1. the basic functions of LV switchgear

the role of switchgear is that of:
- electrical protection;
- safe isolation from live parts;
- local or remote switching.

National and international standards define
the manner in which electric circuits of LV
installations must be realized, and the
capabilities and limitations of the various
switching devices which are collectively
referred to as switchgear.

The main functions of switchgear are:
- electrical protection;
- electrical isolation of sections of an
installation;
- local or remote switching.

These functions are summarized below in
table H2-1.

Electrical protection at low voltage is (apart
from fuses) normally incorporated in circuit
breakers, in the form of thermal-magnetic
devices and/or residual-current-operated
tripping devices (less-commonly, residual-
voltage-operated devices - acceptable to, but
not recommended by IEC).

In addition to those functions shown in table
H2-1, other functions, namely:
- over-voltage protection;
- under-voltage protection are provided by
specific devices (lightning and various other
types of voltage-surge arrester; relays
associated with: contactors, remotely-
controlled circuit breakers, and with combined
circuit breaker/isolators... and so on).

<table>
<thead>
<tr>
<th>electrical protection against</th>
<th>isolation</th>
<th>control</th>
</tr>
</thead>
<tbody>
<tr>
<td>overload currents</td>
<td>- isolation clearly indicated by an authorized fail-proof mechanical indicator - a gap or interposed insulating barrier between the open contacts, clearly visible.</td>
<td>- functional switching - emergency switching - switching off for mechanical maintenance</td>
</tr>
<tr>
<td>short-circuit currents</td>
<td></td>
<td></td>
</tr>
<tr>
<td>insulation failure</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table H2-1: basic functions of LV switchgear.

1.1 electrical protection

electrical protection assures:
- protection of circuit elements against the thermal and mechanical stresses of short-circuit currents;
- protection of persons in the event of insulation failure;
- protection of appliances and apparatus being supplied (e.g. motors, etc.).

The aim is to avoid or to limit the destructive or dangerous consequences of excessive (short-circuit) currents, or those due to overloading and insulation failure, and to separate the defective circuit from the rest of the installation.

A distinction is made between the protection of:
- the elements of the installation (cables, wires, switchgear...);
- persons and animals;
- equipment and appliances supplied from the installation;
- the protection of circuits (see chapter H1):
  1) against overload; a condition of excessive current being drawn from a healthy (unfaulted) installation,
  2) against short-circuit currents due to complete failure of insulation between conductors of different phases or (in TN systems) between a phase and neutral (or PE) conductor.

Protection in these cases is provided either by fuses or circuit breaker, at the distribution board from which the final circuit (i.e. the circuit to which the load is connected) originates. Certain derogations to this rule are authorized in some national standards, as noted in chapter H1 sub-clause 1.4.

- the protection of persons against insulation failures (see chapter G).

According to the system of earthing for the installation (TN, TT or IT) the protection will be provided by fuses or circuit breakers, residual current devices, and/or permanent monitoring of the insulation resistance of the installation to earth.

- the protection of electric motors (see chapter J clause 5) against overheating, due, for example, to long term overloading; stalled rotor; single-phasing, etc. Thermal relays, specially designed to match the particular characteristics of motors are used. Such relays may, if required, also protect the motor-circuit cable against overload. Short-circuit protection is provided either by type aM fuses or by a circuit breaker from which the thermal (overload) protective element has been removed, or otherwise made inoperative.

1.2 isolation

a state of isolation clearly indicated by an approved "fail-proof" indicator, or the visible separation of contacts, are both deemed to satisfy the national standards of many countries.

The aim of isolation is to separate a circuit or apparatus, or an item of plant (such as a motor, etc.) from the remainder of a system which is energized, in order that personnel may carry out work on the isolated part in perfect safety. In principle, all circuits of an LV installation shall have means to be isolated. In practice, in order to maintain an optimum continuity of service, it is preferred to provide a means of isolation at the origin of each circuit.

An isolating device must fulfill the following requirements:
- all poles of a circuit, including the neutral (except where the neutral is a PEN conductor) must be open (1):
- it must be provided with a means of locking open with a key (e.g. by means of a padlock) in order to avoid an unauthorized reclosure by inadvertence;
- it must conform to a recognized national or international standard (e.g. IEC 947-3) concerning clearance between contacts, creepage distances, overvoltage withstand capability, etc. and also:

(1) the concurrent opening of all live conductors, while not always obligatory, is however, strongly recommended (for reasons of greater safety and facility of operation). The neutral contact opens after the phase contacts, and closes before them (IEC 947-1).
1.2 isolation (continued)

- verification that the contacts of the isolating device are, in fact, open. The verification may be:
  - either visual, where the device is suitably designed to allow the contacts to be seen (some national standards impose this condition for an isolating device located at the origin of a LV installation supplied directly from a HV/LV transformer);
  - or mechanical, by means of an indicator solidly welded to the operating shaft of the device. In this case the construction of the device must be such that, in the eventuality that the contacts become welded together in the closed position, the indicator cannot possibly indicate that it is in the open position.
- leakage currents. With the isolating device open, leakage currents between the open contacts of each phase must not exceed:
  - 0.5 mA for a new device,
  - 6.0 mA at the end of its useful life.
- voltage-surge withstand capability, across open contacts. The isolating device, when open must withstand a 1.2/50 µs impulse, having a peak value of 5, 8 or 10 kV according to its service voltage, as shown in table H2-2. The device must satisfy these conditions for altitudes up to 2,000 metres. Consequently, if tests are carried out at sea level, the test values must be increased by 23% to take into account the effect of altitude. See standard IEC 947 and the Note immediately preceding table F-10.

<table>
<thead>
<tr>
<th>service (nominal) voltage (V)</th>
<th>impulse withstand peak voltage (kV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>230/400</td>
<td>5 kV</td>
</tr>
<tr>
<td>400/690</td>
<td>8 kV</td>
</tr>
<tr>
<td>1,000</td>
<td>10 kV</td>
</tr>
</tbody>
</table>

Industrial LV switchgear which affords isolation when open is marked on the front face by the symbol . This symbol may be combined with those indicating other features where a device also performs other functions as shown in figure H2-4.

![fig. H2-3: symbol for a disconnector* also commonly referred to as an isolator.](image)

- switch-disconnector*, also referred to as a load-break isolating switch

![circuit breaker suitable for circuit isolation](image)

- circuit breaker suitable for circuit isolation

![fig. H2-4: symbols for circuit isolation capability incorporated in other switching devices.](image)

* IEC 617-7 and 947-3.

Note. In this guide the terms “disconnector” and “isolator” have the same meaning.

1.3 switchgear control

---

switchgear-control functions allow system operating personnel to modify a loaded system at any moment, according to requirements, and include:
- functional control (routine switching, etc.);
- emergency switching;
- maintenance operations on the power system.

In broad terms “control” signifies any facility for safely modifying a load-carrying power system at all levels of an installation. The operation of switchgear is an important part of power-system control.

functional control

This control relates to all switching operations in normal service conditions for energizing or de-energizing a part of a system or installation, or an individual piece of equipment, item of plant, etc.

Switchgear intended for such duty must be installed at least:
- at the origin of any installation;
- at the final load circuit or circuits (one switch may control several loads).

Marking (of the circuits being controlled) must be clear and unambiguous.

In order to provide the maximum flexibility and continuity of operation, particularly where the switching device also constitutes the protection (e.g. a circuit breaker or switch-fuse) it is preferable to include a switch at each level of distribution, i.e. on each outgoing way of all distribution and sub-distribution boards.

The manœuvre may be:
- either manual (by means of an operating lever on the switch) or;
- electric, by push-button on the switch or at a remote location (load-shedding and re-connection, for example).

These switches operate instantaneously (i.e. with no deliberate delay), and those that provide protection are invariably omni-polar*.

The main circuit breaker for the entire installation, as well as any circuit breakers used for change-over (from one source to another) must be omni-polar units.

* one break in each phase and (where appropriate) one break in the neutral (see table H1-65).
**emergency switching - emergency stop**

An emergency switching is intended to de-energize a live circuit which is, or could become, dangerous (electric shock or fire). An emergency stop is intended to arrest a movement which has become dangerous. In the two cases:

- the emergency control device or its means of operation (local or at remote location(s)) such as a large red mushroom-headed emergency-stop pushbutton must be recognizable and readily accessible, in proximity to any position at which danger could arise or be seen;
- a single action must result in a complete switching-off of all live conductors (1) (2);
- a “break glass” emergency switching initiation device is authorized, but in unmanned installations the re-energizing of the circuit can only be achieved by means of a key held by an authorized person.

It should be noted that in certain cases, an emergency system of braking, may require that the auxiliary supply to the braking-system circuits be maintained until final stoppage of the machinery.

(1) Taking into account stalled motors.
(2) In a TN schema the PEN conductor must never be opened, since it functions as a protective earthing wire as well as the system neutral conductor.

---

**switching-off for mechanical maintenance work**

This operation assures the stopping of a machine and its impossibility to be inadvertently restarted while mechanical maintenance work is being carried out on the driven machinery. The shutdown is generally carried out at the functional switching device, with the use of a suitable safety lock and warning notice at the switch mechanism.
2. the switchgear and fusegear

2.1 elementary switching devices

disconnecter (or isolator)
This switch is a manually-operated, lockable, two-position device (open/closed) which provides safe isolation of a circuit when locked in the open position. Its characteristics are defined in IEC 947-3. A disconnector is not designed to make or to break current* and no rated values for these functions are given in standards. It must, however, be capable of withstanding the passage of short-circuit currents and is assigned a rated short-time withstand capability; generally for 1 second, unless otherwise agreed between user and manufacturer. This capability is normally more than adequate for longer periods of (lower-valued) operational overcurrents, such as those of motor-starting. Standardized mechanical-endurance, overvoltage, and leakage-current tests, must also be satisfied.

