Selecting the protection system for electrical installations is fundamental to correct economical and functional service and to reduce problems caused by abnormal service conditions or actual faults.

A theoretical outline of selectivity

Within the sphere of this analysis, the coordination between the various devices dedicated to protection of sections of installation or specific components is studied to:

- Guarantee safety of the installation and of people.
- Identify and exclude the area involved in the problem only, without indiscriminate trips which reduce the availability of energy in areas not involved in the fault.
- Reduce the effects of the fault on other integral parts of the installation (reduction in the voltage value and loss of stability in rotating machines).
- Reduce the stress on components and damage to the area involved.
- Guarantee service continuity with good quality power supply voltage.
- Guarantee adequate support in the case of malfunction of the protection delegated to opening.
- Provide maintenance and management personnel with the information needed to restore service to the rest of the network as rapidly as possible and with the least interference.
- Achieve a good compromise between reliability, simplicity and cost-effectiveness.

In detail, a good protection system must be able to perceive what has happened and where, discriminate between abnormal but tolerable situations and fault situations within its zone of competence, and avoid unwanted trips which cause unjustified stoppage of a sound part of the installation. It must also act as rapidly as possible to limit damage (destruction, accelerated ageing, etc.), safeguarding power supply, continuity and stability.

The solutions come from a compromise between these two contrasting requirements – precise identification of the fault and rapid tripping – and are defined according to the privileged requirement.

For example, in the case where it is more important to prevent unwanted trips, an indirect protection system is generally preferred, based on interlocks and data transmission between different devices which measure the electrical values locally, whereas speeds and limitation of the destructive effects of the short-circuit require direct action systems with protection releases integrated directly in the devices. The latter solution is normally preferred in LV systems for primary and secondary distribution.

The Italian Standard CEI 64-8 “Electrical user installations with rated voltage below 1000 V in alternating current and 1500 V in direct current” for LV installations states that, when several protection devices are placed in series and when the service needs justify it, their operating characteristics must be selected to disconnect only the part of the installation where the fault is.

It also adds that “the operating situations which require selectivity are defined by the customer or by the designer of the installation.” This standard therefore states that the operating characteristics

![Fig. 1: Overload zone = In + 8 – 10 ln.](image)
must be selected to have selectivity, when the service needs justify it.

In general, designing a selective installation not only means realising a “state-of-the-art” project, but also designing a good installation which does, in fact, respond to the customer’s requirements, not simply to the aspects of the standards.

**Definitions**

**Selectivity**

The definition of selectivity is given by Low voltage equipment IEC 60947-1: Part 1: General rules for low voltage equipment: “Co-ordination between the operating characteristics of two or more overcurrent protection devices, so that when an overcurrent within established limits occurs, the device destined to operate within those limits trips, whereas the others do not trip” where, by overcurrent, a current of a higher value than the rated current is intended, due to any cause (such as overload, short-circuit etc.).

There is therefore selectivity between two circuit-breakers in series when, for an overcurrent which passes through both, the load-side circuit breaker opens, thereby protecting the circuit, while the supply-side circuit breaker remains closed, guaranteeing power supply to the rest of the installation.

The definitions of total selectivity and partial selectivity are, on the other hand, given in Part 2 of the same standard: “Overcurrent selectivity where, in the presence of two protection devices against overcurrent in series, the loadside protection device carries out the protection without making the other device trip.” Partial selectivity is defined as “overcurrent selectivity where, in the presence of two protection devices against overcurrent in series, the load-side protection device carries out the protection up to a given level of overcurrent, without making the other device trip.”

Total selectivity is where there is selectivity for any overcurrent value possible in the installation. We speak of total selectivity between a pair of circuit-breakers when there is selectivity up to the lesser of the Icu values of the two breakers, as the maximum prospective short-circuit current of the installation will be less or equal to the smaller of the Icu values of the two circuit-breakers.

In partial selectivity, there is only selectivity up to a certain Is current value (ultimate selectivity value). If the current exceeds this value, selectivity between the two circuit-breakers will no longer be guaranteed.

