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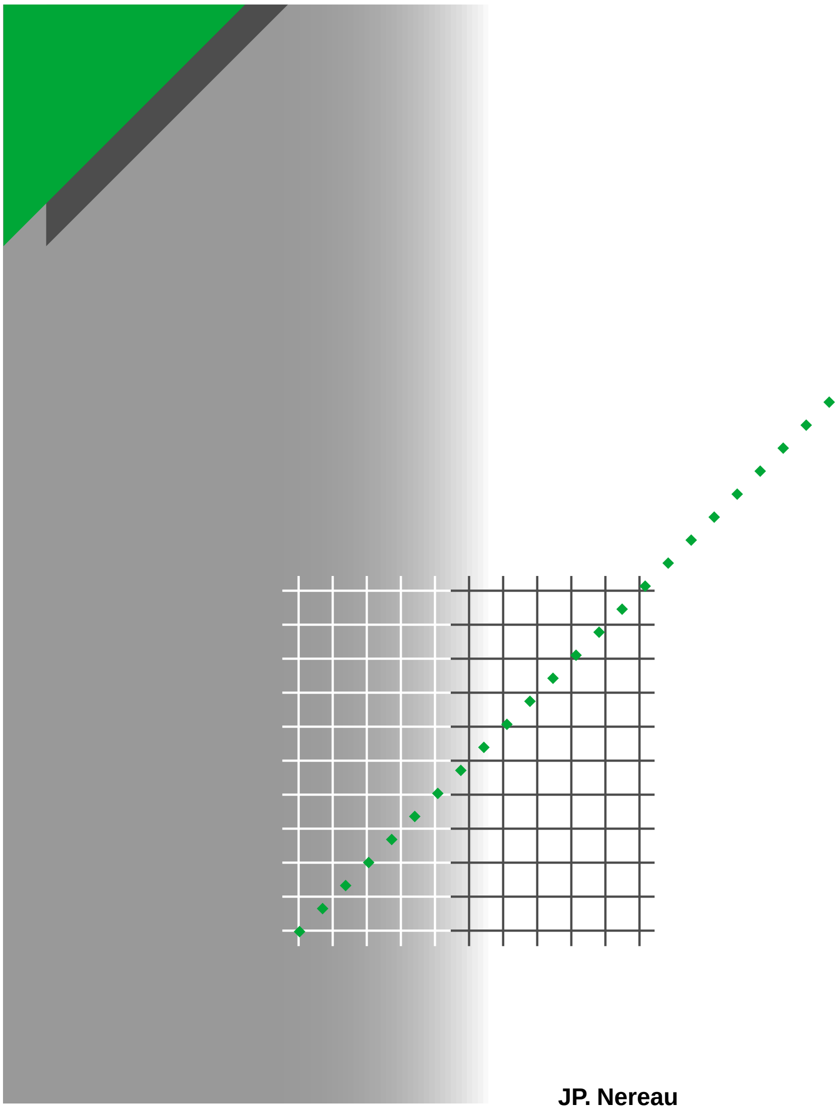
Discrimination with LV power circuit-breakers



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Foreword

no. 201

Discrimination with LV power circuit-breakers

Jean-Pierre NEREAU

An IEG graduate engineer, he joined Merlin Gerin in 1981; during his time in the design office of the Low Voltage Switchgear division, he was involved in developing a number of products, initially the range of moulded case circuit-breakers, then the range of power circuit-breakers.
He is currently the Manager of Schneider Electric's Advanced Design Office for this division.

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Lexicon

Breaking capacity: This is the usual name for the ultimate breaking capacity (I_{cu}). I_{cu} is the highest short-circuit current intensity which the circuit-breaker is able to interrupt. It is defined for a given rated operating voltage U_e.

Cascading: Using the limiting capacity of the upstream circuit-breaker to increase the actual breaking capacity of the unit downstream. Enables use of circuit-breakers with a lower breaking capacity than the prospective short-circuit current downstream of a current-limiting circuit-breaker.

Current limiting circuit-breaker: Circuit-breaker which, when interrupting a short-circuit current, limits the current to a value considerably less than the prospective current.

DIN: “Déclencheur INstantané”: Instantaneous self-protection release. By assimilation, the corresponding threshold.

DINF (or **MCR**)**:** “Déclencheur INstantané à la Fermeture” or “Making Current Release”, instantaneous release intended for self-protection of the breaker during the closing operation.

Electrodynamic withstand (EDW): Capacity of a unit to tolerate, by nature of its construction, the electrodynamic effects of a short-circuit current, in particular without repulsion of its main or plug-in contacts.

I_{sc}: Short-circuit current, given as a peak value, actually crossing the circuit-breaker, taking account of any limitation.

I_{cw}: Short-time withstand current. This is the maximum short-circuit current (as an rms value), which the circuit-breaker can withstand for a defined period (0.5 or 1 or 3 s) without alteration of its characteristics.

IDMTL: (Inverse Definite Minimum Time Lag) This refers to long-time delay curves where the slope can take different values (see section on IDMTL trip units).

I_n: Nominal current of the device.

I_p: Prospective short-circuit current which would develop in the absence of protective devices (rms value).

I_r: Current (as an rms value) corresponding to the overload protection setting. Generally varies from 0.4 to 1 times I_n.

Instantaneous release : Release without intentional time delay (short-circuit protection).

Long-time delay release (LT): Release with intentional time delay lasting several seconds (overload protection). This delay is generally dependent on the current.

Partial discrimination: Discrimination is said to be partial when it is ensured only up to a current value lower than the prospective short-circuit current.

Rating: Current (= I_n) corresponding to the maximum trip unit setting.

Selective circuit-breaker: Circuit-breaker with high I_{cw} (capable of withstanding a short-circuit current for several hundred milliseconds).

Sellim: Discrimination principle which allows both discrimination and current limitation.

Short-time delay release (ST): Release with an intentional time delay from tens to hundreds of milliseconds.

t_c: Actual breaking time (arc suppression).

Total discrimination: Discrimination is said to be total when it is ensured up to the prospective short-circuit current.

Discrimination with LV power circuit-breakers

The purpose of this “Cahier Technique” is to set out the discrimination techniques which apply specifically to low voltage power circuit-breakers. These devices are characterized by their high rating (800 A to 6300 A), and their location at the head of the LV installation, generally directly downstream of an MV/LV transformer.
This location justifies the strict discrimination requirements which apply to them.
This article begins with a resumé of discrimination techniques, followed by an explanation of the links between discrimination and general circuit-breaker characteristics. Finally, some practical examples will be provided on selection of devices to be installed.

Contents

1 LV discrimination

1.1 Introduction

In a radial feeder layout (see **fig. 1**) the purpose of discrimination is to disconnect only the faulty load or feeder from the network and no others, while keeping as much as possible of the installation powered up.

Safety can thus be combined with continuity of service, and the fault easily located. It is an especially important concept for high-power equipment, since this is generally located at the head of the installation and therefore has even greater consequences in the event of false tripping.

Discrimination is said to be total if it is assured irrespective of the value of the fault current, up to the maximum value available in the installation. If this is not the case, it is said to be partial.

The faults encountered in an installation are of different types:

- overload
- short-circuit

as well as:

- earth fault
- voltage dip or momentary loss of supply

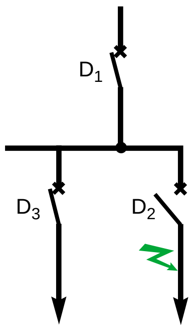


Fig. 1: Discrimination

For each type of fault there is a specific corresponding protective device (protection against overload, short-circuit or earth fault currents, or against loss of voltage, etc).

Each of these faults can cause a loss of discrimination if coordination of the protective devices has not been taken into account.

1.2 Discrimination according to the type of fault

The techniques for using discrimination have to be adapted to the phenomena involved, and therefore differ according to the type of fault.

Overloads

These are currents between 1 and 10 times the duty current. They should be eliminated within a period which is compatible with the thermal withstand of the conductors concerned. The trip time is generally inversely proportional to the square of the current (this is known as “inverse time” tripping).

Circuit-breaker discrimination works by comparing the time/current curves for the long-time delay releases affected by the fault (see **fig. 2**)

It is effective if, for any overload current value, the time during which the upstream circuit-breaker D_1 does not trip is greater than the maximum breaking time for the downstream circuit-breaker D_2 (including the arc suppression time). In practice, this condition is achieved if the ratio I_{r1}/I_{r2} is greater than 1.6.

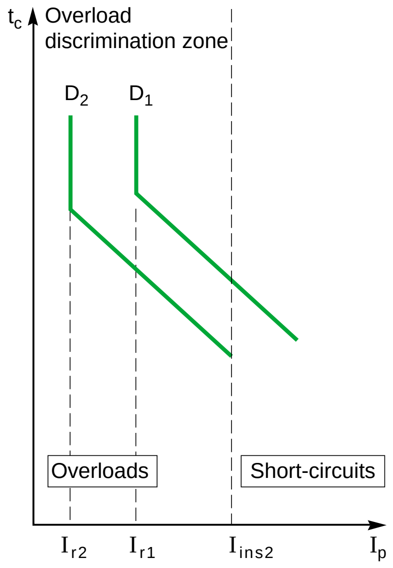


Fig. 2: Discrimination in the overload zone

Short-circuits

Because of the magnitude of short-circuit currents, and especially the presence of electrical arcs which generally accompany them, the circuits concerned should be interrupted almost instantly, in less than a few hundred milliseconds.

Discrimination can work, to some extent, by comparing the time/current curves, provided that time t_c is at least thirty or forty milliseconds. Below that time, these curves are not sufficiently precise to reach a verdict with certainty.

Moreover, the time and current are not then the only discriminating criteria. Depending on the situation, it may be necessary to take account of the peak current, limiting, or a combination of time and current (for example, $\int i^2 dt$). It is then necessary to refer to the discrimination tables published by the relevant circuit-breaker manufacturer.

Various techniques can be used to achieve discrimination in the event of a short-circuit between 2 circuit-breakers, and these are outlined in the following section.

Earth leakage currents

Here too, discrimination has to be taken into account so as to prevent an insulation fault at some point in the installation leading to tripping of the main devices.