* i.e. a LV disconnector is essentially a dead-system switching device to be operated with no voltage on either side of it, particularly when closing, because of the possibility of an unsuspected short-circuit on the downstream side. Interlocking with an upstream switch or circuit breaker is frequently used.

load-breaking switch
This control switch is generally operated manually (but is sometimes provided with electrical tripping for operator convenience) and is a non-automatic two-position device (open/closed). It is used to close and open loaded circuits under normal unfaulted circuit conditions. It does not consequently, provide any protection for the circuit it controls. IEC standard 947-3 defines:
- the frequency of switch operation (600 close/open cycles per hour maximum);
- mechanical and electrical endurance (generally less than that of a contactor);
- current making and breaking ratings for normal and infrequent situations.

IEC 947-3 also recognizes 3 categories of load-breaking switch, each of which is suitable for a different range of load power factors, as shown in table H2-7.
**H2-7: utilization categories of LV a.c. switches according to IEC 947-3.**

<table>
<thead>
<tr>
<th>nature of current</th>
<th>utilization category frequent operation</th>
<th>utilization category infrequent operation</th>
<th>typical applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>alternating current</td>
<td>AC-20A</td>
<td>AC-20B</td>
<td>connecting and disconnecting under no-load conditions</td>
</tr>
<tr>
<td></td>
<td>AC-21A</td>
<td>AC-21B</td>
<td>switching of resistive loads including moderate overloads</td>
</tr>
<tr>
<td></td>
<td>AC-22A</td>
<td>AC-22B</td>
<td>switching of mixed resistive and inductive loads, including moderate overloads</td>
</tr>
<tr>
<td></td>
<td>AC-23A</td>
<td>AC-23B</td>
<td>switching of motor loads or other highly inductive loads</td>
</tr>
</tbody>
</table>

Category AC-23 includes occasional switching of individual motors. The switching of capacitors or of tungsten filament lamps shall be subject to agreement between manufacturer and user.

The utilization categories referred to in table H2-7 do not apply to an equipment normally used to start, accelerate and/or stop individual motors. The utilization categories for such an equipment are dealt with in chapter J, table J5-4.

**Example:**
A 100 A load-break switch of category AC-23 (inductive load) must be able:
- to make a current of 10 In (= 1,000 A) at a power factor of 0.35 lagging;
- to break a current of 8 In (= 800 A) at a power factor of 0.35 lagging;
- to withstand short-circuit currents (not less than 12 In) passing through it for 1 second, where 12 In equals the r.m.s. value of the a.c. component, while the peak value (expressed in kA) is given by a factor “n” in table XVI of IEC 947- Part 1, reproduced below for reader convenience (table H2-8).

<table>
<thead>
<tr>
<th>test current I (A)</th>
<th>power-factor</th>
<th>time-constant</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ≤ I ≤ 500</td>
<td>0.95</td>
<td>5</td>
<td>1.41</td>
</tr>
<tr>
<td>1 500 &lt; I ≤ 3 000</td>
<td>0.9</td>
<td>5</td>
<td>1.42</td>
</tr>
<tr>
<td>3 000 &lt; I ≤ 4 500</td>
<td>0.8</td>
<td>5</td>
<td>1.47</td>
</tr>
<tr>
<td>4 500 &lt; I ≤ 6 000</td>
<td>0.7</td>
<td>5</td>
<td>1.53</td>
</tr>
<tr>
<td>6 000 &lt; I ≤ 10 000</td>
<td>0.5</td>
<td>5</td>
<td>1.7</td>
</tr>
<tr>
<td>10 000 &lt; I ≤ 20 000</td>
<td>0.3</td>
<td>10</td>
<td>2.0</td>
</tr>
<tr>
<td>20 000 &lt; I ≤ 50 000</td>
<td>0.25</td>
<td>15</td>
<td>2.1</td>
</tr>
<tr>
<td>I &gt; 50 000</td>
<td>0.2</td>
<td>15</td>
<td>2.2</td>
</tr>
</tbody>
</table>

**table H2-8: factor “n” used for peak-to-rms value (IEC 947-part1).**

**bistable switch (télérupteur)**
This device is extensively used in the control of lighting circuits where the depression of a pushbutton (at a remote control position) will open an already-closed switch or close an open switch in a bistable sequence.

Typical applications are:
- two-way switching on stairways of large buildings;
- stage-lighting schemes;
- factory illumination, etc.

Auxiliary devices are available to provide:
- remote indication of its state at any instant;
- time-delay functions;
- maintained-contact features.

**fig. H2-9: symbol for a bistable remotely-operated switch (télérupteur).**
2.1 elementary switching devices (continued)

contactor
The contactor is a solenoid-operated switching device which is generally held closed by (a reduced) current through the closing solenoid (although various mechanically-latched types exist for specific duties). Contactors are designed to carry out numerous close/open cycles and are commonly controlled remotely by on-off pushbuttons.

For each type of fuse.

- a rated current making and breaking performance according to the category of utilization concerned.

Example:
A 150 A contactor of category AC3 must have a minimum current-breaking capability of 8 In (= 1,200 A) and a minimum current-making rating of 10 In (= 1,500 A) at a power factor (lagging) of 0.35.

![fig. H2-10: symbol for a contactor.]

Discontactor
A contactor equipped with a thermal-type relay for protection against overloading defines a "discontactor". Discontactors are used extensively for remote push-button control of lighting circuits, etc., and may also be considered as an essential element in a motor controller, as noted in sub-clause 2.2. "combined switchgear elements".

The discontactor is not the equivalent of a circuit breaker, since its short-circuit current-breaking capability is limited to 8 or 10 In. For short-circuit protection therefore, it is necessary to include either fuses or a circuit breaker in series with, and upstream of, the discontactor contacts.

*This term is not defined in IEC publications.

![fig. H2-10: symbol for a contactor.]

Fuses
Fuses exist with and without "fuse-blown" mechanical indicators.

Fuses break a circuit by controlled melting of the fuse element when a current exceeds a given value for a corresponding period of time; the current/time relationship being presented in the form of a performance curve for each type of fuse.

Standards define two classes of fuse:
- Those intended for domestic installations, manufactured in the form of a cartridge for rated currents up to 100 A and designated type gG in IEC 269-3;
- Those for industrial use, with cartridge types designated gG (general use); and gM and aM (for motor-circuits) in IEC 269-1 and 2.

The main differences between domestic and industrial fuses are the nominal voltage and current levels (which require much larger physical dimensions) and their fault-current breaking capabilities.

Type gG fuse-links are often used for the protection of motor circuits, which is possible when their characteristics are capable of withstanding the motor-starting current without deterioration.

A more recent development has been the adoption by the IEC of a fuse-type gM for motor protection, designed to cover starting, and short-circuit conditions. This type of fuse is more popular in some countries than in others, but at the present time the aM fuse in combination with a thermal overload relay is more widely used.

![fig. H2-11: symbol for fuses.]

two classes of LV cartridge fuse are very widely used:
- For domestic and similar installations type gG
- For industrial installations type gG, gM or aM
The conditions of fusing (melting) of a fuse are defined by standards, according to their class.

1. **Class GG Fuses**
   - These fuses provide protection against overloads and short-circuits.
   - Conventional non-fusing and fusing currents are standardized, as shown in figure H2-12 and in table H2-13.
   - The conventional non-fusing current $I_{nf}$ is the value of current that the fusible element can carry for a specified time without melting. Example: a 32 A fuse carrying a current of 1.25 $I_{nf}$ (i.e. 40 A) must not melt in less than one hour (table H2-13).
   - The conventional fusing current $I_{f}$ (= $I_{2}$ in fig. H2-12) is the value of current which will cause melting of the fusible element before the expiration of the specified time. Example: a 32 A fuse carrying a current of 1.6 $I_{nf}$ (i.e. 52.1 A) must melt in one hour or less (table H2-13).
   - IEC 269-1 standardized tests require that a fuse-operating characteristic lies between the two limiting curves (shown in figure H2-12) for the particular fuse under test. This means that two fuses which satisfy the test can have significantly different operating times at low levels of overloading.
   - The two examples given above for a 32 A fuse, together with the foregoing notes on standard test requirements, explain why these fuses have a poor performance in the low overload range.
   - It is therefore necessary to install a cable larger in ampacity than that normally required for a circuit, in order to avoid the consequences of possible long term overloading (60% overload for up to one hour in the worst case).
   - By way of comparison, a circuit breaker of similar current rating:
     - which passes 1.05 $I_{nf}$ must not trip in less than one hour; and
     - when passing 1.25 $I_{nf}$ it must trip in one hour, or less (25% overload for up to one hour in the worst case).

2. **Class GM Fuses**
   - These fuses require a separate overload relay, as described in the note at the end of sub-clause 2.1.

3. **Class AM (Motor) Fuses**
   - These fuses afford protection against short-circuit currents only and must necessarily be associated with other switchgear (such as discontactors or circuit breakers) in order to ensure overload protection $< 4 I_{nf}$. They are not therefore autonomous. Since AM fuses are not intended to protect against low values of overload current, no levels of conventional non-fusing and fusing currents are fixed. The characteristic curves for testing these fuses are given for values of fault current exceeding approximately 4 $I_{nf}$ (see figure H2-14), and fuses tested to IEC 269 must give operating curves which fall within the shaded area.
   - Note: the small "arrowheads" in the diagram indicate the current/time "gate" values for the different fuses to be tested (IEC 269).

