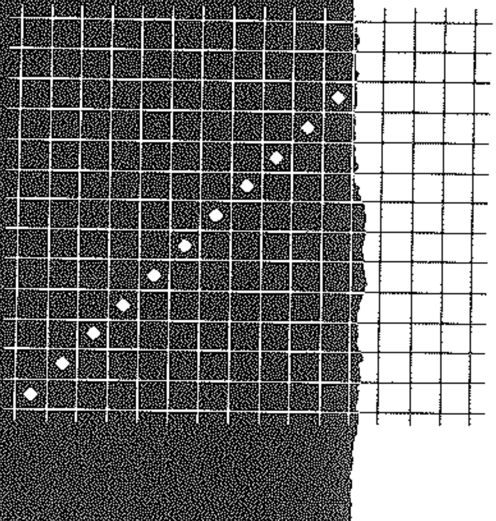
cahiers techniques

n° 174

protection of industrial and commercial MV networks



MERLIN GERIN

GROUPE SCHNEIDER

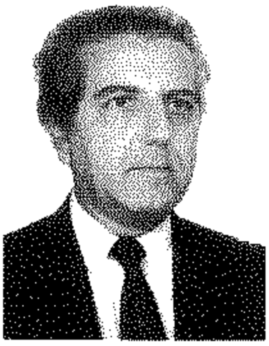
Cahiers Techniques are a collection of documents intended for people in the industry who are looking for information in greater depth in order to complement that given in display product catalogues.

Certain Cahiers Techniques go beyond this stage and constitute practical training tools for executives and technicians in the electrical and electronical industries and for trainees engineers.

They contain data allowing to design and implement electrical equipement, industrial electronics and electrical transmission and distribution and give a better understanding regarding special phenomenon they can note.

Inquiries regarding content of a Cahier Technique can be mailed or faxed to:
SCHNEIDER
Service COM TECH
F 38050 GRENOBLE CEDEX 09
Fax: 76 41 98 60

A full list of the Cahiers Techniques produced can be obtained on application from:
SCHNEIDER Com' Service
F 38050 GRENOBLE CEDEX 09
Fax: 76 60 67 32
or your Schneider local correspondant



André SASTRE

Specialist in electrotechnical measurements and industrial automatic control systems since 1966.
Self-taught, he achieved engineer status in 1971.
He joined Merlin Gerin in 1988, where he participated in the creation of the MV Protection and Control activity.
He is currently head of the sales network for this activity.

n° 174

protection of industrial and commercial MV networks

E/CT 174 first issued may 1996

glossary

FMECA:
Failure Mode and Effect Criticality Analysis: an analysis in which, according to an IEC 812 definition, "a failure mode is an effect which materializes the failure of an element in the system under analysis".

LV category A, LV category B:
voltage categories defined by the decree of 14th November, 1988:

- for AC voltages
  $50\ \text{V} < \text{LVA} \leqslant 500\ \text{V}$
  $500\ \text{V} < \text{LVB} \leqslant 1{,}000\ \text{V}$;
- for DC voltages (ripple factor < 10 %)
  $120\ \text{V} < \text{LVA} \leqslant 750\ \text{V}$
  $750\ \text{V} < \text{LVB} \leqslant 1{,}500\ \text{V}$.

These two categories are grouped together into class I in accordance with IEC 364 and standard NF C 15-100.

differential residual current:
vectoral sum of the currents flowing through the active conductors (phases and neutral) of a circuit at any point in the installation (also known simply as the residual current).

electrification:
the act of transferring an electrical charge to a body; the state of a person in contact with a live part.

electrocution:
accidental death caused by an electric current; the ultimate phase of electrification.

MV, HV:
different voltage levels are classified in accordance with decrees, standards and other specifications such as those applied by certain utilities. Thus, for AC voltages higher than 1,000 V:

- french decree of 14th November, 1988 defines two voltage categories:
  $\text{MV} = 1\ \text{kV} < U \leqslant 50\ \text{kV}$,
  $\text{HV} = U > 50\ \text{kV}$;
- publication IEC 71 specifies the highest voltage ranges for equipment:
  - ☐ range $A = 1\ \text{kV} < U < 52\ \text{kV}$,
  - ☐ range $B = 52\ \text{kV} \leqslant U < 300\ \text{kV}$,
  - ☐ range $C = U \geqslant 300\ \text{kV}$.

A review of the above is planned. It will include only two ranges:

- ☐ range $\text{I} = 1\ \text{kV} < U \leqslant 245\ \text{kV}$,
- ☐ range $\text{II} = U \geqslant 245\ \text{kV}$.

RMS -Root Mean Square- measurement:
RMS current value; includes harmonic currents =

$$\text{Irms} = \sqrt{I_{h_1}^2 + I_{h_3}^2 + I_{h_5}^2 + \ldots + I_{h_n}^2 + \ldots}$$

where
h_1 = 1st harmonic,
h_3 = 3rd harmonic,
h_n = nth harmonic.

Pcc:
short-circuit power.

dynamic stability of a network:
The ability of a network containing several synchronous and asynchronous rotating machines to return to normal operation following temporary (e.g. in the case of a short-circuit) or permanent (e.g. line opened) modification of its configuration.

protection of industrial and commercial MV networks

The protection of electrical networks requires the use of numerous and varied techniques. These are organized into a "protection plan" which requires the know-how of a specialist.

To accomplish such a task, it is necessary to be familiar with the regulations and standards and to be able to satisfy often contradictory technical and financial concerns. The specialist must meet the needs of the operator in terms of safety and availability of the electrical energy. Achieving the required dependability depends largely on the selectivity of the protective devices.

This specification sheet gives a simple explanation of protection and selectivity techniques with the intention of providing non-specialists with the means of dialoguing with the designer of a medium voltage installation. The more knowledgeable reader can go straight to chapter two; the specialist to chapter three.

contents

1. electrical protection and dependability

the consequences of an electrical fault

The consequences of an electrical fault are varied, not always obvious and theoretically difficult to imagine. Below are a few examples:

- downstream of the fault, the de-energized network induces partial and unexpected stoppage of the installation;
- the site of the fault is often damaged, requiring removal, repair, replacement return to factory for expert inspection etc;
- during the fault, the personnel runs the risk of electric shocks and burns (thermal effects), or trauma (e.g. projections, falls).

The consequences can also affect the sound parts of the network, for example during a short-circuit:

- voltage drops likely to result in pull-in or damage to logical controllers and data processing equipment;
- rotating machines lose stability and this can continue to worsen even after elimination of the fault, causing total failure of the distribution and of back-up sources intended to ensure continuity of supply.

Thus, in nearly all cases, a fault causes a break in the power supply and in production, which, given the economical consequences, is less and less acceptable.
However, it is possible to limit the stoppage to a part of the network, depending on:

- the location of the fault;
- the efficiency of the protection equipment;
- the selectivity technique implemented.

To reduce the risk of interruption, an adequate protection plan must be devised. Protection systems are intended to rapidly isolate the part of the network affected by the fault in order to limit the consequences. The purpose of selectivity is to de-energize only the affected part of the network (see fig. 1).

the operator's needs

If we could sum up these needs in one word, that word would be **dependability**.
This word has several interpretations (see "Cahiers Techniques" n° 134 and 144). In this document, two meanings are implied:

- safety;
- availability,

as seen from the point of view of electrical protection.

Thus, protection systems greatly affect safety, since they must eliminate a fault as quickly as possible in order to protect personnel and property from the consequences (personal injury, damage to equipment).

These same systems greatly affect availability, since:

- they limit the part affected by a fault through their selectivity;
- they minimize the time required to restore the voltage;
- they are equipped with self-tests and self-diagnosis systems which reduce the risk of failure and nuisance tripping;
- they provide the operator with the possibility of remote diagnosis (through the communication function);
- they can incorporate automatic control to restore operation (load restoring, restart sequences, switching, etc.).

Note that safety and availability are contradictory terms since automatic protection equipment often causes interruptions. Thus, the level of dependability selected for an installation is the result of a compromise which takes into account a whole range of choices formally set out by the protection plan.

Consequently, any modification whether under study or planned, must be carefully analyzed from the point of view of its effect on safety and availability. For this purpose, the different dependability levels required for a network must be set out:

- from the design stage, therefore before selecting the components;
- and also when selecting the operating mode.

the design of an electrical network

The design is often represented by a single-line diagram showing the main components of the network (transformer, AC generator, machines, etc.) and how they are interconnected (line, busbars, etc.). The level of continuity of service greatly depends on the design.

Selection of the types of protection equipment and selectivity techniques depend on the selected design (aerial, double shunt, loop, single or double busbar system), but also on the relative location of the components (see "Cahier Technique" n° 169).

In order to meet the needs of the operator as economically as possible, the method below can be used.
It includes four phases:
1 - set out the dependability objectives for each power requirement zone,
2 - create a network design based on the power requirements (single-line diagram),
3 - draw up a protection plan specifying the selected protection techniques and the selectivity analysis,

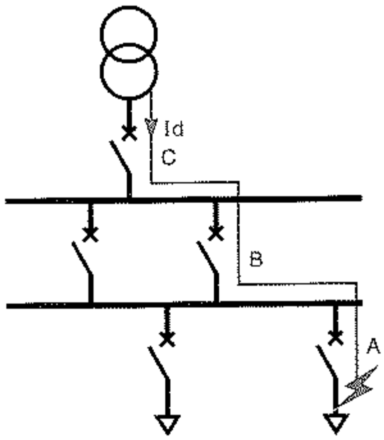


fig. 1: there is said to be selectivity between protective devices A and B and between B and C when, for any fault downstream of A, only circuit-breaker A opens, where as the fault current Id has also been detected by B and C.

4 - check that the dependability objectives are met.
If not, then phase 2 (design) must be modified, then phases 3 and 4 repeated.

For the availability analysis, the designers can use expert systems such as the ADELIA system currently used by Merlin Gerin in the design of power distribution networks. These systems are based on FMECA reliability data and failure trees (see "Cahier Technique" n° 144). In this way, it is possible to estimate the availability of different designs so that the most adequate can then be selected.

the protection plan

The protection plan consists of a number of consistent, efficient pieces of protection equipment selected in order to meet the objectives of power availability and protection of personnel and equipment.
The protection plan sets out the conditions in which protection equipment should trip or should not trip in the event of faults during normal transients (e.g. caused by operating controls), and also in the event of harmonics and induced or radiated interference...

The plan is based on general data and data specific to the installation in question such as:

- regulations;
- standards;
- standard procedures;
- operating conditions;
- receivers;
- the neutral point arrangement;
- the co-ordination of the protection equipment;
- the consequences of a faultt
- the presence or absence of the different power sources.

All these data present the different potential risks, which are very varied, often interdependent and difficult to estimate. For example:

- risks induced by the network configuration (aerial, closed loop, load shedding, parallel sources, neutral point arrangement, etc.), which depend on the type of neutral point arrangement selected, but also on the environment (access, relative humidity, altitude, etc.);
- risks inherent in the receivers: a transformer is not subjected to the same risks as a motor; a rolling mill does not have the same requirements as a crusher, etc.

