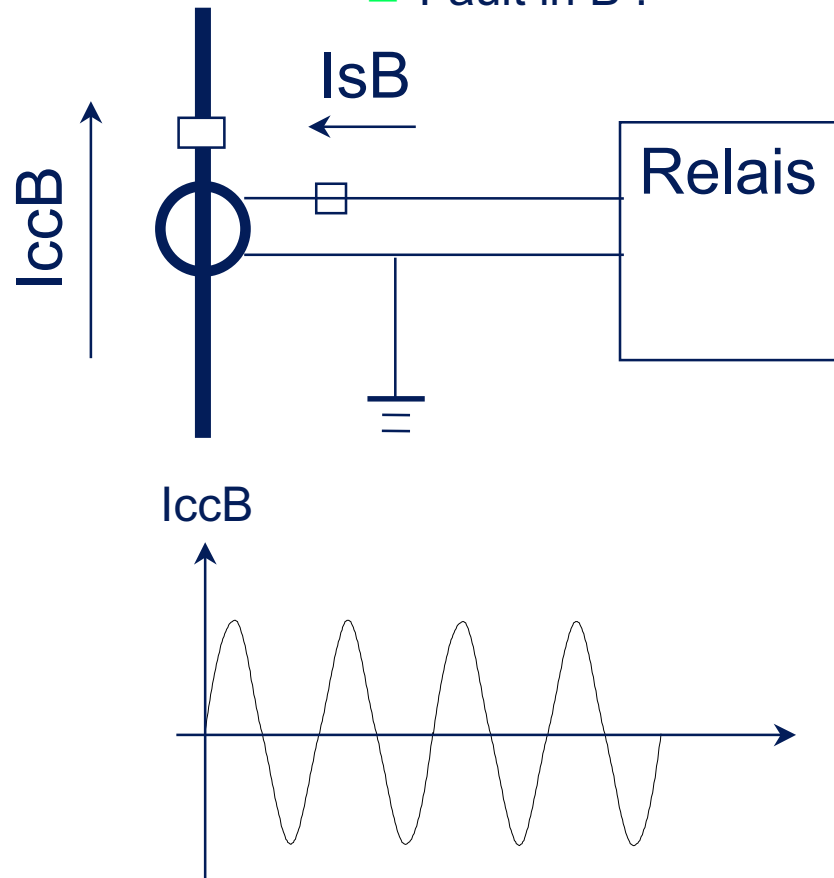
■ Fault in B :

SUBSTATION PROTECTION
Phase directional overcurrent (cont'd) (67) :

- Measurement of the phase shift angle between a reference voltage, called the polarization voltage, and a current makes it possible to determine the current direction

- In practice:
  - polarization by phase-to-phase voltage
  - measurement of $\varphi 1$= phase shift (U32,I1), $\varphi 2$= phase shift (U13,I2) and $\varphi 3$ = phase shift (U21,I3)

SUBSTATION PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Conventions :**

I1

I1 in normal direction

$\varphi 1$

$\varphi 1$

U32

I1

I1 in inverse direction

■ $\varphi 1$ = phase shift (U32,I1)
varies according to the impedance of the circuit under consideration

■ Conventional current direction:
- Normal direction = from busbar to cable
- Inverse direction = from cable to busbar

■ Conventional CT wiring:
normal direction   inverse direction

I

I

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SUBSTATION PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Characteristic angle θ :**

Normal zone

θ

U32

Inverse zone

■ Division of a current vectorial plane into 2 half-planes:
  • normal zone
  • inverse zone

■ Characteristic angle θ =
angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage

■ Setting values of θ :
  • 30° if high reactance circuit (φ1minimum)
  • 45° average case
  • 60° if high resistance circuit (φ1 maximum)

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SUBSTATION PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Principle :**

Phase overcurrent
Direction detection in normal direction
Directional protection function
tripping zone

■ Association of 2 functions:

- phase overcurrent protection function
  adjustable setting Is
  Definite or IDMT time

- detection of the current direction
  characteristic angle θ

■ Three-phase protection

- I1 and φ1 (phase shift U32,I1)

- I2 and φ2 (phase shift U13,I2)

- I3 and φ3 (phase shift U21,I3)

■ Protection operational if:
polarization voltage > 1.5%Un

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SUBSTATION PROTECTION

■ **Directional earth fault (67N) :**

- Necessary to have horizontal discrimination in case of several earthing systems operating in parallel

1st earthing system

2nd earthing system

67N					67N
51	trip		No trip		51

Busbar

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SUBSTATION PROTECTION

■ **Directional earth fault (67N) :**

- Necessary to have horizontal discrimination in case of several feeders with high capacitive current comparing with maximum earthing fault current

Busbar

67N   trip

67N   No trip
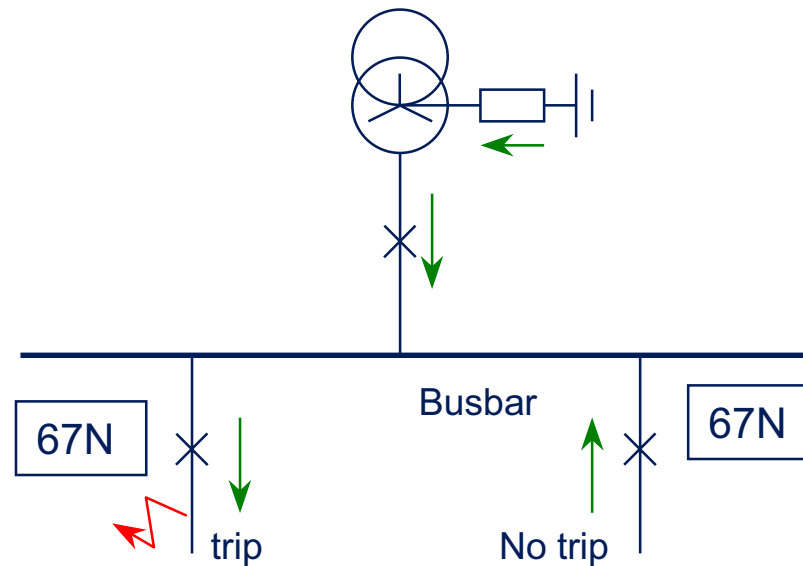
SUBSTATION PROTECTION
Directional earth fault (67N) :

SUBSTATION PROTECTION
Directional earth fault (67N) (cont'd):

φ0A

V2

Fault at A

N

V1

Vrsd

Normal direction

IrsdA

V3

$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\,\vec{Z}_N \times \vec{I}_{rsd}$$

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SUBSTATION PROTECTION
Directional earth fault (67N) (cont'd):

IrsdB   V2   **Fault at B**

φ0B

N

V1   Vrsd

Reverse direction

V3
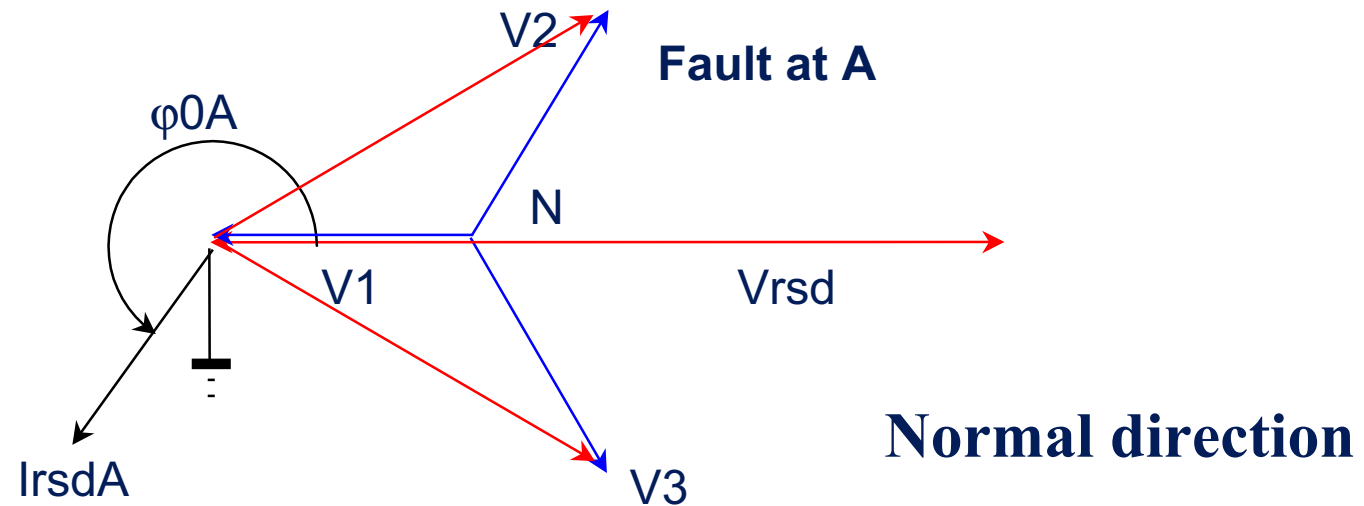
$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\,\vec{Z}_N \times \vec{I}_{rsd}$$

SUBSTATION PROTECTION
Directional earth fault (67N) (cont'd):

■ Measurement of the phase shift angle between the residual voltage - called the polarization voltage - and the earth fault current makes it possible to determine the direction

SUBSTATION PROTECTION
Directional earth fault (67N) (cont'd):

Inverse zone

Vrsd

Normal zone

- Division of a current vectorial plane into 2 half-planes:
  - normal zone
  - inverse zone

- Characteristic angle $\theta0$ = **angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage**

- Typical values of $\theta0$:
  - 0° if N earthed by resistance
  - 15°, 30°, 45°, 60°: intermediate values
  - 90° if isolated neutral (Irsd=Icapa)
  - -45° if N earthed by reactance

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SUBSTATION PROTECTION
Directional earth fault (67N) (cont'd):

inverse zone

$\theta0=45°$

$\varphi0$ Is0

Vrsd

Ip

normal zone

Irsd

Earth fault
Direction detection in normal direction
Directional protection function
tripping zone

- Association of 2 functions:
  - earth fault protection function adjustable setting Is0 Definite time
  - detection of the current direction characteristic angle $\theta0$

- Plane single-pole protection
  - Ip : projection of Irsd on the characteristic line
  - $\varphi0$: phase shift (Vrsd,Irsd)

- Protection operational if: polarization voltage >= 2.6% Un

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SUBSTATION PROTECTION
Directional earth fault (67N) (cont'd):

COMPENSATED NEUTRAL SYSTEM :

■ Petersen coil + resistor:

- • designed to compensate capacitive currents
  => Irsd is highly resistive

=> characteristic angle not adjustable: $\theta 0 = 0°$

- • self-extinguishing earth fault
  => short, recurring faults

=> protection memory time adjustable
    Tmem ~ 250 ms

- • in practice, the system is slightly dissymmetrical and the residual voltage is not zero when there is no fault

=> Vs0 setting adjustable

SUBSTATION PROTECTION

■ **Rate Of Change Of Frequency protection (81R) :**

- Loss of main application

- Load shedding application

- Complement to underfrequency (81L) and overfrequency (81H) protections

- ROCOF measurement based on positive sequence voltage

Underfrequency protection (81L)

$$t2 = \frac{f - f\min}{df / dt} + timesetting$$

Time setting

f

fmin

t1   t2

t

SUBSTATION PROTECTION

■ **Rate Of Change Of Frequency protection (81R) (cont'd) :**

Tripping time (s) (y-axis): 1, 0.8, 0.6, 0.4, 0

df/dt (Hz/s) (x-axis): 0, 1, 2, 3, 4, 5

Underrfrequency protection :

Fs ≤ 49.5 Hz T = 0.1 s

Low set point

ROCOF protection

High set point

Low set point :

$$df/dt = \frac{\Delta P \times Fn}{2 \times Sn \times H}$$

$$H = \frac{J \times \omega^2}{2 \times Sn}$$

Sn : Rated power

Fn : Rated frequency

H : Inertia constant

J : Inertia moment

ω : machine speed (rd/s)

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SUBSTATION PROTECTION

- **Rate Of Change Of Frequency protection (81R) (cont'd) :**

  - Typical inertia constant value :

  $0.5 \leq H \leq 1.5$ for diesel and low rated generators (≤ 2 MVA)

  $2 \leq H \leq 5$ for gas turbine and medium rated generators (≤ 40 MVA)

  - Low set point :

    - $df/dt \approx 0.2$ Hz $T \approx 0.3 - 0.5$ s

    - Disturbances such as fault, load variation... causes frequency swing

  - High set point :

    - $df/dt \approx 1$ Hz $T \approx 0.15$ s

    - To provide faster tripping than the frequency protection

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RING NETWORK PROTECTION

OPEN RING NETWORK PROTECTION

source

51

51

substation

substation

Fault detector

fault

open

substation

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CLOSED RING NETWORK PROTECTION
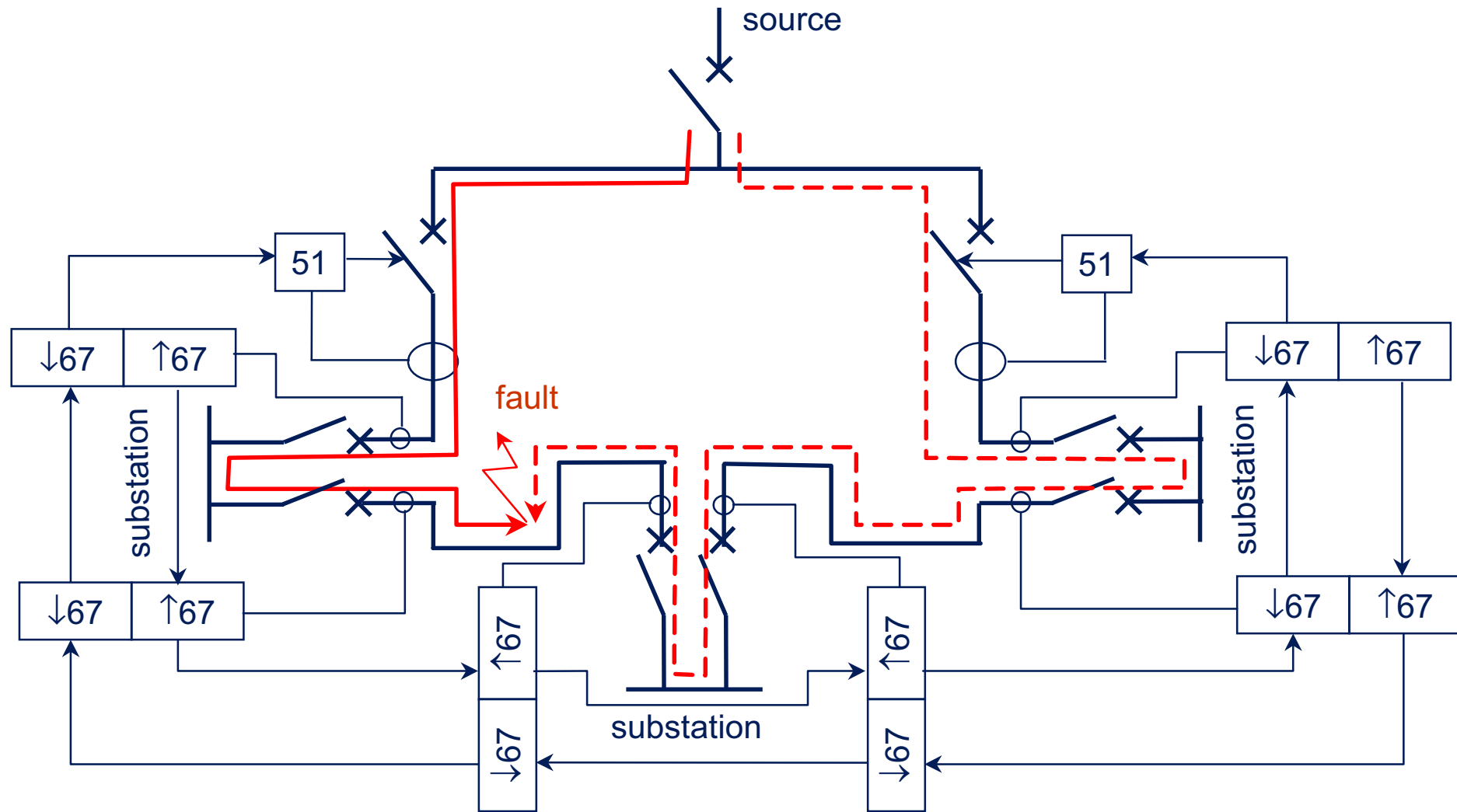
CAPACITOR PROTECTION