### Table H2-13: Zones of Fusing and Non-Fusing for LV Types GG and GM Class Fuses (IEC 269-1 and 269-2-1).

<table>
<thead>
<tr>
<th>Class</th>
<th>Rated Current</th>
<th>Conventional Non-Fusing Current $I_{nf}$</th>
<th>Conventional Fusing Current $I_{f}$</th>
<th>Conventional Time h</th>
</tr>
</thead>
<tbody>
<tr>
<td>GG</td>
<td>$I_{nf} \leq 4$ A</td>
<td>1.5 $I_{nf}$</td>
<td>2.1 $I_{nf}$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>$4 &lt; I_{nf} \leq 16$ A</td>
<td>1.5 $I_{nf}$</td>
<td>1.9 $I_{nf}$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>$16 &lt; I_{nf} \leq 63$ A</td>
<td>1.25 $I_{nf}$</td>
<td>1.6 $I_{nf}$</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>$63 &lt; I_{nf} \leq 160$ A</td>
<td>1.25 $I_{nf}$</td>
<td>1.6 $I_{nf}$</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>$160 &lt; I_{nf} \leq 400$ A</td>
<td>1.25 $I_{nf}$</td>
<td>1.6 $I_{nf}$</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>$400 &lt; I_{nf}$</td>
<td>1.25 $I_{nf}$</td>
<td>1.6 $I_{nf}$</td>
<td>4</td>
</tr>
</tbody>
</table>

* $I_{nf}$ for GM fuses

---

**gM fuses require a separate overload relay, as described in the note at the end of sub-clause 2.1.**

**Class aM Fuses**

Class aM fuses protect against short-circuit currents only, and must always be associated with another device which protects against overload.

---

**fig. H2-12: Zones of Fusing and Non-Fusing for GG and GM Fuses.**

**fig. H2-14: Standardized Zones of Fusing for Type aM Fuses (All Current Ratings).**
2. elementary switching devices (continued)

rated short-circuit breaking currents
A characteristic of modern cartridge fuses is that, owing to the rapidity of fusion in the case of high short-circuit current levels*, a current cut-off begins before the occurrence of the first major peak, so that the fault current never reaches its prospective peak value (fig. H2-15).

This limitation of current reduces significantly the thermal and dynamic stresses which would otherwise occur, thereby minimizing danger and damage at the fault position. The rated short-circuit breaking current of the fuse is therefore based on the r.m.s. value of the a.c. component of the prospective fault current.

No short-circuit current-making rating is assigned to fuses.

*for currents exceeding a certain level, depending on the fuse nominal current rating, as shown below in figure H2-15A.

Reminder
Short-circuit currents initially contain d.c. components, the magnitude and duration of which depend on the $X/L$ ratio of the fault-current loop.

Close to the source (HV/LV transformer) the relationship $I_{peak} / I_{rms}$ (of a.c. component) immediately following the instant of fault, can be as high as 2.5 (standardized by IEC, and shown in figure H2-15A).

At lower levels of distribution in an installation, as previously noted, $X_L$ is small compared with $R$ and so for final circuits $I_{peak} / I_{rms} \approx 1.41$, a condition which corresponds with figure H2-15 above and with the "$n$" value corresponding to a power factor of 0.95 in table H2-8.

The peak-current-limitation effect occurs only when the prospective r.m.s. a.c. component of fault current attains a certain level. For example, in the above graph the 100 A fuse will begin to cut off the peak at a prospective fault current (r.m.s.) of 2 kA (a). The same fuse for a condition of 20 kA r.m.s. prospective current will limit the peak current to 10 kA (b). Without a current-limiting fuse the peak current could attain 50 kA (c) in this particular case.

As already mentioned, at lower distribution levels in an installation, $R$ greatly predominates $X_L$, and fault levels are generally low.

This means that the level of fault current may not attain values high enough to cause peak-current limitation. On the other hand, the d.c. transients (in this case) have an insignificant effect on the magnitude of the current peak, as previously mentioned.

Note on gM fuse ratings.
A gM type fuse is essentially a gG fuse, the fusible element of which corresponds to the current value $I_{ch}$ which may be, for example, 63 A.

This is the IEC testing value, so that its time/current characteristic is identical to that of a 63 A gG fuse.

This value (63 A) is selected to withstand the high starting currents of a motor, the steady-state operating current ($I_n$) of which may be in the 10-20 A range.
This means that a physically smaller fuse barrel and metallic parts can be used, since the heat dissipation required in normal service is related to the lower figures (10-20 A).

A standard gM fuse, suitable for this situation would be designated 32M63 (i.e. In M Ich).

The first current rating In concerns the steady-load thermal performance of the fuse-link, while the second current rating (Ich) relates to its (short-time) starting-current performance.

It is evident that, although suitable for short-circuit protection, overload protection for the motor is not provided by the fuse, and so a separate thermal-type relay is always necessary when using gM fuses.

The only advantage offered by gM fuses, therefore, when compared with aM fuses, are reduced physical dimensions and slightly lower cost.

2.2 combined switchgear elements

Single units of switchgear do not, in general, fulfil all the requirements of the three basic functions, viz: protection, control and isolation.

Where the installation of a circuit breaker is not appropriate (notably where the switching rate is high, over extended periods) combinations of units specifically designed for such a performance are employed.

The most commonly-used combinations are described below:

switch and fuse combinations

Two cases are distinguished:

- the type in which the operation of one (or more) fuse(s) causes the switch to open. This is achieved by the use of fuses fitted with striker pins, and a system of switch tripping springs and toggle mechanisms. This type of combination is generally used for current levels exceeding 100 A, and is commonly associated with a thermal-type overcurrent relay for overload protection (for which the fuses alone may not be suitable).

- the type in which a non-automatic switch is associated with a set of fuses in a common enclosure. In some countries, and in IEC 947-3, the terms “switch-fuse” and “fuse-switch” have specific meanings, viz:
  - a switch-fuse comprises a switch (generally 2 breaks per pole) on the upstream side of three fixed fuse-bases, into which the fuse carriers are inserted (figure H2-17(a)),
  - a fuse-switch consists of three switch blades each constituting a double-break per phase. These blades are not continuous throughout their length, but each has a gap in the centre which is bridged by the fuse cartridge. Some designs have only a single break per phase, as shown in figures H2-17(a) and (b).
The current range for these devices is limited to 100 A maximum at 400 V 3-phase, while their principal use is in domestic and similar installations.

To avoid confusion between the first group (i.e. automatic tripping) and the second group, the term "switch-fuse" should be qualified by the adjectives "automatic" or "non-automatic".

**fuse - disconnector + discontactor**

**fuse - switch-disconnector + discontactor**

As previously mentioned, a discontactor does not provide protection against short-circuit faults. It is necessary, therefore, to add fuses (generally of type aM) to perform this function.

The combination is used mainly for motor-control circuits, where the disconnector or switch-disconnector allows safe operations such as:

- the changing of fuse links (with the circuit isolated);
- work on the circuit downstream of the discontactor (risk of remote closure of the discontactor).

The fuse-disconnector must be interlocked with the discontactor such that no opening or closing manoeuvre of the fuse-disconnector is possible unless the discontactor is open (figure H2-18 (a)), since the fuse-disconnector has no load-switching capability. A fuse-switch-disconnector (evidently) requires no interlocking (figure H2-18 (b)). The switch must be of class AC22 or AC23 if the circuit supplies a motor.

**circuit-breaker + contactor**

**circuit-breaker + discontactor**

These combinations are used in remotely-controlled distribution systems in which the rate of switching is high, or for control and protection of a circuit supplying motors. The protection of induction motors is considered in chapter J, clause J5.
3. choice of switchgear

3.1 tabulated functional capabilities

After having studied the basic functions of LV switchgear (clause 1, table H2-1) and the different components of switchgear (clause 2), table H2-19 summarizes the capabilities of the various components to perform the basic functions.

<table>
<thead>
<tr>
<th>switchgear item</th>
<th>isolation</th>
<th>control</th>
<th>emergency switching</th>
<th>emergency stop (mechanical)</th>
<th>switching for mechanical maintenance</th>
<th>electrical protection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>functional</td>
<td>(*)</td>
<td>(1)</td>
<td>(1)</td>
<td>(*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>emergency switching</td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>overload</td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>short-circuit</td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>differential</td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>isolator (or disconnector) (4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>switch (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>residual device (RCCB) (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>switch-disconnector</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>contactor</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>bistable-switch</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>(telerupteur)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>fuse</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>circuit breaker (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>circuit breaker disconnector (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>residual and overcurrent circuit breaker (RCBO) (5)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(*)</td>
</tr>
<tr>
<td>point of installation (general principle)</td>
<td></td>
<td>origin of each circuit</td>
<td>all points where, for operational reasons it may be necessary to stop the process</td>
<td>in general at the incoming circuit to every distribution board</td>
<td>at the supply point to each machine and/or on the machine concerned</td>
<td>origin of each circuit</td>
</tr>
</tbody>
</table>

Table H2-19: functions fulfilled by different items of switchgear.

1. Where cut-off of all active conductors is provided
2. It may be necessary to maintain supply to a braking system
3. If it is associated with a thermal relay (the combination is commonly referred to as a “discontactor”)
4. In certain countries a disconnector with visible contacts is mandatory at the origin of a LV installation supplied directly from a HV/LV transformer
5. Certain items of switchgear are suitable for isolation duties (e.g. RCCBs according to IEC 1008) without being explicitly marked as such.

3.2 switchgear selection

Software is being used more and more in the field of optimal selection of switchgear. Each circuit is considered one at a time, and a list is drawn up of the required protection functions and exploitation of the installation, among those mentioned in table H2-19 and summarized in table H2-1. A number of switchgear combinations are studied and compared with each other against relevant criteria, with the aim of achieving:

- satisfactory performance;
- compatibility among the individual items; from the rated current In to the fault-level rating Icu;
- compatibility with upstream switchgear or taking into account its contribution;
- conformity with all regulations and specifications concerning safe and reliable circuit performance.