There are 2 major protection "families" with regard to leakage currents. For low or very low current values (typically between 30 mA and 30 A), a sensor is used which surrounds all the live conductors. This sensor naturally adds up the total current, and provides a signal which is proportional to the fault current. The presence of an earth (or ground) fault current causes the sum of $I_1+I_2+I_3+I_n$ to be other than zero.
This system is generally known as "residual protection" or "vigi".
For higher leakage current values, above 20% of the nominal current, one sensor is used per live conductor. The system, which is called simply "ground fault protection", adds up all the signals provided by each of these sensors.

In both cases, discrimination works by differentiating between thresholds and time delays. It can be controlled by time/current curves (see **fig. 3**).

Voltage dips or loss of supply

These phenomena can be generated by a short-circuit in the installation, or by a fault upstream of it, and lead to tripping of the main devices if they are equipped with an undervoltage trip unit.
The solution consists of using time-delayed undervoltage trip units, with a reaction time which is longer than the short-circuit trip time of the equipment located downstream.

Even without a time delay, undervoltage trip units should offer immunity against undervoltages lasting approximately ten milliseconds, in order that they are not affected during short-circuits eliminated by equipment located near the loads.

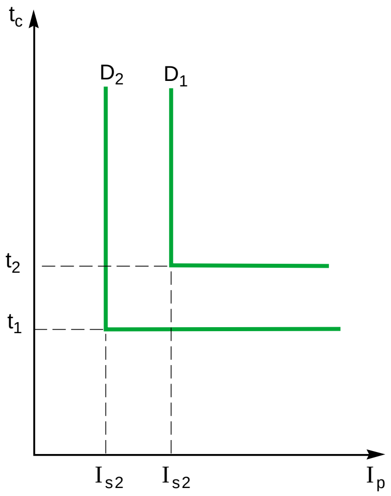


Fig. 3: D1 is selective with regard to D2.

2 Discrimination techniques for short-circuits

Improving discrimination generally comes down to “restraining” tripping by the circuit-breaker concerned as opposed to the circuit-breakers located downstream in the installation.

This goal can be achieved by:

- Creating a difference between the trip thresholds, which is **current discrimination**
- Delaying - by a few tens or hundreds of milliseconds - tripping of the upstream circuit-breaker, which is **time discrimination**
- Using a more sophisticated discrimination criterion, for example detection of the number of current waves, or the form of these waves ($\int i\,dt$, $\int i^2 dt$, etc), which is **“Sellim”** or **“energy-based” discrimination**
- Communicating threshold overshoot information from one circuit-breaker to the other, which is **zone selective interlocking**

2.1 Current discrimination

This results from the difference between the thresholds of the instantaneous or short-time delay releases of circuit-breakers in series in a circuit.

It is applied in the event of short-circuit faults and generally leads, unless associated with another type of discrimination (time, Sellim or energy-based), to partial discrimination limited to the intervention threshold of the upstream device (see **fig. 4**).

Discrimination is ensured if the maximum threshold of the trip unit for the downstream device is less than the minimum threshold of that for the upstream device, including all tolerances.

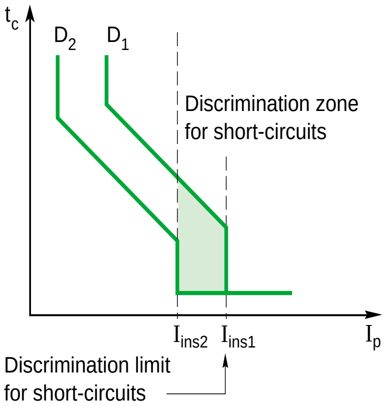


***Fig. 4**: Current discrimination*

2.2 Time discrimination

To ensure discrimination above the short-time threshold (I_{CR1}) of the upstream device, it is possible to use a time delay, which may or may not be adjustable, on the trip unit for the upstream device D_1 (see **fig. 5**).

This solution can only be used if the device can withstand the short-circuit current during this time delay. It therefore only applies to devices with high electrodynamic withstand, which are also called “selective”.

On two circuit-breakers in series, the different time bands, when they exist, are arranged so that they discriminate between one another. The maximum operating time of one band, including the breaking time, should be less than the minimum detection time of the following band.

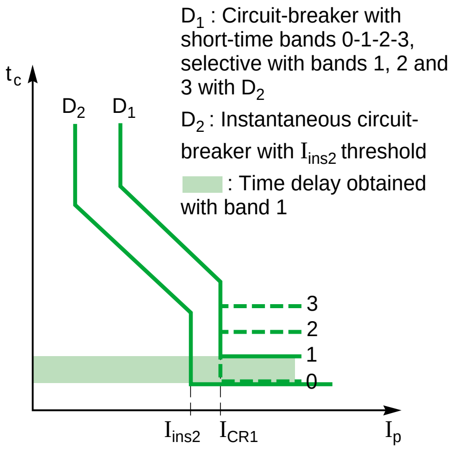


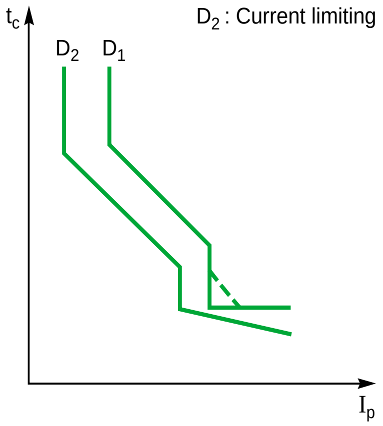
***Fig. 5**: Time discrimination*

2.3 Pseudo-time discrimination

If a limiting circuit-breaker is being used downstream, the magnitude and duration of the actual short-circuit current is significantly reduced, especially if the prospective current is high. The trip unit on the upstream device therefore detects a much weaker current than if there is no downstream circuit-breaker. This can be shown on the time/current trip curve for the downstream device by an "equivalent" time, which diminishes considerably when the prospective short-circuit current increases.

The comparison with the detection curve for the device highlights the discrimination between the two devices. It is called pseudo-time, since it does not use an intentional time delay (see **fig. 6**).

This solution, with its limiting effect and the speed with which the fault is eliminated, can also be used to limit the thermal and electrodynamic stresses in the installation.



Note: If a short-time dependent release (dotted line) is used on D1, discrimination will be much improved.

***Fig. 6**: Pseudo-time discrimination*

2.4 "SELLIM" or energy-based discrimination

These principles, developed by Schneider Electric, are particularly useful for medium power equipment (100 to 630 A), where current limiting is a necessity. This type of equipment, with very active electrodynamic repulsion, cannot even withstand a delay of a few hundred milliseconds. Time discrimination relating to downstream equipment is therefore unsuitable, or limited to a very low current value.

The solution consists of using more sophisticated trip criteria than just the value of the current or time, generally a combination of both these values, for example $\int i^2 dt$. The type of criterion, and the threshold value, are adapted very precisely to the upstream/downstream combination of equipment under consideration. They can be used to ensure discrimination over several stages, while limiting considerably the thermal and electrodynamic stresses on the installation.

This discrimination is used in Merlin Gerin's Compact NS circuit-breakers.

For a more detailed explanation, the reader may like to refer to "Cahier Technique" no. 167 entitled "Energy-based discrimination for low voltage protective devices".

2.5 Zone selective interlocking

This technique requires data transmission between the trip units of the circuit-breakers at the various levels in the feeder network.

The operating principle is simple (see **fig. 7**):

- A trip unit that detects a current greater than its trip threshold sends a logic wait instruction to the trip unit for the circuit-breaker which is next upstream. The time delay will be that displayed on the trip unit.
- The trip unit of the circuit-breaker located immediately upstream of the short-circuit does not receive a wait instruction and reacts immediately, regardless of the time delay displayed.

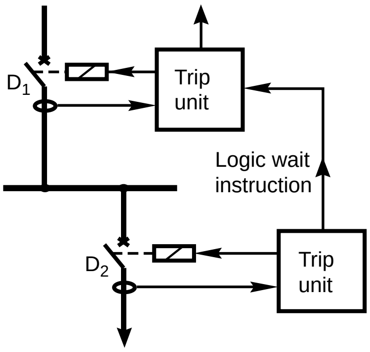


***Fig. 7**: Zone selective interlocking*

Zone selective interlocking is a technique used in addition to time discrimination. It is used to reduce fault clearing times, which reduces the stress on the installation. It is applied to high-amp selective LV circuit-breakers, but it is also used on HV industrial networks. It requires the trip units to be compatible with one another.

For further details, see “Cahier Technique” no. 2 entitled “Protection of electrical distribution networks by the logic selectivity system”.

2.6 Combining the different types of discrimination

The choice of a type of discrimination in an electrical feeder network depends on the type of device and their location in the installation. Different techniques can be combined between two devices in order to obtain the best availability of electrical energy; see example in **figure 8**.

Current discrimination is, without exception, the first link in the discrimination chain.

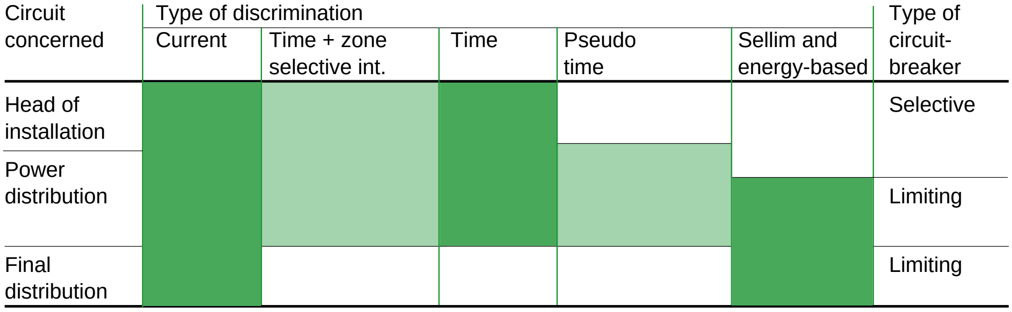


Fig. 8: Example of uses for different types of discrimination

3 Discrimination with power circuit-breakers

LV power circuit-breakers, due to their position at the head of the installation, are especially concerned by discrimination requirements.