Finally, for all components of a network, including the generators, conductors and receivers, the protection plan defines at least the selected protection equipment and their settings to protect against phase-phase and phase-earth short-circuit faults.

Regulations

This means the legal or applicable texts which impose certain mandatory choices (for example, in France, the decree concerning the protection of employees).

Standards

The standards applicable to the installation concerned must be taken into account.
For electrical installations, the applicable standards depend on the voltage levels of each circuit and normally depend on different parameters. Thus, in France, standard NF C 13-200 applicable to "private HV installations" also takes climate and environment into account.

Standard procedures

Although they concern the selected design, type of protection and operating mode, standard procedures are not always formally set out.
Yet the application of standard procedures makes for smoother operation, for they provide the user with operating principles with which he is familiar.

Operating conditions

These include the choice of centralized network control, the possibility of local control, makeup of shifts, imposed on-site work, down times, etc. and all affect the protection plan.

Receivers

Each receiver has its own effect: motors because of their startup characteristics, AC generators because of their reactance, transformers because of their short-circuit voltages, cables because of their capacitance and short-circuit resistance, etc.

Neutral point arrangement

(see "Cahier technique" n° 62)
The network earth connection configuration or neutral point arrangement is determined based on the required level of the following:

- personnel safety and equipment protection;
- the need to ensure operational continuity.

It must take the following into account:

- the qualifications of the operators;
- the risks of damage to the equipment;
- the need to limit overvoltages.

The selected design affects the fault current value determined by the earthing system. This value is a compromise between:

- the need to ensure a sufficiently high current to:
  - □ ensure efficient selectivity: the residual current must be detected without being confused with the capacitive currents of the sound lines (cables),
  - □ protect against overvoltages by reducing the network-to-earth impedance;
- and the need to ensure that the current is sufficiently low to limit damage (in particular in rotating machines and transformers), but also to limit the risk of fire or explosion in sensitive areas (petrochemical industry, mines, etc.).

For an existing installation, the protection equipment used and the selectivity analysis are directly affected by the existing neutral point arrangement.

For a new installation, the selectivity analysis serves to validate the selected options (neutral point arrangement, maximum earth fault current and suitable location of earthing system), or to select other options.

Co-ordination of protection equipment

Co-ordination means "harmonizing the operation of the protection equipment" and more specifically, "ensuring its selectivity".

A distribution network is rarely totally independent of other installations. In particular, co-ordination is essential between:

- the planned installation network and the existing installation network,

or between;

- the planned installation network and the upstream and/or public installation network.

The analysis is based on:

- protection equipment operating curves, for example it is advisable to use reciprocal time protection equipment to co-ordinate with a fuse;
- tripping times (selectivity).

Note

Public electrical utilities generally impose the maximum regulations applicable to the supply substation (in France, EDF requires 0.2 s for 20 kV MV substations).

A co-ordination study specifies the times required to eliminate faults, which must:

- be satisfactory to ensure personnel safety;
- comply with the equipment withstand levels (thermal, resistance to electrodynamic stress);
- be selective with respect to the nearby installations.

The consequences of a fault

This includes personal injury, damage or destruction of equipment, production stoppages, etc.

They are estimated in terms of:

- for the personnel, the fault current, the increased potential in accessible chassis, the earth circuit impedances... The risks are reduced the shorter the the person is in direct or indirect contact with a live part;
- for the equipment, its thermal and/or electrodynamic resistance, the risk of burning or perforation of the steel plating in the magnetic circuits of the equipment and its sensitivity to voltage drops or failures;
    - □ overheating and electrodynamic stresses have more effect on the service life of the equipment if they are long-lived and of greater magnitude. Eliminating them rapidly prevents premature aging of the equipment,
    - □ voltage failures, often caused by a fault detected by protection equipment. They affect the entire downstream network,
        - they can be short-lived, as is the case for power failures followed by automatic source switching or restoring. They particularly affect electronic equipment (e.g. control or data processing equipment), but have less effect on high-inertia equipment (ovens, fans, etc.),
        - they can be long-lived if repair work has to be carried out before restoral of the voltage, and therefore can be financially prejudicial to the company,
    - □ voltage drops, often caused by short-circuits. Their impact increases the nearer they are to the point of failure and can cause serious problems, even in sound parts of the network. Limiting the duration of these voltage faults helps reduce the effect on operation;
- the type of equipment (synchronous or asynchronous motors, immersed or cast resin transformers, AC generators, etc.);
- when operation is separate from the public distribution network, depending on the relative magnitude of the cumulative power in the rotating machines (motors and AC generators), a lack of stability may lead to total failure of the power distribution and of the back-up sources intended to ensure power supply continuity. Note that even once a fault has been eliminated, this lack of stability can continue to worsen.

The shorter-lived the fault, the more chance there is of maintaining operation of all rotating machines, both synchronous and asynchronous.

To conclude, the speedy elimination of a fault is essential to reduce the risks; moreover, it improves availability and maintainability.

Once they have been estimated, the consequences of a fault are discussed then finally accepted or rejected, and any special measures determined:

- partial selectivity;
- cutoff transformer;
- temporary neutral point arrangement;
- time-dependent or logic protection;
- authorization or inhibition of parallel source operation;
- zero sequence generator connected to busbars;
- etc.

When different sources are present

When a network is supplied by different sources in different configurations for certain periods, the phase-phase and phase-earth short-circuit currents must be determined for each case. They are in general very different and knowledge of these is essential in order to ensure protection and selectivity in all situations. The protection equipment will require different thresholds and time delays depending on the configuration (see fig. 2a). In particular, it is necessary to "back up" fuses by using indirect protection equipment to ensure

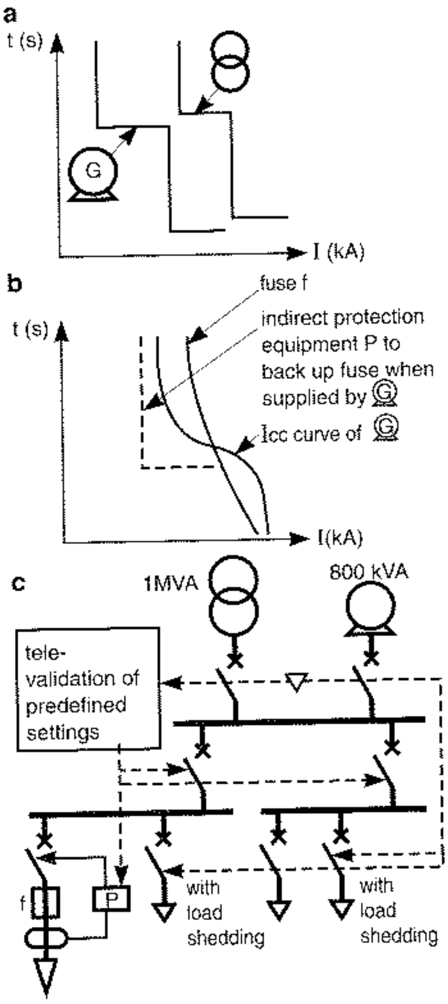


fig. 2: an example of the advantages of televalidation.
*When changing the power supply source, the feeder bay protection equipment must be reset by modifying the threshold (**a**) and/or bringing other protection equipment into play (**b**).*
*Televalidation (**c**) improves dependability (availability and safety).*

selectivity when the fault currents are likely to be low (high impedance on a fault, or source power limited). This situation is shown in figure 2b where $Icc_{transformer} >> Icc_{AC\ generator}$.

A practical solution is telecontrol, however the ideal solution is televalidation or remote selection of predefined and tested values (see fig. 2c).

selectivity

Selectivity consists in de-energizing only the part of the network affected by a fault. It organizes tripping of the different phase and earth protection equipment, which must be as rapid as possible (see "Cahier Technique" n° 62).

For this purpose, a "selectivity analysis" is normally carried out for each installation with the aim of confirming that all predictable faults will be eliminated within the technical limits set for both the installation equipment (e.g. breaking capacity) and for the load (e.g. maximum down time).

To do this, the designers strive to achieve the most adequate architecture by positioning protection equipment at certain points in the layout of the electrical network.

Contents of a selectivity analysis

In practice, a selectivity analysis consists in determining the different settings and adjustments (time delays and thresholds) for the protection equipment while ensuring compatibility between the down times defined for the upstream and the downstream equipment.

This type of analysis is an important task, since:

- it takes into account the different fault currents likely to occur at different points of a network;
- it checks that each probable fault can be eliminated by two different pieces of protection equipment, in order to back up the potential failure of the nearest piece of protection equipment or of one of its associated elements such as cabling, current adapters, circuit-breaker, connectics, etc.

Note that the settings of the equipment upstream of the network (incomer side) are often imposed by the power distributor whereas the settings of the downstream equipment (load side) are often imposed by the circuit with the highest power rating.

Description of a selectivity analysis

A selectivity analysis should include:

□ a description of the operating modes taken into account in the analysis,
□ a simplified single-line diagram,
□ the selectivity diagrams, phase protection diagrams and earth fault protection diagrams,
□ a technical data sheet,
□ a settings record sheet,

- the simplified single-line diagram: this represents the skeleton of the network, the essential operating mechanisms and the protection equipment with their identification (see fig. 3a);
- the selectivity diagrams: these diagrams (see fig. 3b) show the tripping curves of each piece of protection equipment along with their identifications corresponding to those indicated on the single-line diagram (see fig. 3 a);
- the technical data file: this describes the selectivity principles which it is not possible to show on the diagrams (logic or differential selectivity, for example). It presents and explains the results, in particular the tripping time obtained for the circuit-breaker at the most upstream end of the installation. It indicates the risks and, if necessary, proposes solutions which, as indicated above, may affect the distribution configuration.

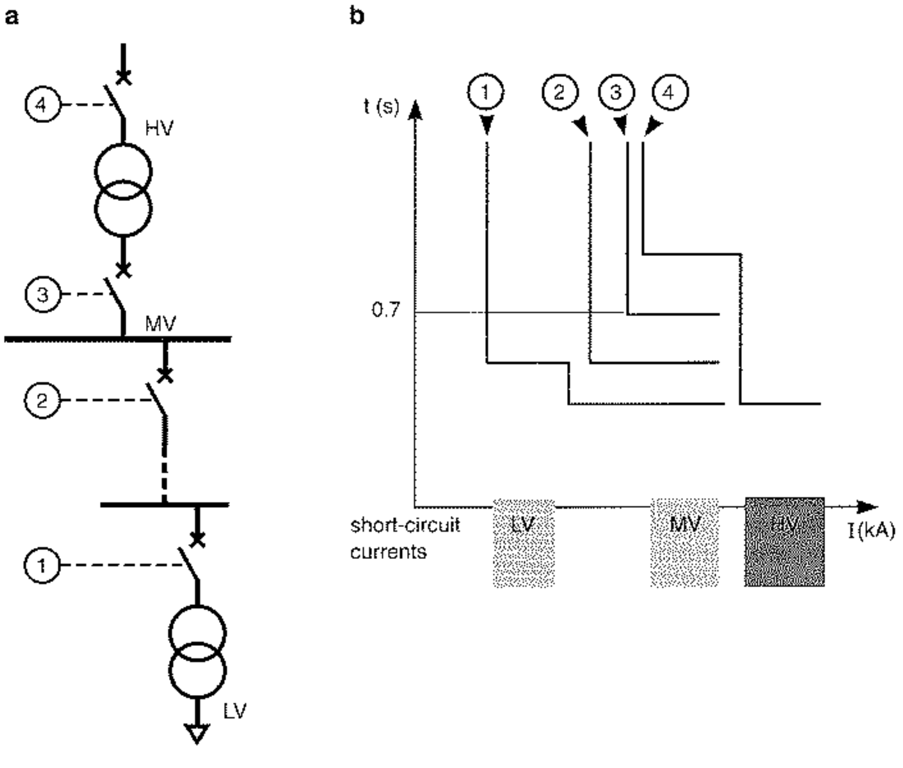


*fig. 3: example of a single-line diagram (**a**) and a selectivity diagram for protection equipment (**b**). Note that, in order to allow comparison, the short-circuit currents are expressed for the same voltage level.*

Some examples are shown in the table in figure 4.
This non-exhaustive list shows the important links between the analyses of:

  - the configuration,
  - the short-circuit currents,
  - the selectivity.