In order to determine the number of poles for an item of switchgear, reference is made to chapter H1, clause 7, table H1-65. Multifunction switchgear, initially more costly, reduces installation costs and problems of installation or exploitation. It is often found that such switchgear provides the best solution.
the circuit breaker/disconnector fulfills all of the basic switchgear functions, while, by means of accessories, numerous other possibilities exist.

As shown in table H2-19 the circuit breaker/disconnector is the only item of switchgear capable of simultaneously satisfying all the basic functions necessary in an electrical installation. Moreover, it can, by means of auxiliary units, provide a wide range of other functions, for example: indication (on-off - tripped on fault); undervoltage tripping; remote control… etc. These features make a circuit-breaker/disconnector the basic unit of switchgear for any electrical installation.

<table>
<thead>
<tr>
<th>functions</th>
<th>possible conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>isolation</td>
<td></td>
</tr>
<tr>
<td>control</td>
<td>functional</td>
</tr>
<tr>
<td></td>
<td>emergency switching</td>
</tr>
<tr>
<td></td>
<td>(with the possibility of a tripping coil for remote control)</td>
</tr>
<tr>
<td></td>
<td>switching-off for mechanical maintenance</td>
</tr>
<tr>
<td>protection</td>
<td>overload</td>
</tr>
<tr>
<td></td>
<td>short-circuit</td>
</tr>
<tr>
<td></td>
<td>insulation faulty</td>
</tr>
<tr>
<td></td>
<td>(with differential-current relay)</td>
</tr>
<tr>
<td></td>
<td>undervoltage</td>
</tr>
<tr>
<td></td>
<td>(with undervoltage-trip coil)</td>
</tr>
<tr>
<td>remote control</td>
<td>added or incorporated</td>
</tr>
<tr>
<td>indication and measurement</td>
<td>(generally optional with an electronic tripping device)</td>
</tr>
</tbody>
</table>

Table H2.20: functions performed by a circuit-breaker/disconnector.

4.1 standards and descriptions

Industrial circuit breakers must conform with IEC 947-1 and 947-2 or other equivalent standards. Corresponding European standards are presently being developed. Domestic-type circuit breakers should conform to IEC standard 898, or an equivalent national standard.

Standards

For industrial LV installations the relevant IEC standards are, or are due to be:
- 947-1: general rules;
- 947-2: part 2: circuit breakers;
- 947-3: part 3: switches, disconnectors, switch-disconnectors and fuse combination units;
- 947-4: part 4: contactors and motor-starters;
- 947-5: part 5: control-circuit devices and switching elements;
- 947-6: part 6: multiple function switching devices;
- 947-7: part 7: ancillary equipment.

Corresponding European and many national standards are presently in the course of harmonization with the IEC standards, with which they will be in very close agreement. For domestic and similar LV installations, the appropriate standard is IEC 898, or an equivalent national standard.
**description**

Figure H2-21 shows schematically the principal parts of a LV circuit breaker and its four essential functions:

1 - the circuit-breaking components, comprising the fixed and moving contacts and the arc-dividing chamber.

2 - the latching mechanism which becomes unlatched by the tripping device on detection of abnormal current conditions. This mechanism is also linked to the operation handle of the breaker.

3 - a trip-mechanism actuating device: either: a thermal-magnetic device, in which a thermally-operated bi-metal strip detects an overload condition, while an electromagnetic striker pin operates at current levels reached in short-circuit conditions, or: an electronic relay operated from current transformers, one of which is installed on each phase.

4 - a space allocated to the several types of terminal currently used for the main power-circuit conductors.

---

**fig. H2-21: principal parts of a circuit breaker.**

---

**fig. H2-22: domestic-type circuit breaker providing overcurrent protection and circuit isolation features.**

---

**fig. H2-23: domestic-type circuit breaker as above (H2-22) plus protection against electric shocks by the addition of a modular block.**
apart from the above-mentioned functions further features can be associated with the basic circuit breaker by means of additional modules, as shown in figure H2-24; notably remote control and indication (on-off-fault).

moulded-case type industrial circuit breakers conforming to IEC 947-2 are now available, which, by means of associated adaptable blocks provide a similar range of auxiliary functions to those described above (figure H2-25).

* Merlin Gerin product.
heavy-duty industrial circuit breakers of large current ratings, conforming to IEC 947-2, have numerous built-in communication and electronic functions (figure H2-26).

4.2 fundamental characteristics of a circuit breaker

the fundamental characteristics of a circuit breaker are:
- its rated voltage Ue
- its rated current In
- its tripping-current-level adjustment ranges for overload protection (Ir** or Irth**) and for short-circuit protection (Im)**
- its short-circuit current breaking rating (Icu for industrial CBs; Icn for domestic-type CBs).

rated operational voltage (Ue)
This is the voltage at which the circuit breaker has been designed to operate, in normal (undisturbed) conditions. Other values of voltage are also assigned to the circuit breaker, corresponding to disturbed conditions, as noted in sub-clause 4.3.

Example:
A circuit breaker rated at In = 125 A for an ambient temperature of 40 °C will be equipped with a suitably calibrated overcurrent tripping relay (set at 125 A). The same circuit breaker can be used at higher values of ambient temperature however, if suitably "derated".
Thus, the circuit breaker in an ambient temperature of 50 °C could carry only 117 A indefinitely, or again, only 109 A at 60 °C, while complying with the specified temperature limit.

Derating a circuit breaker is achieved therefore, by reducing the trip-current setting of its overload relay, and marking the CB accordingly. The use of an electronic-type of tripping unit, designed to withstand high temperatures, allows circuit breakers (derated as described) to operate at 60 °C (or even at 70 °C) ambient.

Note: In for circuit breakers (in IEC 947-2) is equal to Iu for switchgear generally, Iu being rated uninterrupted current.

* Merlin Gerin products.
** Current-level setting values which refer to the current-operated thermal and "instantaneous" magnetic tripping devices for over-load and short-circuit protection.

4.2 fundamental characteristics of a circuit breaker (continued)

**overload relay trip-current setting (Irth or Ir)**

Apart from small circuit breakers which are very easily replaced, industrial circuit breakers are equipped with removable, i.e. exchangeable, overcurrent-trip relays. Moreover, in order to adapt a circuit breaker to the requirements of the circuit it controls, and to avoid the need to install over-sized cables, the trip relays are generally adjustable.

The trip-current setting Ir or Irth (both designations are in common use) is the current above which the circuit breaker will trip. It also represents the maximum current that the circuit breaker can carry without tripping.

That value must be greater than the maximum load current Ib, but less than the maximum current permitted in the circuit Iz (see chapter H1, sub-clause 1.3).

Example (figure H2-27): a circuit breaker equipped with a 320 A overcurrent trip relay, set at 0.9, will have a trip-current setting:

\[ I_{tr} = 320 \times 0.9 = 288 \text{ A} \]

Note: for circuit breakers equipped with non-adjustable overcurrent-trip relays, \( I_r = I_n \).

**short-circuit relay trip-current setting (Im)**

Short-circuit tripping relays (instantaneous or slightly time-delayed) are intended to trip the circuit breaker rapidly on the occurrence of high values of fault current.

Their tripping threshold Im is:

- either fixed by standards for domestic type CBs, e.g. IEC 898, or,
- indicated by the manufacturer for industrial-type CBs according to related standards, notably IEC 947-2.

For the latter circuit breakers there exists a wide variety of tripping devices which allow a user to adapt the protective performance of the circuit breaker to the particular requirements of a load.

<table>
<thead>
<tr>
<th>type of protective relay</th>
<th>overload protection</th>
<th>short-circuit protection</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEC 898</td>
<td>( I_f = I_n )</td>
<td>low setting type B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3 ( I_m ) ( \leq I_m ) ( &lt; 5 ) ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>standard setting type C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high setting circuit type D</td>
</tr>
<tr>
<td>IEC 947-2</td>
<td>( I_f = I_n ) fixed</td>
<td>low setting type B or Z</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3.2 ( I_m ) ( \leq I_m ) ( &lt; 4.8 ) ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>standard setting type C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>high setting type D or K</td>
</tr>
<tr>
<td>electronic</td>
<td>long delay</td>
<td>adjustable:</td>
</tr>
<tr>
<td></td>
<td>( 0.4 ) ( I_m ) ( \leq I_m ) ( &lt; 1 ) ( I_m ) fixed</td>
<td>low setting: 2 to 5 ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- standard setting: 5 to 10 ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>adjustable:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- low setting: 2 to 5 ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- standard setting: 5 to 10 ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>instantaneously fixed:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.5 ( I_m ) ( \leq I_m ) ( &lt; 10 ) ( I_m )</td>
</tr>
<tr>
<td></td>
<td></td>
<td>( I = 12 ) to 15 ( I_m )</td>
</tr>
</tbody>
</table>

Table H2.28: tripping-current ranges of overload and short-circuit protective devices for LV circuit breakers.

(1) 50 \( I_m \) in IEC 898, which is considered too unrealistically high by most European manufacturers (M-G = 10 to 14 \( I_m \)).

(2) For industrial use, IEC standards do not specify values. The above values are given only as being those in common use.
Isolating feature
A circuit breaker is suitable for isolating a circuit if it fulfills all the conditions prescribed for a disconnector (at its rated voltage) in the relevant standard (see sub-clause 1.2). In such a case it is referred to as a circuit breaker-disconnector and marked on its front face with the symbol All Multi 9, Compact NS and Masterpact LV switchgear of Merlin Gerin manufacture is in this category.