CAPACITOR PROTECTION

- Logic discrimination
- 49 : Thermal overload
- 51 : Unbalance overcurrent protection
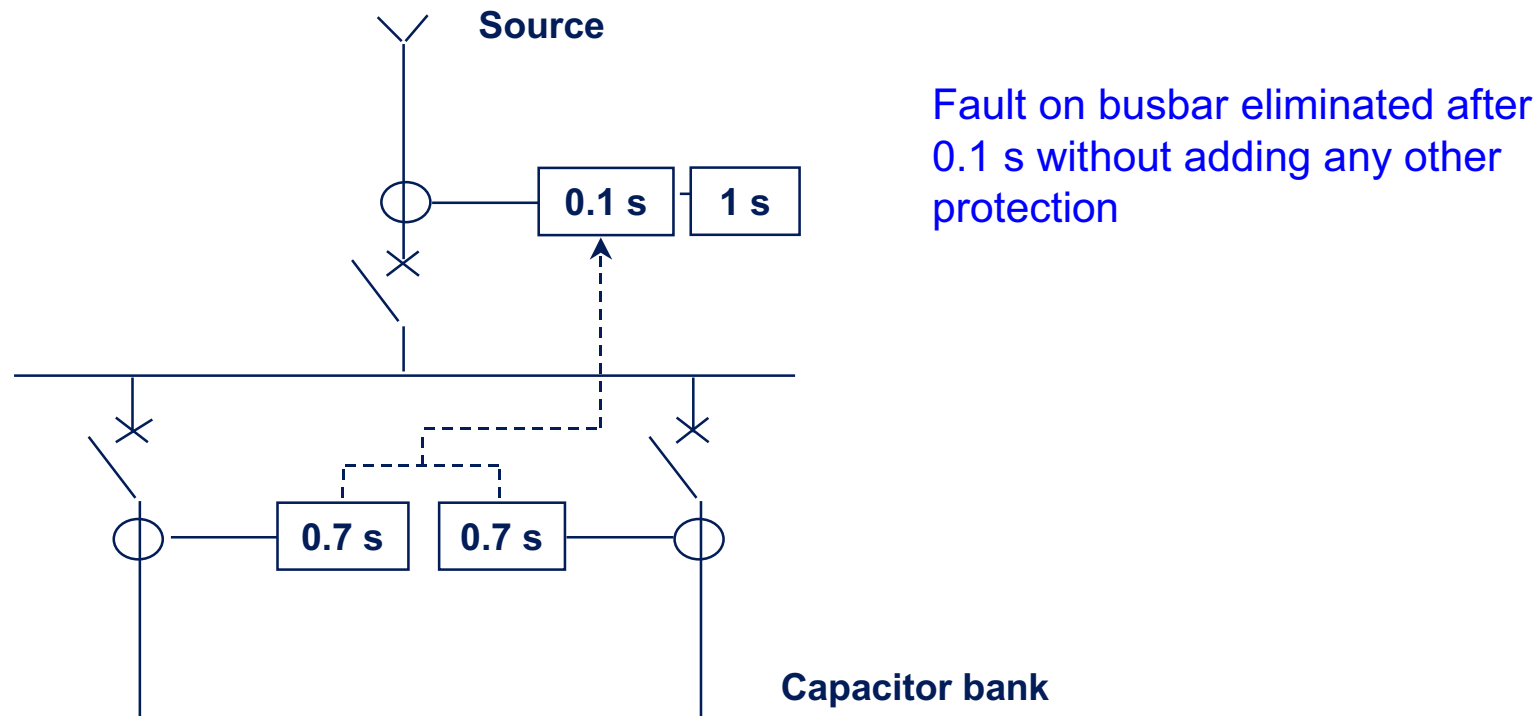
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CAPACITOR PROTECTION

■ **Logic discrimination :**

Source

0.1 s ╌ **1 s**

Fault on busbar eliminated after 0.1 s without adding any other protection

0.7 s **0.7 s**

Capacitor bank

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CAPACITOR PROTECTION

■ **Logic discrimination :**

Overcurrent (inst)

Earth fault (inst)

≥1

Inhibition of
BI transmision
if fault not cleared

Output O14 : BI transmision

t   0

T3 = 0.2s

&

Overcurrent (time)

Earth fault (time)

≥1

tripping

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CAPACITOR PROTECTION

■ **Thermal overload (49) :**

- Heat rise calculation :

$$T \times \frac{dE}{dT} + E = \left(\frac{Ieq}{Ib} \right)^2$$

$$Ieq^2 = I^2 + K \times Ii^2$$

- I is the greatest value of I1, I2, I3 (at 50 Hz) and I1rms
- Ii is the negative sequence current

$$E = \left[Eo - \left(\frac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\frac{Ieq}{Ib} \right)^2$$

- Eo : initial heat rise

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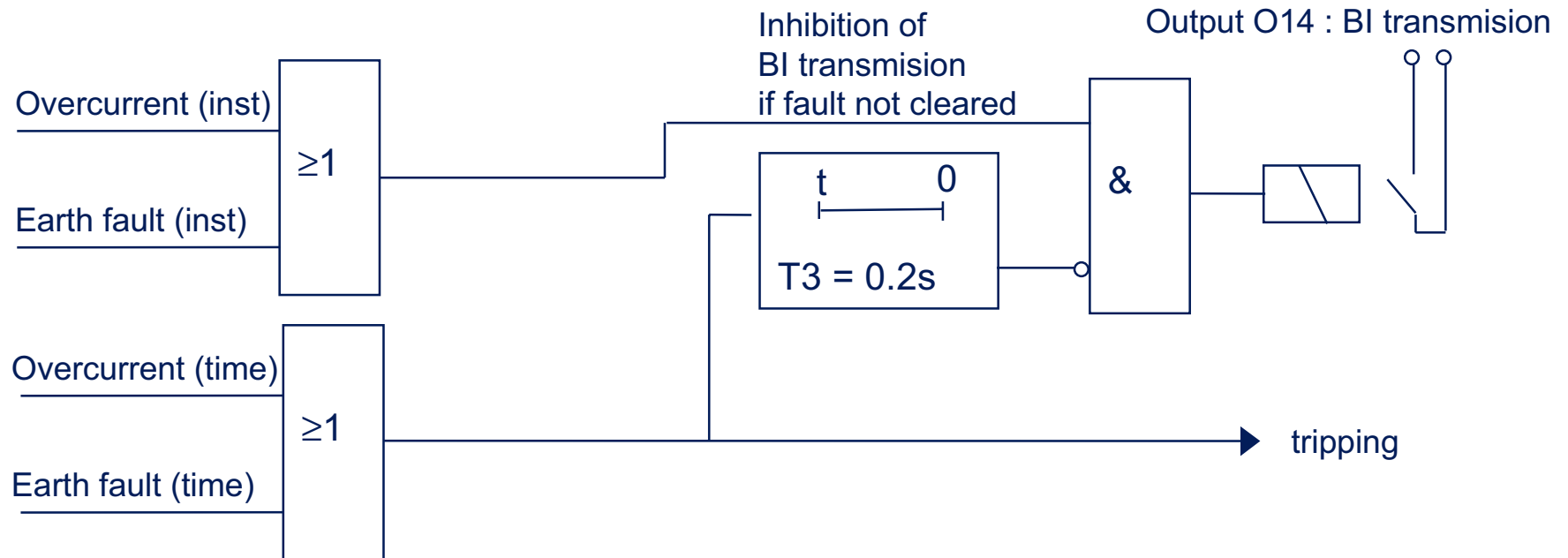
CAPACITOR PROTECTION

■ **Thermal overload (49) (cont'd) :** $E = \left[Eo - \left(\dfrac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\dfrac{Ieq}{Ib} \right)^2$

CAPACITOR PROTECTION

■ **Unbalance overcurrent protection (51N) :**

  • To detect if some elements of the capacitor are damaged

![Schneider Electric logo]
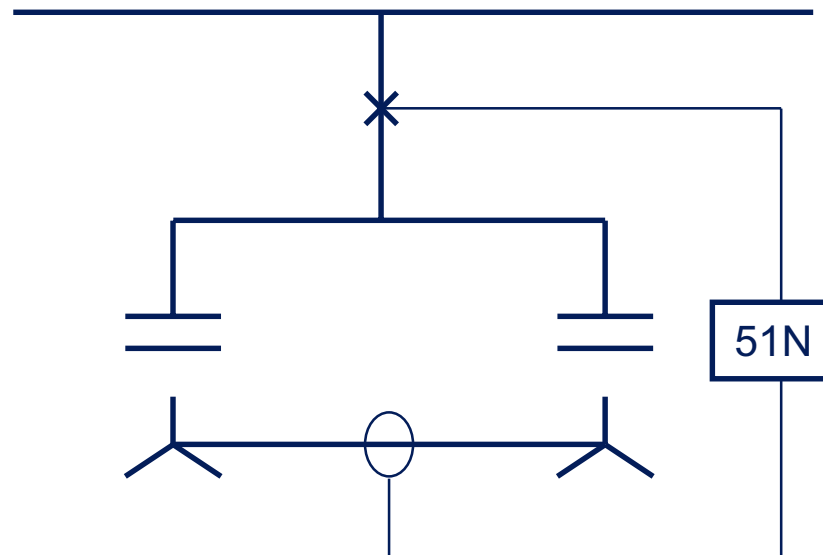
MOTOR PROTECTION

Merlin Gerin
Modicon
Square D
Telemecanique

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ASYNCHRONOUS MOTOR PROTECTION

■ **Generalities :**

- Main characteristics
- Protection by circuit breaker
- Protection by fuse
- Logic discrimination

■ **Protection functions :**

- 49 : thermal overload
- 50/51 : phase overcurrent
- 50N/51N : earth fault protection
- 46 : negative phase unbalanced protection
- 48/51LR : excessive starting time and locked rotor
- 37 : phase undercurrent
- 66 : starts per hour
- 27D : positive sequence undervoltage
- 47 : phase rotation direction check
- 67N : directional earth fault
- 32P : real overpower
- 32Q/40 : reactive overpower/field loss
- 38/49T : temperature monitoring
- 87M : motor differential

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ASYNCHRONOUS MOTOR PROTECTION

■ **MAIN CHARACTERISTICS :**

Starting current = k1/Un

Motor torque = $k2.U^2n$

Resistive torque

0   1   Slip
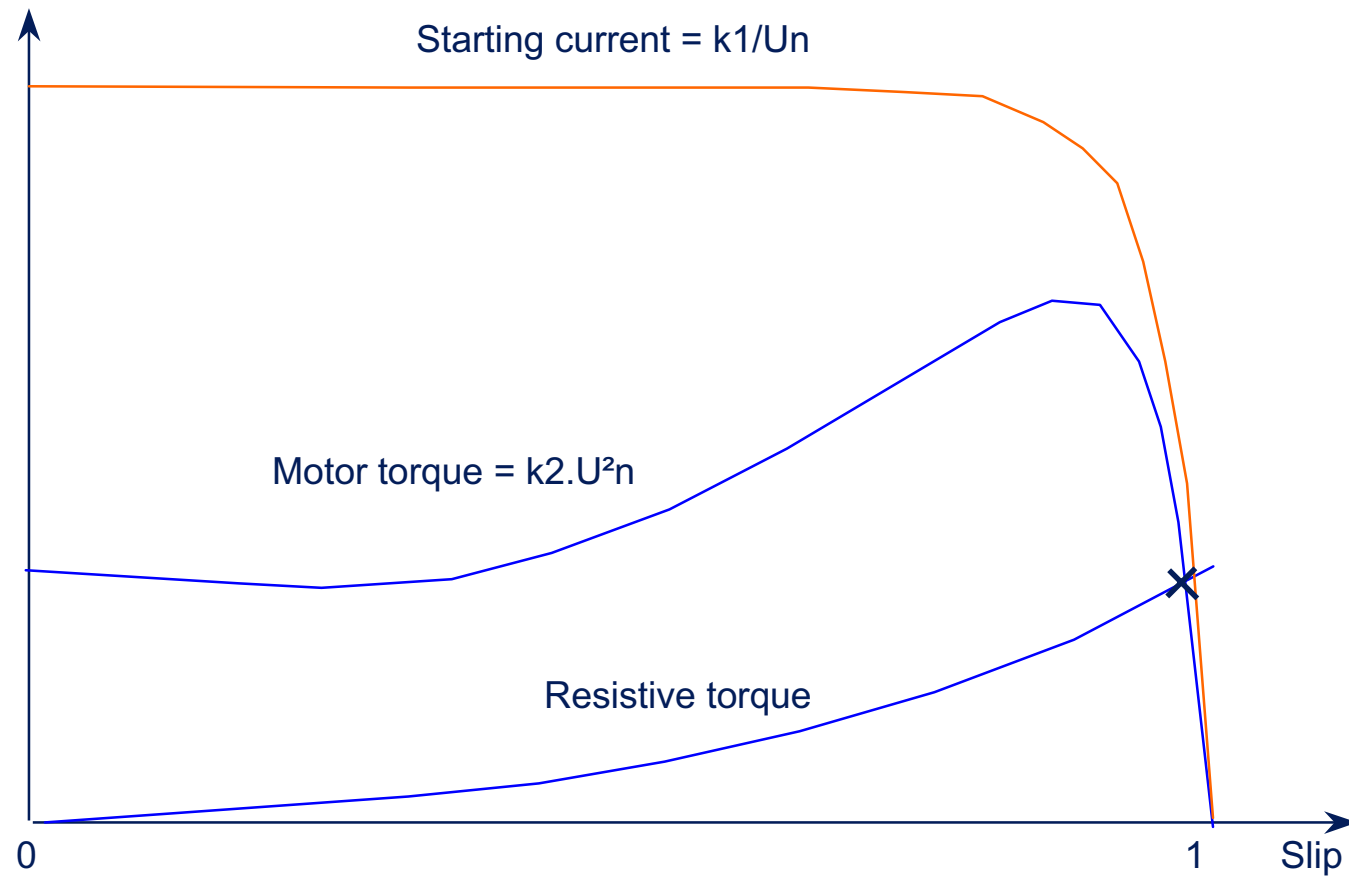
ASYNCHRONOUS MOTOR PROTECTION

■ **Circuit breaker and definite time**
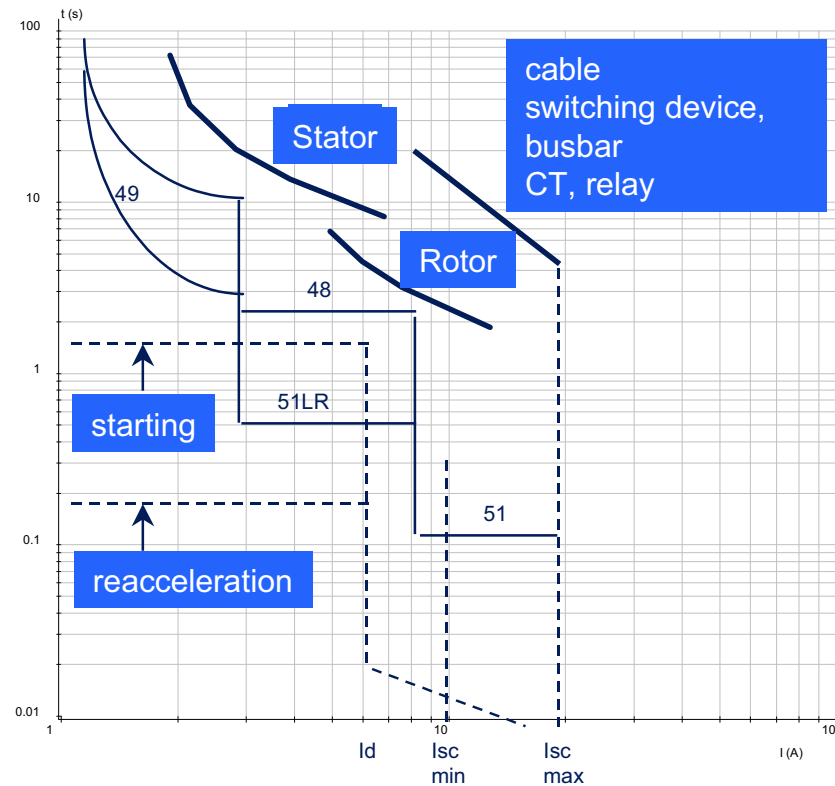
ASYNCHRONOUS MOTOR PROTECTION

■ **Contactor and fuses**
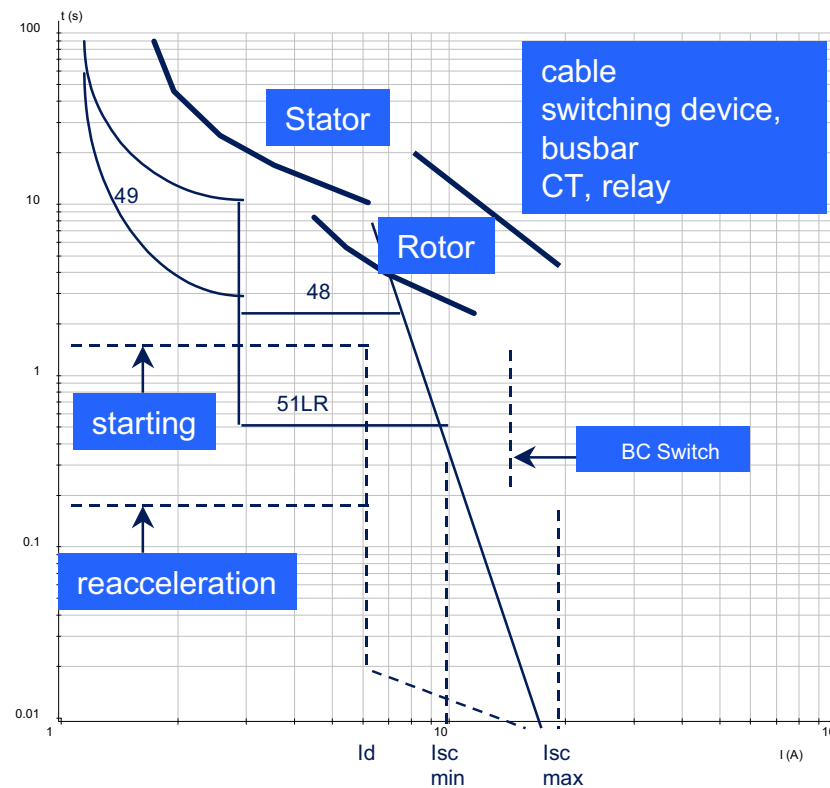
ASYNCHRONOUS MOTOR PROTECTION

■ **Logic discrimination :**

Fault on busbar eliminated after 0.1 s without adding any other protection

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ASYNCHRONOUS MOTOR PROTECTION

■ **Logic discrimination :**

Overcurrent (inst)

Earth fault (inst)

≥1

Inhibition of
BI transmision
if fault not cleared

Output O14 : BI transmision

t   0

T3 = 0.2s

&

Overcurrent (time)

Earth fault (time)

≥1

tripping

ASYNCHRONOUS MOTOR PROTECTION

■ **Overcurrent (50/51) :**

- I setting $\approx$ 1.2 x I starting
- Time setting $\approx$ 0.1 s
- DT and IDMT curves

Transient overreach = (Iso - Is1) / Is1

Iso = setting current, that is, r.m.s. value of steady state current required to operate the relay

Is1 = steady state r.m.s. value of the fault current which when fully offset will just operate the relay

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ASYNCHRONOUS MOTOR PROTECTION

■ **Overcurrent (50/51) :**

• Current shape in case of saturation of CT:

I ct

Peak value

Right value

Fundamental
value

t

Low value of fundamental current ⇒ risk of no detection of
the fault ⇒ measurement of peak value

ASYNCHRONOUS MOTOR PROTECTION

■ **Overcurrent (50/51) :**

   • Current shape in case of no saturation of CT :

I ct

Peak value

Filtered peak value

t

Transient overreach can be very high if only the peak value is
considered ⇒ peak value is filtered (no DC component)

ASYNCHRONOUS MOTOR PROTECTION

■ **Overcurrent (50/51) :**

- Conclusion :

- Filtered peak detection is used to ensure tripping in case of CT saturation
- Efficace value avoids the risk of unexpected tripping

SEPAM MIX THE TWO MEASUREMENTS TO GUARANTEE A GOOD TRANSIENT OVERREACH (LESS THAN 10% FOR ANY TIME CONSTANT)

ASYNCHRONOUS MOTOR PROTECTION

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Harmonic 2 restrain

An earth fault current (including harmonic 2) could appear
in case of CT saturation if earth fault is measured by means
of the sum of 3 TC.