Their natural robust nature means that time discrimination is mainly used in the event of a short-circuit. This does not exclude the additional use of “pseudo-time” discrimination (current limiting circuit-breaker downstream of a selective circuit-breaker), and zone selective interlocking (logical wiring between the various levels in the feeder network).

In this section we will examine the characteristics which have an influence on this discrimination, first considering those of the circuit-breaker itself, and then those of the trip unit fitted on it.

The special case of discrimination on circuit-breaker closing is then analyzed, along with the characteristics which determine it.

3.1 Circuit-breaker characteristics

Short-time withstand current (I_{cw})

The short-time withstand current (I_{cw}) characterizes the capacity of devices to withstand short-circuit currents, which may be very high, for a sufficient period for them to be eliminated by circuit-breakers or protective devices located downstream. It is therefore an essential characteristic for power circuit-breakers which are always found at the head of the installation.

The higher the I_{cw}, the higher the usage limit for time discrimination. This is why devices with high I_{cw} are often known as “selective” devices. It is, of course, essential that the switchboard where the device is installed, and all the conductors located upstream, are capable of withstanding such currents.

■ Constraints

Short-circuit currents generate 2 types of phenomenon:

□ **Electrodynamic forces** between the various parts of the circuit conducting the current:
These forces may be either repulsion or attraction depending on the respective direction of the currents; they appear instantly, and the resistance of the device to these forces, called “electrodynamic withstand” (marked EDW) will therefore be characterized by the maximum instantaneous value of the current it can withstand, measured in “peak” kA.
Above this value, parts may be irreversibly deformed, or electrical arcs may be produced which could damage the parts concerned.

□ **Temperature rise** in the parts conducting the current:
This temperature rise is not a function of the instantaneous value of the current, but of its rms value and its duration; the device withstand can therefore be expressed in kA_{rms} and in seconds.

The “short-time withstand current” is defined by a number of standards, including IEC 60947-2 which has allocated it the symbol “I_{cw}”. The associated test can be used to test the behavior of the device both from the electrodynamic point of view, when the short-circuit occurs, and from the thermal point of view, since the current is maintained for a predefined period (usually 0.5 s, 1 s or 3 s). Since the maximum peak current is fixed by the standard as a function of the rms current, if this is known, the I_{cw} can be defined.
It is clear that the I_{cw} is limited by the most severe phenomena, whether electrodynamic or thermal, and its value therefore often diminishes when the associated time increases: an I_{cw} lasting 3 s is thermally 9 times more restrictive than an I_{cw} lasting 1 s.

The I_{cw} value to be taken into account for discrimination is that which corresponds to the maximum time setting for the short-time delay release, generally 0.5 s. As this value is usually determined directly by the electrodynamic withstand, the thermal stress is easily controlled. Values at 1 s, or even 3 s, are only an indication of extra robustness in this case.

■ Construction recommendations to obtain a good I_{cw}

All these requirements specify:

□ Robust and rigid device construction, which holds the current-carrying parts firmly in place; compared to the old construction techniques based on metal parts which were cut, bent and then assembled, the use today of thermosetting polyester moulded cases offers a notable improvement in the structural rigidity of circuit-breakers.

- Excellent rigidity of the mechanism to keep the contacts in the closed position
- Special arrangement of the moving contacts and disconnecting contact fingers (see **fig. 9**) to ensure automatic compensation of the repulsion forces generated between the contact points:
  - The disconnecting contact fingers are located on either side of the conductors to be linked; the parallel currents circulating in these fingers create an attraction force Fm which compensates the repulsion forces Fr generated at the contacts (**fig. 9a**).
  - The moving contacts incorporate a hinge pin located approximately one-third of the distance between the incoming conductors. Therefore, the result of the repulsion forces Fm produced by the current loop creates a torque on the contacts which compensates that generated by the repulsion Fr at the contact points (**fig. 9b**). Compensation of these forces does however have the effect of increasing the forces transmitted to the mechanism, which constitutes a restriction for the manufacturer.
- Generous dimensioning of the power circuit cross-section, so as to avoid reaching an excessive temperature when the time delay on the trip unit is set to maximum
- Use of thermosetting moulded materials (with no melting point), or special thermoplastics with a high melting point, near the power circuit

Breaking capacity

In order to use a circuit-breaker on a given circuit, its ultimate breaking capacity (I_{cu}) must be higher than the prospective short-circuit capacity of this circuit at the point under consideration.

Usually, on low voltage power circuit-breakers, this breaking capacity equals the I_{cw} at 0.5 s. In this case, time discrimination can be used up to the breaking capacity, since the device is capable of withstanding these currents for the corresponding time. Total discrimination is therefore achieved.

However, the values of I_{cw} obtained, even with the best types of construction, are at present typically limited to around 85 kA_{rms}, which therefore limits the breaking capacities. Yet an increasing number of installations can generate short-circuit currents above this value, reaching 150 kA in some cases, or even more. This is particularly the case for installations incorporating several high-power transformers in parallel, or networks looped with multiple generators.

There is now a response to this need, with circuit-breakers which have a **breaking capacity higher than the I_{cw}**.

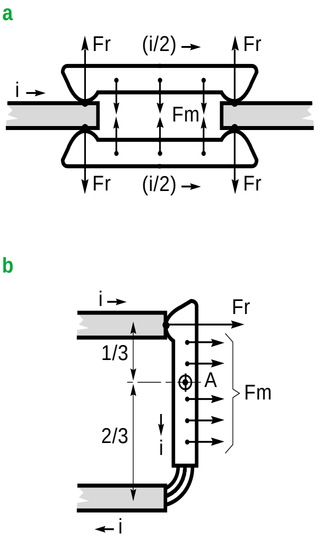
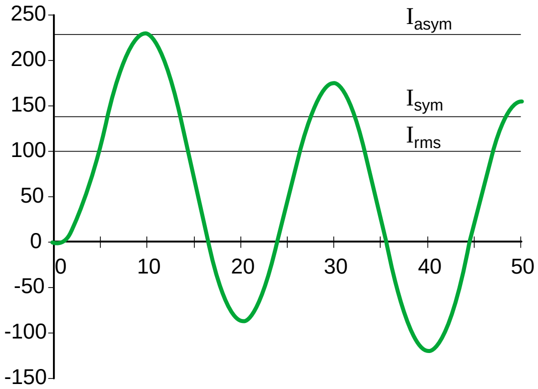


Fig. 9: Construction recommendations to ensure compensation of repulsion forces in a circuit-breaker

a: Asymmetrical energization



b: Symmetrical energization

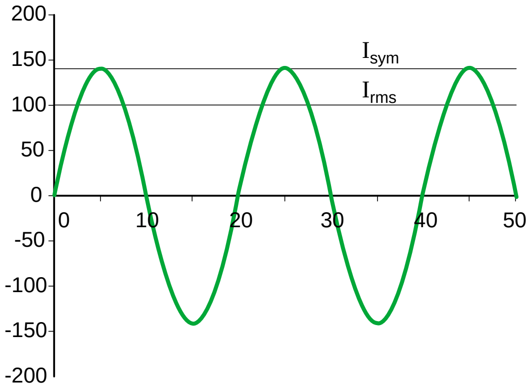


Fig. 10: Timing diagram of the current in the event of asymmetrical or symmetrical energization

- Devices with breaking capacity higher than the I_{cw}, construction requirements

For their own protection, circuit-breakers with a breaking capacity higher than the I_{cw}/0.5 s require instantaneous tripping (DIN) as soon as the current exceeds their electrodynamic withstand, as they cannot withstand arcs of such intensity produced on contact repulsion for several hundred milliseconds.

However, this condition is not sufficient of itself, and controlling the breaking capacity of these devices requires the expertise of specialists in interruption of electrical arcs. In particular, as these devices are not limiting, the current on breaking powerful short-circuits can reach approximately 2.3 times the rms value of the prospective current in asymmetrical operation, ie. 230 kA_{peak} in the case of a prospective short-circuit of 100 kA_{rms} (see **fig. 10**). The electrodynamic constraints are therefore significant on the device itself, with the consequences being amplified by effective opening of the device at the very moment when these stresses are strongest.

These considerations limit the maximum breaking capacity that can be obtained with devices with high I_{cw}, and only an extremely robust construction combined with an exceptional ability to control phenomena associated with breaking high currents enables values higher than 100 kA rms to be obtained. Merlin Gerin's type H3 Masterpact NW devices, which offer a breaking capacity of 150 kA at 440 V, for an I_{cw} of 65 kA/3 s are an excellent illustration of this expertise.

Note that in this case, the withstand of the switchboard and the installation also requires very robust construction of the busbar sets and their supports. The use of factory-produced LV switchboards, tested to standard IEC 439, ensures the reliability of this construction (see "Cahier Technique" no. 162).

- Current limiting devices

When, on devices with high I_{cw}, the maximum breaking capacity indicated by the manufacturer is insufficient, the only remaining option is to use **current limiting circuit-breakers**, which usually have breaking capacities of as much as 150 kA at 400 V.

By their very nature, these devices limit the maximum value reached by the current, and provide a high breaking capacity, while reducing the effects of the short-circuit on the installation and the device itself.

High-rated current limiting circuit-breakers do however suffer from a handicap, with regard to discrimination with devices located downstream, as their EDW is always relatively low. In fact, current limiting is usually obtained by using an electrodynamic contact repulsion effect, which conflicts directly with the EDW. The threshold for the instantaneous self-protection release (DIN) should therefore be set very low, which restricts discrimination with downstream equipment to low values, **unless more sophisticated trip criteria are used** (see "Cahier Technique" no. 167, "Energy-based discrimination for low voltage protective devices").

Here too, it is the clever design of current limiting power circuit-breakers that enables manufacturers to offer high breaking capacity and effective current limiting, while still ensuring good EDW. This is particularly the case with Merlin Gerin's Masterpact NW current limiting devices, which have an EDW of as high as **37 kA_{rms}**!
This EDW would never be as high, however, as a non-limiting device.