Rated short-circuit breaking capacity (Icu or Icn)
The short-circuit current-breaking rating of a CB is the highest (prospective) value of current that the CB is capable of breaking without being damaged. The value of current quoted in the standards is the r.m.s. value of the a.c. component of the fault current, i.e. the d.c. transient component (which is always present in the worst possible case of short-circuit) is assumed to be zero for calculating the standardized value. This rated value (Icu) for industrial CBs and (Icn) for domestic-type CBs is normally given in kA r.m.s.

Icu (rated ultimate s.c. breaking capacity) and Ics (rated service s.c. breaking capacity) are defined in IEC 947-2 together with a table relating Ics with Icu for different categories of utilization A (instantaneous tripping) and B (time-delayed tripping) as discussed in sub-clause 4.3.

Tests for proving the rated s.c. breaking capacities of CBs are governed by standards, and include:
• operating sequences, comprising a succession of manoeuvres, i.e. closing and opening on short-circuit;
• current and voltage phase displacement. When the current is in phase with the supply voltage (cos ϕ for the circuit = 1), interruption of the current is easier than that at any other power factor. Breaking a current at low lagging* values of cos ϕ is considerably more difficult to achieve; a zero power-factor circuit being (theoretically) the most onerous case.

In practice, all power-system short-circuit fault currents are (more-or-less) at lagging power factors, and standards are based on values commonly considered to be representative of the majority of power systems. In general, the greater the level of fault current (at a given voltage), the lower the power factor of the fault-current loop, for example, close to generators or large transformers.

Table H2-31 below extracted from IEC 947-2 relates standardized values of cos ϕ to industrial circuit breakers according to their rated Icu.

<table>
<thead>
<tr>
<th>Icu (kA)</th>
<th>cos ϕ</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 kA &lt; Icu &lt; 10 kA</td>
<td>0.5</td>
</tr>
<tr>
<td>10 kA &lt; Icu &lt; 20 kA</td>
<td>0.3</td>
</tr>
<tr>
<td>20 kA &lt; Icu &lt; 50 kA</td>
<td>0.25</td>
</tr>
<tr>
<td>50 kA &lt; Icu</td>
<td>0.2</td>
</tr>
</tbody>
</table>

The short-circuit current-breaking performance of a LV circuit breaker is related (approximately) to the cos ϕ of the fault-current loop. Standard values for this relationship have been established in some standards.

*The term 'lagging' is used to describe the condition where the phase of the current is at some angle behind the phase of the voltage; conversely, the term 'leading' is used where the current is at an angle ahead of the voltage.
4.3 other characteristics of a circuit breaker

Familiarity with the following less-important characteristics of LV circuit breakers is, however, often necessary when making a final choice.

rated insulation voltage (Ui)
This is the value of voltage to which the dielectric tests voltage (generally greater than 2 Ui) and creepage distances are referred. The maximum value of rated operational voltage must never exceed that of the rated insulation voltage, i.e. \( U_e < U_i \).

rated impulse-withstand voltage (Uimp)
This characteristic expresses, in kV peak (of a prescribed form and polarity) the value of voltage which the equipment is capable of withstanding without failure, under test conditions. For further details see chapter F, clause 2.

category (A or B) and rated short-time withstand current (Icw)
As already briefly mentioned (sub-clause 4.2) there are two categories of LV industrial switchgear, A and B, according to IEC 947-2:
- those of category A, for which there is no deliberate delay in the operation of the "instantaneous" short-circuit magnetic-tripping device (figure H2-32), are generally moulded-case type circuit breakers, and,
- those of category B for which, in order to discriminate with other circuit breakers on a time basis, it is possible to delay the tripping of the CB, where the fault-current level is lower than that of the short-time withstand current rating (Icw) of the CB (figure H2-23). This is generally applied to large open-type circuit breakers and to certain heavy-duty moulded-case types. Icw is the maximum current that the B category CB can withstand, thermally and electrodynamically, without sustaining damage, for a period of time given by the manufacturer.
**rated making capacity (Icm)**

Icm is the highest instantaneous value of current that the circuit breaker can establish at rated voltage in specified conditions. In a.c. systems this instantaneous peak value is related to Icu (i.e. to the rated breaking current) by the factor k, which depends on the power factor \(\cos \phi\) of the short-circuit current loop (as shown in table H2-34).

Example: a LV circuit breaker has a rated breaking capacity Icu of 100 kA r.m.s. Its rated making capacity Icm will be 100 \(\times 2.2 = 220\) kA peak.

![Table H2.34: relation between rated breaking capacity Icu and rated making capacity Icm at different power-factor values of short-circuit current, as standardized in IEC 947-2.](image)

**rated service short-circuit breaking capacity (Ics)**

The rated breaking capacity (Icu) or (Icn) is the maximum fault-current a circuit breaker can successfully interrupt without being damaged. The probability of such a current occurring is extremely low, and in normal circumstances the fault-currents are considerably less than the rated breaking capacity (Icu) of the CB. On the other hand it is important that high currents (of low probability) be interrupted under good conditions, so that the CB is immediately available for reclosure, after the faulty circuit has been repaired.

It is for these reasons that a new characteristic (Ics) has been created, expressed as a percentage of Icu, viz: 25, 50, 75, 100% for industrial circuit breakers. The standard test sequence is as follows:

- O - CO - CO* (at Ics);
- tests carried out following this sequence are intended to verify that the CB is in a good state and available for normal service.

For domestic CBs, Ics = k Icn. The factor k values are given in IEC 898 table XIV.

In Europe it is the industrial practice to use a k factor of 100% so that Ics = Icu.

Note: O represents an opening operation.

**fault-current limitation**

The fault-current limitation capacity of a CB concerns its ability, more or less effective, in preventing the passage of the maximum prospective fault-current, permitting only a limited amount of current to flow, as shown in figure H2-35.

The current-limitation performance is given by the CB manufacturer in the form of curves (figure H2-36 diagrams (a) and (b)).

- diagram (a) shows the limited peak value of current plotted against the r.m.s. value of the a.c. component of the prospective fault current ("prospective" fault-current refers to the fault-current which would flow if the CB had no current-limiting capability);
- limitation of the current greatly reduces the thermal stresses (proportional \(I^2 t\)) and this is shown by the curve of diagram (b) of figure H2-36, again, versus the r.m.s. value of the a.c. component of the prospective fault current.

LV circuit breakers for domestic and similar installations are classified in certain standards (notably European Standard EN 60 898). CBs belonging to a class of current limiters) have standardized limiting \(I^2t\) let-through characteristics defined by that class. In these cases, manufacturers do not normally provide characteristic performance curves.
4. circuit breakers (continued)

4.3 other characteristics of a circuit breaker (continued)

Current limitation reduces both thermal and electrodynamic stresses on all circuit elements through which the current passes, thereby prolonging the useful life of these elements. Furthermore, the limitation feature allows “cascading” techniques to be used (see 4.5) thereby significantly reducing design and installation costs.

**The advantages of current limitation**

The use of current-limiting CBs affords numerous advantages:

- Better conservation of installation networks: current-limiting CBs strongly attenuate all harmful effects associated with short-circuit currents;
- Reduction of thermal effects: conductors (and therefore insulation) heating is significantly reduced, so that the life of cables is correspondingly increased;
- Reduction of mechanical effects: forces due to electromagnetic repulsion are lower, with less risk of deformation and possible rupture, excessive burning of contacts, etc.;
- Reduction of electromagnetic-interference effects: less influence on measuring instruments and associated circuits, telecommunication systems, etc.

These circuit breakers therefore contribute towards an improved exploitation of:

- Cables and wiring;
- Prefabricated cable-trunking systems;
- Switchgear, thereby reducing the ageing of the installation.

Example:

On a system having a prospective short-circuit current of 150 kA r.m.s., a circuit breaker limits the peak current to less than 10% of the calculated prospective peak value, and the thermal effects to less than 1% of those calculated.

Cascading of the several levels of distribution in an installation, downstream of a limiting CB, will also result in important economies. The technique of cascading, described in sub-clause 4.5 allows, in fact, substantial savings on switchgear (lower performance permissible downstream of the limiting CB(s)) enclosures, and design studies, of up to 20% (overall).

Discriminative protection schemes and cascading are compatible, in the range Compact NS*, up to the full short-circuit breaking capacity of the switchgear.

* A Merlin Gerin product.

4.4 selection of a circuit breaker

The choice of a CB is made in terms of:

- Electrical characteristics of the installation for which the CB is destined;
- Its eventual environment: ambient temperature, in a kiosk or switchboard enclosure, climatic conditions, etc.;
- Short-circuit current breaking and making requirements;
- Operational specifications: discriminative tripping, requirements (or not) for remote control and indication and related auxiliary contacts, auxiliary tripping coils, connection into a local network (communication or control and indication) etc.

The following notes relate to the choice of a LV circuit breaker for use in distribution systems.

**Choice of rated current in terms of ambient temperature**

The rated current of a circuit breaker is defined for operation at a given ambient temperature, in general:

- 30 °C for domestic-type CBs;
- 40 °C for industrial-type CBs.

Performance of these CBs in a different ambient temperature depends principally on the technology of their tripping units.

**Fig. H2-37: Ambient temperature.**

**Choice of rated current in terms of ambient temperature**

The rated current of a circuit breaker is defined for operation at a given ambient temperature, in general:

- 30 °C for domestic-type CBs;
- 40 °C for industrial-type CBs.

Performance of these CBs in a different ambient temperature depends principally on the technology of their tripping units.
uncompensated thermal-magnetic tripping units

Circuit breakers with uncompensated thermal tripping elements have a tripping-current level that depends on the surrounding temperature. If the CB is installed in an enclosure, or in a hot location (boiler room, etc.), the current required to trip the CB on overload will be sensibly reduced. When the temperature in which the CB is located exceeds its reference temperature, it will therefore be "derated". For this reason, CB manufacturers provide tables which indicate factors to apply at temperatures different to the CB reference temperature. It may be noted from typical examples of such tables (tables H2-38) that a lower temperature than the reference value produces an up-rating of the CB.