Carrying out these analyses from the start of a project is thus particularly useful;

- the settings sheet:
This document records all the setting values of all the protection equipment. Essential for startup, it is the end product of the selectivity analysis.

protection reliability

The reliability of the protection equipment is an essential factor for the safety and availability of an electrical installation. During development and production, protection equipment designers pursue a dual objective:

- ensure tripping
➡ safety;

- avoid nuisance tripping
➡ availability.

This objective has now been attained using digital-technology protection equipment, since:

- after undergoing numerous EMC tests during the design and production stage, they can then be installed in severe environments;
- once installed:
  - they permanently carry out self-tests (known as the watchdog function),
  - in the event of a fault, they provide a self-diagnosis which indicates the cause, thus reducing the down time.

However, whatever type of protection is used, the overall objective can only be attained if:

- good quality sensors are used;
- the auxiliary power supply is reliable;
- the device is correctly operated and adjusted.

integration of the protection with monitoring and control functions

Microprocessor-enhanced protection equipment (see fig. 5) can ensure numerous functions:

- it can process data from voltage and current sensors and display various measurements (I,W, power factor, P, Q, etc.) to ensure parameter-dependent protection;
- they also provide local automatic control functions:
  - switching (or automatic transfer),
  - alarm preprocessing,
  - storage of data such as tripping, blocking, etc,
  - mutual tripping between two terminations of a line or the primary and secondary windings of a transformer,
  - logic selectivity (see "Cahier Technique" n° 2),
  - load shedding and restoring.

These remote automatic control functions are as important as selectivity itself as far as the operational continuity objective is concerned.

The protection, monitoring and control units or assemblies are also able to communicate with each other, thus meeting the principle of remote intelligence.
Remote intelligence means that the decision is taken by the device nearest to the action required, i.e.:

risks detected	**solution**
incompatibility between the protection equipment time delays	■ revise configuration to improve selectivity; ■ modifiy protection plan to use logic or differential selectivity; ■ negotiate with the utility for increased substation time; ■ change distribution and/or service voltage.
incompatibility between short-circuit current and equipment.	■ do not allow parallel-coupling of sources; ■ increase transformers Ucc; ■ add limiting inductances; ■ use different equipment.
fuse does not blow	■ change fuse ratings; ■ add an indirect protection relay with switch; ■ replace fuses by a circuit-breaker; ■ modify source: □ increase short-circuit power; □ reduce Ucc of upstream transformer.
down time too long	■ use double shunt type power supply; ■ provide a replacement source that can be rapidly implemented (back-up generator) and, if necessary, load shed low priority loads; ■ use automatic switching and motor-driven switchgear.

fig. 4: risks and solutions affecting the configuration of a distribution network.

- tripping following a short-circuit is decided and initiated immediately upstream the point of failure;
- load shedding is decided depending on the extent of the overload, either at workshop level (local management unit) or at incoming feeder level (central management unit).

This principle is advantageous from the point of view of availability and management of the electrical network, since these intercommunicating units can be used with computers to acquire numerous parameters which can then be compared with reference values in order to detect serious deviations. It is then possible to trigger a warning in order to ensure preventive maintenance, for example:

- a warning can be given before blocking occurs by detecting a significant increase in the starting current of a motor;
- premature aging of equipment can be predicted following a prolonged overload;
- a warning can be given before a short-circuit occurs by detecting an increase in the residual current (insulation level drop).

fig. 5: Sepam, a range of microprocessor-based protection equipment integrating a monitoring and control capability (Merlin Gerin).

2. types of selectivity and protection equipment

The type of protection equipment selected when drawing up the protection plan has a direct effect on selectivity.

This chapter gives a brief summary of the different types of selectivity and protection equipment.

These types of selectivity and protection equipment are the outcome of the following concepts:
- standard procedures;
- operating mode;
- the influence of the distribution utilities;
- technological developments;
- techniques devised by the manufacturers.

They last because they all have advantages. The correct choice for any given point in the network must therefore be based on one of the above concepts, in other words, the one which ensures most advantages.

This freedom to optimize any one choice is made easier by the use of devices capable of offering several solutions within the same equipment.

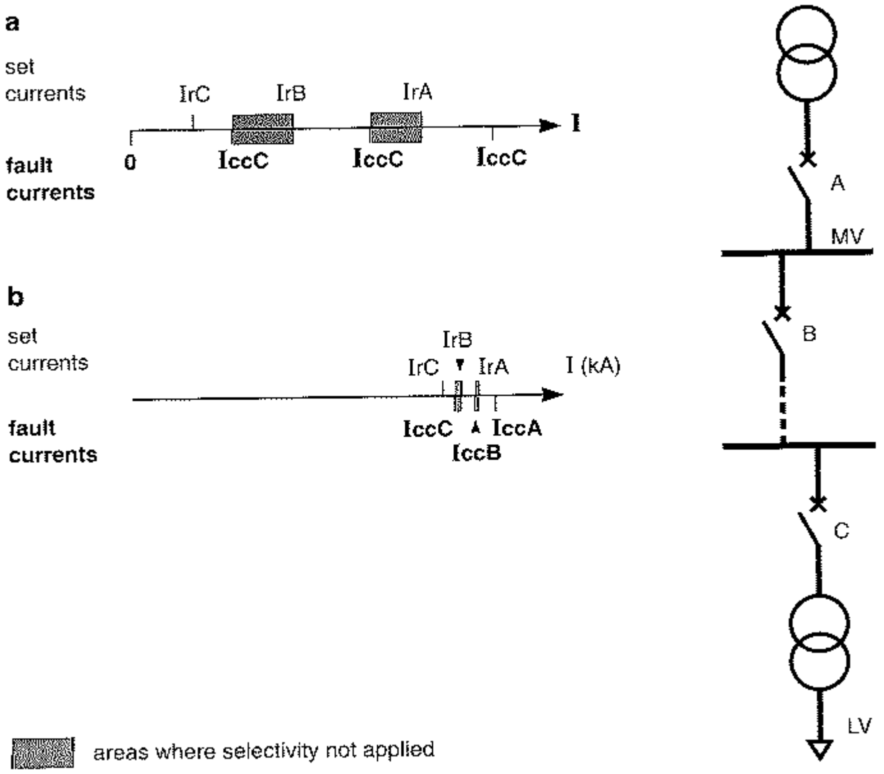


*fig. 6: in theory **(a)**, to ensure amp-dependent selectivity, check that: IccA > IrA > IccB > IrB > IccC > IrC.*
*In practice **(b)**, the closeness of the adjustment values only allows partial selectivity.*

current-dependent selectivity

In current-dependent selectivity, the monitored variable is the current.

In a network, the farther a point of failure is from the source, the weaker the short-circuit current.

Thus, in theory, selectivity can be obtained by setting the threshold of the protection equipment to the predicted short-circuit current according to their position in the distribution network (see fig. 6a).

This type of selectivity does not include the notion of time delay, since it is instantaneous, each piece of protection equipment being independent of the others. It is frequently used for LV class A end consumer, but rarely for MV installations, since the actual short-circuit current variations between any two points are too small (the coupled impedances are negligible), thus selectivity is only partial (see fig. 6b). Note that for HV installations in general an impedance-inducing fault rapidly deteriorates into a total breakdown.

The major disadvantage of this type of selectivity is that the upstream side does not back up the downstream side of an installation (i.e. there is no redundancy).

Finally, the main handicap of amp-dependent selectivity is that the threshold of a piece of protection equipment increases the nearer it is to the source, hence the risk of greater damage. So, by favouring the safety aspect, it often compromises the dependability objective defined in chapter 1.

time-dependent selectivity

This type of selectivity integrates the concept of time into the monitored variable, i.e. the current. A time delay is added to the action of the current-dependent protection equipment.

To do this, the trigger thresholds are defined with increasing time delays from the downstream to the upstream side. Thus, upstream of a fault, several pieces of equipment will be sensitized (redundancy), but if a fault occurs, only the device located immediately upstream of the fault will trip: since the fault point is no longer energized, the other protective devices stop "seeing" the fault before their time delays have elapsed.

Operation can be checked by comparing (i.e. superposing) the operating curves (see fig. 7), which must be sufficiently spaced to ensure correct selectivity (0.3 s, for example). However, when two pieces of equipment monitor the same rated current (with or without a voltage change), the thresholds must also be shifted 20 % in order to be able to ignore the tolerances.
The time delays are of two types: either dependent on the magnitude of the fault current, or independent of it (see fig. 8).

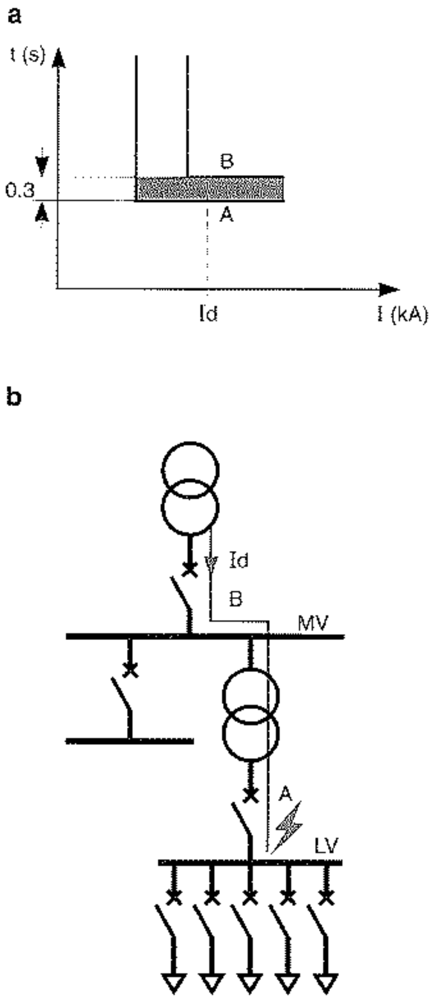
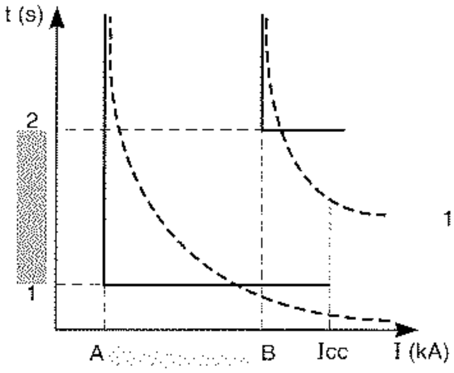


*fig. 7: by superposing the trigger curves (**a**), it is possible to check the selectivity between circuit-breakers A and B (**b**) which detect the same fault current Id.*

Time-dependent selectivity is frequently used because of its simplicity. However, it does have one inconvenience:
the time delay increases by between 0.2 s and 0.3 s at each "stage" as the source is neared. This is necessary to take account of the response time tolerances of the components making up the protection system (sensors, electronics, release device and circuit-breaker) and of the arcing time of the downstream circuit-breaker. Therefore, the higher the energy level of a fault and the nearer it is to the source, the longer it will remain energized (hence greater damage).