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ASYNCHRONOUS MOTOR PROTECTION

■ **Thermal overload (49) :**

• Heat rise calculation :

$$T \times \frac{dE}{dT} + E = \left(\frac{Ieq}{Ib} \right)^2$$

$$Ieq^2 = I^2 + K \times Ii^2$$

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• Eo : initial heat rise

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ASYNCHRONOUS MOTOR PROTECTION

■ **Thermal overload (49) (cont'd) :** $\quad E = \left[Eo - \left(\dfrac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\dfrac{Ieq}{Ib} \right)^2$

• **Operation**

ASYNCHRONOUS MOTOR PROTECTION

■ **Thermal overload (49) (cont'd) :**

Thermal overload function is used to protect the motor against too high requested active power that is to say if the power of the load increases.

Cold curve : Eo = 0

Hot curve : Eo = 100%
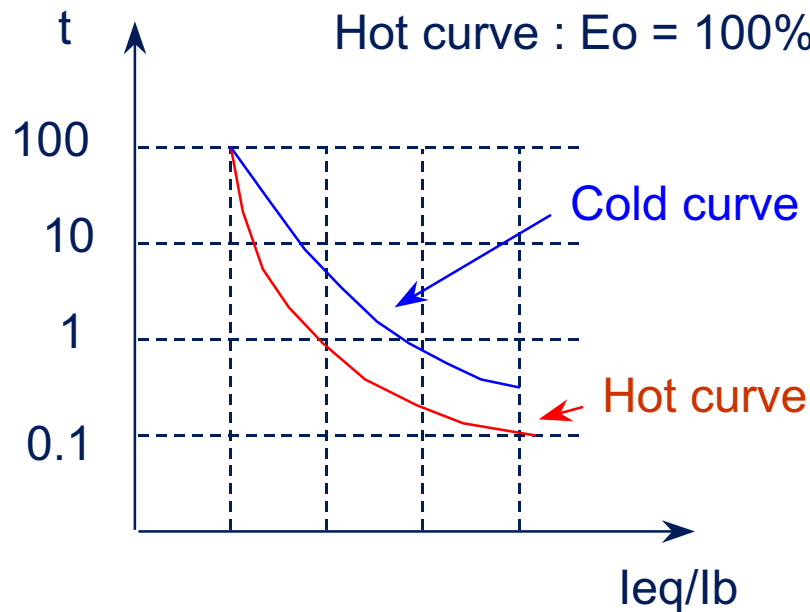
$$Ieq^2 = I^2 + K \times Ii^2$$

$$t = T \times Log \dfrac{\left(\dfrac{Ieq}{Ib}\right)^2}{\left(\dfrac{Ieq}{Ib}\right)^2 - Es2}$$

Ii = current negative sequence

Es2 = thermal setting point in %

$$t = T \times Log \dfrac{\left(\dfrac{Ieq}{Ib}\right)^2 - 1}{\left(\dfrac{Ieq}{Ib}\right)^2 - Es2}$$

T = heat rise (T1) or cooling (T2) time constant

ASYNCHRONOUS MOTOR PROTECTION

■ **Thermal overload (49) (cont'd) :**

A **K** factor is used to take into account of the negative sequence current which induce high power losses in the rotor (because of the double frequency rotating current)

$$K = 2 \times \frac{Cd}{Cn} \times \frac{1}{g \times \left(\dfrac{Id}{Ib}\right)^2} - 1$$

Cd, Cn = rated and starting torque

Ib, Id = rated and starting current

g = pole slipping

The **T1** and **T2** time constants are global constants for the machine and are higher than the rotor time constant.

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ASYNCHRONOUS MOTOR PROTECTION

■ **Thermal overload (49) (cont'd) :**

- Two groups of parameters are available to take into account of thermal withstand with locked rotor
- Switching from one mode to the other when the current is greater than an adjustable set point Is
- Accounting for ambient temperature when the temperature measured exceeds 40°
- Initial heat rise Eso can be use to reduce the cold tripping time

$$t = T \times Log \frac{\left(\dfrac{Ieq}{Ib}\right)^2 - Eso}{\left(\dfrac{Ieq}{Ib}\right)^2 - Es2}$$

ASYNCHRONOUS MOTOR PROTECTION

■ **Number of starts (66):**

This function is used to protect the rotor of the motor during starting operation. Note that the starting current remains constant and equal to the standstill current for the whole of the starting period.

We can consider there is no/a little thermal exchange between rotor and stator during this period. So, there is no relation with the heating time constant of the machine and the limitation of the number of starts (cold, warm and per hour)

Is
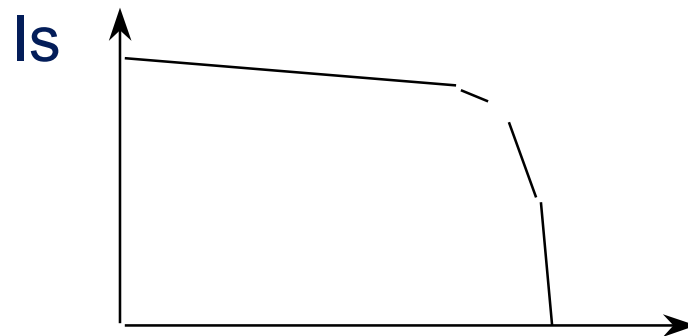
ASYNCHRONOUS MOTOR PROTECTION

■ **Number of starts (66) (cont'd) :**

    • How to set the hot point Es1?

We can consider the hot state point Es1 corresponds at nominal operation of the motor during a sufficient time. That's to say we advise to set Es1 from 60% to 75%. This setting is only used to define cold state and hot state for the repeated starts function.

ASYNCHRONOUS MOTOR PROTECTION

■ **Number of starts (66) (cont'd) :**

Consecutive starts are counted over an interval of 60/Nstarts, i.e. 12 minutes
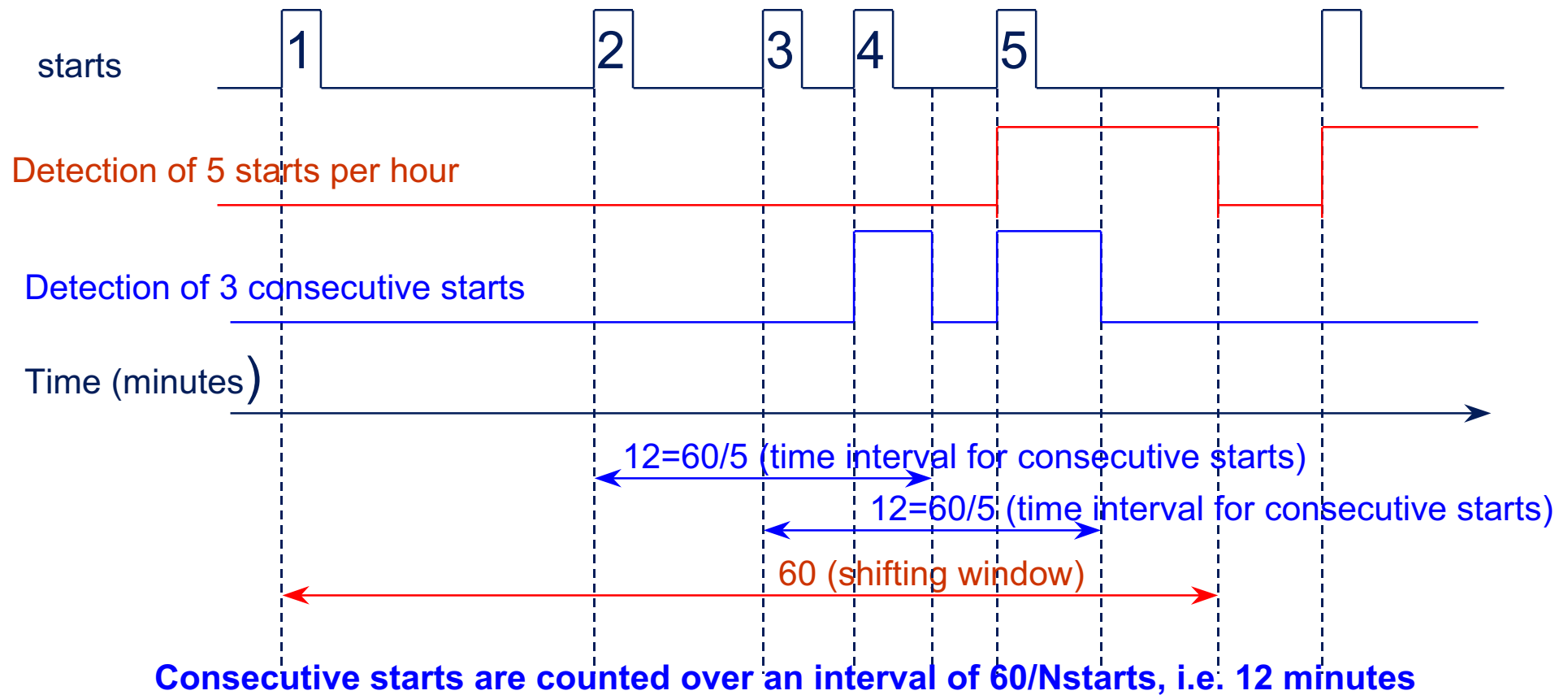
ASYNCHRONOUS MOTOR PROTECTION

■ **Excessive starting time (48) and locked rotor (51LR) :**

Analog explanation as for number of starts i.e thermal overload is a global protection for steady state operation. Rotor losses increase a lot during locked rotor period and if there is a too long starting time.

Current setting ≈ Starting current/2

Starting time setting ≈ starting time + several seconds

Locked rotor tripping time ≈ 0;5 to 1 second

ASYNCHRONOUS MOTOR PROTECTION

■ **Excessive starting time (48) and locked rotor (51LR) (cont'd) :**

t

Stator thermal withstand

cold

1 st 49

hot

Rotor thermal withstand

cold

48

hot   2 nd 49

Starting current

51LR   51

I/Ib
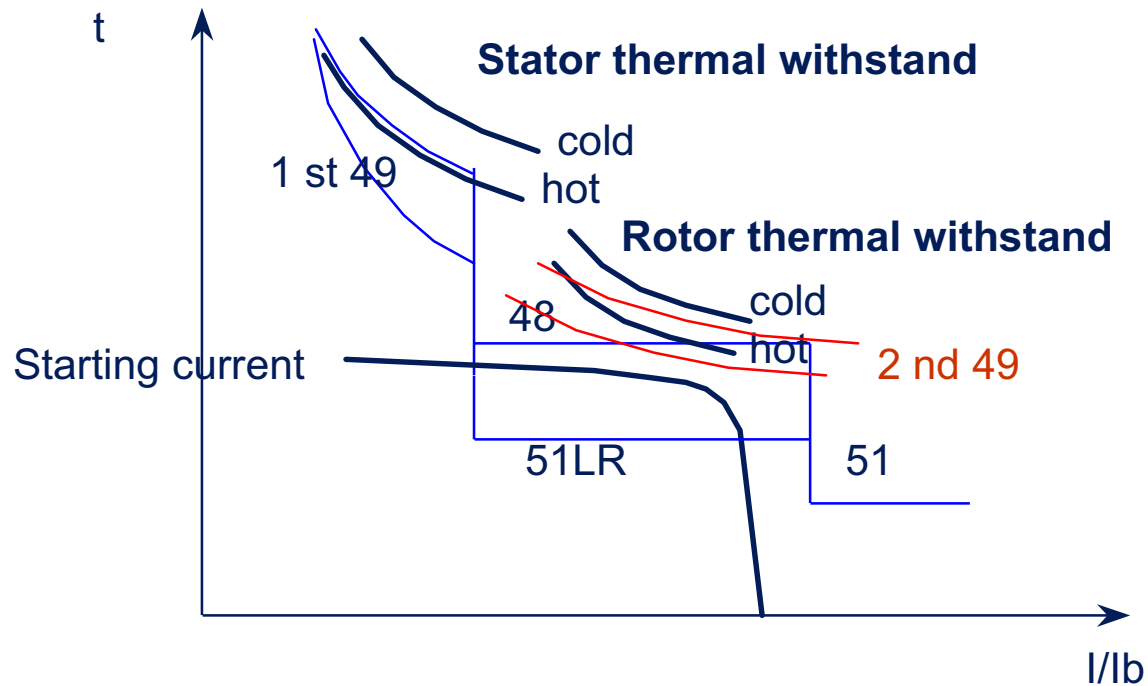
No discrimination between rotor thermal withstand and 48 function. Only 2nd
49 function can be used

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ASYNCHRONOUS MOTOR PROTECTION

■ **Excessive starting time (48) and locked rotor (51LR) (cont'd) :**

• **Reacceleration :**

During reacceleration, the motor absorbs current that is similar to starting current without the current having previously dropped to a value less than 5% of Ib*.