Moreover, small modular-type CBs mounted in juxtaposition, as shown typically in figure H2-24, are usually mounted in a small closed metal case. In this situation, mutual heating, when passing normal load currents, generally requires them to be derated by a factor of 0.8.

compensated thermal-magnetic tripping units

These tripping units include a bi-metal compensating strip which allows the overload trip-current setting (Ir or Irth) to be adjusted, within a specified range, irrespective of the ambient temperature. For example:
- in certain countries, the TT system is standard on LV distribution systems, and domestic (and similar) installations are protected at the service position by a circuit breaker provided by the supply authority.
- This CB, besides affording protection against indirect-contact hazard, will trip on overload; in this case, if the consumer exceeds the current level stated in his supply contract with the power authority. The circuit breaker ( ≤ 60 A) is compensated for a temperature range of - 5 °C to + 40 °C.
- LV circuit breakers at ratings ≤ 630 A are commonly equipped with compensated tripping units for this range (- 5 °C to + 40 °C).

Example

What rating (In) should be selected for a CB protecting a circuit, the maximum load current of which is estimated to be 34 A; installed side-by-side with other CBs in a closed distribution box; in an ambient temperature of 50 °C.

A circuit breaker rated at 40 A would be derated to 35.6 A in ambient air at 50 °C (see table H2-38). To allow for mutual heating in the enclosed space, however, the 0.8 factor noted above must be employed, so that, 35.6 x 0.8 = 28.5 A, which is not suitable for the 34 A load. A 50 A circuit breaker would therefore be selected, giving a (derated) current rating of 44 x 0.8 = 35.2 A.
4. Selection of a circuit breaker

**General note concerning derating of circuit breakers**

It is evident that a CB rated to carry a current In at its reference ambient temperature (30 °C) would overheat when carrying the same current at (say) 50 °C. Since LV CBs are provided with overcurrent protective devices which (if not compensated) will operate for lower levels of current in higher ambient temperatures, the CB is automatically derated by the overload tripping device, as shown in the tables H2-36. Where the thermal tripping units are temperature-compensated, the tripping current level may be set at any value between 0.7 to 1 x In in the ambient temperature range of -5 °C to +40 °C. The reference ambient temperature in this case is 40 °C (i.e. on which the rating In is based).

For these compensated units, manufacturers' catalogues generally also give derated values of In for ambient temperatures above the compensated range, e.g. at +50 °C and +60 °C; typically, 95 A at +50 °C and 90 A at +60 °C, for a 100 A circuit breaker.
**electronic tripping units**

An important advantage with electronic tripping units is their stable performance in changing temperature conditions. However, the switchgear itself often imposes operational limits in elevated temperatures, as mentioned in the general note above, so that manufacturers generally provide an operating chart relating the maximum values of permissible trip-current levels to the ambient temperature (figure H2-39).

<table>
<thead>
<tr>
<th>M25N/H/L</th>
<th>≤ 40 °C</th>
<th>45 °C</th>
<th>50 °C</th>
<th>55 °C</th>
<th>60 °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circuit breaker A</td>
<td>In (A)</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2450</td>
</tr>
<tr>
<td></td>
<td>Maximum adjustment Ir</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.98</td>
</tr>
<tr>
<td>Circuit breaker B</td>
<td>In (A)</td>
<td>2500</td>
<td>2500</td>
<td>2500</td>
<td>2350</td>
</tr>
<tr>
<td></td>
<td>Maximum adjustment Ir</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.94</td>
</tr>
</tbody>
</table>

**fig. H2-39: derating of two circuit breakers having different characteristics, according to the temperature.**

**selection of an instantaneous, or short-time-delay, tripping threshold**

Principal characteristics of magnetic or short-time-delay tripping units. Type classification according to IEC 898. See also table H2-28.

<table>
<thead>
<tr>
<th>Type</th>
<th>Tripping unit</th>
<th>Applications</th>
</tr>
</thead>
</table>
| Low setting | type B | - Sources producing low-short-circuit-current levels (standby generators)
| | | - Long lengths of line or cable |
| Standard setting | type C | - Protection of circuits: general case |
| High setting | type D or K | - Protection of circuits having high initial transient current levels (e.g. motors, transformers, resistive loads) |
| 12 In | type MA | - Protection of motors in association with discontactors (contactors with overload protection) |

**table H2-40: different tripping units, instantaneous or short-time-delayed.**
4. circuit breakers (continued)

4.4 selection of a circuit breaker (continued)

the installation of a LV circuit breaker requires that its short-circuit breaking capacity (or that of the CB together with an associated device) be equal to or exceeds the calculated prospective short-circuit current at its point of installation.

selection of a circuit breaker according to the short-circuit breaking capacity requirements

The installation of a circuit breaker in a LV installation must fulfil one of the two following conditions:

- either have a rated short-circuit breaking capacity \( I_{cu} \) (or \( I_{cn} \)) which is equal to or exceeds the prospective short-circuit current calculated for its point of installation, or

- if this is not the case, be associated with another device which is located upstream, and which has the required short-circuit breaking capacity.

The selection of main and principal circuit breakers

- a single transformer

Table C-13 (in chapter C) gives the short-circuit current level on the downstream side of a commonly-used type of HV/LV distribution transformer. If the transformer is located in a consumer's substation, certain national standards require a LV circuit breaker in which the open contacts are clearly visible.*

Example (figure H2-41):

What type of circuit breaker is suitable for the main circuit breaker of an installation supplied through a 250 kVA HV/LV (400 V) 3-phase transformer in a consumer's substation? In transformer = 360 A \( I_{sc} \) (3-phase) = 8.9 kA.

A 400 A CB with an adjustable tripping-unit range of 250 A-400 A and a short-circuit breaking capacity \( I_{cu} \) of 35 kA* would be a suitable choice for this duty.

* A type Visucompact NS400N of Merlin Gerin manufacture is recommended for the case investigated.

- several transformers in parallel

(figure H2-42)

- the circuit breakers CBP outgoing from the LV distribution board must each be capable of breaking the total fault current from all transformers connected to the busbars, viz: \( I_{sc1} + I_{sc2} + I_{sc3} \).

- the circuit breakers CBM, each controlling the output of a transformer, must be capable of dealing with a maximum short-circuit current of (for example) \( I_{sc2} + I_{sc3} \) only, for a short-circuit located on the upstream side of CBM1.

From these considerations, it will be seen that the circuit breaker of the smallest transformer will be subjected to the highest level of fault current in these circumstances, while the circuit breaker of the largest transformer will pass the lowest level of short-circuit current. The ratings of CBMs must be chosen according to the kVA ratings of the associated transformers.

Note: the essential conditions for the successful operation of 3-phase transformers in parallel may be summarized as follows:

1. the phase shift of the voltages, primary to secondary, must be the same in all units to be paralleled.
2. the open-circuit voltage ratios, primary to secondary, must be the same in all units.
3. the short-circuit impedance voltage \( Z_{sc} \) must be the same for all units. For example, a 750 kVA transformer with a \( Z_{sc} = 6\% \) will share the load correctly with a 1,000 kVA transformer having a \( Z_{sc} \) of 6%, i.e. the transformers will be loaded automatically in proportion to their kVA ratings. For transformers having a ratio of kVA ratings exceeding 2, parallel operation is not recommended, since the resistance/reactance ratios of each transformer will generally be different to the extent that the resulting circulating current may overload the smaller transformer.

In the second case, the characteristics of the two devices must be co-ordinated such that the energy permitted to pass through the upstream device must not exceed that which the downstream device and all associated cables, wires and other components can withstand, without being damaged in any way.

This technique is profitably employed in:

- associations of fuses and circuit breakers;
- associations of current-limiting circuit breakers and standard circuit breakers.

The technique is known as "cascading" (see sub-clause 4.5 of this chapter).
Table H2-43 indicates, for the most usual arrangement (2 or 3 transformers of equal kVA ratings) the maximum short-circuit currents to which main and principal CBs (CBM and CBP respectively, in figure H2-42) are subjected. The table is based on the following hypotheses:
- the short-circuit 3-phase power on the HV side of the transformer is 500 MVA;
- the transformers are standard 20/0.4 kV distribution-type units rated as listed;
- the cables from each transformer to its LV circuit breaker comprise 5 metres of single-core conductors;
- between each incoming-circuit CBM and each outgoing-circuit CBP there is 1 metre of busbar;
- the switchgear is installed in a floor-mounted enclosed switchboard, in an ambient-air temperature of 30 °C.
Moreover, this table shows selected circuit breakers of M-G manufacture recommended for main and principal circuit breakers in each case.

