4. CIRCUIT BREAKERS (Continued)

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 creep age distances are referred. The maximum value of rated operational voltage must never exceed that of the rated insulation voltage, i.e. Ue < Ui.

**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.

**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 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.

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 electro dynamically, 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 j) of the short-circuit current loop.

**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 x 2.2 = 220 kA peak.

<table>
<thead>
<tr>
<th>Icu</th>
<th>Cos Φ</th>
<th>Icm = kIcu</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 kA &lt; Icu ≤ 10 kA</td>
<td>0.5</td>
<td>1.7 x Icu</td>
</tr>
<tr>
<td>10 kA &lt; Icu ≤ 20 kA</td>
<td>0.3</td>
<td>2 x Icu</td>
</tr>
<tr>
<td>20 kA &lt; Icu ≤ 50 kA</td>
<td>0.25</td>
<td>2.1 x Icu</td>
</tr>
<tr>
<td>50 kA ≤ Icu</td>
<td>0.2</td>
<td>2.2 x Icu</td>
</tr>
</tbody>
</table>

*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.*

**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. CO represents a closing operation followed by 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. The current-limitation performance is given by the CB manufacturer in the form of curves 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 $I^2t$) 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.

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.

Choice 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.,
- Installation regulations; in particular: protection of persons;
- Load characteristics, such as motors, fluorescent lighting, LV/LV transformers, 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.
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 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.

C60a. C60H: curve C. C60N: curves B and C (reference temperature: 30 °C)

<table>
<thead>
<tr>
<th>Rating(A)</th>
<th>20°C</th>
<th>25°C</th>
<th>30°C</th>
<th>35°C</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>1</td>
<td>1.05</td>
<td>1.02</td>
<td>1.00</td>
<td>0.98</td>
<td>0.95</td>
<td>0.93</td>
<td>0.90</td>
<td>0.88</td>
<td>0.85</td>
</tr>
<tr>
<td>2</td>
<td>2.08</td>
<td>2.04</td>
<td>2.00</td>
<td>1.96</td>
<td>1.92</td>
<td>1.88</td>
<td>1.84</td>
<td>1.80</td>
<td>1.74</td>
</tr>
<tr>
<td>3</td>
<td>3.18</td>
<td>3.09</td>
<td>3.00</td>
<td>2.91</td>
<td>2.82</td>
<td>2.70</td>
<td>2.61</td>
<td>2.49</td>
<td>2.37</td>
</tr>
<tr>
<td>4</td>
<td>4.24</td>
<td>4.12</td>
<td>4.00</td>
<td>3.88</td>
<td>3.76</td>
<td>3.64</td>
<td>3.52</td>
<td>3.36</td>
<td>3.24</td>
</tr>
<tr>
<td>6</td>
<td>6.24</td>
<td>6.12</td>
<td>6.00</td>
<td>5.88</td>
<td>5.76</td>
<td>5.64</td>
<td>5.52</td>
<td>5.40</td>
<td>5.30</td>
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<tr>
<td>10</td>
<td>10.6</td>
<td>10.3</td>
<td>10.0</td>
<td>9.70</td>
<td>9.30</td>
<td>9.00</td>
<td>8.60</td>
<td>8.20</td>
<td>7.80</td>
</tr>
<tr>
<td>16</td>
<td>16.8</td>
<td>16.5</td>
<td>16.0</td>
<td>15.5</td>
<td>15.2</td>
<td>14.7</td>
<td>14.2</td>
<td>13.8</td>
<td>13.5</td>
</tr>
<tr>
<td>20</td>
<td>21.0</td>
<td>20.6</td>
<td>20.0</td>
<td>19.4</td>
<td>19.0</td>
<td>18.4</td>
<td>17.8</td>
<td>17.4</td>
<td>16.8</td>
</tr>
<tr>
<td>25</td>
<td>26.2</td>
<td>25.7</td>
<td>25.0</td>
<td>24.2</td>
<td>23.7</td>
<td>23.0</td>
<td>22.2</td>
<td>21.5</td>
<td>20.7</td>
</tr>
<tr>
<td>32</td>
<td>33.5</td>
<td>32.9</td>
<td>32.0</td>
<td>31.4</td>
<td>30.4</td>
<td>29.8</td>
<td>28.4</td>
<td>28.2</td>
<td>27.5</td>
</tr>
<tr>
<td>40</td>
<td>42.0</td>
<td>41.2</td>
<td>40.0</td>
<td>38.8</td>
<td>38.0</td>
<td>36.8</td>
<td>35.6</td>
<td>34.4</td>
<td>33.2</td>
</tr>
<tr>
<td>50</td>
<td>52.5</td>
<td>51.5</td>
<td>50.0</td>
<td>48.5</td>
<td>47.4</td>
<td>45.5</td>
<td>44.0</td>
<td>42.5</td>
<td>40.5</td>
</tr>
<tr>
<td>63</td>
<td>66.2</td>
<td>64.9</td>
<td>63.0</td>
<td>61.1</td>
<td>58.0</td>
<td>56.7</td>
<td>54.2</td>
<td>51.7</td>
<td>49.2</td>
</tr>
</tbody>
</table>
Examples of tables for the determination of derating/uprating factors to apply to CBs with uncompensated thermal tripping units, according to temperature

### Example

What rating \( I_n \) 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. To allow for mutual heating in the enclosed space, however, the 0.8 factor noted above must be employed, so that,

\[
35.6 \times 0.8 = 28.5 \text{ A},
\]

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.