A logic data input may be used to

• reset the excesive starting time protection

• set the locked rotor protection time delay to a low value

* starting is detected when the absorbed current is 5% of Ib

ASYNCHRONOUS MOTOR PROTECTION

■ **Negative sequence / unbalance (46) :**

• You want to detect the loss of one phase in motor circuit

⇒DT curve with setting Is < 30% of Ib and time setting = starting time

• You want to protect the rotor against negative sequence current
    High frequency currents in the rotor induce high power losses

⇒use IDMT curve or similar

Setting indication : 30% of Ib and time setting = starting time

ASYNCHRONOUS MOTOR PROTECTION

■ **Undercurrent (37) :**

To protect pump against running down

Case of current sag

Case of circuit breaker opening

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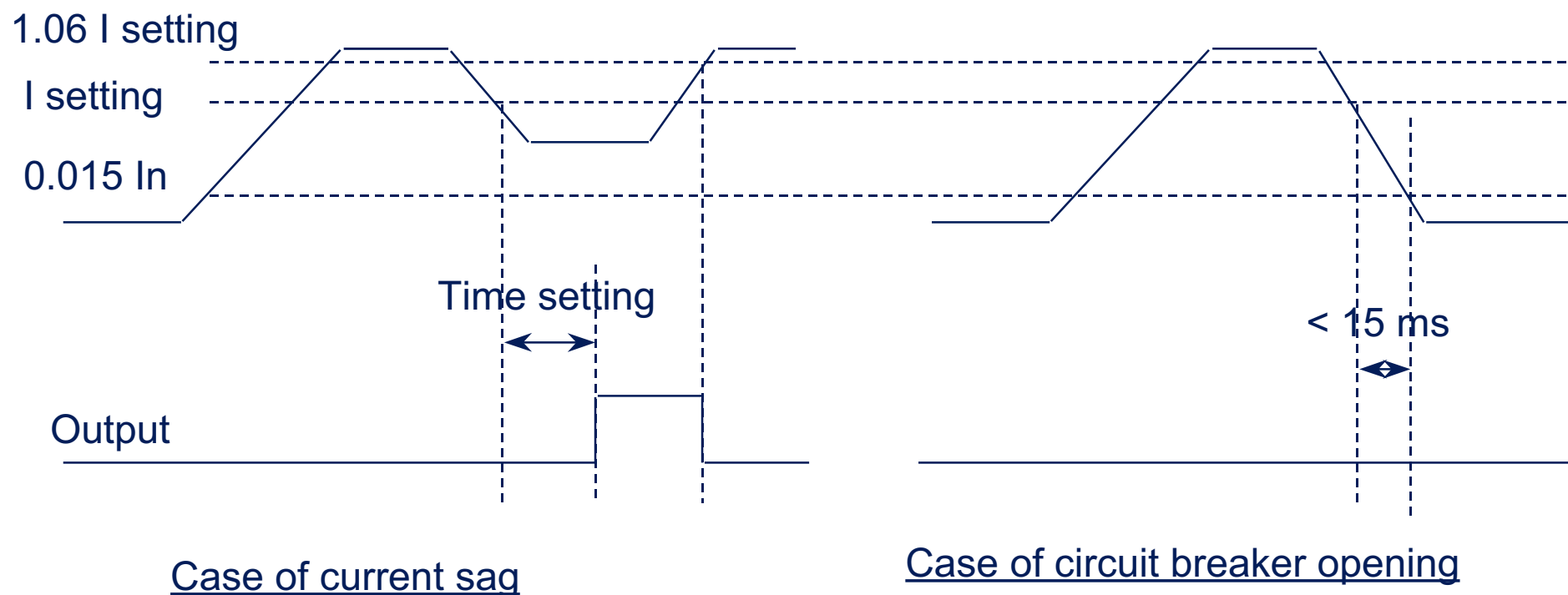
ASYNCHRONOUS MOTOR PROTECTION

■ **Positive sequence undervoltage (27D) :**

Motor torque is proportional to the square of the rated positive sequence voltage

Setting indication :

Voltage setting = 0.8 rated voltage

Time setting = 1 second

ASYNCHRONOUS MOTOR PROTECTION

Positive sequence undervoltage (27D) : coordination with overcurrent protection

■ Undervoltage protection

■ Overcurrent protection
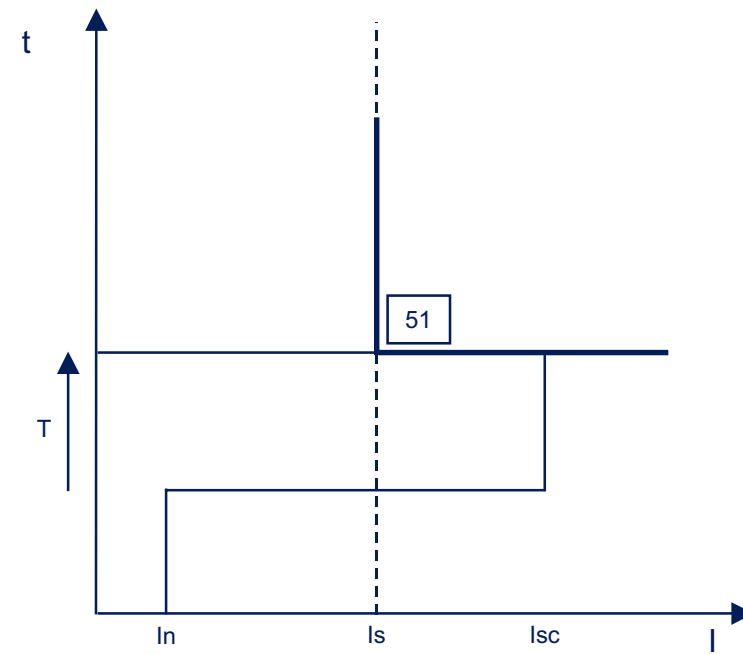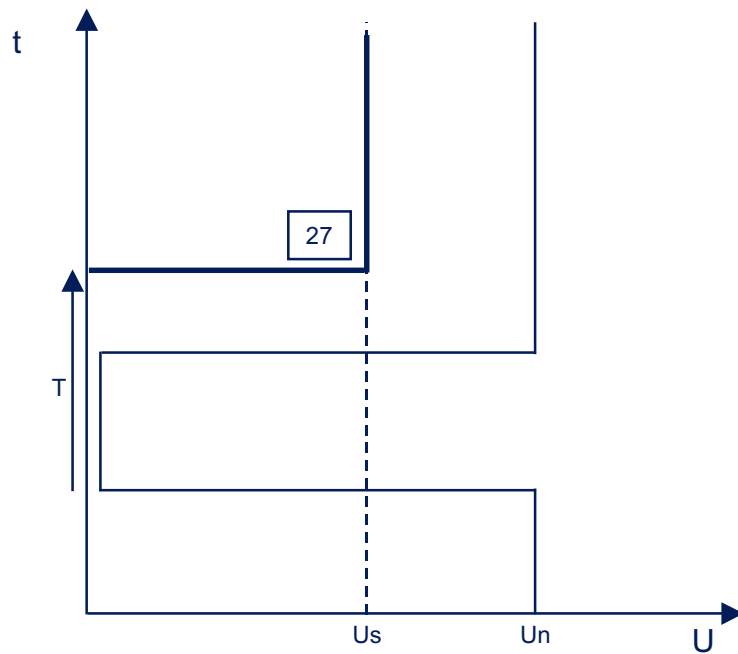
ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) :
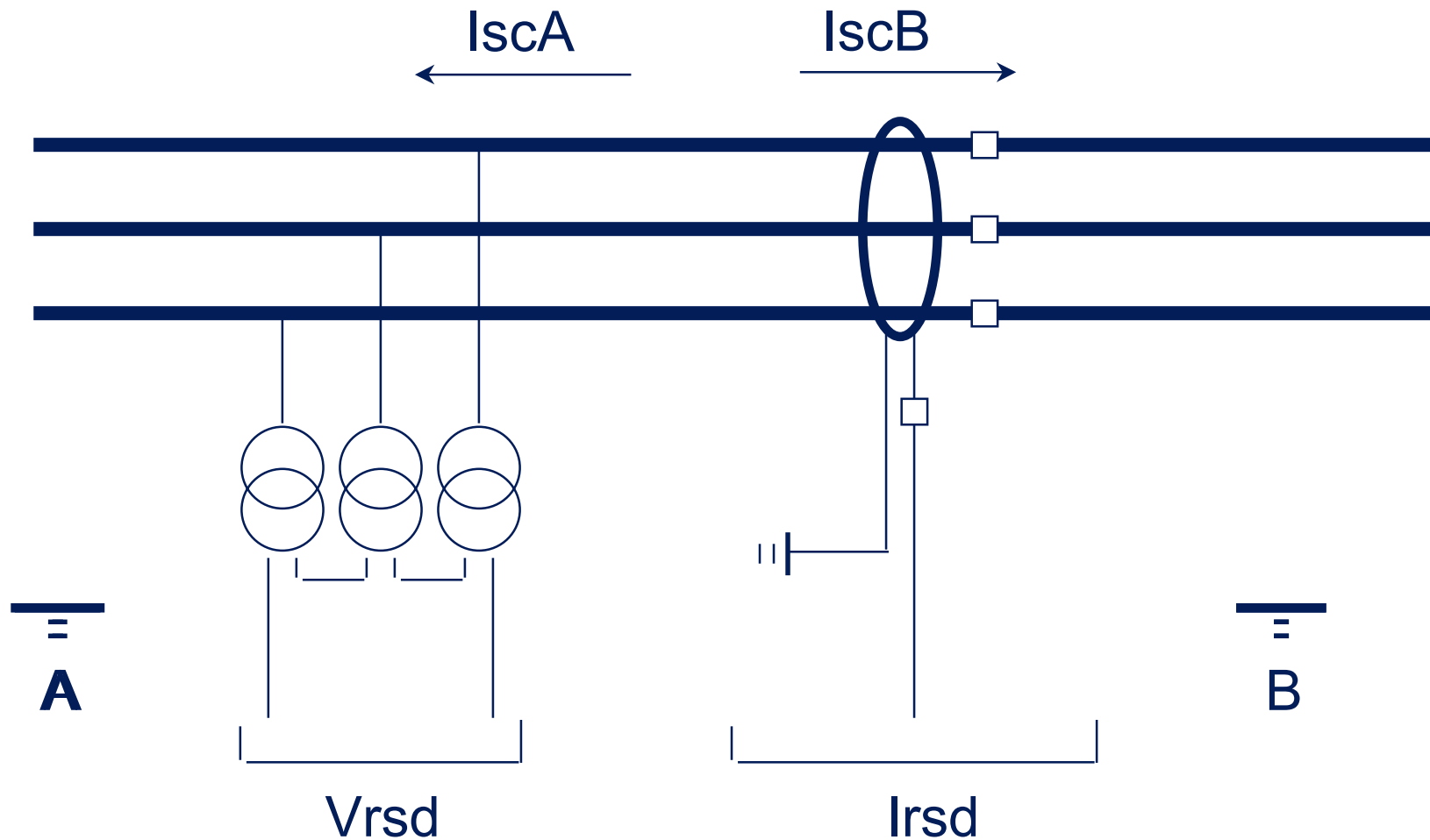
ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) (cont'd):

$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\,\vec{Z}_N \times \vec{I}_{rsd}$$

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ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) (cont'd):

IrsdB   V2

Fault at B

φ0B

N

V1   Vrsd

Reverse direction

V3
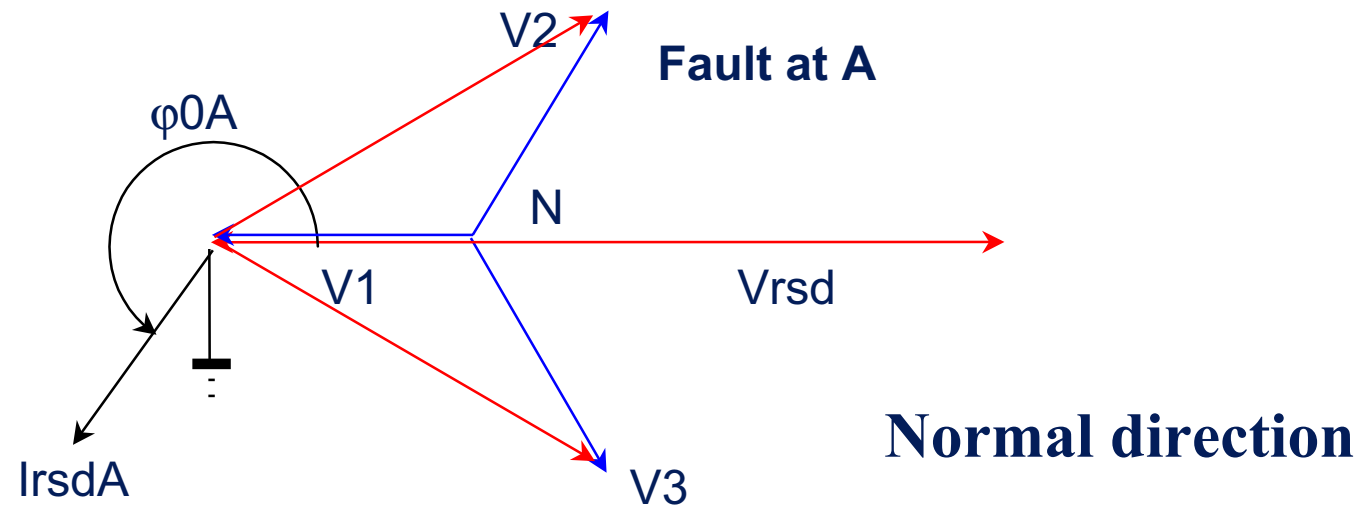
$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\,\vec{Z}_N \times \vec{I}_{rsd}$$

ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) (cont'd):

■ Measurement of the phase shift angle between the residual voltage - called the polarization voltage - and the earth fault current makes it possible to determine the direction

ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) (cont'd):
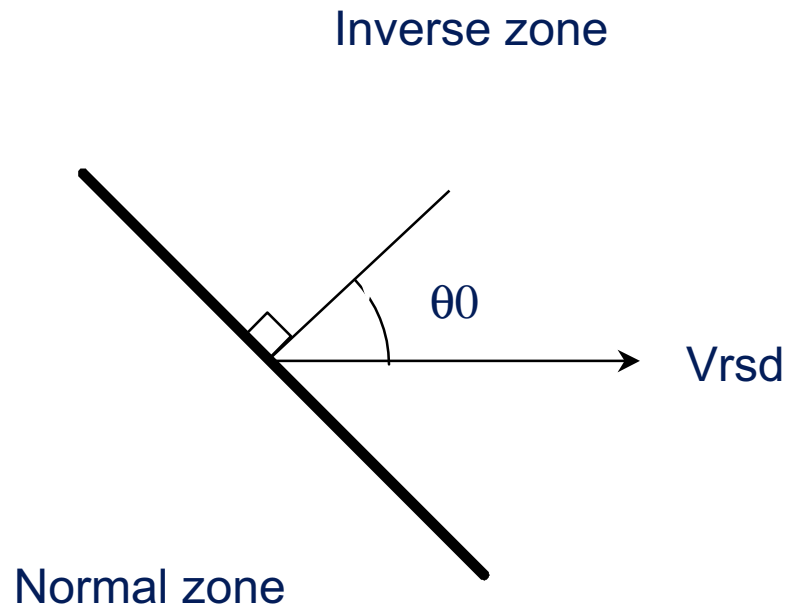
Inverse zone

$\theta 0$

Vrsd

Normal zone

- Division of a current vectorial plane into 2 half-planes:
  - normal zone
  - inverse zone

- Characteristic angle $\theta 0$ = **angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage**

- Typical values of $\theta 0$:
  - 0° if N earthed by resistance
  - 15°, 30°, 45°, 60°: intermediate values
  - 90° if isolated neutral (Irsd=Icapa)
  - -45° if N earthed by reactance

ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) (cont'd):

inverse zone

$\theta 0 = 45°$

$\varphi 0$ Is0

Vrsd

Ip

normal zone

Irsd

Earth fault
Direction detection in normal direction
Directional protection function
tripping zone

- Association of 2 functions:
  - earth fault protection function adjustable setting Is0 Definite time
  - detection of the current direction characteristic angle $\theta 0$

- Plane single-pole protection
  - Ip : projection of Irsd on the characteristic line
  - $\varphi 0$: phase shift (Vrsd,Irsd)

- Protection operational if: polarization voltage >= 2.6% Un

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ASYNCHRONOUS MOTOR PROTECTION
Directional earth fault (67N) (cont'd):

COMPENSATED NEUTRAL SYSTEM :

■ Petersen coil + resistor:

- designed to compensate capacitive currents
  => Irsd is highly resistive

=> characteristic angle not adjustable: $\theta 0 = 0°$

- self-extinguishing earth fault
  => short, recurring faults

=> protection memory time adjustable

  Tmem ~ 250 ms

- in practice, the system is slightly dissymmetrical and the residual voltage is not zero when there is no fault

=> Vs0 setting adjustable

ASYNCHRONOUS MOTOR PROTECTION

■ **Motor differential (87M) :**

$Id = I - I'$

X In

Without harmonic 2 restrain

100%

Current transformers 5P20

$Id1^2/8 - It1^2/32 = (0.05In)^2$

I   I'

M

$Id^2 - It^2/32 = Is^2$

Harmonic 2 restrain

Only one setting :

$0.05\ In < Is < 0.5\ In$

External fault induces saturation of the CTs and false differential current

$It = (I + I')/2$

X In

$\sqrt{2}$
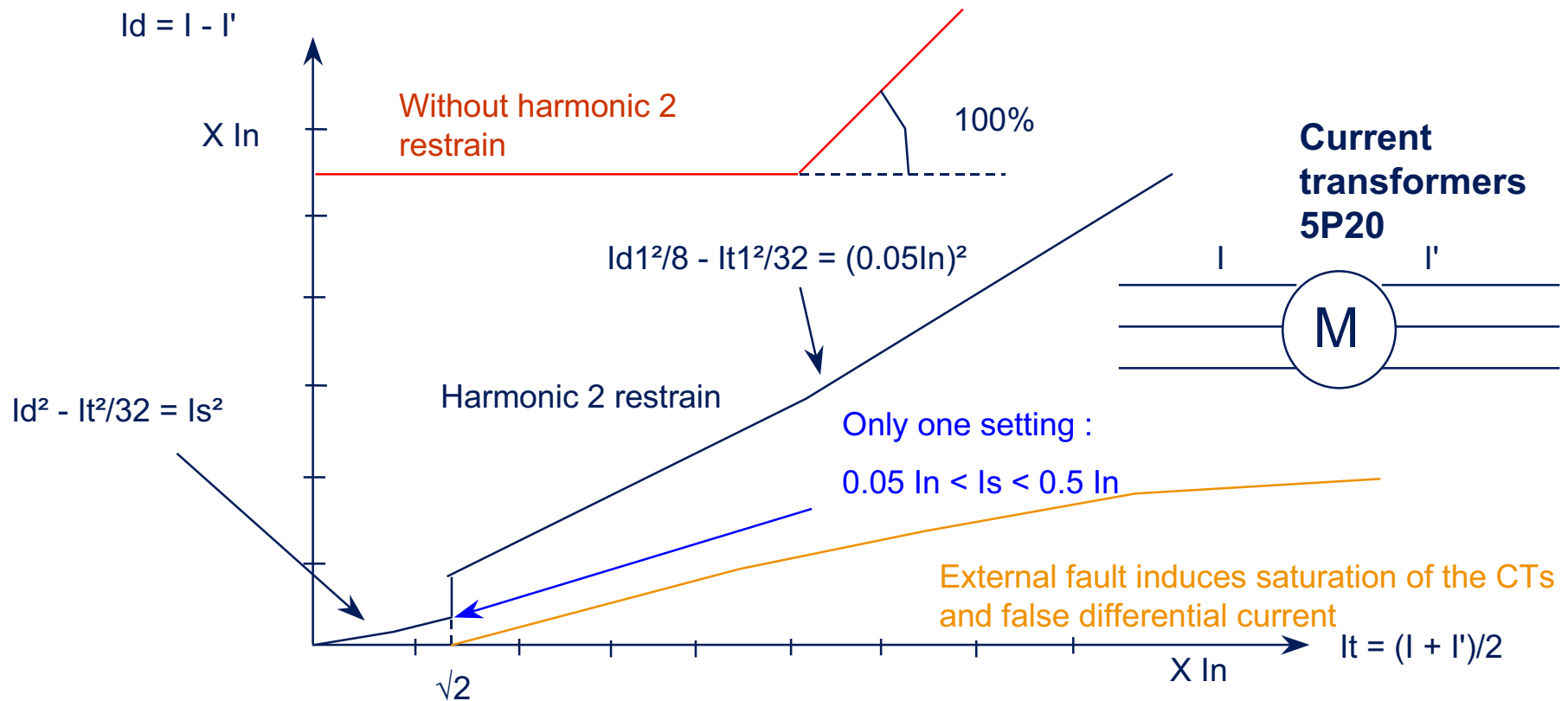
ASYNCHRONOUS MOTOR PROTECTION