Thus, the maximum breaking capacity of devices with high I_{cw}, by avoiding the need to use current limiting devices at the head of the installation, is a fundamental element of discrimination.

Current limiting

The instantaneous value of a sinusoidal alternating current, in steady state, oscillates between + $\sqrt{2}$ and - $\sqrt{2}$ times its rms value.
During energization, this instantaneous value can reach approximately 2.3 times the rms value on the first wave, due to the asymmetry of the current.
The actual value depends on the circuit inductance; in practice, it is also related to the level of short-circuit in question, and increases with it. If the incoming circuit-breaker is fitted with an instantaneous self-protection release (DIN), because its breaking capacity is higher than its I_{cw}, discrimination with the downstream device is limited by the presence of this instantaneous

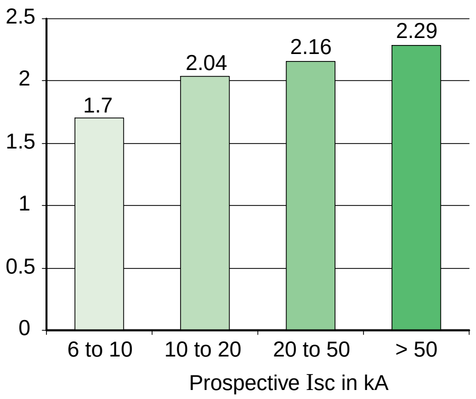


***Fig. 11**: Asymmetry coefficients as a function of the prospective rms current acc. to standard IEC 60947-1*

release. If the value of its threshold is known (in kA_{peak}), this value simply has to be divided by the asymmetry coefficient (see **fig. 11**) to find out the discrimination limit (in kA_{rms}). However, if the device located downstream of the circuit-breaker in question is a current limiting type, and if the short-circuit occurs downstream of this current limiting device, the maximum instantaneous value mentioned earlier will not be achieved. In this case, the discrimination limit obtained is increased, even more so if the circuit-breaker downstream has a high current limiting capacity (pseudo-time discrimination).

In extreme circumstances, if the maximum current limited by the downstream circuit-breaker is less than the instantaneous threshold of the upstream device, there is total discrimination between the two devices (see **fig. 12**).

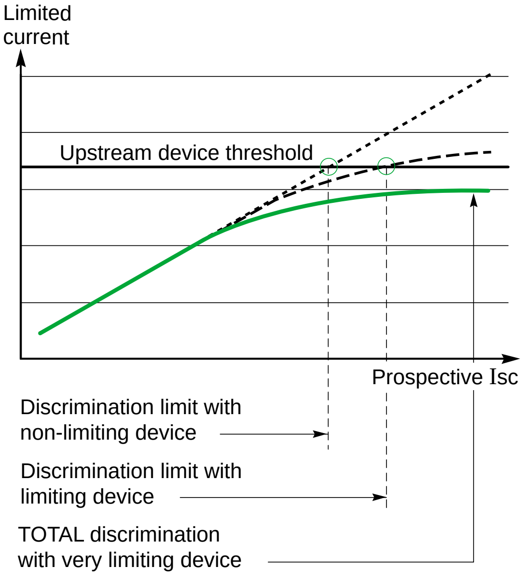


***Fig. 12**: Partial or total discrimination obtained between two devices, depending on the current limiting capacity of the downstream device*

3.2 Trip unit characteristics

The discrimination potential of a device can only be fully exploited by using an appropriate trip unit.

Types of trip unit

On high-rated equipment, trip units are exclusively electronic nowadays. There are a number of different types, with different setting options (see **fig. 13**).

- Simple trip units

These usually offer an inverse time curve with an adjustable threshold, for overload protection, and an instantaneous trip threshold (< 10 ms), also adjustable, for short-circuit protection.
This instantaneous threshold generally has a maximum value of 10 to 12 In.
It is this maximum value which **limits the actual discrimination** which can be obtained using this trip unit.

- “Selective” trip units

These offer, in addition to the overload and short-circuit protection described above, a trip threshold with time delay, where both the threshold and the time delay can be adjusted (from 0 to 500 ms), and an instantaneous release which can be adjusted up to the maximum permissible value for the breaker.

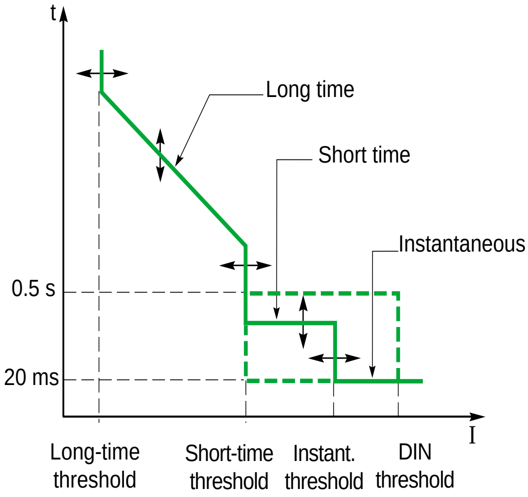


***Fig. 13**: Trip curve for a circuit-breaker, illustrating the setting parameters*

If the circuit-breaker I_{cw} equals its breaking capacity, this maximum value can be “infinite”, equivalent to the “Off” position: instantaneous tripping will never occur - see section on Breaking capacity). In this case, **discrimination is then total**, otherwise the actual discrimination is limited by the value of the instantaneous threshold set as for a simple trip unit.

If the I_{cw} is less than the breaking capacity, this instantaneous threshold can nonetheless be very high (much greater than 12 In) when the EDW is high (see section on Breaking capacity). **Discrimination is then partial**, up to the rms current corresponding to this instantaneous threshold, **or even total** if the downstream protective device is sufficiently limiting for this value never to be reached (see section on Current limiting).

Below this threshold, time discrimination has to be used, for example: a 3rd level device is time-delayed by 100 ms, a level 2 device by 200 ms, and a level 1 device by 300 ms.

- Trip units with “zone selective interlocking”.

A hard-wired link connects the circuit-breaker trip units on a single circuit.
A trip unit which detects a short-circuit sends a time delay command to the upstream trip unit. This trips instantaneously above its “short-time” threshold (whatever its time delay setting), if it has not received a wait command from downstream.

This function does not modify the rules for discrimination, but it reduces the stresses on the installation since the circuit-breaker immediately upstream of the fault will always trip instantaneously.

- Trip units with “IDMTL” curves

In a very different area from the previous considerations, which concern circuit-breaker discrimination in short-circuit situations, some “top-of-the-range” trip units offer trip curves known as “IDMTL”, as defined by standard IEC 60255-3. These curves can be used to improve circuit-breaker discrimination in the area of **overloads**, where discrimination can easily be studied by comparing the trip curves for the upstream and downstream protective devices (see **fig. 14**).

With these trip units it is possible to set not only the threshold and time delay for the “long-time” delay release, **but also the slope of the trip time as a function of the current**. As standard, this slope is at $I^2\,t$ = constant (the trip time is inversely proportional to the square of the current) and it offers constant thermal stress protection.

IDMTL curves permit different trip times, as required by the user:

□ Constant
(t = constant; DT = “Definite Time”)

□ Inversely proportional to the current
($I\,t$ = constant; VIT = “Very Inverse Time”)

□ Inversely proportional to the square of the current
($I^2\,t$ = constant; EIT = “Extremely Inverse Time”)

□ Inversely proportional to power 4 of the current
($I^4\,t$ = constant; HVF = “High Voltage Fuse”)

This offers improved discrimination, especially with **medium-voltage circuit-breakers** located upstream, which often have constant trip times, or with **medium-voltage fuses**, which have a slope higher than I^2t (see section 4.3).

The self-protection release function

As we saw earlier (see section on Current limiting devices), a circuit-breaker whose breaking capacity is higher than the I_{cw} needs to have an instantaneous release (DIN) for its own protection.

- Standard DIN

The DIN threshold should be selected so that, even in the least favorable withstand conditions, it is still less than the ultimate circuit-breaker withstand. In particular, the tolerance of the current measurement system should be taken into account.
If there is a wide degree of tolerance, the nominal threshold must be reduced by the same amount. However, if this system is very precise,

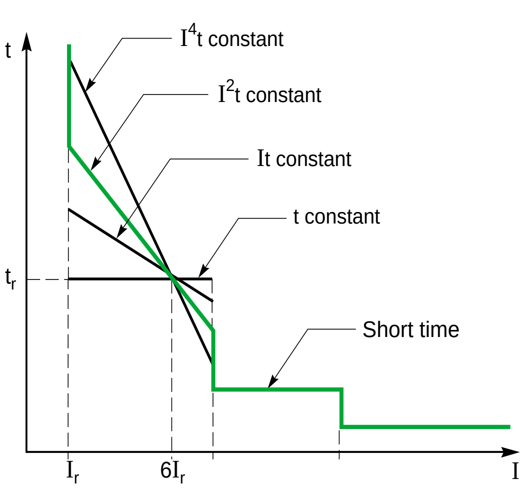


Fig. 14: Circuit-breaker “IDMTL” trip curve

the nominal threshold can be set nearer the limit withstand value for the device (see **fig. 15**).

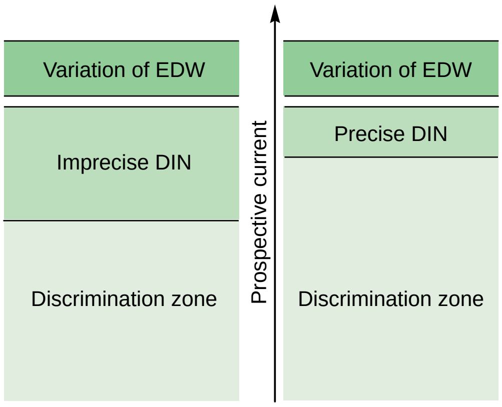


Fig. 15: Effect of the accuracy of a circuit-breaker's current measurement system on discrimination

■ DIN with di/dt

To improve breaking performance, and obtain a certain degree of short-circuit current limiting on non-limiting devices, a self-protection release can be used which is not based on the instantaneous current value, but on its differential coefficient (di/dt).