Partial selectivity between a pair of circuit-breakers is when there is selectivity up to a certain Is value below the Icu values of the two circuit-breakers. If the maximum prospective short-circuit current of the installation is lower than or equal to the Is selectivity value, we still speak of total selectivity.

**Overload, short-circuit zones**

The concepts of “overload zone” and “short-circuit zone” are introduced for the purposes of the selectivity analysis made in this article.

By “overload zone” is meant the ranges of current values, and therefore the relative part of the circuit breaker trip curves coming between the rated current of the circuit breaker itself and eight to ten times this value (see Fig. 1).

This is the zone in which the thermal protection for thermomagnetic releases and protection L for electronic releases are normally called on to intervene.

These currents usually correspond to circuits where a load results in overload. These events are more likely to occur than real faults.

By “short-circuit zone” is meant the ranges of current values, and therefore the relative part of the trip curves of the circuit-breaker, which are eight to ten times higher than the rated current of the circuit-breaker (see Fig. 2).

This is the zone in which the magnetic protection for thermomagnetic releases or protections S, D and I for electronic releases are normally called on to intervene. These current values usually correspond to a fault on the supply circuit. This event is more unlikely to happen than simple overload.

**Real currents in the circuit breakers**

When the time-current curves of two circuit breakers are compared, one is often led to assess the trip times of the two devices as if they were passed through by the same current. This consideration is only true when there are no other shunts between the two circuit breakers placed in series, i.e. there is a single incoming and a single outgoing feeder insisting on the same node (see Fig. 3).

When, on the other hand, there are several supply-side circuit breakers insisting on the same busbar or several outgoing feeders on the load side, the currents passing through the apparatus can be considerably different.

The three main cases to consider regarding real currents circulating in the circuit breakers, are:

- A single circuit breaker on the supply side of a single circuit breaker on the load side (passed through by the same current).
- A single circuit breaker on the supply side of several circuit breakers on the load side (supply-side circuit breaker passed through by a current higher than that of the load-side circuit-breaker).
Two or more circuit breakers on the supply side and several on the load side.

Selectivity techniques

Time-current selectivity

The protections against overload generally have a definite time characteristic, whether they are made by means of a thermal release or by means of function L of an electronic release. A definite time characteristic is intended as a trip characteristic where, as the current increases, the trip time of the circuit breaker decreases.

The selectivity technique used is time-current selectivity when there are protections with characteristics of this type. Time-current selectivity makes trip selectivity by adjusting the protections so that the load-side protection, for all possible overcurrent values, trips more rapidly than the supply-side circuit-breaker.

When the trip times of the two circuit-breakers are analysed, it is necessary to consider the tolerances over the thresholds and trip times and the real currents circulating in the circuit-breakers.

Current selectivity

This type of selectivity is based on the fact that the closer the fault point is to the power supply, the higher the short-circuit current is. It is therefore possible to discriminate the zone in which the fault occurred by setting the instantaneous protections to different current values.

Total selectivity can normally be achieved in specific cases only where the fault current is not high and where there is a component with high impedance interposed between the two protections (e.g. transformer, very long cable or a cable with reduced cross-section) and therefore a great difference between the short-circuit current values.

This type of coordination is therefore used above all in the distribution terminal (low-rated current and short-circuit current values, and high impedance of the connection cables). The time-current trip curves of the devices are used for this study.

It is intrinsically fast (instantaneous), easy to realise and economical.

However, the ultimate selectivity current is usually low and therefore selectivity is often only partial, and the setting level of the protections against overcurrents rises rapidly. Redundancy of the protections, which guarantees elimination of the fault in the case of one protection not operating, is impossible.

It is a type of selectivity which can also be made between circuit breakers of the same size and without protection against delayed short-circuit (S).

Time selectivity

This type of selectivity is an evolution of current selectivity. In this type of coordination, a trip time is also defined: a certain current value will make the protections trip after a defined time delay, which allows any protections placed closer to the fault to trip (excluding the area which is the seat of the fault).

