1 Selectivity of protection –discrimination

Selectivity of protection is of paramount importance when designing complex electric power supply networks. Selectivity of protection is advisable to minimize damage to equipment and to maximize the availability of power under all fault and overload conditions. In cascaded power supply systems, selectivity of protection can easiest and most reliably be achieved by means of fuses. Their physical principle of operation enables over-current discrimination from very low up to the highest fault levels.

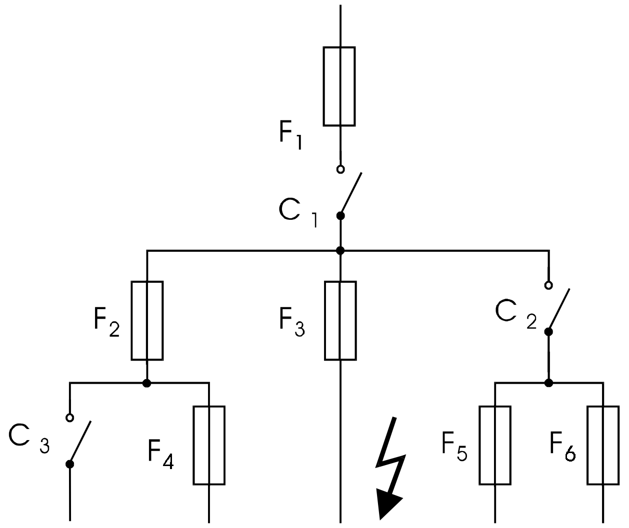

Fig. 1 – Schematic of radial network

The aim of over-current discrimination is to disconnect the overloaded or faulted circuit or device only, while leaving all other circuits and devices unaffected. In a network according to fig. 1, e.g. the fault indicated by the arrow symbol would be disconnected by the fuse F_3 without operation of the fuse F_1 or circuit-breaker C_1. Correct discrimination requires thorough co-ordination of the operating characteristics of all over-current protective devices connected in series. The relevant characteristics for the co-ordination of fuses and other protective devices, mainly circuit-breakers, are time-current and Joule-integral (I^2t) characteristics. Depending on the characteristics of two protective devices in series, discrimination may exist for all fault current levels (total discrimination) or only for currents up to a defined discrimination limit current I_D (partial discrimination).

2 Co-ordination of fuses

Fuses are very easy to co-ordinate for over-current discrimination as their time-current characteristics are essentially running in parallel (fig. 2). This is because all fuses, h.v. fuses and l.v. fuses alike, follow the same physical principle of operation, which is especially true for high fault currents that melt the fuse-elements within a few milliseconds or even less than one millisecond. In this range, the pre-arcing time is governed by easy to control parameters like conductivity and geometry of melting-elements only. For the purpose of co-ordination of fuses or fuses and other protective devices, l.v. fuse characteristics are closely defined in IEC 60269 while h.v. fuse characteristics may be taken from manufacturer's literature. The relevant time-current characteristics may be used for periods down to 100 ms. For high fault levels that lead to fuse operation in less than 100 ms, the relevant I^2t values may be used.

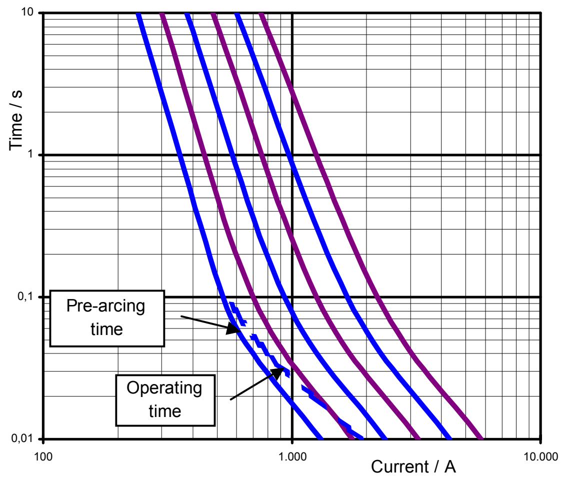

Fig. 2 – Time-current characteristics of fuses

Note – The Joule integral I^2t represents the energy released by the fault current in 1 Ω of resistance during the pre-arcing or operating time interval.
If time-current characteristics supplied by fuse manufacturers, cover a time range below 100 ms, it needs to be mentioned that these curves do not represent real pre-arcing or operating time values but virtual time values calculated from I^2t values. Depending on the initial short-circuit current wave form including potential displacement by d.c. components, the real time values may differ

significantly from the calculated virtual time values. Virtual time-current characteristics shall therefore never be used to co-ordinate protective devices that are not connected in series and do not operate based on an I^2t characteristic.