□ Principle

At known frequency, the maximum differential coefficient of the current is in fact directly linked to its rms value by the equation:

$di/dt_{max} = I_{rms} \sqrt{2}\ 2\pi\, f$, where f is the network frequency, which gives

$di/dt_{max} = 0.443\ I_{rms}$ at 50 Hz (differential coefficient in kA/ms if I_{rms} is in kA)

$di/dt_{max} = 0.531\, I_{rms}$ at 60 Hz

The least favorable case in terms of speed of establishing the short-circuit current consists of a symmetrical wave, which develops in the form of a sinusoidal equation:

$I_{rms} \sqrt{2}\ \sin(2\pi\ f\ t)$ (see fig. 16)

To limit the maximum current produced by this type of wave, it is essential to act extremely quickly. The current differential coefficient offers this opportunity, since its maximum value, in this case, is reached as soon as the short-circuit is initiated, while the value of the current instantaneous threshold may only be reached a few milliseconds later. Thus, for a short-circuit of 100 kA_{rms} at 50 Hz, the symmetrical wave will generate a maximum current of 140 kA_{peak} at the end of 5 ms (see **fig. 16**).
With a self-protection release based on an instantaneous threshold value of 100 kA_{peak}, it is necessary to wait approximately 2.5 ms before reaching the threshold. Too little time then remains to limit the current in any significant fashion.

With a trip unit which is sensitive to the current differential coefficient, the trip command can be given instantaneously, although still with a very short time delay in order to avoid false tripping due to interference.

□ Effect on discrimination

This type of self-protection release does, however, behave in a particular way in terms of discrimination. In fact, even a very limiting device placed downstream of this device has no immediate effect on the differential coefficient for the current of a fault that it detects: some time, however minimal, is necessary for its contacts to open and for the arc voltage generated to slow down the current rise, before stopping it altogether. In this case, **discrimination will therefore be limited by the threshold value of the current differential coefficient, irrespective of the downstream protective device.**
It is therefore vital for discrimination that the manufacturer sets this threshold at the highest possible value, compatible with the desired current limiting and the device electrodynamic withstand.
In the previous example, if the threshold is set at a value of 44.3 kA/ms, corresponding to a prospective current of 100 kA_{rms} at 50 Hz, current limiting only comes into effect above this prospective current value and then discrimination will occur with downstream devices up to this same value.

□ For 60 Hz:

$di/dt_{max} = 0.531\, I_{rms}$ so a threshold set at 44.3 kA/ms corresponds to a limit of 83 kA_{rms} (instead of 100 kA_{rms} at 50 Hz).

■ Contact separation detector

One way of completely eliminating current sensor inaccuracy is not to use them. Using photoelectric light sensors to detect, between the

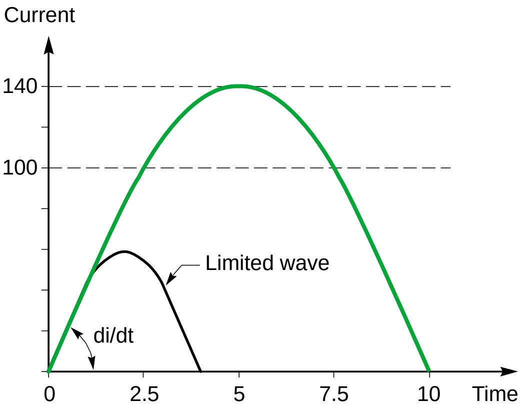


Fig. 16: Detection principle for a short-circuit, based on the current instantaneous differential coefficient and limiting obtained

contacts of each of the poles, the appearance of an arc when the electrodynamic withstand is exceeded, is one technique for commanding the circuit-breaker to open. In this case, discrimination is no longer affected by the tolerance of the current sensor, but only by that of the electrodynamic withstand itself.
In practice, these complex devices can only be justified to remedy the inaccuracy of conventional magnetic sensors on high currents.

Current sensors

The accuracy of the measurement system depends on the sensor accuracy. Two major families of sensors are used on circuit-breakers:

☐ Magnetic circuit current transformers

☐ Current transformers with non-magnetic toroids

■ Magnetic circuit current transformers

☐ Their technology

This is the oldest type and offers satisfactory accuracy for equipment with a low EDW. These transformers are fitted with a secondary winding with n turns around a core of **magnetic** material, with the passage of the main conductor across the magnetic circuit constituting the primary (see **fig. 17**).

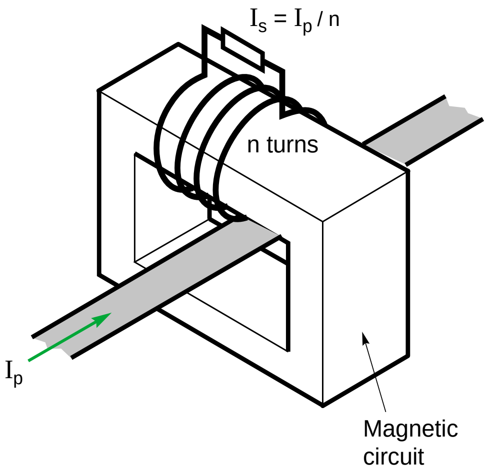


Fig. 17: Schematic diagram of a current transformer with magnetic circuit

This transformer draws a current (I_s) from the secondary equal to the primary current (I_p) divided by the number of turns (n) in the secondary.

☐ Their accuracy

Accuracy is satisfactory as long as the magnetic circuit is not saturated, ie. up to 5 to 10 times the nominal current. Thereafter, the secondary current is significantly weaker than I_p/n (see **fig. 18**).

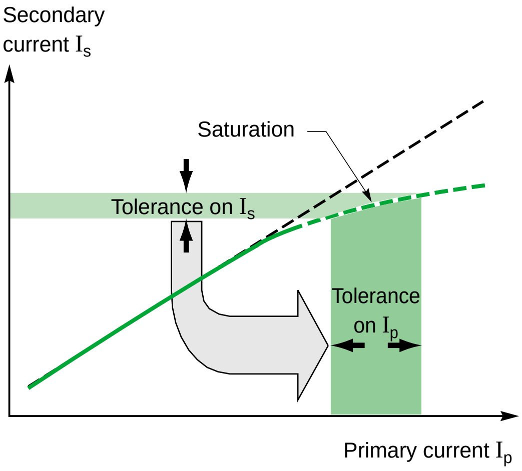


Fig. 18: Variation in the secondary current of a transformer as a function of the primary current (effect of saturation of the magnetic circuit)

Moreover, when the circuit-breaker closes due to a short-circuit, the response of the sensor on the first current wave depends to a large extent on the magnetic state (remanent induction) in which it was left by the previous current. If the primary current on closing is in the same direction as the previous current, the secondary current I_s is noticeably attenuated on the first wave; if it is in the opposite direction, I_s is increased. Consequently, the measurement system may be marred by a significant error, the DIN threshold therefore needs to be set well below the EDW value by the manufacturer.

■ Current transformers with non-magnetic toroids

☐ A new technology (see **fig. 19**)

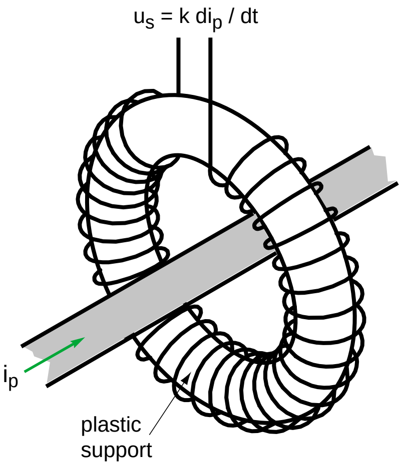


Fig. 19: Schematic diagram of a current transformer with non-magnetic toroid

These current transformers, or Rogowski toroids, consist of a secondary winding wound onto **non-magnetic** material surrounding the primary circuit. They provide the secondary with a voltage proportional to the variation of the primary current. The integration of this voltage by the electronic circuits gives an image of the primary current.

□ Their accuracy

The absence of a magnetic circuit gives these sensors perfect linearity for all current values. They enable optimum usage of circuit-breakers.

The accuracy of these sensors means that the trip threshold can be set as close as possible to the limit value of the device electrodynamic withstand (EDW), and the discrimination limit is correspondingly increased.

The downside of this characteristic is:
- the low value of the voltage delivered
- the fact that this sensor delivers no power
- the sensitivity of the secondary signal to the toroid dimensions.

These various points can be solved respectively by:
- careful signal processing
- installation of a second, magnetic, sensor which delivers the power required to supply the trip unit electronics
- controlling the toroid dimensions by the use of suitable materials, ie. which are stable, not sensitive to temperature and reproducible

3.3 Discrimination on closing

Risks associated with switch-on-to-fault

When a device closes, the mechanism should supply the necessary power for contact operation, and in particular for compression of the springs which provide the bearing force for the moving contacts on the fixed contacts. It is this force which ensures that the current flows correctly through the mechanism, without causing an excessive temperature rise.

When the device closes on a normal or overload current, the above conditions are not significantly altered.

However, when the device closes on a short-circuit current, considerable electrodynamic forces are generated between the contacts even before the mechanism closes completely, and may lead to closing being prevented, and then unwarranted reopening. This situation should be avoided, otherwise the device may be rapidly destroyed by an uninterrupted series of make and break attempts, without intervention by the trip unit.

Necessity of distinguishing between instances of closing on a normal current, or a short-circuit current

There is therefore a clear difference between the current which the device can withstand when it is closed (electrodynamic withstand), and the current which the device can fully make (make capacity), also known as “close & latch”.

It is possible to control the value of the current which the device is capable of fully making, by controlling the power of the control mechanism. By increasing this power, the limit current is also increased.
However, as this additional power is not consumed to overcome electrodynamic forces during operations where there is no current or with “normal” currents, it is dissipated by jolts in the mechanism. This power cannot therefore be increased with impunity without compromising the endurance of the mechanism, a value which is essential to the user as it determines the service life of the device.

The 2-step release solution

There is a solution which enables a device to be used on circuits where the current can reach values higher than its make capacity. It consists of tripping the device if the current exceeds this capacity on closing the circuit. Opening then occurs in controlled conditions which do not lead to any particular difficulties.