The dependability objective is not totally attained, but by applying this type of selectivity between two or three stages, a satisfactory compromise between safety and availability can be obtained.

Note 1
Given its simplicity of use, this type of selectivity is useful for protecting a link between two remote substations.



1 = minimum time setting
2 = maximum time setting
→ time setting range = 1 to 2 ▨

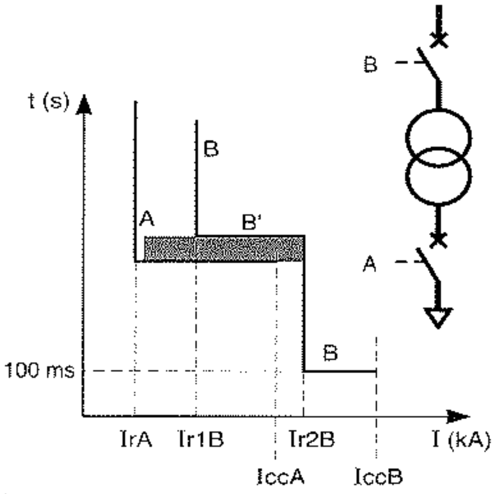
A = minimum threshold setting
B = maximum threshold setting
→ threshold setting range = A to B ░

fig. 8: time-dependent (or constant [——]) and non time-dependent (or reciprocal [- - - -]) trigger curves.

Note 2
Mixing the time-dependent and current-dependent types of selectivity is particularly useful for protecting the primary winding of a transformer, since the differences in the short-circuit current between the primary and secondary circuits are considerable (see fig. 9). It is therefore possible to install a quick-break protective device (≈ 100 ms) on the primary circuit if its threshold is set to a level higher than the secondary current Icc as "seen" with respect to the primary winding.

logic selectivity

(see "Cahier Technique" n° 2)
This type of selectivity is also known as a logic selectivity system (SSL), for which Merlin Gerin currently have a patent pending. It operates on the principle of data transfer between the protection systems. The variable monitored is the current.



Ir1B = lower threshold ≥ 1.2 IrA to compensate inaccuracies. A 300 ms (curve B') selectivity interval is usually applied to back up A.

Ir2B = upper threshold < IccB, but Ir2B > IccA, with a 100 ms rapid-action timing in order to withstand the closing overcurrent.

fig. 9: application of current-dependent and time-dependent selectivity types to transformation substations.

All SSL protection systems communicate through a hard link (known as the pilot line): each unit affected by a fault instantaneously transmits a logic hold pulse through this circuit to the upstream unit. In this way, only the protection equipment located immediately upstream of the fault remains free to operate since it has not received a hold signal (see fig. 10). The advantage of the logic selectivity system is that it reduces the tripping times (see fig. 11), in particular near the source:

- either, by setting the same time delay on all the units;
- or, by decreasing the time delays from the downstream to the upstream side, contrary to time-dependent selectivity (see above).

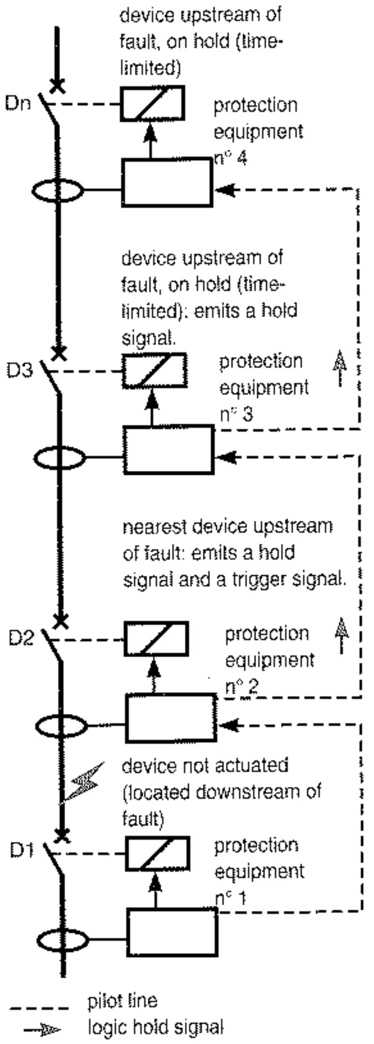


fig. 10: logic selectivity principle.

As with time-dependent selectivity, all protection equipment located upstream of a fault are sensitized (i.e. redundancy).

However, in spite of having to connect all logic selectivity system protection units through a pilot line, this type of selectivity comes closer to attaining the dependability objective than the other methods described above.

Note

This type of selectivity is useful for the protection of incoming and outgoing feeders of the same panelboard. In this case, the connecting wires are not an installation constraint, since they are only routed through the panelboard and can therefore be factory-integrated. Moreover, with this solution, the fault down times are shorter for incoming feeders than for outgoing feeders.

differential protection

In principle, when there are no faults, the currents input into each element of an electrical distribution installation are the same, phase for phase, as those output. The purpose of differential protection is to monitor this situation, to measure any difference between two currents (i.e. caused by a fault), and to transmit a trip signal at a predetermined threshold. The faulty element is then isolated from the network (see fig. 12).

This type of protection can be used to monitor a well-defined part of the network using two current adapters (or current transformers): it is auto-selective and can therefore be instantaneous. It is an advantage which must be conserved for times when transient phenomena occur; however, its sensitivity must be limited to phenomena induced by fault conditions and not by normal conditions (such as

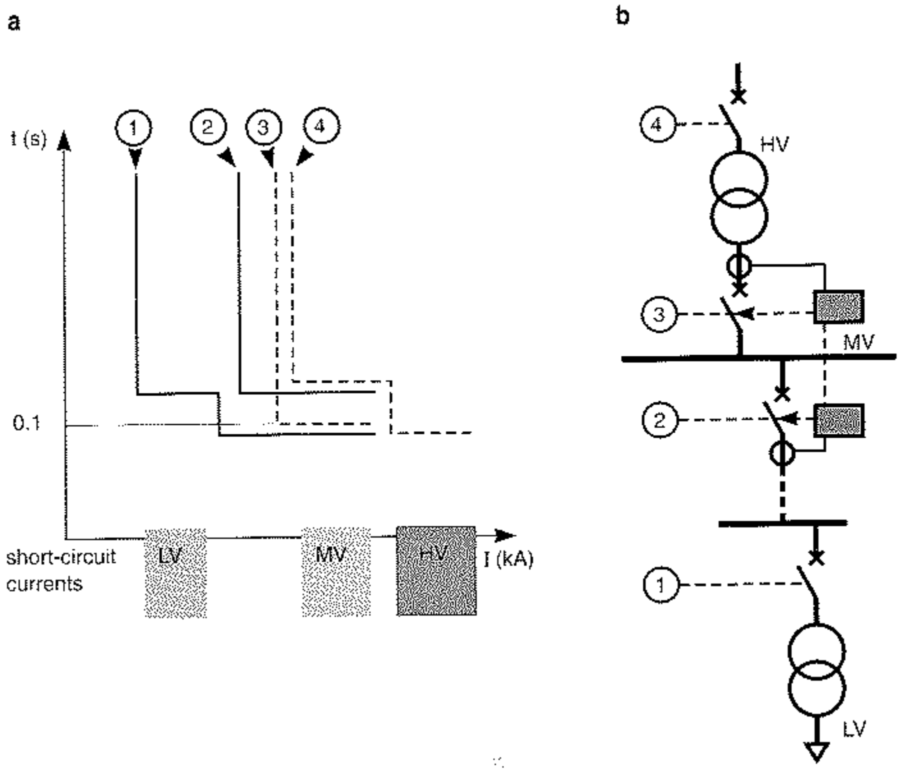


fig. 11: example of a single-line diagram and a selectivity diagram for protection equipment with a logic selectivity stage (between stages 2 and 3).
Compare this diagram with that shown in figure 3 (modified curves are shown in orange). It shows that, for the same circuit, this type of selectivity significantly reduces the trip times (for circuit-breaker 3 for example, the reduction is from 0.7 to 0.1 s).

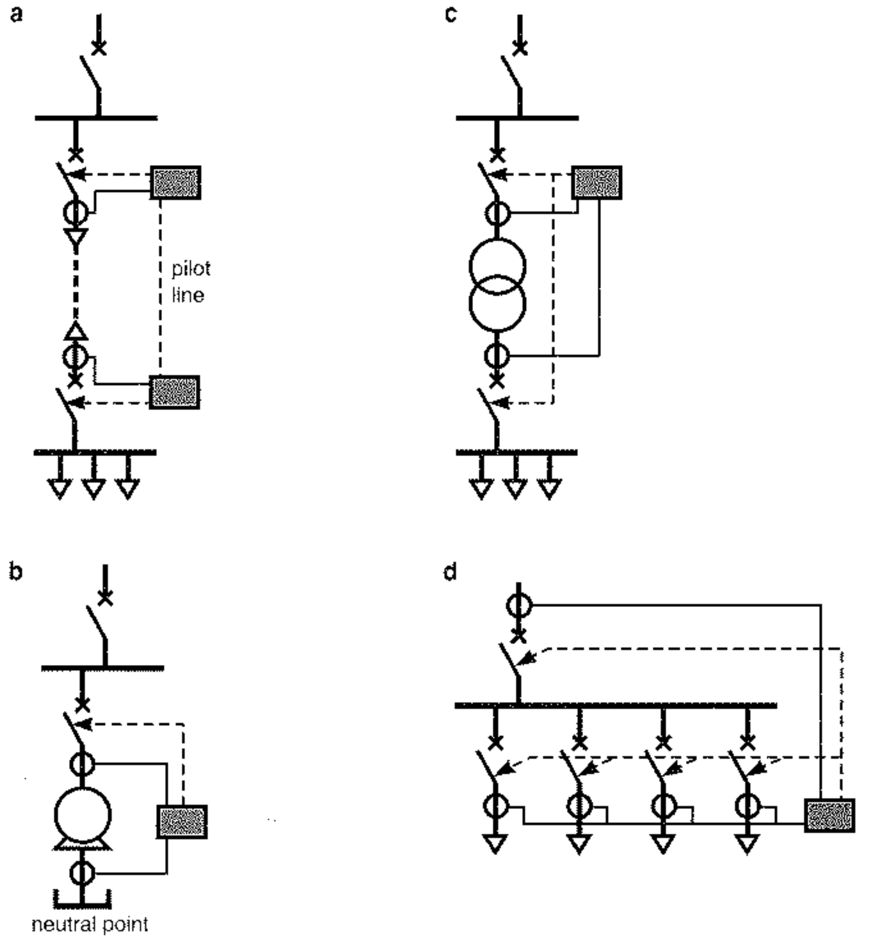


fig. 12: examples of use of differential protection.
***a** - differential protection of cables; in the event of a fault, the 2 circuit-breakers open,*
***b** - differential protection of machines, motors or AC generators,*
***c** - differential protection of transformers; if there are downstream sources, both circuit-breakers will open in the event of a fault,*
***d** - differential protection of busbars; if there are downstream sources, all circuit-breakers will open in the event of a fault.*

trigger currents or fault currents caused by another part of the network).