<table>
<thead>
<tr>
<th>number and kVA ratings of 20/0.4 kV transformers</th>
<th>minimum S.C. breaking capacity of main CBs (Icu)* kA</th>
<th>main circuit breakers (CBM) total discrimination with out going-circuit breakers (CBP)</th>
<th>minimum S.C. breaking cap. of principal CBs (Icu)* kA</th>
<th>rated current In of principal circuit breaker (CPB) 250 A</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 x 400</td>
<td>14</td>
<td>M08 N1/C 801 N ST</td>
<td>27</td>
<td>NS 250 N</td>
</tr>
<tr>
<td>3 x 400</td>
<td>27</td>
<td>M08 N1/C 801 N ST</td>
<td>40</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>2 x 630</td>
<td>22</td>
<td>M10N1/C1250/C 1001 N ST</td>
<td>43</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>3 x 630</td>
<td>43</td>
<td>M10H1/C1250/C 1001 N ST</td>
<td>42</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>2 x 800</td>
<td>24</td>
<td>M12N1/C1250/C 1251 N</td>
<td>48</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>3 x 800</td>
<td>48</td>
<td>M12H/1/C1250/C 1251 N</td>
<td>71</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>2 x 1000</td>
<td>27</td>
<td>M16N1/C1600</td>
<td>54</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>3 x 1000</td>
<td>54</td>
<td>M16H/2/C1600</td>
<td>80</td>
<td>NS 250 L</td>
</tr>
<tr>
<td>2 x 1250</td>
<td>31</td>
<td>M20N1/C2000</td>
<td>60</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>3 x 1250</td>
<td>62</td>
<td>M20H/1/C2000</td>
<td>91</td>
<td>NS 250 L</td>
</tr>
<tr>
<td>2 x 1600</td>
<td>36</td>
<td>M25N1/C2500</td>
<td>70</td>
<td>NS 250 H</td>
</tr>
<tr>
<td>3 x 1600</td>
<td>70</td>
<td>M25H/2/C2500H</td>
<td>105</td>
<td>NS 250 L</td>
</tr>
<tr>
<td>2 x 2000</td>
<td>39</td>
<td>M32H/1/C3200H</td>
<td>75</td>
<td>NS 250 L</td>
</tr>
<tr>
<td>3 x 2000</td>
<td>77</td>
<td>M32H/2/C3200H</td>
<td>112</td>
<td>NS 250 L</td>
</tr>
</tbody>
</table>

* or Ics in countries where this alternative is practised.

Example: (figure H2-44)
- circuit breaker selection for CBM duty:
  For an 800 kVA transformer = 1.126 A (at 410 V, i.e. no-load voltage) Icu (minimum) = 48 kA (from table H2-43), the CBM indicated in the table is a Compact C1251 N (Icu = 50 kA) (by Merlin Gerin) or its equivalent;
- circuit breaker selection for CBP duty:
The s.c. breaking capacity (Icu) required for these circuit breakers is given in the table (H2-43) as 71 kA.
A recommended choice for the three outgoing circuits 1, 2 and 3 would be current-limiting circuit breakers types NS 400 L, NS 100 L and NS 250 L respectively (by MG) or their equivalents. The Icu rating in each case = 150 kA.
These circuit breakers provide the advantages of:
- absolute discrimination with the upstream (CBM) breakers,
- exploitation of the "cascading" technique, with its attendant economy for all downstream components.
The short-circuit fault-current levels at any point in an installation may be obtained from tables. Choice of outgoing-circuit CBs and final-circuit CBs can be based on these tables. From this table, the value of 3-phase short-circuit current can be determined rapidly for any point in the installation, knowing:

- The value of short-circuit current at a point upstream of that intended for the CB concerned;
- The length, c.s.a., and the composition of the conductors between the two points.

A circuit breaker rated for a short-circuit breaking capacity exceeding the tabulated value may then be selected.

To calculate more precisely the short-circuit current, notably, when the short-circuit current-breaking capacity of a CB is slightly less than that derived from the table, it is necessary to use the method indicated in chapter H1 clause 4.

Two-pole circuit breakers (for phase and neutral) with one protected pole only

These CBs are generally provided with an overcurrent protective device on the phase pole only, and may be used in TT, TN-S and IT schemes. In an IT scheme, however, the following conditions must be respected:

- Condition (c) of table H1-65 for the protection of the neutral conductor against overcurrent in the case of a double fault;
- Short-circuit current-breaking rating: A 2-pole phase-neutral CB must, by convention, be capable of breaking on one pole (at the phase-to-phase voltage) the current of a double fault equal to 15% of the 3-phase short-circuit current at the point of its installation, if that current is below 10 kA; or 25% of the 3-phase short-circuit current if it exceeds 10 kA;
- Protection against indirect contact: this protection is provided according to the rules for IT schemes, as described in chapter G sub-clause 6.2.

In low-voltage distribution systems it sometimes happens, especially in heavy-duty networks, that the Isc calculated exceeds the Icu rating of the CBs available for installation, or system changes upstream result in lower-level CB ratings being exceeded.

Solution 1: check whether or not appropriate CBs upstream of the CBs affected are of the current-limiting type, allowing the principle of cascading (described in sub-clause 4.5) to be applied;

Solution 2: install a range of CBs having a higher rating. This solution is economically interesting only where one or two CBs are affected;

Solution 3: associate current-limiting fuses (gG or aM) with the CBs concerned, on the upstream side. This arrangement must, however, respect the following rules:

- The fuse rating must be appropriate;
- No fuse in the neutral conductor, except in certain IT installations where a double fault produces a current in the neutral which exceeds the short-circuit breaking rating of the CB. In this case, the blowing of the neutral fuse must cause the CB to trip on all phases. This solution is economically interesting a range of CBs having a higher rating. This solution is economically interesting where one or two CBs are affected.
4.5 coordination between circuit breakers

Preliminary note on the essential function of current limiting circuit breakers

Low-voltage current-limiting CBs exploit the resistance of the short-circuit current arc in the CB to limit the value of current. An improved method of achieving current-level limitation is to associate a separate current-limiting module (in series) with a standard CB. A contact bar (per phase) in the module bridges two (specially-designed heavy-duty) contacts, the contact pressure of which is accurately maintained by springs. Other rigidly-fixed conductors are arranged in series with, and close to the contact bar, such that when current is passed through the ensemble, the electromagnetic force tends to move the contact bar to open its contacts. This occurs at relatively low values of short-circuit current, which then passes through the arcs formed at each contact. The resistance of the arcs is comparable with system impedances at low voltage, so that the current is correspondingly restricted. Furthermore, the higher the current, the more the repulsive force on the bar and the greater the arc resistance as its path lengthens, i.e. the current magnitude is (to some extent) self-regulating. The circuit breaker is easily able to break the resulting low value of current, particularly since the power factor of the fault-current loop is increased by the resistive impedance of the arcs.

When used in a cascading scheme as described below, the tripping of the limiting CB main contacts is briefly delayed, to allow downstream high-speed circuit breakers to clear the (limited) current, i.e. the current-limiter CB remains closed. The contact bar in the limiter module resets under the influence of its pressure springs when the flow of short-circuit current ceases. Failure of downstream CBs to trip will result in the tripping of the current-limiting CB, after its brief time delay.

cascading

Definition of the cascading technique

By limiting the peak value of short-circuit current passing through it, a current-limiting CB permits the use, in all circuits downstream of its location, of switchgear and circuit components having much lower short-circuit breaking capacities, and thermal and electromechanical withstand capabilities than would otherwise be the case. Reduced physical size and lower performance requirements lead to substantial economies and to the simplification of installation work.

It may be noted that, while a current-limiting circuit breaker has the effect on downstream circuits of (apparently) increasing the source impedance during short-circuit conditions, it has no such effect at any other time; for example, during the starting of a large motor (where a low source impedance is highly desirable). A new range of Compact* current-limiting circuit breakers with powerful limiting performances (namely: NS 100, NS 160, NS 250 and NS 400) is particularly interesting.

Conditions of exploitation

Most national standards permit use of the cascading technique, on condition that the amount of energy "let through" by the limiting CB is less than that which all downstream CBs and components are able to withstand without damage.

In practice this can only be verified for CBs by tests performed in a laboratory. Such tests are carried out by manufacturers who provide the information in the form of tables, so that users can confidently design a cascading scheme based on the combination of circuit breaker types recommended. By way of an example, table H2-45 indicates the possibilities of cascading circuit breaker types* C 60 and NC 100 when installed downstream of current-limiting CBs NS 250 N, H or L for a 230/400 V or 240/415 V 3-phase installation.

* Merlin Gerin products
4. circuit breakers (continued)

4.5 coordination between circuit breakers (continued)

Advantages of cascading

The limitation of current benefits all downstream circuits that are controlled by the current-limiting CB concerned.

The principle is not restrictive, i.e. current-limiting CBs can be installed at any point in an installation where the downstream circuits would otherwise be inadequately rated.

The result is:

- simplified short-circuit current calculations;
- simplification, i.e. a wider choice of downstream switchgear and appliances;
- the use of lighter-duty switchgear and appliances, with consequently lower cost;
- economy of space requirements, since light-duty equipment is generally less voluminous.

Short-circuit breaking capacity of the upstream (limiter) CBs

<table>
<thead>
<tr>
<th>kA r.m.s.</th>
<th>Upstream CB</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>NS250L</td>
</tr>
<tr>
<td>100</td>
<td>NS250H</td>
</tr>
<tr>
<td>70</td>
<td>NS250N</td>
</tr>
<tr>
<td>36</td>
<td>NS250N</td>
</tr>
<tr>
<td>25</td>
<td>NS250N</td>
</tr>
<tr>
<td>22</td>
<td>NS250N</td>
</tr>
</tbody>
</table>

Short-circuit breaking capacity of the downstream CBs (benefiting from the cascading technique)

<table>
<thead>
<tr>
<th>kA r.m.s.</th>
<th>Downstream CB</th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>NC100LS</td>
</tr>
<tr>
<td>100</td>
<td>NC100LS</td>
</tr>
<tr>
<td>70</td>
<td>NC100LS</td>
</tr>
<tr>
<td>50</td>
<td>NC100L</td>
</tr>
<tr>
<td>40</td>
<td>C60L &lt; 40</td>
</tr>
<tr>
<td>30</td>
<td>C60L &lt; 40</td>
</tr>
<tr>
<td>25</td>
<td>C60L</td>
</tr>
<tr>
<td>20</td>
<td>C60L</td>
</tr>
<tr>
<td>15</td>
<td>C60L</td>
</tr>
</tbody>
</table>

Discriminative tripping (selectivity)

Discrimination is achieved by automatic protective devices if a fault condition, occurring at any point in the installation, is cleared by the protective device located immediately upstream of the fault, while all other protective devices remain unaffected (figure H2-46).