- **The 1:1,6 rule for l.v. "gG" fuse-links**

A typical l.v. power supply networks of radial structure, e.g. as shown in fig 1, would ideally be protected by general purpose ("gG") fuses on all hierarchic levels. "gG" fuses acc. to IEC 60269 provide over-current discrimination within a wide range of rated currents from 16 A up to 1250 A, independent on their physical size or mechanical design. A rated current ratio of 1:1,6 or less (i.e. two or more steps in rated currents of standard "gG" fuse-links) is the only selection rule to be observed to achieve correct discrimination between fuses connected in series. As the time-current characteristics of "gG" fuses are essentially running in parallel, total discrimination is achieved over the whole range of over-currents, from unacceptable overloads up to the highest fault levels. The 1:1,6 rule guaranties that in standard applications at all over-current levels the pre-arcing time (or pre-arcing I^2t) of the major fuse is greater than the operating time (or operating I^2t) of the minor fuse. Referring to fig. 1, total discrimination between fuses F_4, F_2 and F_1 may easily be achieved by selecting fuse ratings of 16 A, 25 A and 40 A respectively. No other technical data than rated currents need to be considered for discrimination of "gG" fuses rated 16 A and higher.

- **Co-ordination of other fuses**

Pre-arcing and operating characteristics may be applied to co-ordinate other fuse types, including h.v. fuses and "gG" fuses having rated currents of 12 A and below. Two different over-current levels need to be considered when selecting fuses to discriminate.-

- For overloads and low fault currents, discrimination may be verified by comparing the minimum pre-arcing time-current characteristic of the major fuse to the maximum operating time-current characteristic of the minor fuse.
- Medium and high fault levels require the comparison of the corresponding I^2t values.

Fuse manufacturers provide the relevant data and, where applicable, may additionally provide discrimination ratios of rated currents for their products. In any case, total discrimination can generally be achieved when using fuses.

3 Fuses and circuit-breakers

When fuses are combined with circuit-breakers, over-current discrimination is not as easy to achieve. Due to the inertia of moving parts, circuit-breaker tripping characteristics run almost horizontally under high fault conditions, while fuse pre-arcing characteristics exhibit a constant slope (see fig. 3). Consequently, partial discrimination only can be achieved between fuses and downstream circuit-breakers. In a network acc. to fig. 1, circuit-breaker C_3 and fuse F_2 discriminate up to the discrimination limit current I_D. Fault currents above I_D will open both protective devices and de-energize additionally the branch of F_4. Circuit-breakers upstream fuses, e.g. C_1 upstream F_2 or C_2 upstream F_5 and F_6 are less difficult to co-ordinate, as the characteristics don't necessarily intersect (see fig. 3). Total over-current discrimination is achieved if the operating time-current characteristic of the fuse F_2 does not intersect with the minimum tripping characteristic of circuit-breaker C_1. The intersection of the time-current characteristic of fuse F_1 and tripping characteristic of circuit-breaker C_1 at I_{to} does not represent a discrimination issue, but a back-up protection application that follows different rules of co-ordination.

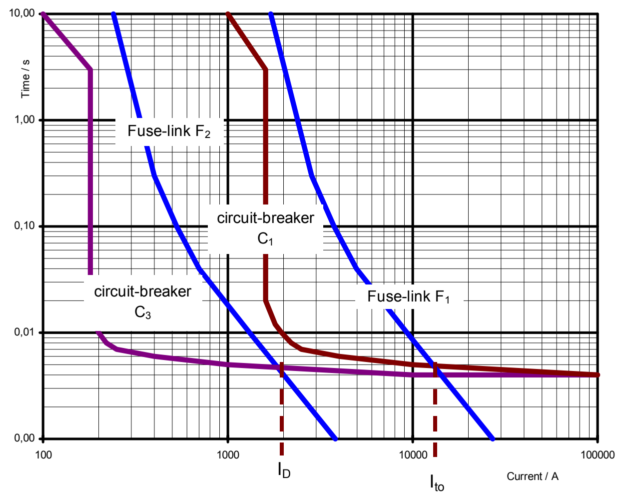

Fig. 3 – Co-ordination of fuses and circuit-breakers

Note – In the range below 100 ms, time-current characteristics represent virtual time values calculated from I^2t values.