■ **Temperature monitoring (49T/38) :**

- The protection detects if an RTD is shorted or disconnected.
    - RTD shorting is detected when the measured temperature is less than -70 $\pm$ 10°C
    - RTD disconnection is detected when the measured temperature is greater than 302 $\pm$ 27°C
- For Sepam 1000+, RTD can be Pt100, NI100, NI120 type
- For Sepam 2000, RTD can be Pt100 only

SYNCHRONOUS MOTOR PROTECTION

■ **Real overpower (32P) :**

Against generator operation :
Reverse real power (ANSI 32P)

- Ps = 0.05 Pn
- Time delay ~ 1 sec

■ **Reactive overpower (32Q) :**

Against field loss :

Reactive overpower (ANSI 32Q) Equivalent to 40 function by adding 27 function

- Qs ~ 0.3 Sn
- Time delay : several seconds

GENERATOR PROTECTION

Merlin Gerin
Modicon
Square D
Telemecanique

Schneider Electric

GENERATOR PROTECTION

Generalities :

- Main applications
- Logic discrimination

Protection functions :

- 38/49T : temperature set points
- 64REF : restricted earth fault
- 87G : bias differential
- 25 : synchronism check

Protection functions :

- 50/51 : phase overcurrent
- 49 : thermal overload
- 50V/51V : voltage restrained overcurrent
- 46 : negative sequence / unbalance
- 50N/51N : earth fault
- 27 : undervoltage
- 59 : overvoltage
- 59N/64 : neutral voltage displacement
- 67 : directional overcurrent
- 67N : directional earth fault
- 32P: reverse real power
- 32Q/40 : reverse reactive power/field loss
- 81L : underfrequency
- 81H : overfrequency

GENERATOR PROTECTION : Single generator not coupled with the network
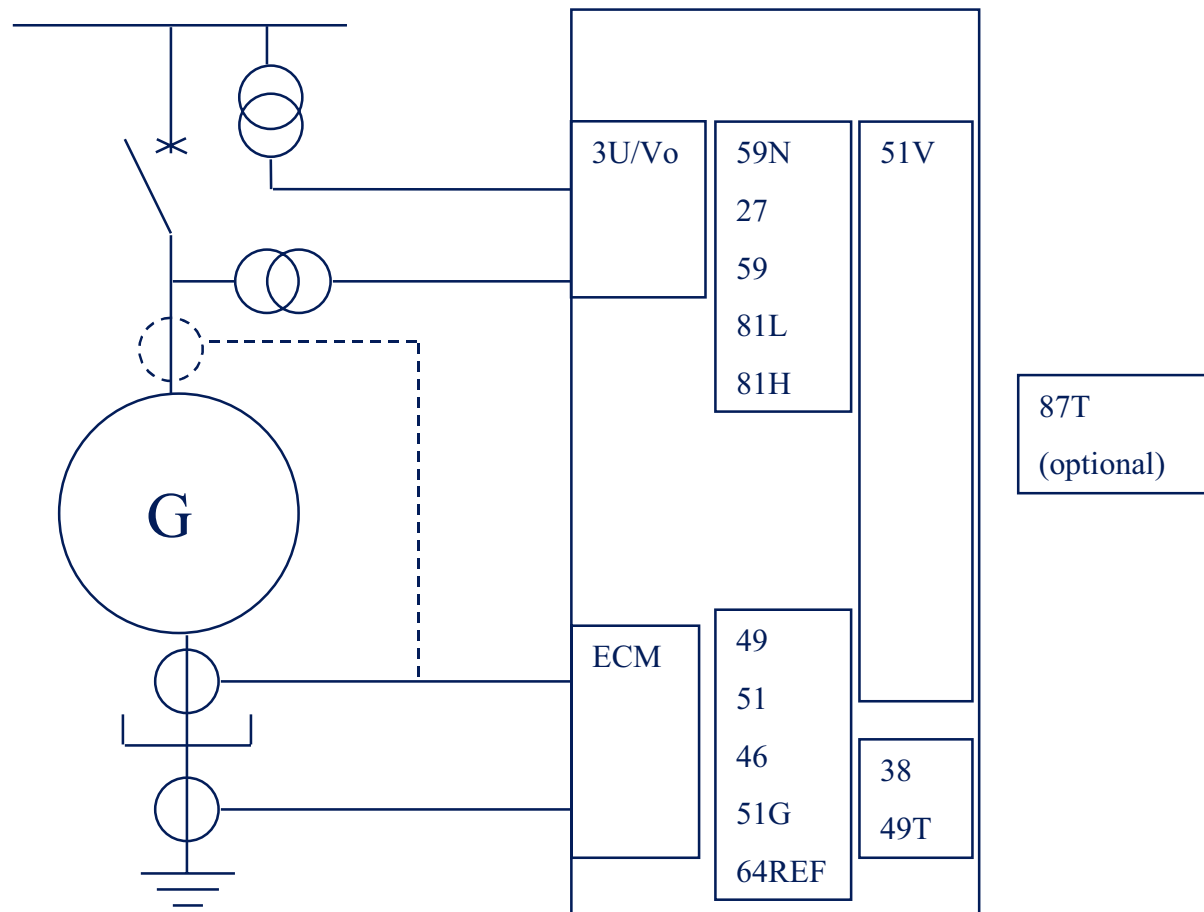
GENERATOR PROTECTION : Single generator coupled with the network
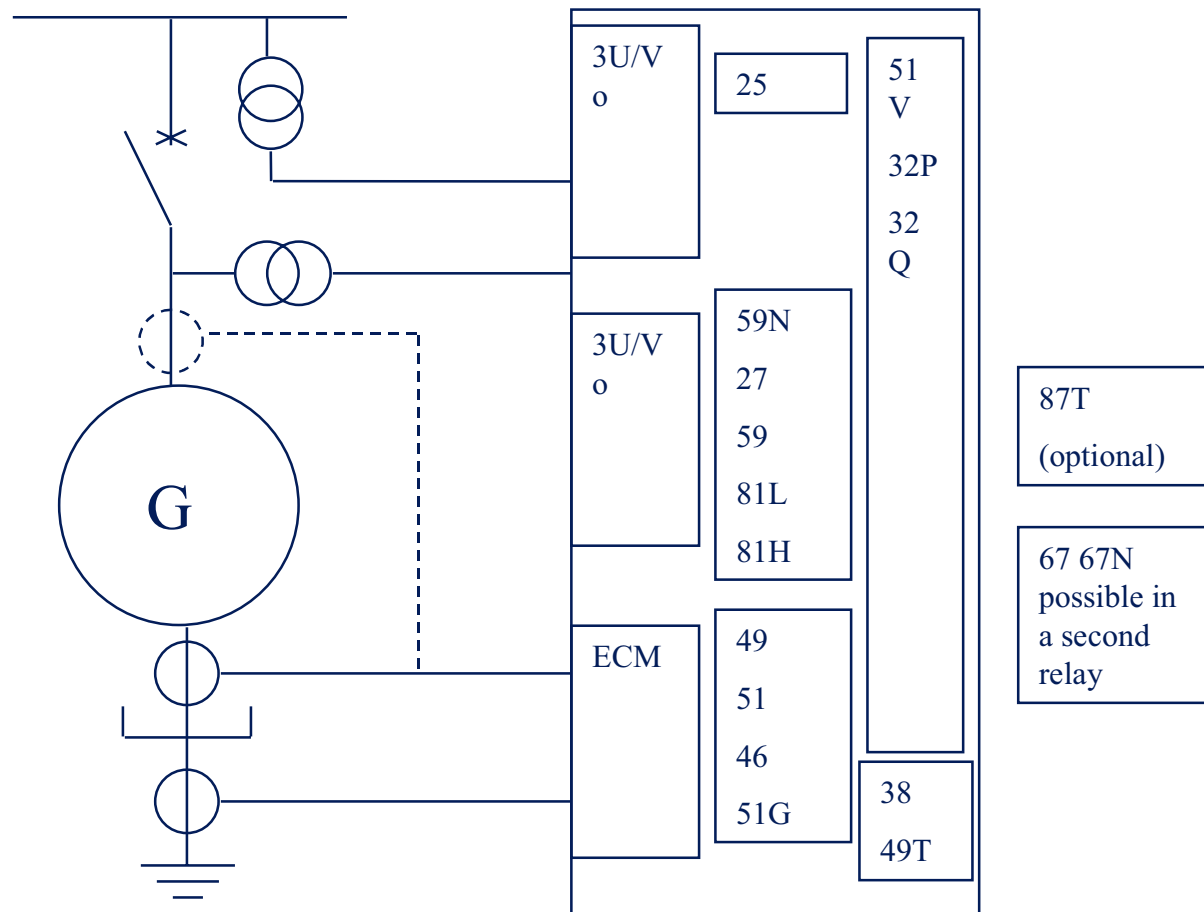
GENERATOR PROTECTION : Generators in parallel

2 solutions

51 V 32P 32 Q	38 49T	59N 27 59 81L 81H	3U/Vo

87 G	51 G	ECM2

49 51 46	ECM1

G   G

3U/Vo	59N 27 59 81L 81H	51 V 32P 32 Q 67 67 N

38 49T

ECM1	49 51 46 51G 64REF

Synchro check function 25 is outside the Sepam

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GENERATOR PROTECTION : Single block set
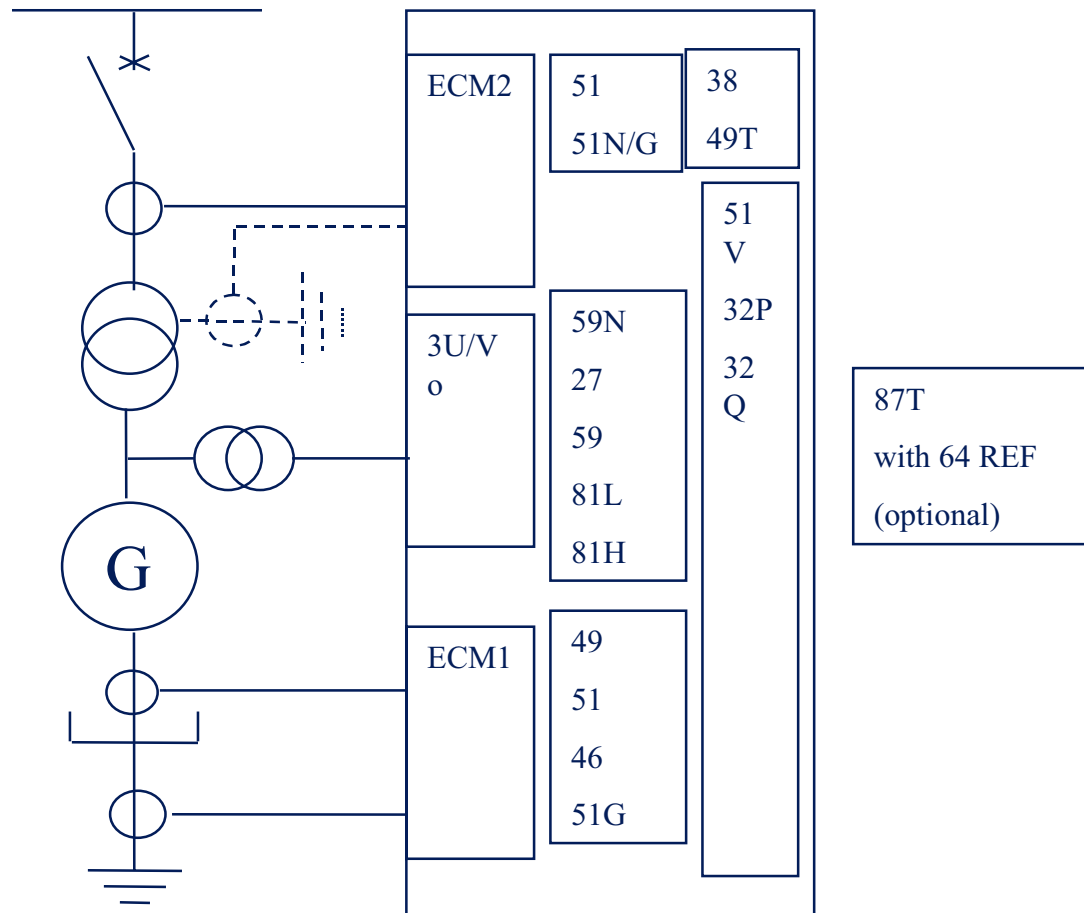
GENERATOR PROTECTION : Block sets in parallel
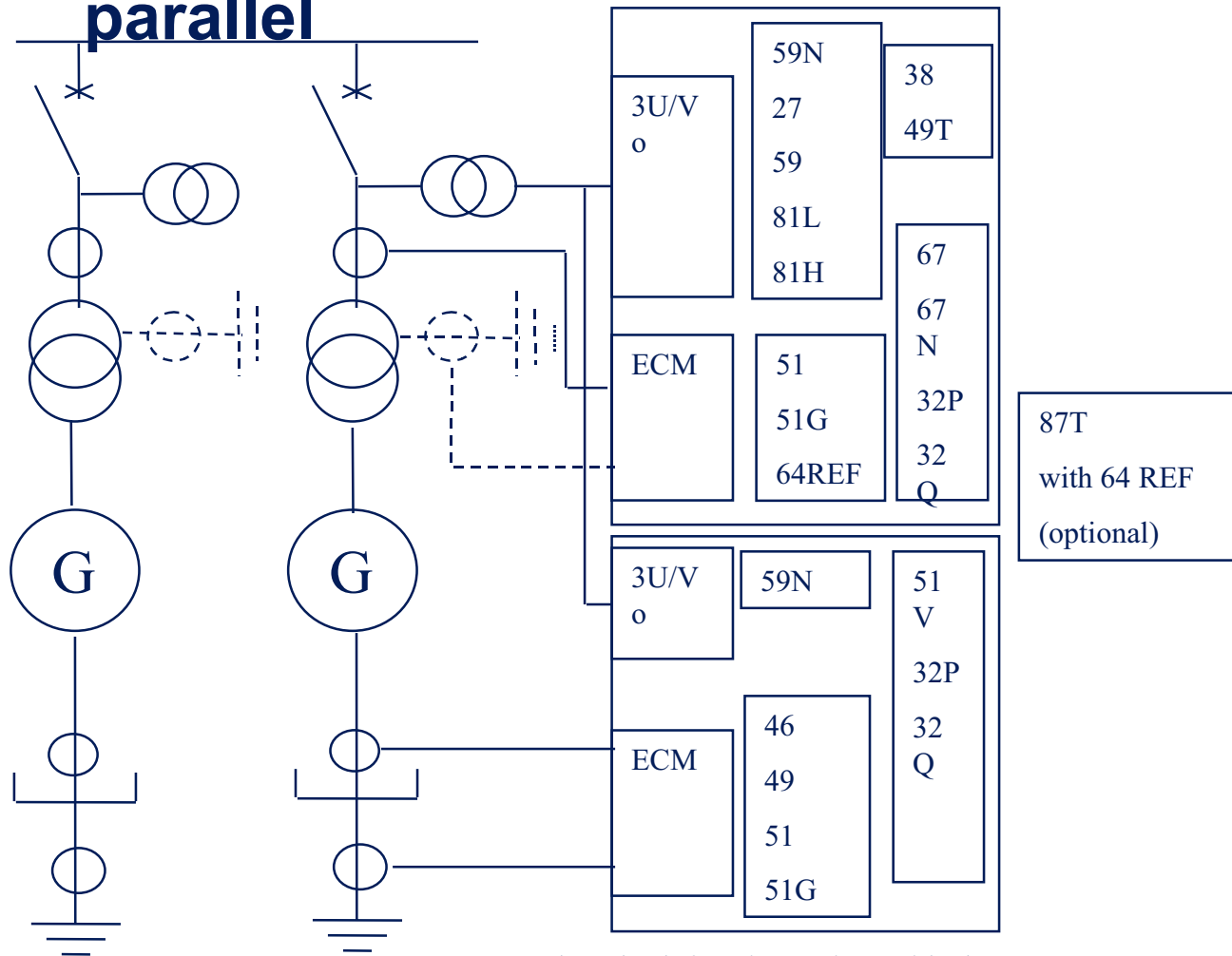
Synchro check function 25 is outside the Sepam