Discrimination between circuit breakers A and B is absolute if the maximum value of short-circuit-current on circuit B does not exceed the short-circuit trip setting of circuit breaker A. For this condition, B only will trip (figure H2-47).

Discrimination is partial if the maximum possible short-circuit current on circuit B exceeds the short-circuit trip-current setting of circuit breaker A. For this maximum condition, both A and B will trip (figure H2-48).

<table>
<thead>
<tr>
<th>Absolute discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
</tr>
<tr>
<td>B</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Partial discrimination</th>
</tr>
</thead>
<tbody>
<tr>
<td>A and B opens</td>
</tr>
</tbody>
</table>

IscA: Current trip setting of circuit breaker A
IscB: Current trip setting of circuit breaker B
Icc: Short-circuit breaking capacity of the downstream CB

fig. H2-46: absolute and partial discrimination.
1. discrimination based on current levels.
This method is realized by setting successive relay tripping thresholds at stepped levels, from downstream relays (lower settings) towards the source (higher settings).
Discrimination is absolute or partial, according to the particular conditions, as noted in the above examples.

2. discrimination based on stepped time delays.
In the two-level arrangement shown, upstream circuit breaker A is delayed sufficiently to ensure absolute discrimination with B (for example: Masterpact electronic).

3. discrimination based on a combination of methods 1 and 2.
A mechanical time-delay added to a current-level scheme can improve the overall discrimination performance.
Discrimination is absolute if $I_{sc} B < I_{rm} A$ (instantaneous).
The upstream CB has two high-speed magnetic tripping thresholds:
- $I_{rm} A$ (delayed) or a SD* electronic timer
- $I_{rm} A$ (instantaneous) standard (Compact type SA)

4. discrimination based on arc-energy levels (Merlin Gerin patent)
In the range of short-circuit currents, this system provides absolute discrimination between two circuit breakers passing the same fault current. This is achieved by using current-limiting CBs and initiating CB tripping by pressure-sensitive detectors in the arcing chambers of the CBs. The heated-air pressure level depends on the energy level of the arc, as described in the following pages (figures H2-54 and H2-55).

Table H2-49: summary of methods and components used in order to achieve discriminative tripping.
4.5 coordination between circuit breakers (continued)

Current-level discrimination
Current-level discrimination is achieved with circuit breakers, preferably limiters, and stepped current-level settings of the instantaneous magnetic-trip elements.

■ the downstream circuit breaker is not a current-limiter.
The discrimination may be absolute or partial for a short-circuit fault downstream of B, as previously noted in 1, above. Absolute discrimination in this situation is practically impossible because $I_{sc\ A} \neq I_{sc\ B}$, so that both circuit breakers will generally trip in unison. In this case discrimination is partial, and limited to the $I_{rms}$ of the upstream circuit breaker.

■ the downstream circuit breaker is a current limiter.
Improvement in discriminative tripping can be obtained by using a current limiter in a downstream location, e.g. for circuit breaker B.
For a short-circuit downstream of B, the limited level of peak current $I_{B}$ would operate the (suitably adjusted) magnetic trip unit of B, but would be insufficient to cause circuit breaker A to trip.

Note: All LV breakers (considered here) have some inherent degree of current limitation, even those that are not classified as current-limiters. This accounts for the curved characteristic shown for the standard circuit breaker A in figure H2-50.

Careful calculation and testing is necessary, however, to ensure satisfactory performance of this arrangement.

■ the upstream circuit breaker is high-speed with a short-delay (SD) feature.
These circuit breakers are fitted with trip units which include a non-adjustable mechanical short-time-delay feature. The delay is sufficient to ensure absolute discrimination with any downstream high-speed CB at any value of s.c. current up to $I_{rms}$ (figure H2-51).

Example:
circuit breaker A: Compact NS250 N fitted with a trip unit which includes a SD feature. $I_{r} = 250$ A, magnetic trip set at 2,000 A
circuit breaker B: Compact NS100N
$I_{r} = 100$ A
The Merlin Gerin distribution catalogue indicates a discrimination limit of 3,000 A (an improvement over the limit of 2,500 A obtained when using a standard tripping unit).

Time-based discrimination
This technique requires:
■ the introduction of "timers" into the tripping mechanisms of CBs;
■ CBs with adequate thermal and mechanical withstand capabilities at the elevated current levels and time delays envisaged.

Two circuit breakers A and B in series (i.e. passing the same current) are discriminative if the current-breaking period of downstream breaker B is less than the non-tripping time of circuit breaker A.

Discrimination at several levels
An example of a practical scheme with (MG) circuit breakers Masterpact (electronic protection devices). These CBs can be equipped with adjustable timers which allow 4 time-step selections, such as:
■ the delay corresponding to a given step is greater than the total current breaking time of the next lower step;

Example:
circuit breaker A: Compact NS250 N fitted with a trip unit which includes a SD feature. $I_{r} = 250$ A, magnetic trip set at 2,000 A
circuit breaker B: Compact NS100N
$I_{r} = 100$ A
The Merlin Gerin distribution catalogue indicates a discrimination limit of 3,000 A (an improvement over the limit of 2,500 A obtained when using a standard tripping unit).

 discrimination based on time-delayed tripping uses CBs referred to as "selective" (in certain countries).
Application of these CBs is relatively simple and consists in delaying the instant of tripping of the several series-connected circuit breakers in a stepped time sequence.
Discrimination schemes based on logic techniques are possible, using CBs equipped with electronic tripping units designed for the purpose (Compact, Masterpact by MG) and interconnected with pilot wires.

**Discrimination logic**
This discrimination system requires CBs equipped with electronic tripping units, designed for this application, together with interconnecting pilot wires for data exchange between the CBs. With 2 levels A and B (figure H2-53), circuit breaker A is set to trip instantaneously, unless the relay of circuit breaker B sends a signal to confirm that the fault is downstream of B. This signal causes the tripping unit of A to be delayed, thereby ensuring back-up protection in the event that B fails to clear the fault, and so on...

This system (patented by Merlin Gerin) also allows rapid localization of the fault.

**Limitation and discrimination by exploitation of arc energy**
The technique of "arc-energy discrimination" (Merlin Gerin patent) is applied on circuits having a short-circuit current level $\geq 25 \text{ In}$ and ensures absolute selectivity between two CBs carrying the same short-circuit current. Discrimination requires that the energy allowed to pass by the downstream CB (B) is less than that which will cause the upstream CB (A) to trip (fig. H2-54 (a)).

**Operation principle**
Both CBs are current limiters, so that the electromagnetic forces due to a short-circuit downstream of CB (B) will cause the current-limiting arcing contacts of both CBs to open simultaneously. The fault current will be very strongly limited by the resistance of the two series arcs. The intense heat of the current arc in each CB causes a rapid expansion of the air in the confined space of the arcing chambers, thereby producing a correspondingly rapid pressure rise. Above a certain level of current, the pressure rise can be reliably detected and used to initiate instantaneous tripping.

**Discrimination principle**
If both CBs include a pressure tripping device suitably regulated, then absolute discrimination between two CBs of different current ratings can be achieved by setting CB (B) to trip at a lower pressure level than that of CB (A) (fig. H2-54). If a short-circuit occurs downstream of CB (A) but upstream of CB (B), then the arc resistance of CB (A) only will limit the current. The resulting current will therefore be significantly greater than that occurring for a short-circuit downstream of CB (B) (where the two arcs in series cause a very strong limitation, as previously mentioned). The larger current through CB (A) will produce a correspondingly greater pressure, which will be sufficient to operate its pressure-sensitive tripping unit (diagrams (b) and (c) of fig. H2-54).

As can be seen from figure H2-49 (4), the larger the short-circuit current, the faster the CB will trip. Discrimination is assured with this particular switchgear if:
- the ratio of rated currents of the two CBs $\geq 2.5$;
- the ratio of the two trip-unit current ratings is $> 1.6$, as shown (typically) in figure H2-55.

For overcurrent conditions less than those of short-circuits $< 25 \text{ In}$, the conventional protection schemes are employed, as previously described in this chapter.
4.6 discrimination HV/LV in a consumer's substation

In general the transformer in a consumer's substation is protected by HV fuses, suitably rated to match the transformer, in accordance with the principles laid down in IEC 787 and IEC 420, by following the advice of the fuse manufacturer.

The basic requirement is that a HV fuse will not operate for LV faults occurring downstream of the transformer LV circuit breaker, so that the tripping characteristic curve of the latter must be to the left of that of the HV fuse pre-arcing curve.

This requirement generally fixes the maximum settings for the LV circuit breaker protection:
- maximum short-circuit current-level setting of the magnetic tripping element;
- maximum time-delay allowable for the short-circuit current tripping element.

See also Chapter C sub-clause 3.2.7, and Appendix C1, for further details.

What is the maximum short-circuit trip current setting and its maximum time delay allowable?

The curves of figure H2-57 show that discrimination is assured if the short-time delay tripping unit of the CB is set at:
- a level $< 6 \text{Ir} = 10.8 \text{kA}$;
- a time-delay setting of step O or A.

A general policy for HV fuse/LV circuit breaker discrimination, adopted in some countries, which is based on standardized manufacturing tolerance limits, is mentioned in chapter C sub-clause 3.2.7, and illustrated in figure C-21.

Where a transformer is controlled and protected on the high-voltage side by a circuit breaker, it is usual to install separate CT- and/or VT- operated relays, which energize a shunt-trip coil of the circuit breaker.

Discrimination can be achieved, together with high-speed tripping for faults on the transformer, by using the methods described in chapter C sub-clause 3.2.