The "transient" characteristics are specific to each element of the network; differential protection equipment is therefore technologically "dedicated", i.e.:

- differential protection of lines and cables;
- differential protection of busbars;
- differential protection of transformers;
- differential protection of motors;
- differential protection of AC generators.

The use of this type of protection is limited, since it requires the careful use of (pilot lines or connection of current transformer secondary windings), current adapters and fine tuning in order to prevent nuisance tripping.
It is used whenever high-speed elimination of faults is essential, i.e.:

- to reduce the upstream time delay in a time-dependent selectivity system by removing one of the stages from the system;
- to improve the dynamic stability of an installation containing rotating machines;
- to provide additional protection of an element which is highly important because of its intrinsic value or the unacceptable consequences of a prolonged stoppage in the event of a fault.

The use of this type of protection also imposes certain conditions:

- a current transformer must be installed per phase at each end of the monitored part;
- a connection must be provided between the two devices in order to ensure differential protection of the cable. In addition, before deciding to use this type of protection, it must be checked to ensure its efficiency for all imaginable types of fault. With the detection principle, often used for pilot line type differential protection equipment, the sensitivity depends on the faulty phase and the type of fault (phase-phase or phase-earth);
- for differential protection of machines, the winding terminations on the neutral point side must be accessible in order to be able to install all the current transformers;
- for differential protection of transformers:
  - depending on whether the protection relay is installed in an upstream or downstream compartment, the wiring required to reach the other current transformer may be relatively long; in this case, care must be taken in determining its cross-section (for power consumption) and its routing (to avoid interference),
  - if the neutral point arrangement is very different on each side of the transformer, earth faults may not all be detected; in this case, a specific procedure is required,
- for differential protection of busbars; with certain types of equipment, all current transformers must have the same winding ratio as the largest current transformer. This high-impedance protection, frequently used in countries under Anglo-Saxon influence, leads to great difficulties:
  - for switching current transformer secondary circuits, when the busbars supply several outgoing feeders with different configurations,
  - for wiring, since its high impedance may induce overvoltages in the wiring at the current transformer secondary winding during the fault. These overvoltages may require the use of surge arrestors.

Reminder: logic selectivity, which is more practical to use, also meets the time-saving objective.

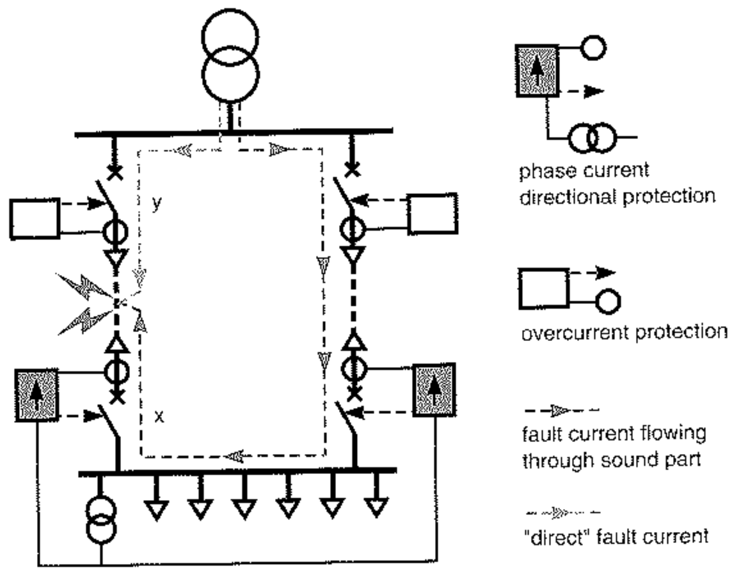


fig. 13: phase current directional protection principle.
On any one line, a directional device is more rapid (250 ms) than an overcurrent device; in the example shown above, tripping occurs at x then at y.
Note that if these lines are replaced by parallel-connected transformers, the principle stays the same.

directional protection

This type of protection operates according to the current, the voltage and the direction of flow of the energy. It is activated when the current or the power exceeds a set threshold and at the same time, the energy is propagated in an abnormal direction.
The following directional protection exists:

- phase current;
- residual current;
- active power;
- reactive power;
- zero sequence power (not dealt with in this Technical Specification, since it is mainly used in corrected neutral public distribution networks).

Phase current directional protection

When two sources, two lines or more normally operate in parallel, there is a risk of total failure of the distribution if a fault occurs in any one of these elements. The reason is that the same fault current flows through all these elements, the current changing direction in the faulty element (see fig. 13).
Directional protective devices are therefore used to detect the faulty element and order it to be isolated from the sound parts. In order to be able to isolate the faulty element, these devices are about 250 ms quicker than the overcurrent devices concerned by the same fault.

Earth fault current directional protection

If a network is supplied by two or more transformers (or AC generators) with their neutral points simultaneously connected to earth, in the event of an earth fault in any one of these sources, a residual current flows through all the sources. Only the source affected by the fault "senses" a residual current flowing in the opposite direction from the others. This principle is used by earth fault directional protection devices in order to distinguish between the sound elements and the faulty element (see fig. 14).
The direction is determined by measuring the phase shift between the "residual current" and "residual voltage" vectors.
These devices are also used to detect a faulty outgoing feeder in networks with high capacitive currents, in particular when the cables are long: a residual current flows in the same direction through all sound outgoing feeders and in the opposite direction in the faulty feeder (see fig 15).

Note

For the latter case, another solution based on the use of earth fault current-measuring protection equipment is possible to ensure selectivity without the use of directional protection.
However, the threshold of this protection equipment must satisfy the relation:

$Ic_{\text{outgoing feeder}} < Is < \sum Ic_{\text{installation}}$

where Ic = capacitive current,
Is = threshold current.
In general Is 1.3 to 1.5 $Ic_{\text{outgoing feeder}}$.
But this solution is only applicable if, for each outgoing feeder:

$Ic_{\text{outgoing feeder}} \ll \sum Ic_{\text{installation}}$

If this is not the case, a zero sequence current generator is required.
Otherwise, the protection equipment on sound but long lines will nuisance trip (sympathetic tripping), since they are activated by the capacitive current generated by the lines together.

Active power directional protection

This type of protection is used for example to:

- disconnect an AC generator from the network which is absorbing energy

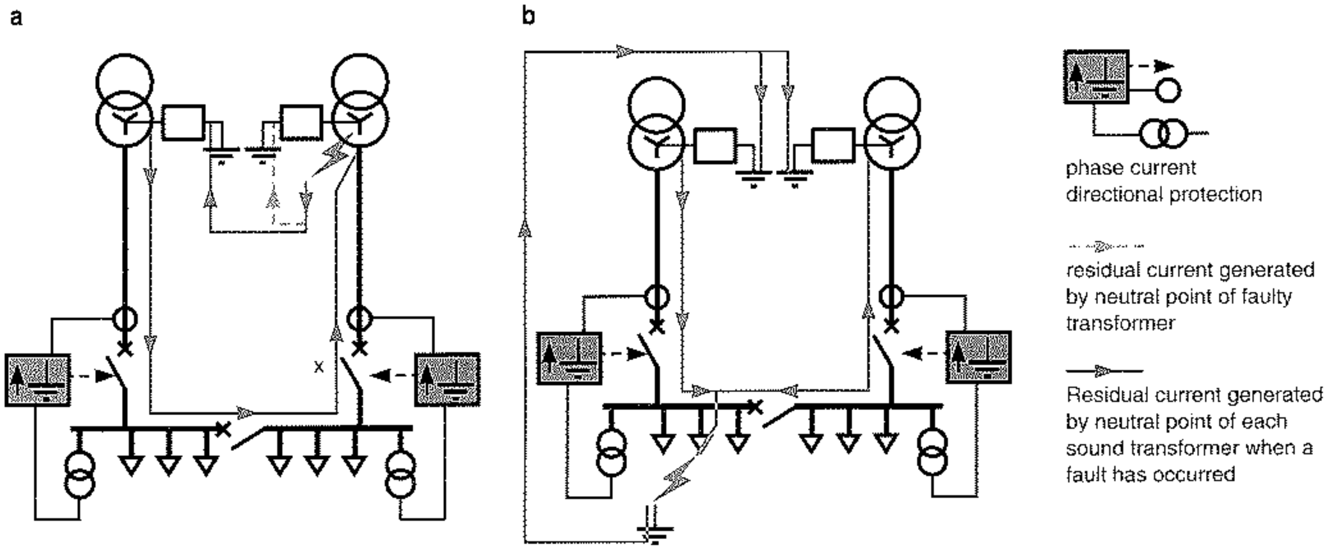


*fig. 14: earth fault current directional protection equipment can detect the faulty transformer (**a**), or can be insensitive to a fault in an outgoing feeder (**b**).*
This principle can be applied to AC generators coupled to the same network with their neutral points earthed.

(running on motor) following failure of the mechanical power source;

- cut the power supply to a motor during a voltage drop.

In addition to measuring currents and voltages, this type of protection also measures the phase shift in order to determine the power:

$P = \sqrt{3}\, U\, I \cos \varphi$.

Reactive power directional protection

This type of protection is used for example to cut off the power supply to a synchronous machine if there is insufficient excitation. In the event of insufficient excitation, the reactive magnetisation energy will be transferred by the network to the machine. In addition to measuring currents and voltages, this type of protection also measures the phase shift in order to determine the power:

$P = \sqrt{3}\, U\, I \sin \varphi$.