GENERATOR PROTECTION
Phase faults

■ Constant excitation current

Ik = 0.5 Ib
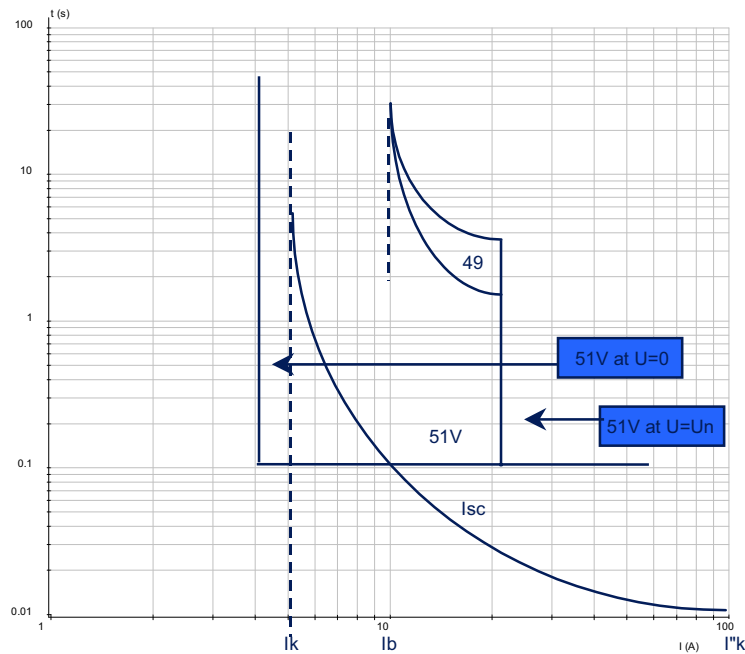
■ Overexcitation

Ik = 2 to 3 Ib
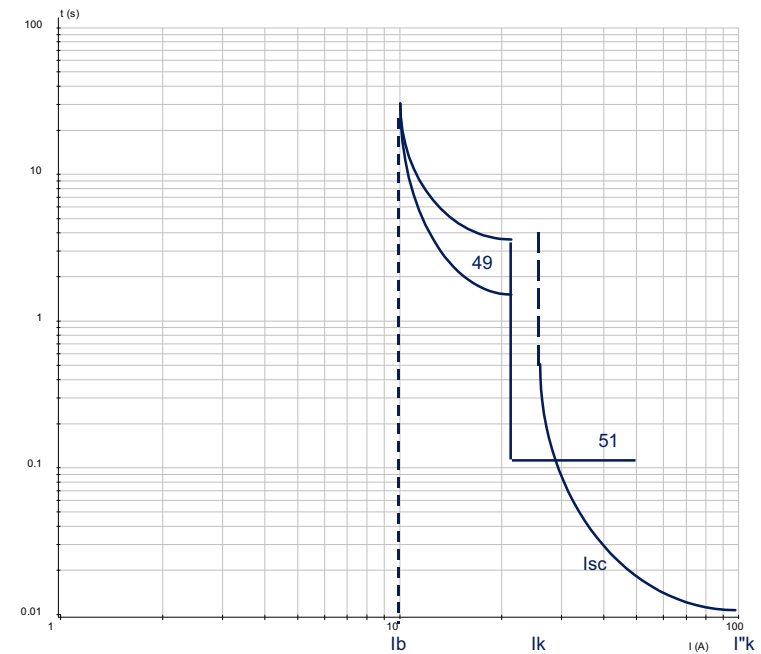
GENERATOR PROTECTION
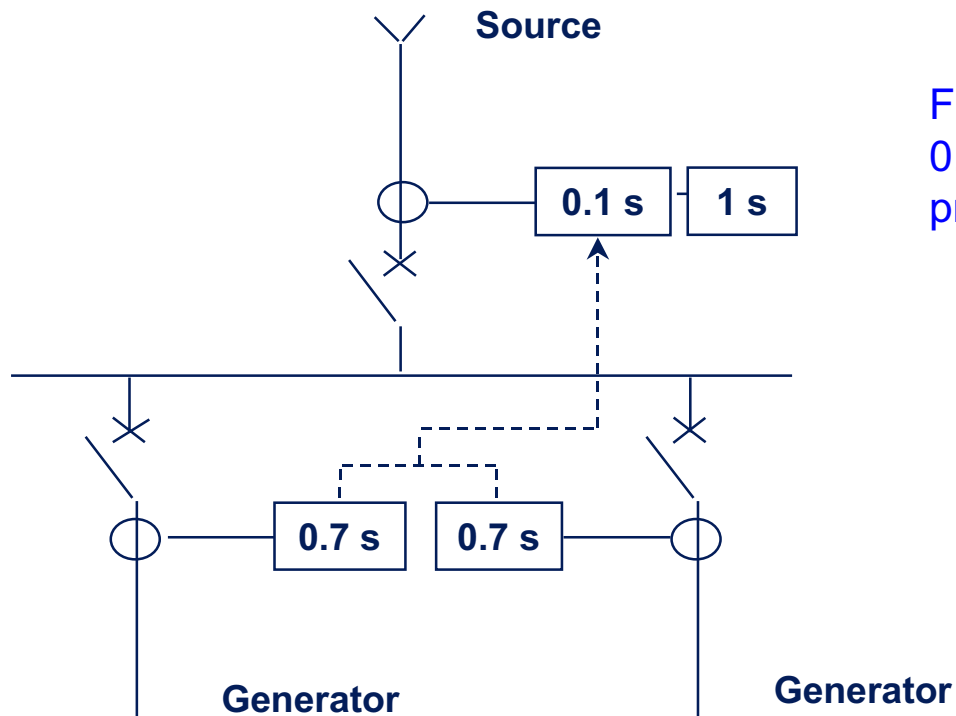
■ **Logic discrimination :**

Source

Fault on busbar eliminated after 0.1 s without adding any other protection

| 0.1 s | 1 s |

| 0.7 s | 0.7 s |

Generator

Generator

Schneider Electric

GENERATOR PROTECTION

■ **Logic discrimination :**

Inhibition of
BI transmision
if fault not cleared

Output O14 : BI transmision

67 (inst)

67N (inst)

67 (time)

67N (time)

51 (time)

51N (time)

51 (logic)

51N (logic)

Input I12 : BI receipt

≥1

≥1

≥1

&

t   0

T3 = 0.2s

&

≥1

tripping

&

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GENERATOR PROTECTION

■ **Overcurrent (50/51) :**

- I setting ≈ 1.2 x I inrush (transformer, motor reacceleration)
- Time setting ≈ 0.1 s
- DT and IDMT curves

Transient overreach = (Iso - Is1) / Is1

Iso = setting current, that is, r.m.s. value of steady state current required to operate the relay

Is1 = steady state r.m.s. value of the fault current which when fully offset will just operate the relay

$$Is1 > Is0$$

GENERATOR PROTECTION
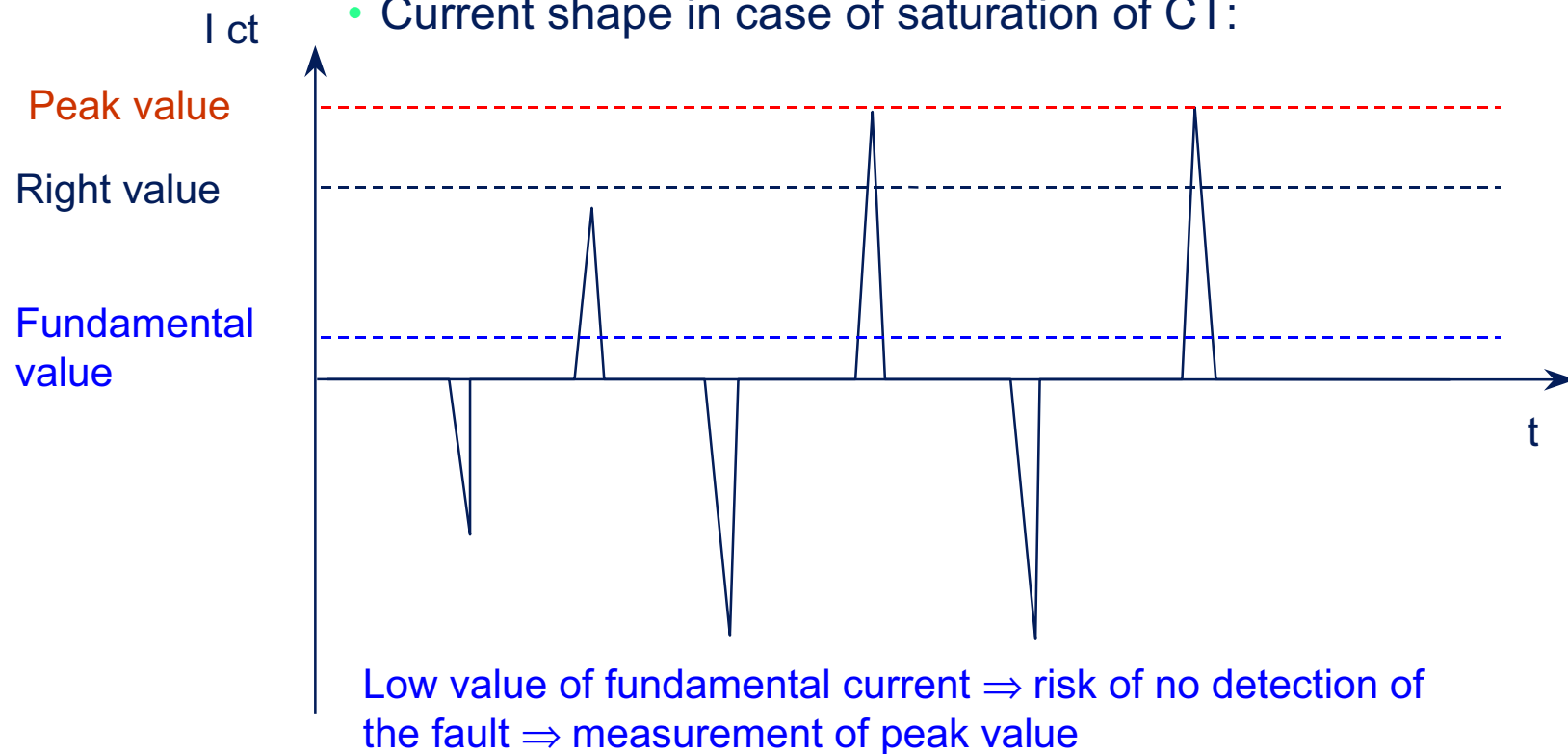
■ **Overcurrent (50/51) :**

   • Current shape in case of saturation of CT:

Low value of fundamental current ⇒ risk of no detection of the fault ⇒ measurement of peak value

I ct

Peak value

Right value

Fundamental value

t

GENERATOR PROTECTION

■ **Overcurrent (50/51) :**

- Current shape in case of no saturation of CT :

Transient overreach can be very high if only the peak value is considered ⇒ peak value is filtered (no DC component)

GENERATOR PROTECTION

■ **Overcurrent (50/51) :**

- Conclusion :

- Filtered peak detection is used to ensure tripping in case of CT saturation
- Efficace value avoids the risk of unexpected tripping

SEPAM MIX THE TWO MEASUREMENTS TO GUARANTEE A GOOD TRANSIENT OVERREACH (LESS THAN 10% FOR ANY TIME CONSTANT)

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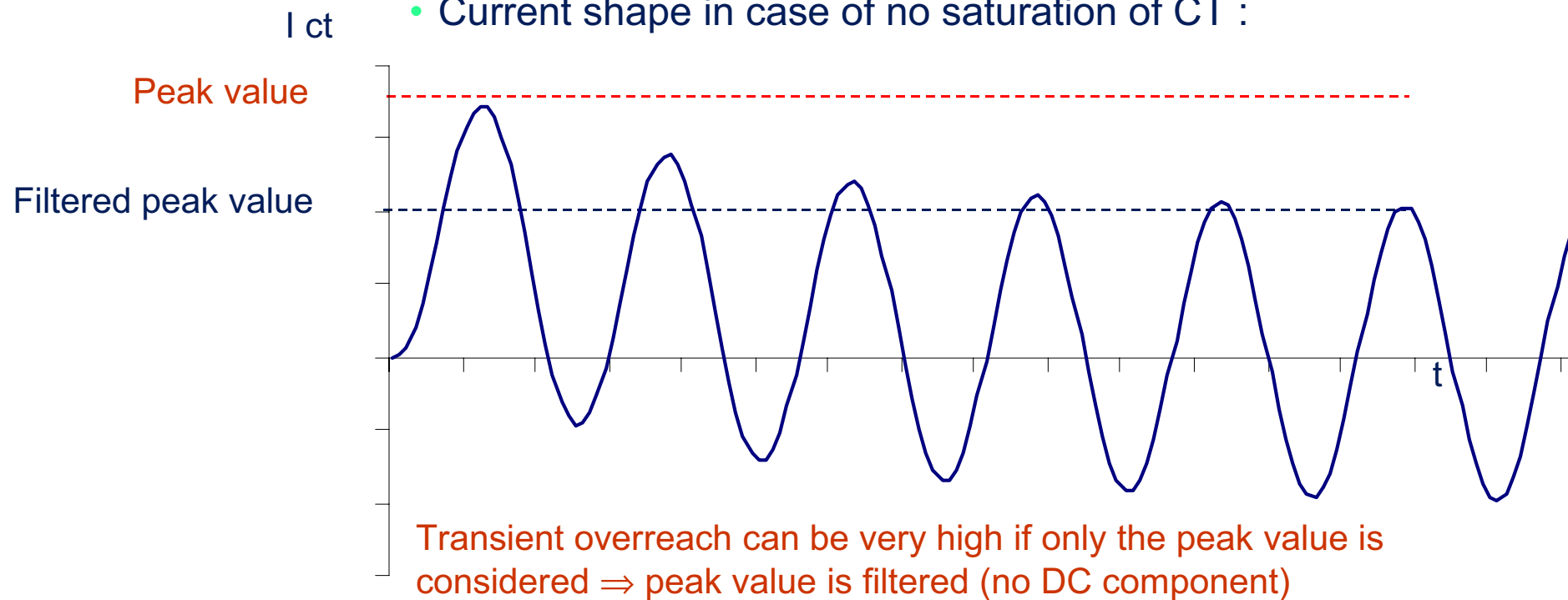
GENERATOR PROTECTION

■ **Voltage restrained overcurrent (50V/51V) :**

Sensors

Measurement of phase currents:
3 CTs or 3 CSPs

I1
I2
I3

U21
U32
U13
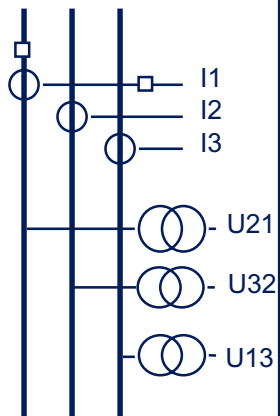
Measurement of phase-to-phase voltages:
3 VTs

Principle

I > k Is

t   0

k
1

0.2

U

0.2Un 0.8Un

k
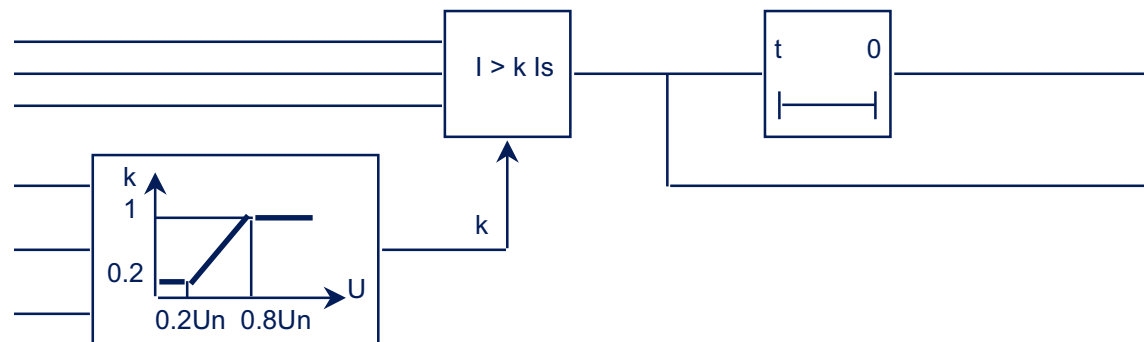
Settings:
- Is: current setting
- T: time-delayed tripping time, definite time only

Fixed parameter:
- Un: rated primary voltage (status)

Outputs

time-delayed

instantaneous

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GENERATOR PROTECTION

■ **Earth fault (50N/51N) :**

Harmonic 2 restrain

An earth fault current (including harmonic 2) could appear
in case of CT saturation if earth fault is measured by means
of the sum of 3 TC.