Of course, since this make capacity is less than its electrodynamic withstand, it is not desirable to simply have an instantaneous release with a threshold lower than this capacity: the whole point of high electrodynamic withstand would then be lost. It is therefore necessary to have a two-step instantaneous release; one “low” step, which is only active on closing (called DINF), the other “high”, which is active when the device is completely closed (DIN).

This system can be used in two ways:

■ The first solution, which is widely used, consists of activating the low threshold for thirty or forty milliseconds after the trip unit detects a current. This solution is easy to use, as it only concerns the trip unit, and can therefore be implemented entirely electronically. It does, however, have a major disadvantage: it is not possible to distinguish between an open device which is closing, and a device which, having been closed with no current or with a very weak current, is suddenly affected by a short-circuit current. This is what happens with a closed incoming circuit-breaker, with no current, when one of the downstream feeder circuit-breakers is closed due to a short-circuit. In this case, the DINF of the first circuit-breaker is activated unnecessarily and adversely affects discrimination, whereas the device would have been sufficiently protected by the DIN threshold.

- A second more satisfactory solution consists of detecting a closure movement by the device, delaying this information for as long as necessary to ensure that the device has closed completely, and to use this information in the form of an electrical contact to switch the trip unit from the DINF state to the DIN state. This solution ensures that the low threshold is only activated at an appropriate moment, and does not reduce discrimination unnecessarily for a device which is already closed.

Advantage of discrimination in the event of closing on short-circuit

Finally, remember that when a circuit-breaker closes, the loss of discrimination caused by DINF protection is of limited consequence, since the device tripping is not likely to switch off part of the installation which would have been supplied with power previously. Nonetheless, discrimination is still useful since it makes it possible, at least up to the DINF threshold, to close the upstream device, and to allow the downstream device affected by the fault to trip, thus making it easier to locate the short-circuit.

4 Examples of circuit-breaker selections for an LV installation

4.1 Presentation of the installation

The LV installation which forms the subject of this study is shown in **figure 20**. This study includes coordination of protection between the LV equipment and the protection located upstream of each MV/LV power supply transformer. The selections refer to Merlin Gerin products.

The installation includes 2 medium voltage 20 kV incoming lines protected by a fuse, each equipped with an MV/LV transformer with characteristics 20 kV/410 V, 1600 kVA, and an incoming LV circuit-breaker (A) or (B). A section switch (C) can be used to operate both parts of the installation together or separately, in order to optimize availability of power in the event of failure of one of the two incoming lines.

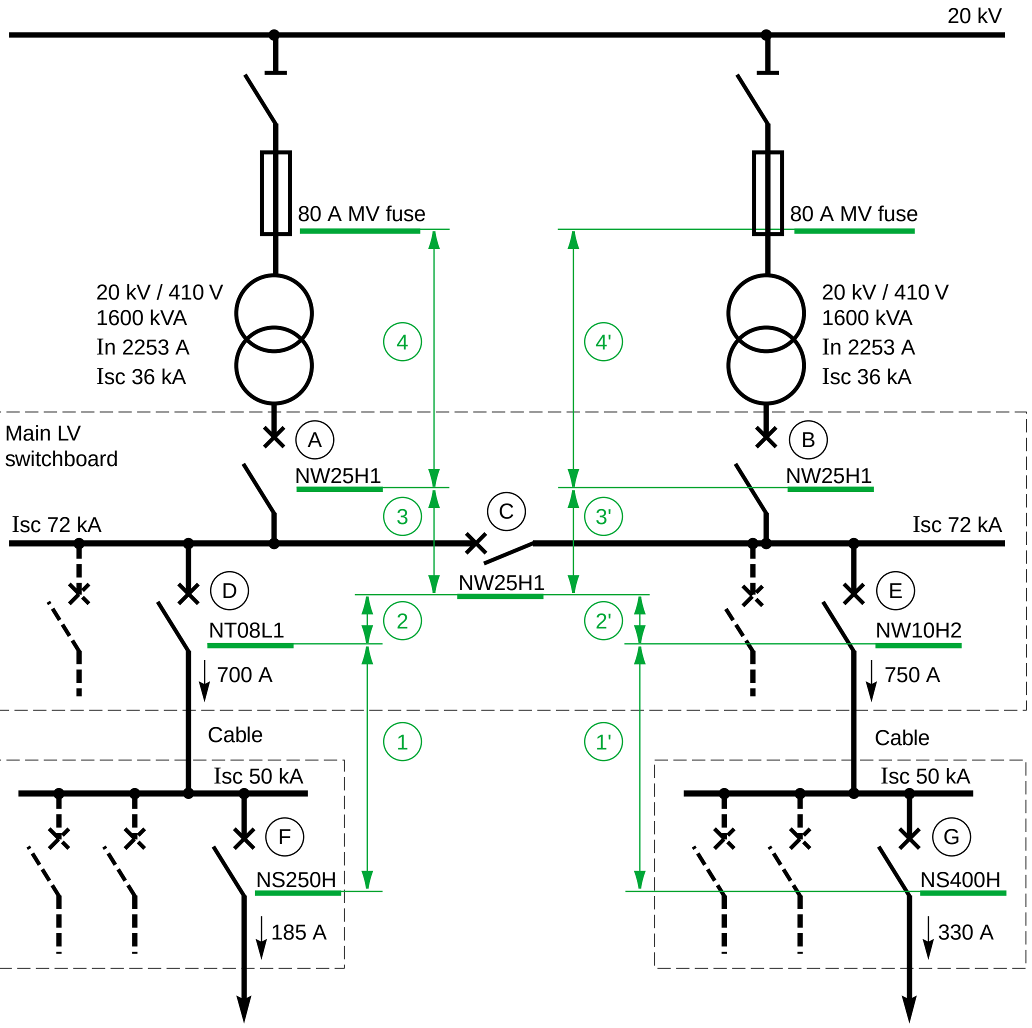


***Fig. 20**: 1st installation example (with 1600 kVA MV/LV transformers) with indication of the order in which discrimination is examined*

4.2 Dimensioning the protective equipment

Rating of devices (A) and (B) installed on LV incoming lines

Determining the nominal current for the LV incoming lines:
1600 kVA at 410 V corresponds to a nominal current of $1{,}600{,}000 / \left(410 \text{ x } \sqrt{3}\right) = 2253$ A.
Incoming devices with a rating of 2500 A are therefore chosen.

Rating of fuses installed on MV incoming lines

The nominal current for the MV incoming lines is:

$$\text{In} = 1{,}600{,}000 / \left(20\ 000 \text{ x } \sqrt{3}\right) = 46 \text{ A}$$

Based on the manufacturers' selection tables, fuses with a rating of 80 A are therefore chosen (in order to take account of inrush and overload currents, while providing thermal protection for the transformer).

Breaking capacity for the various devices

- Determining the short-circuit currents at different points in the installation

Each transformer has a short-circuit current Isc equal to 36 kA (current linked to the transformer power and short-circuit voltage).

When the section switch is closed, downstream of devices (A) and (B) and ignoring the busbar impedances, the short-circuit current is $2 \text{ x } 36 = 72 \text{ kA}_{\text{rms}}$.
Given the cable impedances, the short-circuit current crossing the circuit-breakers located at (F) and (G) is no more than approximately 50 kA.

- Selecting breaking capacity

The breaking capacity required for each device must be determined according to the short-circuit current values at different points in the installation.
Circuit-breakers (D) and (E) must have a breaking capacity higher than 72 kA, while for circuit-breakers (A), (B) and (C), a breaking capacity higher than 36 kA is adequate.
Circuit-breakers (F) and (G) must have a breaking capacity of 50 kA minimum.

4.3 Selecting devices to ensure discrimination

Principle

Discrimination is determined by comparing the characteristics of each circuit-breaker with those of the protective device (circuit-breaker or fuse) located immediately upstream.

The circuit-breakers located furthest downstream in the installation should be selected and set in order to trip "as quickly as possible", so as to limit the stresses on the installation in the event of an overload.

Once the characteristics of these circuit-breakers have been established, one can work back up the installation, ensuring discrimination between circuit-breakers 2 by 2 (downstream circuit-breaker/upstream circuit-breaker).

Discrimination between circuit-breakers (F) and (D) ①

- At F: In = 185 A; Isc = 50 kA

A circuit-breaker with a rating of 250 A is suitable, for example a Compact NS 250 H (breaking capacity 70 kA at 415 V).

- At D: In = 700 A; Isc = 72 kA

A circuit-breaker with a rating of 800 A is suitable, for example a Compact NS 800 L or a Masterpact NT 08 L1 (breaking capacity 150 kA at 415 V).

- Discrimination mechanism

Device (F) is very limiting (the maximum current which can cross it is 22 kA_{peak} for a prospective short-circuit of 50 kA_{rms}), and this circuit-breaker therefore allows "pseudo-time" discrimination with circuit-breaker (D).
This discrimination is improved by applying the "**SELLIM**" principle to circuit-breaker (D). This device, which is also limiting (with low EDW to ensure very good current limiting), enables **total discrimination** between (F) and (D) since, according to the SELLIM principle of discrimination, the device on (D) does not trip on the 1st current wave.
Note: The "SELLIM" function is systematically included in Micrologic - Merlin Gerin trip units, and automatically activated on the devices concerned.

Discrimination between circuit-breakers (G) and (E) (1’)

- At G: In = 330 A; Isc = 50 kA

A circuit-breaker with a rating of 400 A is suitable, for example a Compact NS 400 H (breaking capacity 70 kA at 415 V).

- At E: In = 750 A; Isc = 72 kA

The same circuit-breaker (current limiting) can be used as for (D), but since the NS 400 H current limiting is weaker than on the NS 250 H, this combination will not be totally discriminating.
To achieve this discrimination, a **selective** circuit-breaker must be selected**,** for example Masterpact NW 10 H2 (In 1000 A, breaking capacity 100 kA at 415 V, $I_{cw} = 85 \text{ kA}_{\text{rms}}$ /1 s).

In addition, the current limiting power of device (G) enables, if necessary, pseudo-time discrimination.