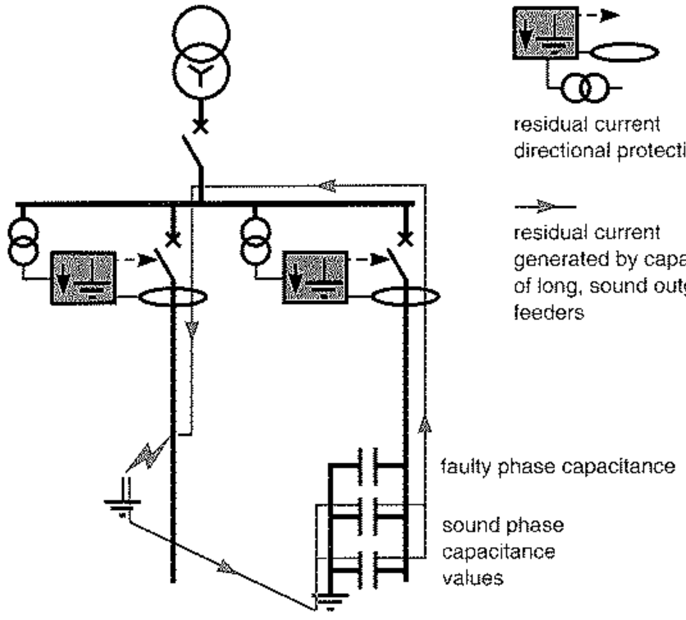


fig. 15: earth fault current directional protection equipment can be used in an installation with long outgoing feeders to distinguish the faulty feeder from the sound feeders.

under-impedance protection

This type of protection operates using the measured variables of current, voltage and direction of flow of the energy. Using this information, the protection equipment calculates the impedance of the equipment being monitored. Its thresholds are adjustable (under-impedance Z - in ohms, or under-admittance 1/Z - in ohm). This type of protection uses the principle of the significant reduction in the impedance of an element when a short-circuit occurs.

It is mainly used on power transmission lines (meshed networks), but also on busbars and large rotating machines and is normally known as "zonal protection". It measures in one direction, or on either side of its location (see fig. 16). Its monitoring potential depends on the measurement range and the linear variation in the impedance of the equipment under protection. Several devices can be installed on the same network and can be independent from each other, since the scope of each is clearly defined. For this same reason, their reaction times can be greatly reduced.

Note

- sudden load variations and current inrushes are "considered" by this protection equipment as impedance variations. In order to prevent nuisance tripping, their operating characteristics (circular, elliptic, polygonal, etc.) must be judiciously selected (see fig. 16);
- the impedance variation is proportional to the length monitored. This longitudinal variation is more rapid for rotating machines or transformers than for cables and overhead lines. Therefore, an under-impedance protective device can monitor a small area delimited by a machine or a transformer. However, if this type of device is used to monitor busbars, its coverage may extend to some of the windings of the transformers connected to these busbars. What would seem to be a disadvantage is in fact an advantage: the first turns of a transformer, which are the most exposed to overvoltages, breakdowns, etc. are thus better protected. This type of protection is mainly used in MV/LV substations of the power transmission or supply network on major industrial sites.

Particular situation: distance protection

This is a specific type of impedance protection used on the HV lines of power transmission networks, and sometimes on certain distribution networks.

optimum selectivity

Experience has shown that all these types of protection equipment selectivity have preferential fields of application, for example:

- current-dependent selectivity = LV distribution;
- time-dependent and logic selectivity = MV distribution;
- distance protection = HV transmission.

To select one type rather than another is often a matter of technical and economical concerns, greatly influenced by habit.

Technological developments, in particular the advent of digital technology, mean that the different protection and selectivity principles can be merged. Thus, it is possible to apply an optimised solution to each section of a network.

Association of different types of selectivity

The diagram in figure 17 shows that optimum selectivity may require the use of the different types of protection described above. Faults can thus be eliminated more rapidly.

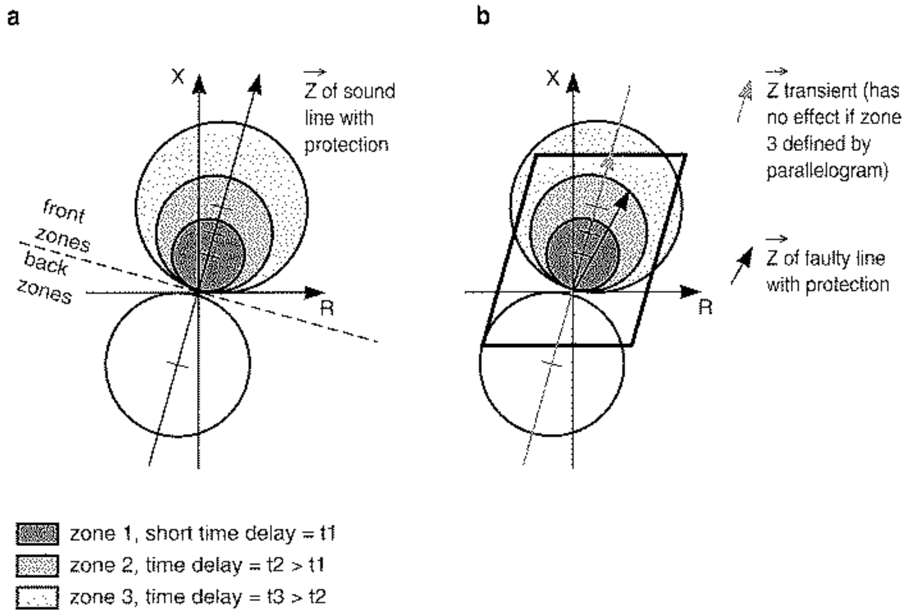
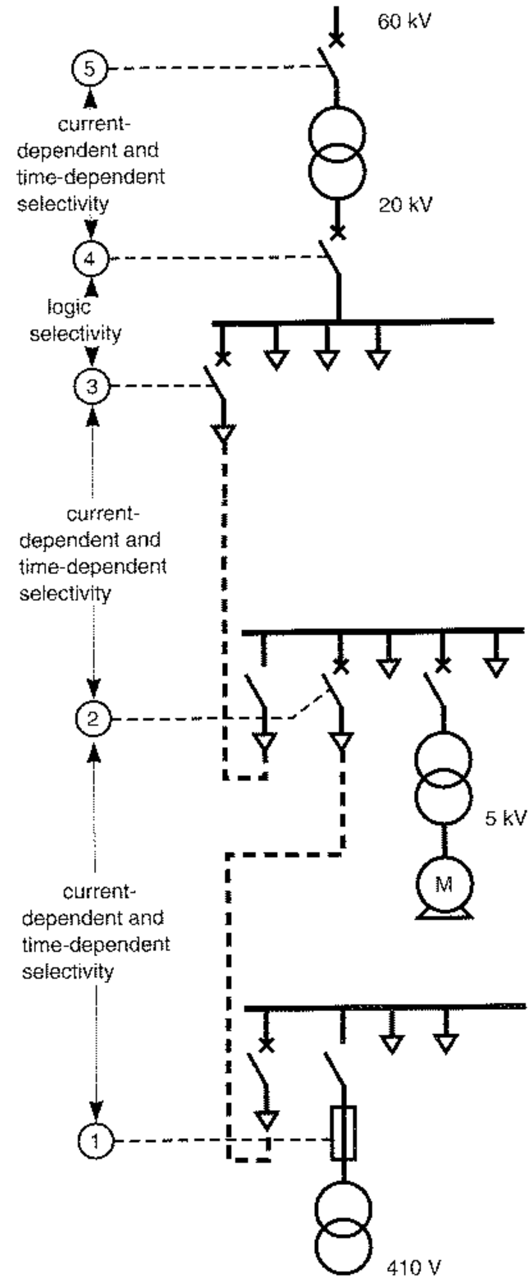
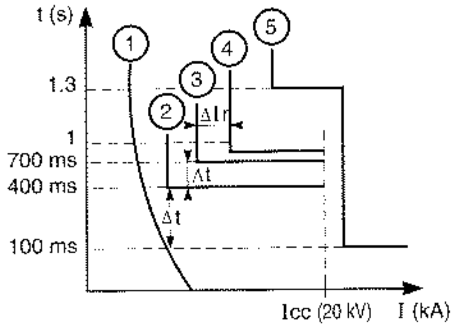
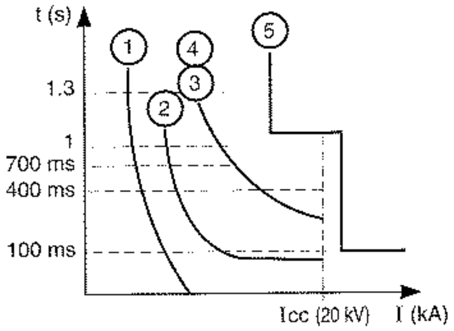


*fig. 16: diagram showing the operation of a zonal protective device (**a**).
Tripping occurs when the end of the impedance vector of the protected line enters one of the operating zones of the device (**b**). A time delay is set for each zone.
To prevent nuisance tripping due to load variations (transient impedance vector), the operating zones can have different forms, either circular or quadrilateral: in drawing **b**, zone 3 is defined by a parallelogram instead of a circle.*





a - selectivity curves diagram using only time-dependent selectivity with constant time protection equipment.
Note that between curves 2, 3 and 4, there must be Δt = 300 ms and Δ r = 20%.



b - selectivity curves diagram using different types of selectivity and protection equipment.

solution	a	b
protect .equip. identification		
1	fuse	fuse
2	400	80
3	700	300
4	700	300
5	100	100

c - comparison of times required by solutions **a** and **b** above to eliminate short-circuits (in ms).

fig. 17: in the example shown above, optimum selectivity is obtained by the use of different techniques.
*diagram **a**: current-dependent, time-dependent and logic techniques.*
*diagram **b**: time-dependent technique with extremely reciprocal ②, reciprocal (and logic) ③ and ④, and constant ⑤ time curves.*

synthesis of the use of different types of protection equipment

type	main applications
current-dependent	■ between line and load side of a transformer.
time-dependent	■ between two substations.
logic	■ between incoming and outgoing feeders on the same switchboard; ■ between line and load side of a transformer; ■ between two substations when it is possible to install the logic link.
differential	■ on any part where safety is of prime concern (cables, machines, etc.).
directional	■ on lines, AC generators and transformers operating in parallel; ■ on outgoing feeders with a high capacitive current; ■ on networks with several neutral points; ■ on networks with a corrected neutral.
under-impedance	■ same application as differential protection when the zone is so complex that summing the incoming and outgoing currents is prohibitive.
distance-dependent	■ for meshed networks (power transmission).

fig. 18: synthesis of the use of the different types of protection equipment described above.

3. use of protection equipment

The use and incorporation of different protection equipment imposes certain precautions. This chapter describes these precautions and also proposes some practical solutions.
It is of course obvious that certain network configurations, and the power supply for machines with specific characteristics, will require specific analysis and cannot be dealt with in this document.

precautions to be taken in the choice and use of protection equipment

The choice of a type of protection and of the equipment to provide this protection must be made only once the risks to the element to be protected and the effects of potential faults have been assessed.

On principle, for all elements of a network, the minimum that should be provided is protection against the risks of:

- phase-phase short-circuits (phase overcurrent protection);
- phase-earth short-circuits (residual overcurrent protection).

When the earth and phase fault currents are of the same magnitude, one single piece of three-phase protection equipment can cover both types of risk, but will not distinguish between them.