GENERATOR PROTECTION

■ **Real overpower (32P) :**

Against motor operation :
Reverse real power (ANSI 32P)

- Turbine :   Ps = 1 to 5% of Pn
- Diesel :   Ps = 5 to 20% of Pn
- Time delay ≥ 1 sec

■ **Reactive overpower (32Q) :**

Against field loss :
 Reactive overpower (ANSI 32Q)

- Qs ~ 0.3 Sn
- Time delay : several seconds

GENERATOR PROTECTION : Reverse reactive power relay / impedance relay (32Q/40)
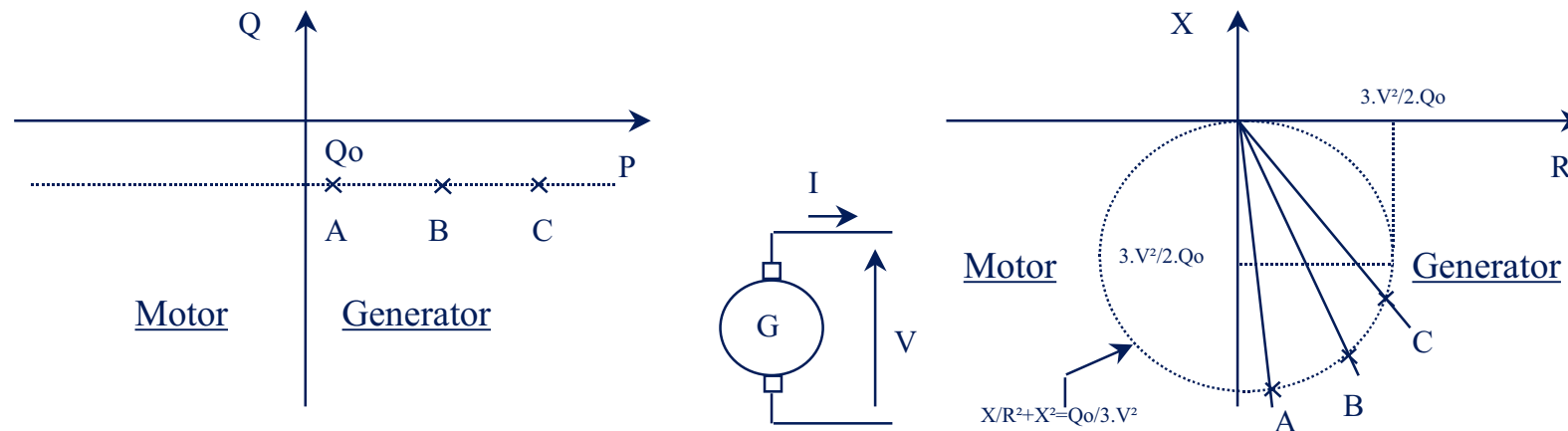
R = Real part (V/I)

X = Imaginary part (V/I)

$Q = 3.X.V^2/X^2+R^2$

$P = 3.R.V^2/X^2+R^2$

$\Rightarrow \quad R.Q = X.P$

Point A : $P \# 0$, $Q = Qo$, $\Rightarrow X = (Qo/P).R$

Point B : $P = P1$, $Q = Qo$, $\Rightarrow X = (Qo/P1).R$

Point C : $P = P2$, $Q = Qo$, $\Rightarrow X = (Qo/P2).R$

Generator connected to a source able to supply reactive power $\Rightarrow$ correct voltage

with reverse reactive power relay : correct operation

with impedance relay : correct operation

Generator connected to a source unable to supply reactive power $\Rightarrow$ drop in voltage

with reverse reactive power relay : correct operation by adding 27 function

with impedance relay : correct operation

GENERATOR PROTECTION

- **Thermal overload (49) :**
  - Heat rise calculation :

  $$T \times \frac{dE}{dT} + E = \left(\frac{Ieq}{Ib} \right)^2$$

  $$Ieq^2 = I^2 + K \times Ii^2$$

  - I is the greatest value of I1, I2, I3 (at 50 Hz) and I1rms
  - Ii is the negative sequence current

  $$E = \left[Eo - \left(\frac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\frac{Ieq}{Ib} \right)^2$$

  - Eo : initial heat rise

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GENERATOR PROTECTION

■ **Thermal overload (49) (cont'd) :** $E = \left[Eo - \left(\dfrac{Ieq}{Ib} \right)^2 \right] \times e^{-\frac{t}{T}} + \left(\dfrac{Ieq}{Ib} \right)^2$

 • **Operation**

GENERATOR PROTECTION

■ **Thermal overload (49) :**

Thermal overload function is used to protect the generator against too high requested active power that is to say if the power of the load increases.
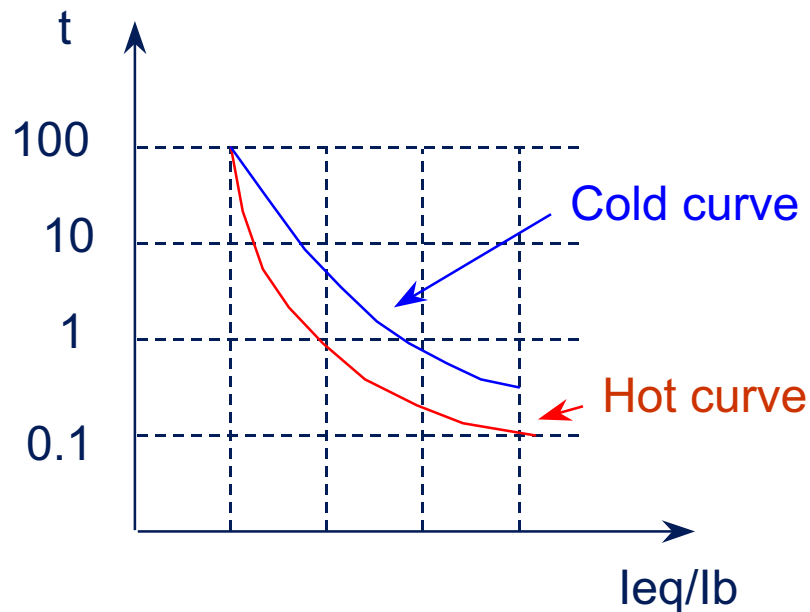
$$t = T \times Log \dfrac{\left(\dfrac{I}{Ib}\right)^2}{\left(\dfrac{I}{Ib}\right)^2 - Es2}$$

$$t = T \times Log \dfrac{\left(\dfrac{I}{Ib}\right)^2 - 1}{\left(\dfrac{I}{Ib}\right)^2 - Es2}$$

Es2 = thermal setting point in %

T = heat rise (T1) or cooling (T2) time constant

NB : For generator, K factor = 0

GENERATOR PROTECTION

■ **Negative sequence / unbalance (46) :**

  • You want to detect the loss of one phase

⇒DT curve with setting Is < 15% of Ib and time setting = several seconds

  • You want to protect the machine against negative sequence current

    High frequency currents in the dampers induce high power losses

 ⇒use IDMT curve or similar

Setting indication : 15% of Ib and time setting = several seconds

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GENERATOR PROTECTION
Phase directional overcurrent (67) :

IccA   IccB

A   B

U   I

GENERATOR PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ Fault in A :

Phase directional overcurrent (cont'd) (67) :

■ Fault in B :

IsB

IccB

Relais

IccB

I2

U13

U21

I1

I3

U32
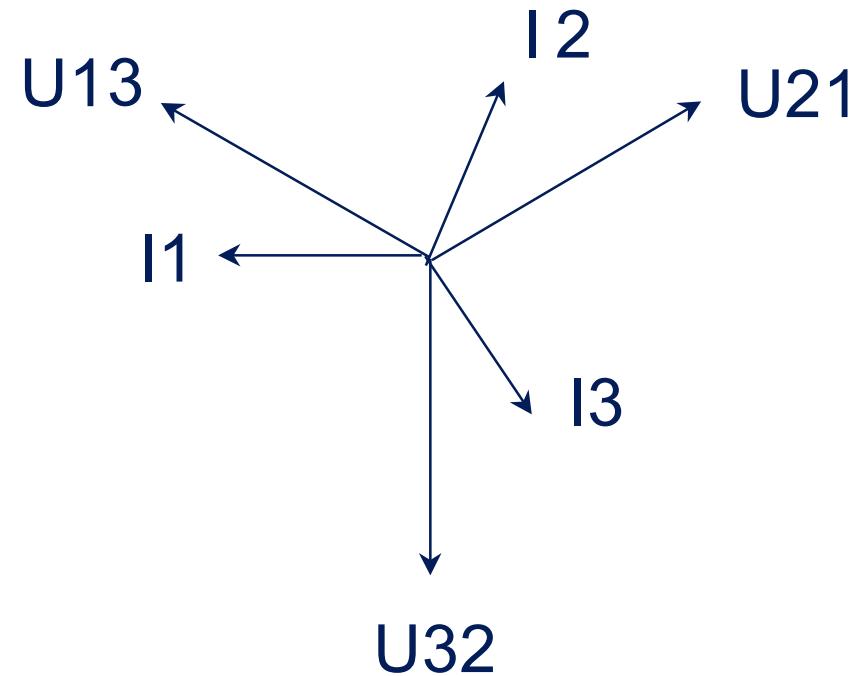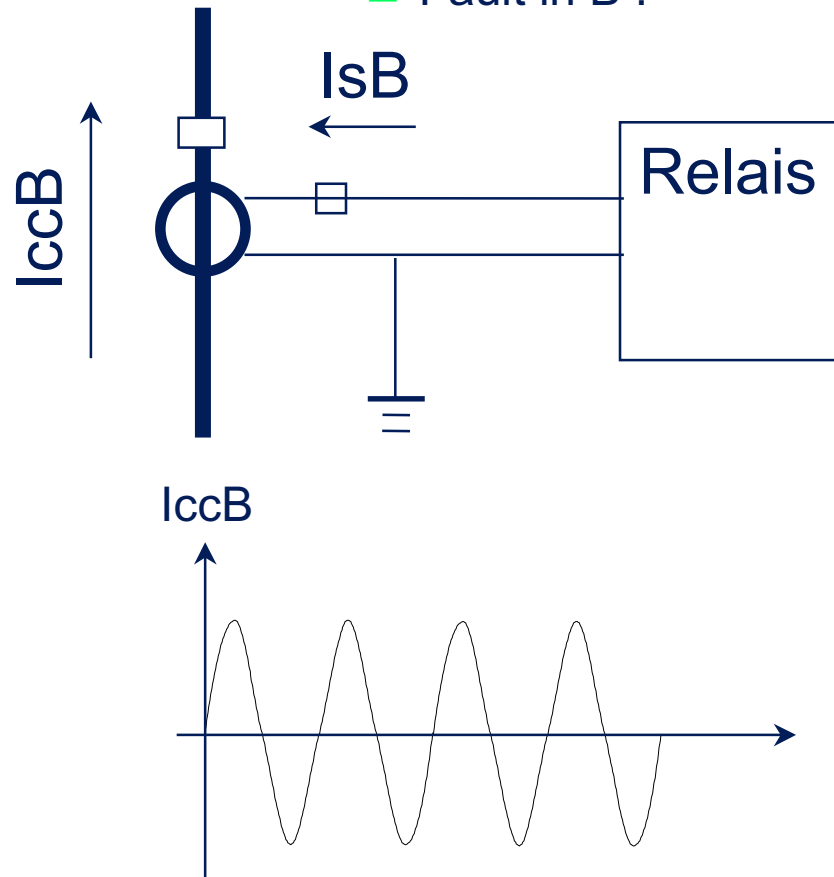
GENERATOR PROTECTION
Phase directional overcurrent (cont'd) (67) :

- Measurement of the phase shift angle between a reference voltage, called the polarization voltage, and a current makes it possible to determine the current direction

- In practice:
  - polarization by phase-to-phase voltage
  - measurement of $\varphi 1$ = phase shift (U32,I1), $\varphi 2$ = phase shift (U13,I2) and $\varphi 3$ = phase shift (U21,I3)

GENERATOR PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Conventions :**

I1

I1 in normal direction

$\varphi 1$

$\varphi 1$

U32

I1

I1 in inverse direction

■ $\varphi 1$ = phase shift (U32,I1)
  varies according to the impedance of the circuit under consideration

■ Conventional current direction:
  - Normal direction = from busbar to cable
  - Inverse direction = from cable to busbar

■ Conventional CT wiring:
  normal direction   inverse direction

  I

  I

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GENERATOR PROTECTION
Phase directional overcurrent (cont'd) (67) :

■ **Characteristic angle θ :**

Normal zone

θ

U32

Inverse zone

■ Division of a current vectorial plane into 2 half-planes:

• normal zone

• inverse zone

■ Characteristic angle θ =
angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage

■ Setting values of θ :

• 30° if high reactance circuit (φ1minimum)

• 45° average case

• 60° if high resistance circuit (φ1 maximum)

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GENERATOR PROTECTION
Phase directional overcurrent (cont'd) (67) :

- **Principle :**

I1

φ1

θ=45°

U32

Is

Phase overcurrent
Direction detection in normal direction
Directional protection function
tripping zone

- Association of 2 functions:
  - phase overcurrent protection function
    adjustable setting Is
    Definite or IDMT time
  - detection of the current direction
    characteristic angle θ

- Three-phase protection
  - I1 and φ1 (phase shift U32,I1)
  - I2 and φ2 (phase shift U11,I2)
  - I3 and φ3 (phase shift U21,I3)

- Protection operational if:
  polarization voltage > 1.5%Un

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GENERATOR PROTECTION
Directional earth fault (67N) :

IscA

IscB

A

B

Vrsd

Irsd

GENERATOR PROTECTION
Directional earth fault (67N) (cont'd):
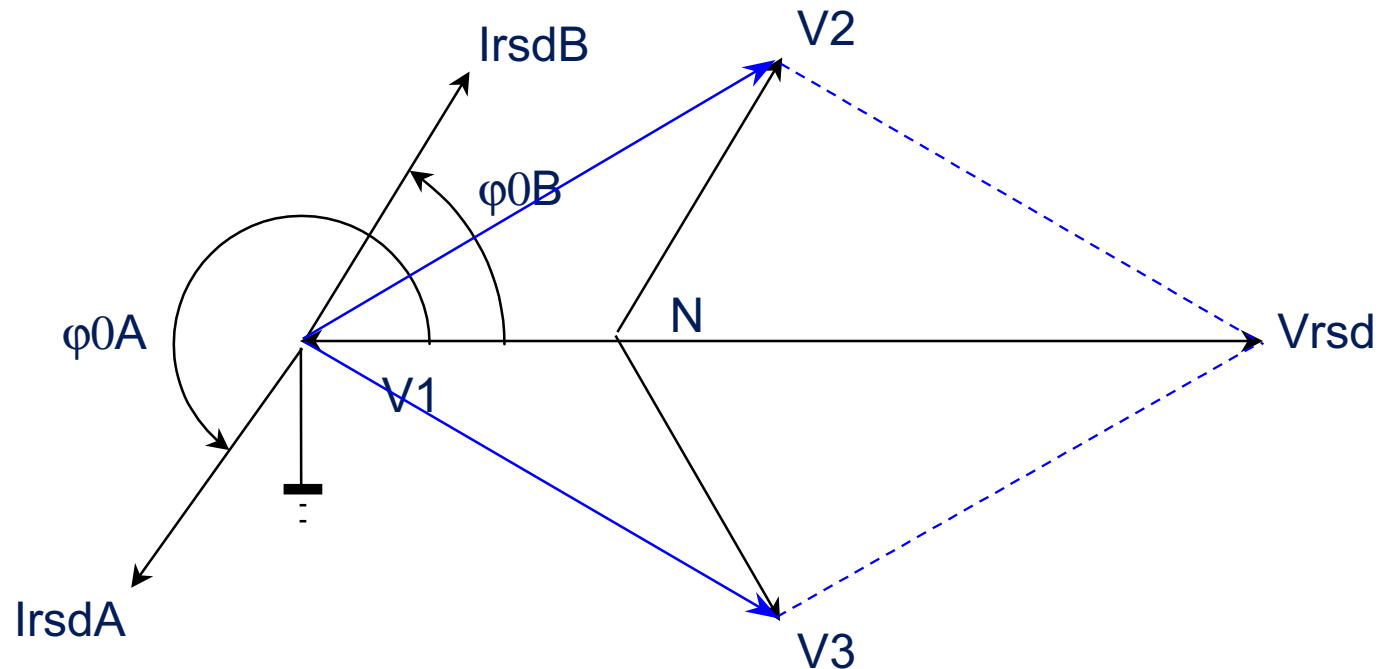

$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3 \vec{Z}_N \times \vec{I}_{rsd}$$

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GENERATOR PROTECTION
Directional earth fault (67N) (cont'd):

IrsdB   V2   **Fault at B**

φ0B

N

V1   Vrsd

Reverse direction

V3

$$\vec{V}_{rsd} = -3 \times \vec{V}_1$$

$$\text{where} \quad \vec{V}_1 = \vec{Z}_N \times \vec{I}_{rsd}$$

$$\Rightarrow \quad \vec{V}_{rsd} = -3\vec{Z}_N \times \vec{I}_{rsd}$$

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GENERATOR PROTECTION
Directional earth fault (67N) (cont'd):

■ Measurement of the phase shift angle between the residual voltage - called the polarization voltage - and the earth fault current makes it possible to determine the direction

GENERATOR PROTECTION
Directional earth fault (67N) (cont'd):
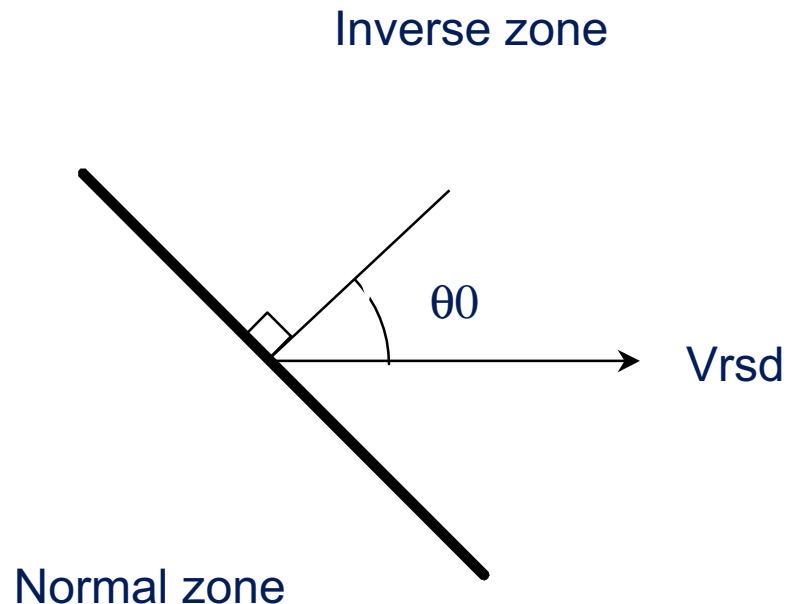
Inverse zone