The setting strategy is therefore to increase the current thresholds and the trip delays progressively as one gets closer to the power supply sources (level of setting directly correlated to the hierarchical level).

The delayed trip thresholds must take into account the tolerances of the two protection devices and the effective currents which circulate in them.

The difference between the delays set for the protections in series must take into account the fault detection and elimination times of the device on the load side and of the inertia time (“overshoot”) of the device on the supply side, i.e. the time interval during which the protection can trip even when the phenomenon is over.

As in the case of current selectivity, the study is made by comparing the time-current trip curves of the protection devices. This type of coordination is generally easy to study and realise and is not very costly. It allows even high selectivity limit values (if Icw is high) and allows for redundancy of the protection functions.

However, the trip times and energy levels let through by the protections, especially by those close to the sources, are high. This is a type of selectivity which can also be made between circuit breakers of the same size, equipped with electronic releases with delayed protection against short-circuit.

Energy selectivity

Coordination of energy type is a particular type of selectivity which exploits the current-limiting characteristics of moulded-case circuit breakers. A current-limiting circuit breaker is “a circuit-breaker with a sufficiently short trip time to prevent the short-circuit current from reaching the peak value which would otherwise be reached” (IEC 60947-2).

Fig. 3: Real currents circulating in the circuit breakers.
In practice, all the ABB SACE moulded-case circuit breakers of the Tmax series, the modular circuit-breakers and the E2L E3L air current-limiting circuit breakers have more or less marked current-limiting characteristics.

Under short-circuit conditions, these circuit breakers are extremely fast and open when there is a strong asymmetrical component. It is therefore not possible to use the time-current trip curves of the circuit-breakers, obtained with symmetrical sinusoidal types of wave forms, for the coordination study. The phenomena are mainly dynamic (therefore proportional to the square of the instantaneous current value) and are heavily dependent on the interaction between the two pieces of apparatus in series. Therefore, the energy selectivity values cannot be determined by the end-user.

Manufacturers make tables, slide-rules and calculation programmes available where the ultimate current selectivity values of Is under short-circuit between different combinations of circuit-breakers are given. These values are defined by theoretically integrating the results of tests carried out in compliance with Annex A of IEC 60947-2.

Zone selectivity

This type of coordination is an evolution of time coordination. In general, zone selectivity is made by means of dialogue between the current measuring devices which, once the setting threshold has been exceeded, allows just the fault zone to be identified correctly and the power supply to it to be cut off.

It can be realised in two ways:

- The measuring devices send the information linked to the exceeded current setting threshold to a supervision system and the latter identifies which protection must intervene.
- When there are current values higher than their setting, each protection sends a lock signal by means of a direct connection or a bus to the hierarchically higher level protection (on the supply side in relation to the power flow direction) and checks that a similar lock signal has not arrived from the load-side protection before intervening. In this way only the protection immediately to the supply side of the fault intervenes.

The second case allows shorter trip times. Compared with coordination of the time type, the need to increase the intentional delay as one moves towards the power supply source is no longer necessary. The delay can be reduced to the time needed to exclude the presence of a possible lock signal coming from the load-side protection.

This is a type of selectivity suitable for radial networks and, when associated with the directional protection, also suitable for meshed networks.

Compared with coordination of time type, zone selectivity allows:

- Reduction of the trip times (these can be lower than 100 ms).
- Reduction of both the damage caused by the fault and of interferences to the power supply system.
- Reduction of the thermal and dynamic stresses on the components of the installation.
- A very high number of selectivity levels to be obtained.

However, it is more burdensome in terms of cost and of complexity of the installation, and it requires an auxiliary supply.

This solution is therefore used mainly in systems with high-rated current and short-circuit current values, with safety and service continuity requirements which are binding.

Contact Paul Louw, ABB,
Tel 010 202-5916,
paul.louw@za.abb.com