Phase overcurrent protection

This type of protection can only be efficient if its operation satisfies the inequality:
I "phase" threshold $<$ Icc min
and
I "phase" threshold $>$ I max in fault-free conditions (transient inrush current).
To this end, the following must be checked:

- the condition "tripping threshold lower than cc min." must be checked in the event of a two-phase fault occurring:
  - in a network supplied by one single transformer, whereas it is normally supplied by several parallel-connected transformers;
  - in a network supplied by a substitute source,
  - at the termination of a long line,
- the condition "tripping threshold value and/or time delay higher than maximum currents in fault-free conditions" must be checked when:
  - starting up motors,
  - switching on transformers,
  - energizing capacitor batteries,
- check the effects of overcurrents resulting from voltage drops, transient power cuts, source switching, etc...

Earth fault overcurrent protection

The threshold, which must be adapted to suit the earthing system, must also satisfy the following two inequalities:
I residual threshold $< 0{,}2\ Io_{limited}$
and
I residual threshold $> 1{,}3\ Io_{capacitive}$
generated by the protected section.
Hence:

- a target threshold of 0.1 to 0.2 $o_{limited}$ to protect at least 80 % of the coil windings;
- a threshold higher than 1.3 $o_{capacitive}$ of the protected line in order to prevent nuisance tripping when faults occur in another part of the network.

For safety installations (or zones) operated with an insulated neutral, the earth fault protective device adjustments are calculated using only the capacitive currents of the network $(Io_{limited} = \sum Io_{capacitive})$.

Reminder : with a view to improving operational continuity, certain small networks are operated with an insulated neutral. French legislation imposes the use of a continuous insulation detector (CPI) in order to detect drops in the insulation level and prevent tripping on an earth fault.

Thermal image/temperature probe type protection

Protection using thermal images should only be envisaged if there is a risk of overloading. Its heating and cooling time constants must be adapted to the characteristics of the protected equipment.
Temperature probes (normally type PT 100 in accordance with standard IEC 751) must be fitted in the coils when:

- a dusty environment affects correct ventilation of the protected equipment;
- the machine is operated with an independent air-blown cooling system.

In both cases, poor ventilation will not cause an overcurrent, but may result in destructive overheating.

Harmonic distortion

Non-linear loads induce pollution in electrical networks. This pollution takes the form of a voltage distortion and by harmonic currents which mainly affect the thermal resistance of rotating machines and transformers. Harmonics can be dealt with in three ways:

- either, by installing filters; the characteristics and location of these filters will be determined by an analysis of the harmonics;
- or, by protection equipment which take into account the RMS current resulting from the quadratic sum of the odd-ranked harmonics;
- or, if the protection equipment does not take the RMS current into account, by down-rating the equipment so that it only operates at a 0.8 or 0.9 fraction of its rated power. The thresholds of their overload protection equipment must be lowered by the same amount if they only take into account the fundamental.

precautions to be taken with sensors

Number

The number of sensors required to detect polyphase faults has evolved with developments in technology: electromechanical protection equipment requires three sensors to detect the faulty phase conductor; digital technology requires only two sensors (the current of the third conductor is calculated). But if the protection plan is to be efficient, it is essential to make sure that the two sensors are installed on the same phase conductors throughout the network.

Reminder: there are three ways of identifying conductors:

- using numbers = 1, 2, and 3;
- using letters = A, B and C, or R, S and T.

Current transformers

These must be designed to allow correct operation of the protection equipment. They should not emit a distorted signal which might be considered by the protection equipment as a fault, resulting in nuisance tripping. Therefore:

- their power rating must be adapted to suit the protection equipment and the cabling;
- their rating must be equal to or higher than the current to be measured;
- their linearity must be checked throughout the entire RMS current range (saturation by currents such as an inrush current can affect the signals at the secondary windings);
- their tolerance must be consistent with the measurement accuracy (threshold).

Note that using the Nicholson setup (see fig. 19) to measure weak residual currents often requires the transformers to be paired. Moreover, the absolute error of the measurement is inhibiting for low residual current thresholds. On the other hand, the linearity and dynamic range of ROGOWSKI type non-magnetic sensors (see "Cahier Technique" n° 170) overcome many of these inconveniences.

Zero sequence toroidal sensors

The use of sensitive earth protection equipment is particularly useful in limiting damage to equipment, since higher limiting impedances are possible. Weak residual currents are detected preferably using a toroidal sensor fitted around the three phases. Note that certain precautions must be taken when using these sensors:

- the earthing strip on the cable armouring may be routed outside or re-routed inside the toroid (see fig. 20);
- the insulation between the active conductors and the toroid must be checked, but it is often provided by the cable sheathing;
- in order to prevent malfunctions, it is preferable to arrange the conductors inside the toroid and to center them.

Voltage transformers

In order to avoid the destructive phenomenon of ferromagnetic resonance (overvoltages), voltage transformers must be loaded to a value similar to their power rating.

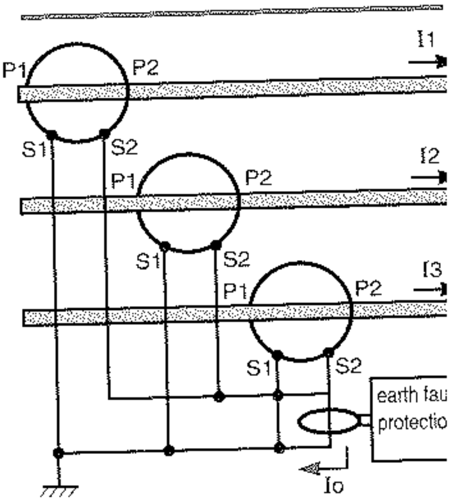


fig. 19: the Nicholson setup.

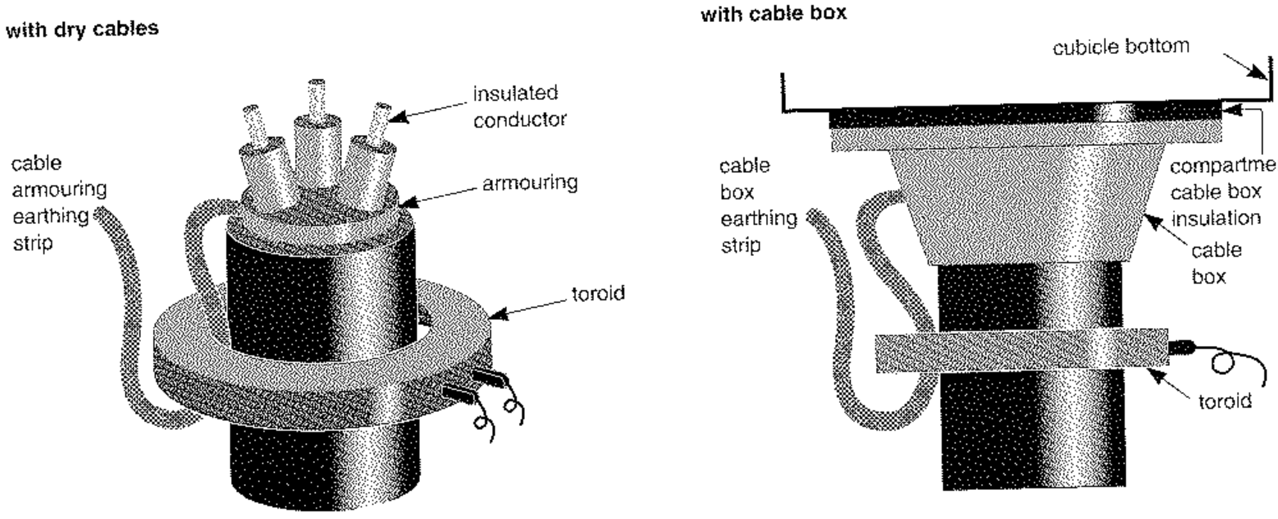


fig. 20: installing a toroid on an HV cable.

precautions to be taken with respect to networks

Network with several earthed neutral points

A network which has several neutral points is likely to be affected by 3rd harmonics and multiples of 3 occurring between these points. To avoid having to desensitize the earth fault protection equipment, they should be equipped with H3 filters.

Network with several earthed neutral points

When operating on the AC generators, if a large part of the power is absorbed by the motors, the protection equipment must act sufficiently rapidly to prevent network breakdown (i.e. to maintain dynamic stability).

Overvoltages

In the event of an earth fault, power distribution through cables generates a capacitive current which, in addition to sympathetic tripping (see chapter 2, "Directional protection"), can also create overvoltages due to resonance (see fig. 21).

The best means of minimising these overvoltages is to earth the neutral through a resistor. This solution is often used for industrial networks.

The rule usually applied is:

$I_{0R} \geqslant 2\, I_{0C}$

where

I_{0R} = desired resistive residual current,

I_{0C} = capacitive residual current inherent in the network.

Modifying a network

As concerns protection, two checks are useful when modifying a network:

- are the existing neutral point arrangement and the earth fault protection equipment compatible with the new capacitive currents?
- is the existing phase protection equipment and the current transformers suitably adapted to the new rated currents and short-circuit currents?

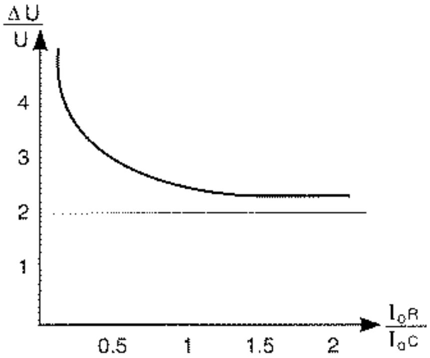


fig. 21: resonance-induced overvoltages likely to be generated during an earth fault by capacitive current cable type distribution systems.

4. selection guide

The table in figure 22 gives an idea of the possible choices depending on the element to be protected.

Note that the wide variety of distribution configurations and operating requirements means that it is not possible to offer a "universal" solution.

Reminder : remember that short-circuit protection and earth fault (or insulation fault) protection must be systematically provided for each element to be protected.

element to be protected	installation concerned	potential risk	required protection	comments
lines and cables	single feeder, parallel, or closed loop type cables	short-circuit	■ differential with pilot line.	
	parallel or looped cables	short-circuit and earth fault	■ directional residual and phase current protection	
	outgoing feeders with high capacitive current, multiple earths, parallel or looped cables	earth fault	■ direction residual current protection	
busbars	panelboards representing an important node in the distribution system, high Pcc panelboards.	short-circuit	■ SSL ■ differential busbar protection	
			■ under-impedance	also partly protects transformers
AC generators		overload	■ thermal image	
		air-blown ventilation failure and/or dust	■ temperature probes	
	machine which is expensive or important for operation	internal fault	■ under-impedance or ■ differential AC generator protection	high-speed protective devices
			■ excitation failure or ■ reactive power feedback	
			■ running on motor	if other parallel-connected source
			■ under- and overvoltage ■ frequency	if group production
			■ phase breakdown and unbalance	if single-phase loads > 10 % of loads
capacitors	parallel banks (double star)		■ unbalance of neutral points	

element to be protected	installation concerned	potential risk	required protection	comments
transformer		overload	■ thermal image	
		air blown ventilation failure and/or dust	■ temperature monitoring	
		overcurrent at secondary winding	■ 1st threshold, time-delayed, primary winding < Icc	
		internal fault	■ 2nd threshold, instantaneous, secondary winding > Icc	
	important transformer	internal fault	■ differential transformer	
asynchronous motor		overload	■ thermal image	
		air blown ventilation failure and/or dust	■ temperature monitoring	
	important machine		■ differential mot. protec.	
	mixer, fan, conveyor, compressor...	abnormally high torque or undervoltage	■ starting delay protection	
			■ rotor jamming with motor running	check current after startup
		rotor jammed at motor startup	■ under-impedance or speed monitoring	
		internal heating	■ monitor successive startups ■ check time intervals between successive startups	as per process and when commissioning a plant (tests)
	pumps	loss of priming	■ undercurrent or active power	
		power supply voltage phase breakdown and unbalance	■ reciprocal component (see Technical Specification No. 18)	
synchronous motor			same protection equipment as for an asynchronous motor, plus: ■ synchronism ■ excitation monitoring	
		runs on generator if fault	■ directional current or power protection	rapid disconnection from supply network
		low motor torque	■ direct, undervoltage	
		random reacceleration	■ remanent, undervoltage	

fig. 22: a selection guide for protection equipment depending on the element to be protected.