Normal zone

Vrsd

$\theta 0$

- ■ Division of a current vectorial plane into 2 half-planes:
  - • normal zone
  - • inverse zone

- ■ Characteristic angle $\theta 0$ =
  angle between the perpendicular at the zone limit - characteristic line - and the polarization voltage

- ■ Typical values of $\theta 0$:
  - • 0° if N earthed by resistance
  - • 15°, 30°, 45°, 60°: intermediate values
  - • 90° if isolated neutral (Irsd=Icapa)
  - • -45° if N earthed by reactance

GENERATOR PROTECTION
Directional earth fault (67N) (cont'd):

inverse zone

$\theta 0=45°$

$\varphi 0$ Is0

Vrsd

Ip

normal zone

Irsd

Earth fault
Direction detection in normal direction
Directional protection function
tripping zone

- Association of 2 functions:
  - earth fault protection function adjustable setting Is0 Definite time
  - detection of the current direction characteristic angle $\theta 0$

- Plane single-pole protection
  - Ip : projection of Irsd on the characteristic line
  - $\varphi 0$: phase shift (Vrsd,Irsd)

- Protection operational if: polarization voltage >= 2.6% Un

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GENERATOR PROTECTION
Directional earth fault (67N) (cont'd):

COMPENSATED NEUTRAL SYSTEM :

■ Petersen coil + resistor:

- designed to compensate capacitive currents
  => Irsd is highly resistive

=> characteristic angle not adjustable: $\theta 0 = 0°$

- self-extinguishing earth fault
  => short, recurring faults

=> protection memory time adjustable

   Tmem ~ 250 ms

- in practice, the system is slightly dissymmetrical and the residual voltage is not zero when there is no fault
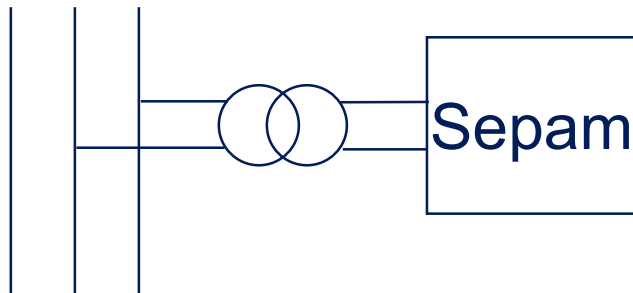
=> Vs0 setting adjustable

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GENERATOR PROTECTION

■ **Generator differential (87G) :**
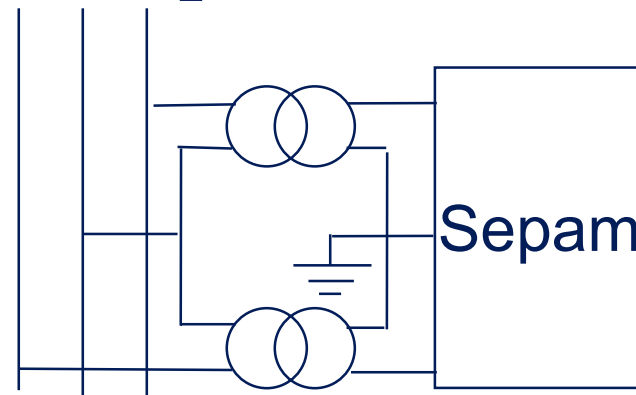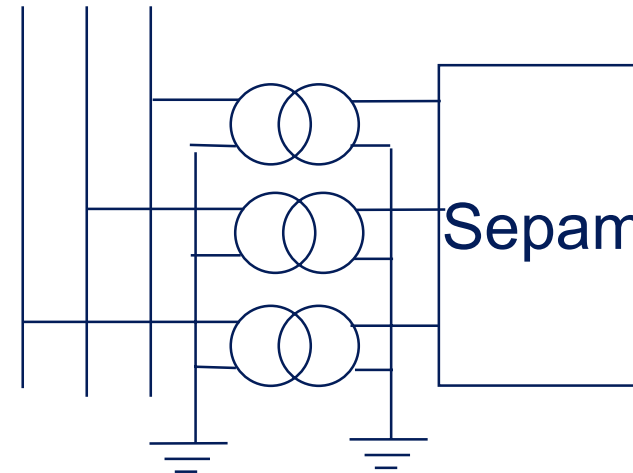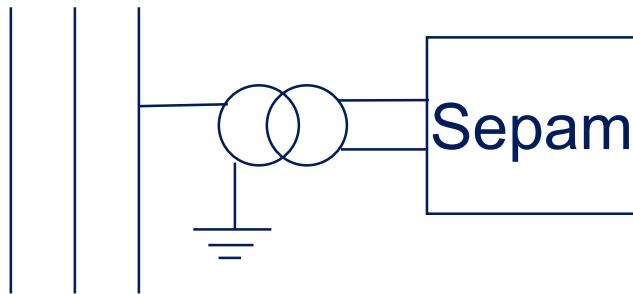
$Id = I - I'$

X In

Without harmonic 2 restrain

100%

$Id1^2/8 - It1^2/32 = (0.05In)^2$

I   I'

M

$Id^2 - It^2/32 = Is^2$

Harmonic 2 restrain

Only one setting :

0.05 In < Is < 0.5 In

External fault induces saturation of the CTs and false differential current

$It = (I + I')/2$

X In

$\sqrt{2}$

GENERATOR PROTECTION

■ **Undervoltage (27) :**

GENERATOR PROTECTION

Undervoltage (27) : coordination with overcurrent protection

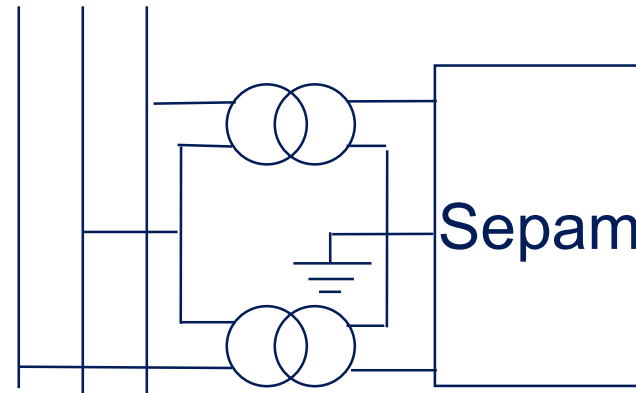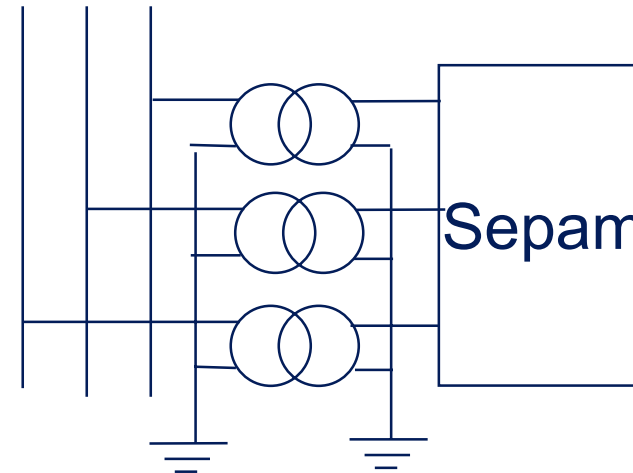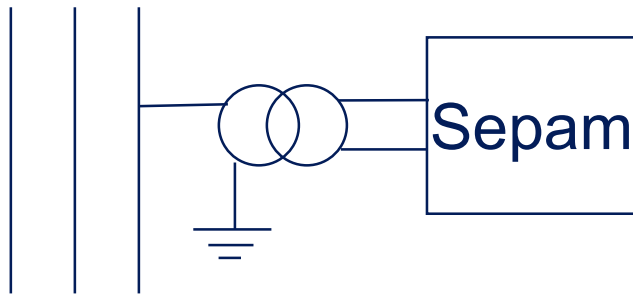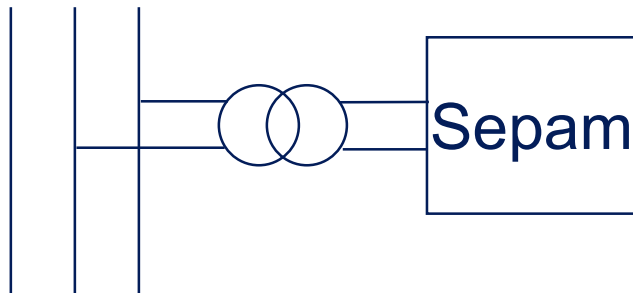- Undervoltage protection
- Overcurrent protection

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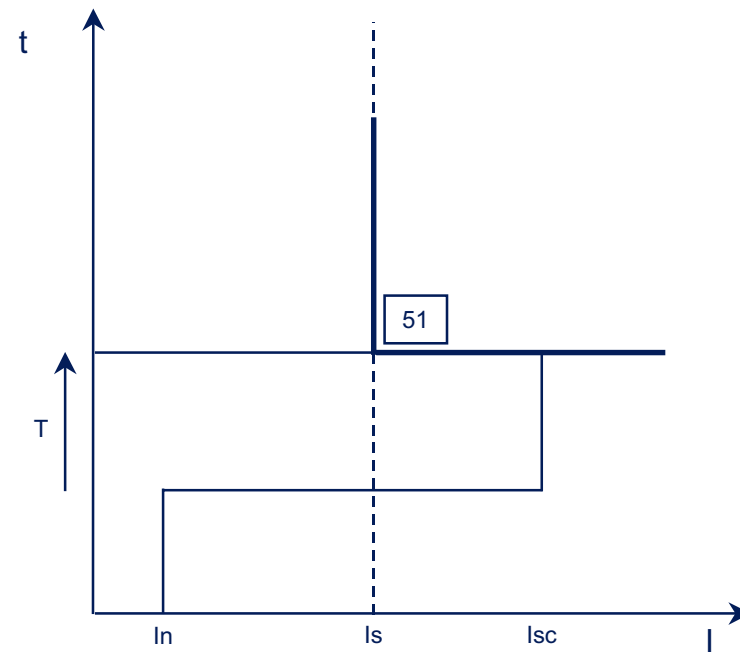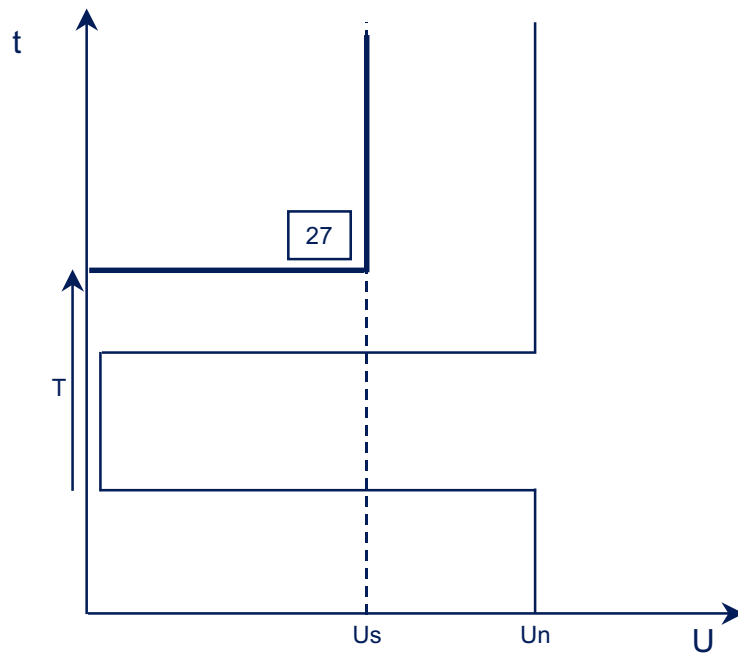
GENERATOR PROTECTION

■ **Overvoltage (59) :**

GENERATOR PROTECTION
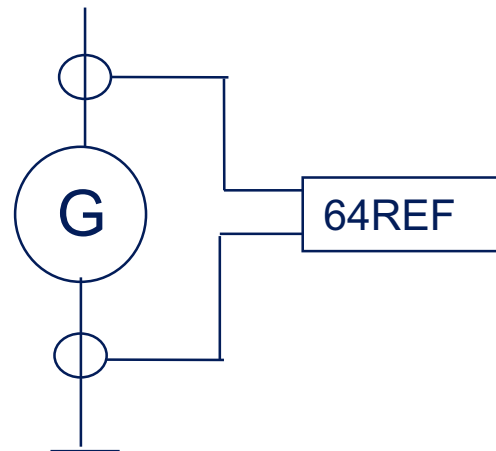
■ **Residual overvoltage (59N) :**

- For isolated neutral 59N protection is required to detect earth fault before closing the circuit breaker

- This function can be located elsewhere in the network (on busbar for example)

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GENERATOR PROTECTION

■ **Restricted earth fault (64REF) :**

- If the protection 64 REF is required

- or if the generator has a power rating of more or equal than 5 MVA the protection 64 REF is required.

- It offers the advantage of having greater sensitivity than differential protection (5% of In)

GENERATOR PROTECTION

■ **Temperature monitoring (49T/38) :**

- The protection detects if an RTD is shorted or disconnected.
  - RTD shorting is detected when the measured temperature is less than -70 $\pm$ 10°C
  - RTD disconnection is detected when the measured temperature is greater than 302 $\pm$ 27°C
- For Sepam 1000+, RTD can be Pt100, NI100, NI120 type
- For Sepam 2000, RTD can be Pt100 only
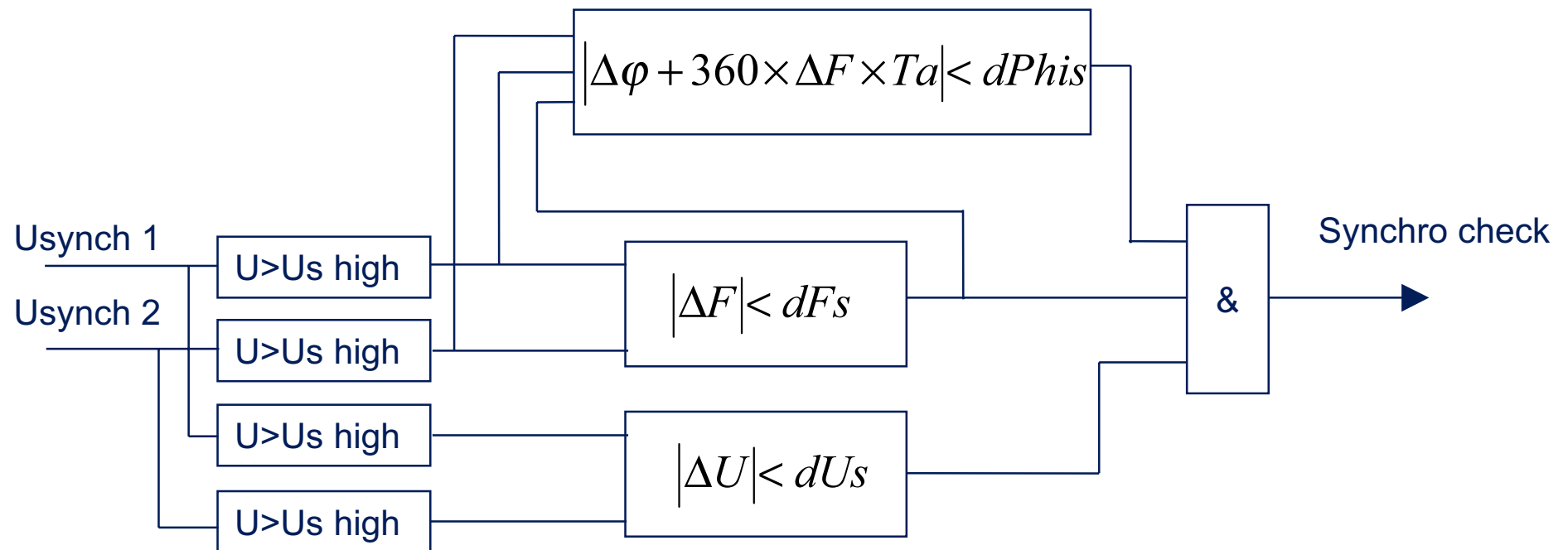
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GENERATOR PROTECTION

■ **Synchro-check (25) :**

- dUs set point : can depend on power transit

- dFs set point :depends only on accuracy

- dPhi set point :can depend on power transit

- Us high : to detect presence of voltage

- Us low : to detect absence of voltage

- Time Ta : to take into account of the circuit breaker closing time

GENERATOR PROTECTION

■ **Synchro-check (25) (cont'd) :**

GENERATOR PROTECTION

■ **Synchro-check (25) (cont'd) :**

• 4 operating modes :

Mode 1

Usynch 1   Usynch 2

Mode 2

Usynch 1   Usynch 2

Mode 3

Usynch 1   ← OR →   Usynch 2

Mode 4

Usynch 1   ← AND →   Usynch 2

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