■ Discrimination mechanism
Since the I_{cw} (85 kA) is less than the breaking capacity (100 kA), this device has an instantaneous self-protection release (DIN) with a threshold of 170 kA$_{peak}$.
With an Isc = 72 kA$_{rms}$, the maximum current at (E) is 72 x 2.3 = 165 kA$_{peak}$. Since the DIN threshold is therefore never reached, no trip will be generated which would hinder discrimination.

Moreover, in the event of a short-circuit at (G), the maximum current, which corresponds to an Isc of 50 kA, will be limited for (G) to 30 kA$_{peak}$! **Discrimination will therefore be total**, as long as device (E) is fitted with a trip unit with an instantaneous threshold higher than 30 kA$_{peak}$, say $30/\sqrt{2}$ = 21 kA$_{rms}$ = 21 I_n, and that the short-time release delay is set on the 0.1 s band.

■ Variant
A current limiting device can also be used at (E), with a better EDW than (D), for example an NW 10 L1 (In 1000 A, breaking capacity 150 kA at 415 V, I_{cw} 30 kA/1s).
Because of its current limiting (125 kA$_{peak}$ to 72 kA$_{rms}$, against 165 kA$_{peak}$ with no current limiting), the choice of this type of circuit-breaker considerably reduces the electrodynamic stresses on the cables between (E) and (G). This circuit-breaker is fitted with an instantaneous self-protection release **80 kA**$_{peak}$, which is never therefore called on if there is a fault downstream of (G) (Isc limited to 30 kA$_{peak}$). This also provides total discrimination, of the pseudo-time type, due to the current limiting of the device downstream.
Note: A non-limiting device at (G) would allow a peak current of 50 kA x 2.3 = 115 kA$_{peak}$ to pass in the event of a short-circuit, which would cause circuit-breaker (E) to trip.

Discrimination between circuit-breakers (E) and (C) ②

This discrimination is not essential if both incoming lines are operational (since opening of the section switch does not interrupt the power supply via (A) and (B)). Conversely, it is essential if incoming line (B) is non-operational.

■ Value of the nominal current In at (C):
To offer the maximum flexibility, the section switch devices have identical dimensions to the incoming devices, ie. In = 2500 A.
As Isc = 36 kA, a selective circuit-breaker placed at (C) allows time discrimination with (E) and even more with (D) which is current limiting, for example a Masterpact NW 25 H1 (In 2500 A, breaking capacity 65 kA at 415 V, I_{cw} 65 kA/1 s).

■ Reason for this selection
Since the I_{cw} for the device equals the breaking capacity, it does not incorporate an instantaneous self-protection release; time discrimination can therefore be applied without restriction up to the breaking capacity. The circuit-breaker (C) must therefore be fitted with a selective trip unit, with its instantaneous release set to the “Off” position, and the short-time delay on the 0.2 s band (since the short-time release delay of circuit-breaker (E) is set on the 0.1 s band).

Discrimination between circuit-breakers (D) and (C) (2')

The solution chosen for discrimination between (E) and (C) is also suitable between (D) and (C) since (C) is totally discriminating up to its breaking capacity.

Discrimination between circuit-breakers (C) and (B) or circuit-breakers (C) and (A) ③ (3')

(A) and (B) are selective devices, without a self-protection instantaneous release. Here too, time discrimination applies up to the breaking capacity, with for (A) and (B): their instantaneous release set to the “Off” position and their short-time delay set on the 0.3 s band (since the short-time release delay of circuit-breaker (C) is set on the 0.2 s band).

Discrimination between circuit-breakers (A) or (B) and MV fuses ④ (4')

To analyze this discrimination, we need to compare the trip curves for LV circuit-breakers and MV fuses.
To do this, transpose the MV fuse curve to LV, by multiplying the current scale by the transformer ratio, or here 20,000/410 = 48.8 (see **fig. 21**).

Discrimination is considered with 2 types of trip unit: a standard selective trip unit, and a trip unit with IDMTL curves.

■ Settings for standard selective trip units

□ Long-time threshold
No problem, the non-tripping limit current for the fuse is well above the limit current for circuit-breaker tripping; the long-time threshold can therefore be set to maximum (ie. I_r = In).

□ Long-time delay and short-time threshold
The blowing characteristic for MV fuses has a much steeper slope than that of the long-time delay release (LT) tripping, with a slope of I^2t (see fig. 21). To avoid the curves intersecting, the long-time delay (tr), or short-time threshold (Isd), must be set to sufficiently low values.
A good compromise in this example consists of setting tr = 12 s (at 6 I_r, in a range generally going from 1 to 24 s), and Isd = 4 I_r (in a range from 1.5 to 10 I_r).

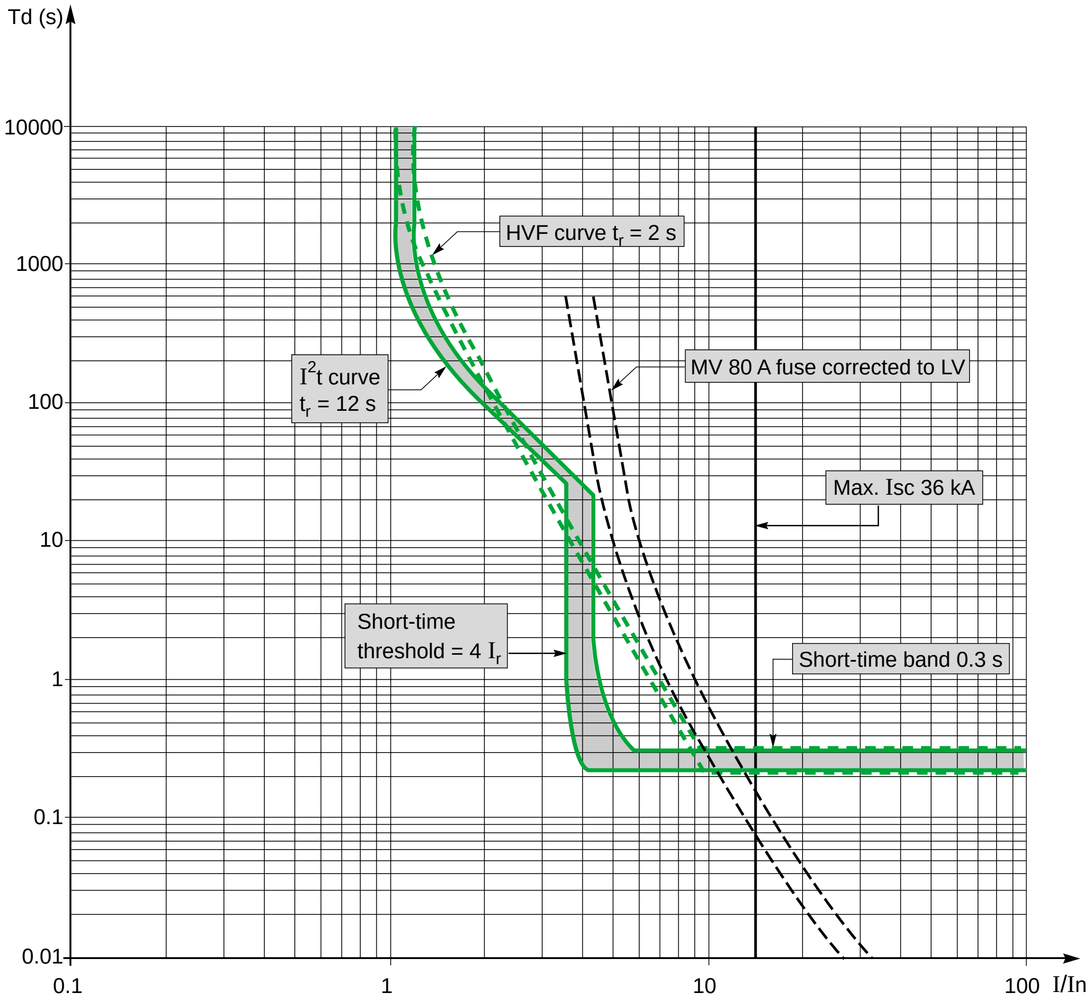


***Fig. 21**: Analysis of discrimination between an LV circuit-breaker and MV fuses - applied to the example of the installation concerned*

These values allow the passage of peak currents at switch-on or starting currents for loads located downstream without false tripping; a detailed study needs to be undertaken on these loads. With a higher short-time delay threshold, 5 I_r for example, tr should be reduced to 4 s.

☐ Short-time delay

As the short-time delay is set on the 0.3 s band, to ensure discrimination with the devices downstream as indicated above, the fuse and circuit-breaker curves cross at around 10 In (see fig. 21). Discrimination between the circuit-breaker and the MV fuse is therefore limited to approx. 25 kA_{rms}, for a maximum short-circuit current Isc of 36 kA_{rms}.

- Settings for trip units with IDMTL curves (see section Trip units with “IDMTL” curves)

With these trip units, it is possible to select the slope of the long-time curve. In this case, we can opt for the “HVF” (High Voltage Fuse) slope, which is the closest to that for the fuse (slope of I^4t). With a delay at 6 I_r of 2s, better immunity to high transient currents (peak currents at switch-on or starting) is possible, in the zone for currents between 5 and 10 I_r, since the short-time threshold can be set at any desired value up to 10 I_r (see fig. 21).

4.4 Variant with zone selective interlocking

This variant requires, for the relevant circuit-breakers, trip units with this function (type Micrologic 5.0 A - Merlin Gerin).

Description

The principle and operation of zone selective interlocking are explained in a “Cahier Technique” dedicated to this type of discrimination.
Remember that each trip unit has four terminals:

- 2 input terminals, for connection to downstream equipment
- 2 output terminals, for connection to upstream equipment

When a trip unit detects a fault above its short-time threshold, it short-circuits both its output terminals.
When a trip unit has a short-circuit on both its input terminals, it activates the short-time delay. Otherwise, it trips instantly.

Implementation in this example

- The first devices (D) and (E) have a permanent short-circuit on their inputs, so that their short-time delay is activated. This ensures discrimination with the stage below (Compact NS circuit-breakers).