### Compensated thermal-magnetic tripping units

These tripping units include a bi-metal compensating strip which allows the overload trip-current setting \( I_r \) or \( I_{rth} \) 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 (i.e 60 A) is compensated for a temperature range of -5 °C to +40 °C.
- LV circuit breakers at ratings i.e 630 A are commonly equipped with compensated tripping units for this range (-5 °C to +40 °C).

**General note concerning derating of circuit breakers**

It is evident that a CB rated to carry a current \( I_n \) 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 H2-38. 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.

<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>Maximum adjustment lr</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.98</td>
<td>0.96</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>Maximum adjustment lr</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.94</td>
<td>0.88</td>
</tr>
</tbody>
</table>

*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.

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

Different tripping units, instantaneous or short-time-delayed

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

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

- Either have a rated short-circuit breaking capacity Icu (or Icn) 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.

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”
The selection of main and principal circuit breakers

- A single transformer

  Table 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

  Isc (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 (Icu) 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

  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:

  \[ \text{Isc}_1 + \text{Isc}_2 + \text{Isc}_3, \]

  - 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) \( \text{Isc}_2 + \text{Isc}_3 \) 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 (Zsc%) must be the same for all units. For example, a 750 kVA transformer with a \( Zsc = 6\% \) will

  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.

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The selection of main and principal circuit breakers

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

- **Several transformers in parallel**
  - 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: Isc1 + Isc2 + Isc3,
  - 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) Isc2 + Isc3 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 (Zsc%) must be the same for all units. For example, a 750 kVA transformer with a Zsc = 6% will share the load correctly with a 1,000 kVA transformer having a Zsc 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.
Example of a transformer in a consumer's substation

Transformers in parallel

The Table 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.
Maximum values of short-circuit current to be interrupted by main and principal circuit breakers (CBM and CBP respectively), for several transformers in parallel

Example:

- Circuit breaker selection for CBM duty: In for an 800 kVA transformer = 1.126 A (at 410 V, i.e. no-load voltage) Icu (minimum) = 48 kA, 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. 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.
Choice of outgoing-circuit CBs and final-circuit CBs

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.

Detailed calculation of the short-circuit current level

In order 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.

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 i 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

Insufficient short-circuit current breaking rating

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.
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.

**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></th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>NS250L</td>
</tr>
<tr>
<td>100</td>
<td></td>
</tr>
<tr>
<td>70</td>
<td>NS250H</td>
</tr>
<tr>
<td>36</td>
<td>NS250N</td>
</tr>
<tr>
<td>25</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td></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></th>
</tr>
</thead>
<tbody>
<tr>
<td>150</td>
<td>NC100LH NC100LMA</td>
</tr>
<tr>
<td>100</td>
<td>NC100LS NC100LNS</td>
</tr>
<tr>
<td>70</td>
<td>NC100LS NC100L</td>
</tr>
<tr>
<td>50</td>
<td>NC100L</td>
</tr>
<tr>
<td>40</td>
<td>C60L ≤ 40 C60L ≤ 40</td>
</tr>
<tr>
<td>30</td>
<td>C60H C60L</td>
</tr>
<tr>
<td></td>
<td>C60N C60N</td>
</tr>
<tr>
<td></td>
<td>C60H C60H</td>
</tr>
<tr>
<td></td>
<td>C60L C60L</td>
</tr>
<tr>
<td></td>
<td>(50 to 63) (50 to 63)</td>
</tr>
<tr>
<td></td>
<td>NC100H NC100H</td>
</tr>
<tr>
<td>25</td>
<td>C60N NC100H</td>
</tr>
<tr>
<td>20</td>
<td>C60a C60a</td>
</tr>
<tr>
<td>15</td>
<td>C60a</td>
</tr>
</tbody>
</table>

*Example of cascading possibilities on a 230/400 V or 240/415 V 3-phase installation.*
**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. 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. 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.
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

This method is implemented by adjusting the time-delayed tripping units, such that downstream relays have the shortest operating times, with progressively longer delays towards the source. In the two-level arrangement shown, upstream circuit breaker A is delayed sufficiently to ensure absolute discrimination with B (for example: Master pact 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.

**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 $I_{rm}$ 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 account for the curved characteristic shown for the standard circuit breaker A. 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 Irms

**Example:**

Circuit breaker A: Compact NS250 N fitted with a trip unit which includes a SD feature. Ir = 250 A, magnetic trip set at 2,000 A circuit breaker B: Compact NS100N Ir = 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).

![Downstream limiting circuit breaker B](image1)

![Use of a "selective" circuit breaker upstream](image2)
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 Master pact (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;
- The delay corresponding to the first step is greater than the total current-breaking time of a high-speed CB (type Compact for example) or of fuses

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 \( u \leq 25 \) 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.

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). 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. 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 \( u \leq 2.5 \);
- The ratio of the two trip-unit current ratings is \( > 1.6 \), as shown (typically).
Ratio of rated currents of CBs and of tripping units, must comply with limits stated in the text, to ensure discrimination

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.
Short-circuit level at HV terminals of transformer: 250 MVA;
 Transformer HL/LV: 1,250 kVA 20/0.4 kV;
 HV fuses: 63 A (table C 11);
 Cabling, transformer - LV circuit breaker: 10 metres single-core cables;
 LV circuit breaker: Visucompact CM 2000 set at 1,800 A (Ir).

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 i 6 Ir = 10.8 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. 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.

Curves of HV fuses and LV circuit breaker

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