5. conclusion

Protection techniques are numerous and varied and it is necessary to be familiar with them in order to make a choice.

Since the advent of logic selectivity, there have been few developments. This is normal, since protection equipment is still designed to limit the consequences of the same electrical or mechanical faults.
On the other hand, technological developments have occurred:

- one-function electromechanical relays;
- one-function analog electronic relays;
- multi-function analog electronic racks, such as the Vigirack, developed in 1970 by Merlin Gerin. This type of "protection unit" requires little power from the sensors and is equipped with factory-prewired alarm and tripping relays;
- multi-function digital units based on the use of microprocessors, for example the Sepam manufactured by Merlin Gerin.
  The multi-function capability includes:
  - protection functions,
  - measurement and metering functions,
  - local automatic control,
  - self-diagnosis,
  - alarm processing and display,
  - communication.

The parameters of these "smart" units can easily be modified by any electrician to provide several of these functions.

This type of equipment minimizes the number of sensors required, since it uses only the protective current transformers to ensure:
- measurements,
- metering,
- protection.

Hence, there is enhanced flexibility for the designer in devising his protection plan and carrying out the selectivity analysis.

Non-magnetic or nonferrous sensors improve the sensitivity and the stability of protection equipment and their variants can ensure both the measurement and the protection functions, therefore the use of these sensors reduces the time required to carry out the analysis.

Present-day components also allow reductions in the cost of very comprehensive, complex protection equipment such as directional protection equipment. So:
- their use is no longer limited to powerful machines, high voltages, or sensitive industrial processes;
- nor are they isolated, too specific, or forgotten. On the contrary, they are now integrated into a communicative multi-function system which processes and controls all the data relative to the monitored element.

By communicating with the network management systems, it is possible to:
- obtain electrical data;
- obtain data concerning faults and events in chronological order;
- know the position of circuit-breakers and other operating mechanisms;
- check that the system is operating correctly (watchdog);
- carry out operations;
- analyse the numerous measurements to ensure more efficient operation;
- ensure better running of the network by means of a comprehensive, user-friendly instrument panel.

The direct impact of these developments: improved safety and energy availability, enhanced efficiency and maintainability.

6. practical information

The list of data given below can be used to carry out a reasonably accurate selectivity analysis.

Where certain items are unknown (pilot project, for example), the designer will define these in his hypotheses. His experience will guide him in the choice of the normal practical values, such as:

- Icc for a given supply voltage level;
- Ucc depending on the types of transformers;
- motor starting times depending on the functions for which they are used.

data required to carry out a selectivity analysis

Network data

- single-line diagram;
- possible operating configurations;
- voltages;
- frequency;
- short-circuit power of the upstream network (minimum and maximum values);
- earth wiring diagrams (neutral point arrangements);
- connections (length and type of cables, number of parallel cables);
- rating of existing current transformers;
- rating of existing fuses;
- settings of existing protection equipment (upstream and downstream).

Transformer data

- power rating;
- short-circuit voltage (Ucc %);
- copper losses;
- coupling;
- load setting (minimum and maximum values).

AC generator data

- type of AC generator (turbo-generator or salient pole generator);
- power rating;
- voltage rating;
- rated power factor;
- sub-transient reactance values (directly along axis and in quadrature);
- permanent short-circuit current (minimum and maximum values);

or

- excitation voltage/rating;
- saturated synchronous reactance.

Motor data

- type (synchronous or asynchronous);
- power rating;
- voltage rating;
- starting current;
- starting time;
- whether there is a risk of rotor jamming (if yes, the time it can withstand the rotor jammed condition);
- number of startups and authorized intervals (for cold and hot starting);
- stator thermal time constant.

selectivity diagram

Diagram layout

A current versus time selectivity diagram should preferably be presented in log-log orthonormed coordinates since these variables can vary in considerable proportions:

- currents can vary from a few amps to several kiloamps;
- time delays can vary from some tens of milliseconds (for instantaneous tripping) to hundreds of seconds (as in the operation of thermal image type overload protection equipment).

In order to be able to compare the curves on the diagram, a reference voltage must be defined, preferably that which is most frequently used in the installation. In this way, a maximum of comparisons and analyses can be carried out by reading the diagram directly; the curves concerning the other voltages can be observed using the reciprocal voltage ratio.

For example, in a diagram where the reference voltage is an MV voltage, therefore:

- □ the MV currents can be read directly,
- □ for LV currents:

$$= \text{LV value } \frac{\text{LV voltage}}{\text{MV voltage}},$$

- □ for HV currents:

$$= \text{HV value } \frac{\text{HV voltage}}{\text{MV voltage}};$$

- the earth fault currents and the phase currents belong to different systems and are therefore represented on different diagrams;
- to make for easier reading of the diagrams, only the relevant part of the diagram is shown, i.e. from the minimum service current to the maximum short-circuit current of the part concerned.

Selectivity principles

- at least two curves must cover each fault current level;
- selectivity is said to be total between two pieces of protection equipment when their different curves do not intersect. This does not apply to logic selectivity (see fig. 11).

Reading a diagram

A diagram of this type (see fig. 23) contains several types of information:

- on the current axis:
  - current rating,
  - short-circuit currents,
  - protective device thresholds.

a = lower threshold of ①

a' = upper threshold of ①

b = threshold of ②

c = threshold of ③

d = lower threshold of ④

d' = upper threshold of ④

- on the time axis:

m = time delay corresponding to upper threshold of ① and ④

n = time delay corresponding to threshold of ② and lower threshold of ①

o = time delay of ③

p = time delay corresponding to lower threshold of ④

The threshold and time delay values are recorded in the settings sheet filled in on commissioning of the installation.

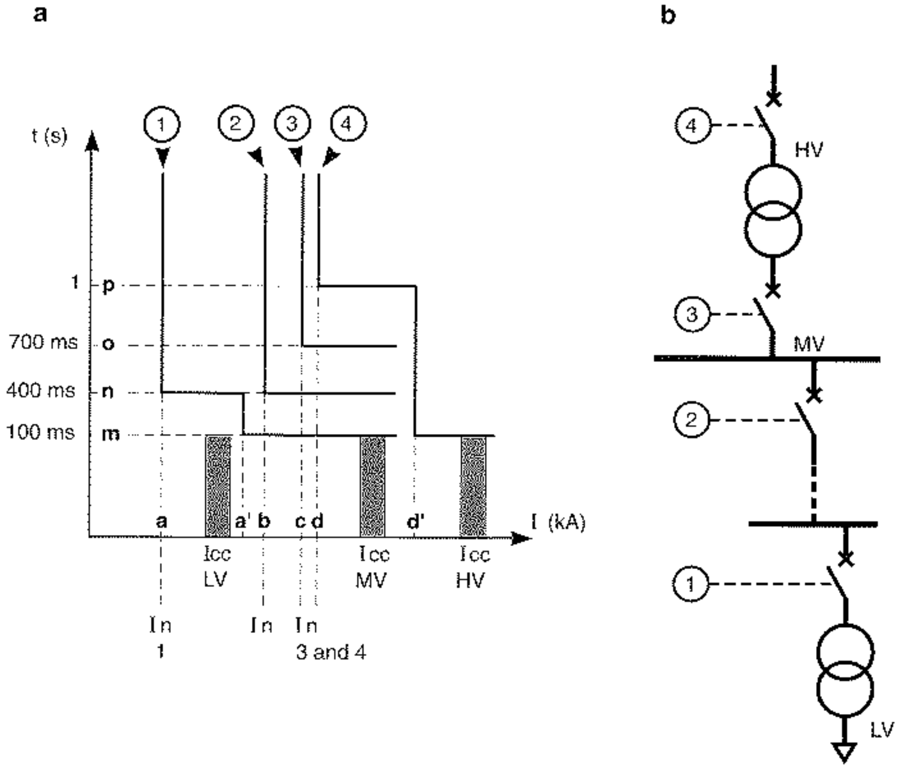


fig. 23: example of a selectivity diagram (a) and a single-line diagram of the protection equipment (b).
Note that, in order to be able to allow comparison, short-circuit currents are expressed for a same voltage level, in this case MV.

7. bibliography

Standards

- ANSI C 37-2: Numbering of protection equipment.
- IEC 117-3: Symbols used for protection equipment.
- IEC 255-3: Non time-dependent measurement relays.
- IEC 255-4: Time-dependent measurement relays.
- IEC 812: Systems reliability analysis techniques - Failure Mode and Effect Criticality Analysis (FMECA) Procedures.
- NF C 13-100: Postes de livraison établis à l'intérieur d'un bâtiment et alimentés par un réseau de distribution publique de deuxième catégorie.
- NF C 13-200: Installations électriques à haute tension: règles.

Merlin Gerin's Cahiers Techniques

- Protection of electrical distribution networks by the logic selectivity system,
  Cahier Technique n° 2,
  F. SAUTRIAU
- Analyse des réseaux triphasés en régime perturbé à l'aide des composantes symétriques,
  Cahier Technique n° 18,
  B. DE METZ NOBLAT
- Earthing of the neutral conductor in High-Voltage networks,
  Cahier Technique n° 62,
  F. SAUTRIAU
- Calculaton of short-circuit currents,
  Cahier Technique n° 158,
  R. CALVAS, B. DE METZ NOBLAT,
  A. DUCLUZAUX and G. THOMASSET.
- Current transformer for HV protection,
  Cahier Technique n° 164,
  M. ORLHAC
- HV industrial network design,
  Cahier Technique n° 169,
  G. THOMASSET
- From current transformer to hybrid sensors, in HV,
  Cahier Technique n° 170,
  C. TEYSSANDIER

Others publications

- Guide to MV protection
  Merlin Gerin, reference CG0021X.
- Selecting a neutral point arrangement for an HV industrial network in the 1 to 36 kV range.
  J. VERSCHOORE,
  RGE review No. 11, November, 1980.

Real.: Illustration Technique - Lyon
Edition: DTE - grenoble
05-96 - 2500 - Printing: Clerc
Printed in France

Merlin Gerin
Service Information
F-38050 Grenoble cedex 9
Fax. 76 41 06 09