- Next the wiring is effected and the short-time delays set according to **figure 22**.

Direct wiring between (E) and (B) on the one hand, (D) and (A) on the other hand, is a means of ensuring discrimination between these devices when the section switch (C) is open. In this case the diodes ensure the independence of both halves of the installation: they avoid (D) acting on (B) and (E) acting on (A).

Operation

- In the event of a fault downstream of (G) (see fig. 20):
  - **(G) trips instantly.**
  - (E) is delayed for 100 ms and does not therefore trip, but sends a signal to (C).
  - (C) is then delayed for 200 ms and does not therefore trip, but retransmits a signal to (A) and (B) which are then delayed like (C).
  - Hence only (G) will trip.

- In the event of a fault between (G) and (E):
  - **(E) trips after 100 ms** and sends a signal to (B) and (C) which are then delayed for 200 ms and therefore do not trip.
  - (C) retransmits the signal to (A) which is then delayed like (C).

If (C) is open, it does not send a signal to (A), which is of no importance since the short-circuit supplied by (B) does not affect (A).

- In the event of a fault between (E) and (C):
  - If (C) is closed, power is supplied to the fault by both incoming lines in parallel.

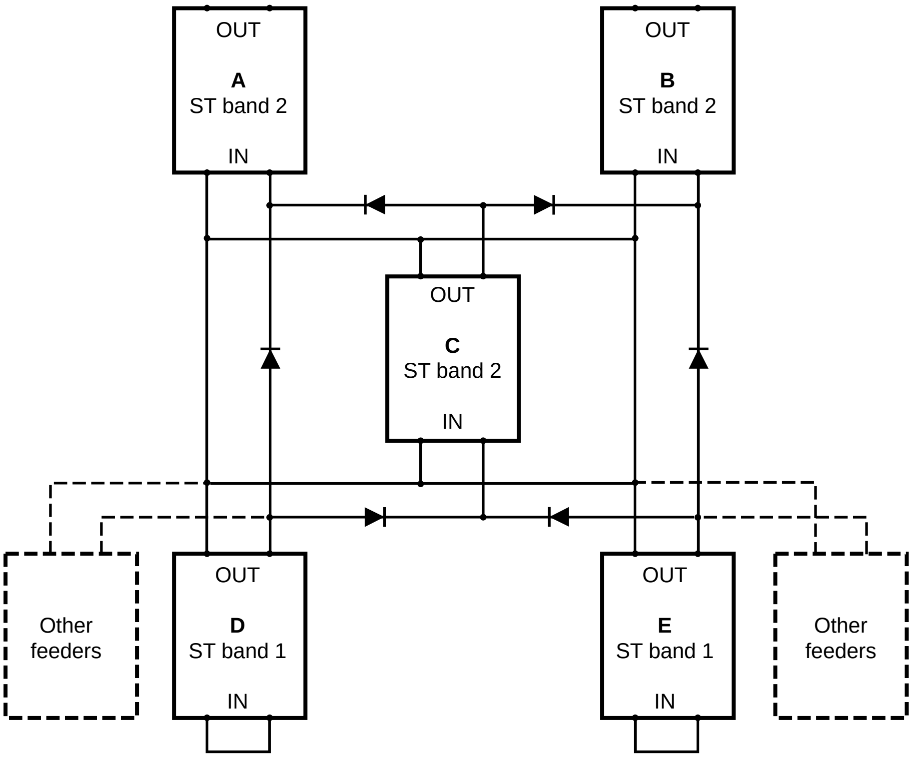


Fig. 22: Use of zone selective interlocking - illustration of time delay settings and trip unit wiring

- **(C) trips instantly** and send a signal to (A) and (B) which are then delayed by 200 ms and therefore do not trip.
- (C) then interrupts the current supplied by the incoming line (A).
- (A) stays closed and maintains the power supply to the part of the installation downstream of its busbar.
- **(B) interrupts** the fault current **after 200 ms**.

□ If (C) is open, it does not send a signal and **(B) trips instantly.**

- In the event of a fault between (C) and (B): **(B) trips instantly.**

NB: A fault between (E) and (C) or between (C) and (B) is extremely unlikely, as these devices are generally located in the same switchboard.

Zone selective interlocking, by reducing or even eliminating the always considerable time delays at the head of the installation, can thus be used to limit stresses on the installation even more effectively when the feeders are close to the network. Therefore, using this technique in this installation, a fault immediately downstream of (A) or (B) is eliminated within tens of milliseconds instead of taking longer than 300 ms.

In addition, since device tripping is instantaneous in nearly all instances, **discrimination with the MV fuses is total**, whereas using time discrimination it was limited to 25 kA$_{rms}$ due to the 300 ms short-time delay of devices (A) and (B).

4.5 Variant with two more powerful incoming lines

This is the same diagram as before, except for the following:

- The transformer power has been increased to **2500 kVA**, and the current on the outgoing circuit at (E) increased to **2200 A.**
- MV protection is provided by MV circuit-breakers (see fig. 23).

The nominal current at (A) and (B) becomes 3520 A and the Isc 54 kA. On the main busbar, Isc becomes 108 kA.

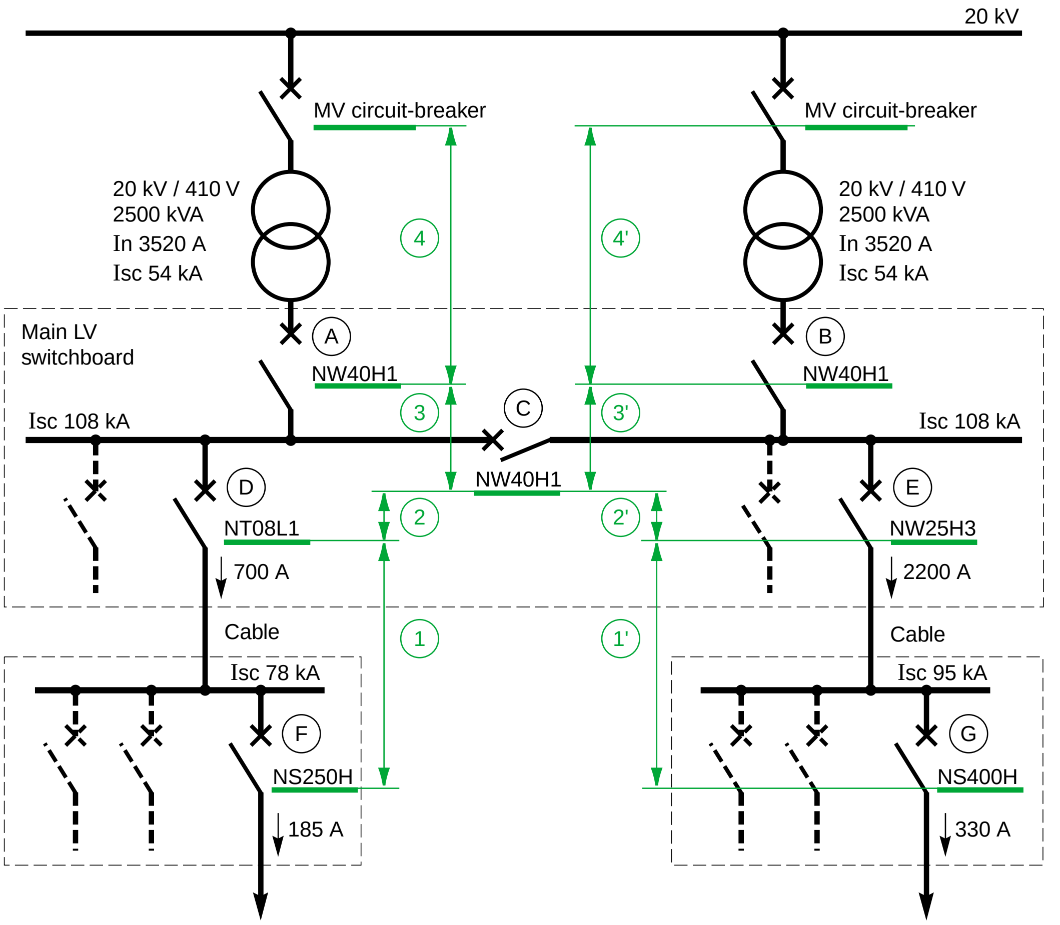


Fig. 23: 2nd installation example (MV/LV transformer power 2500 kVA)

Selecting the MV circuit-breaker

For an MV voltage of 20 kV, it is possible to use a Merlin Gerin “MC-Set” circuit-breaker, with a “transformer” type Sepam protective relay.
This relay has two trip thresholds (see **fig. 24**):

- The first provides protection in the event of a short-circuit between the transformer and the LV circuit-breaker, or in the event of failure of the LV protection.
- The second provides protection in the event of a short-circuit upstream of the transformer.

Selecting the LV circuit-breakers

- Circuit-breaker (E)

Since the Isc is higher than 100 kA, it is not possible to use an NW 25H2 (breaking capacity 100 kA). Nor is it possible to use a current limiting circuit-breaker, since the nominal current does not exceed 2000 A (NW 20L1).
The solution lies in selecting a **selective circuit-breaker with high breaking capacity, such as the NW 25H3**, which offers a breaking capacity of 150 kA, with an I_{cw} of 65 kA/3 s.

- Circuit-breakers (A), (B) and (C)

For In = 3520 A, NW 40H1 type circuit-breakers (In 4000 A, breaking capacity 65 kA, I_{cw} 65 kA/1 s) is chosen.

Setting devices to ensure discrimination

On the basis of the rules defined in section 4.3, the only modifications to be made are for:

①’ the delay for device (E) to be set on the 0.1 s band

②’ device (C) on the 0.2 s band

③ ③’ devices (A) and (B) on the 0.3 s band

If zone selective interlocking is being used, the diagram in figure 22 is still valid.

Setting the protective relay for the MV circuit-breaker ④ ④’

The first threshold should be lower than the short-circuit current downstream of the transformer, ie. 54 kA on the LV side, equivalent to 1100 A on the MV side. It should discriminate against the short-time threshold of circuit-breakers (A) or (B). If this threshold is set at 5 I_r,

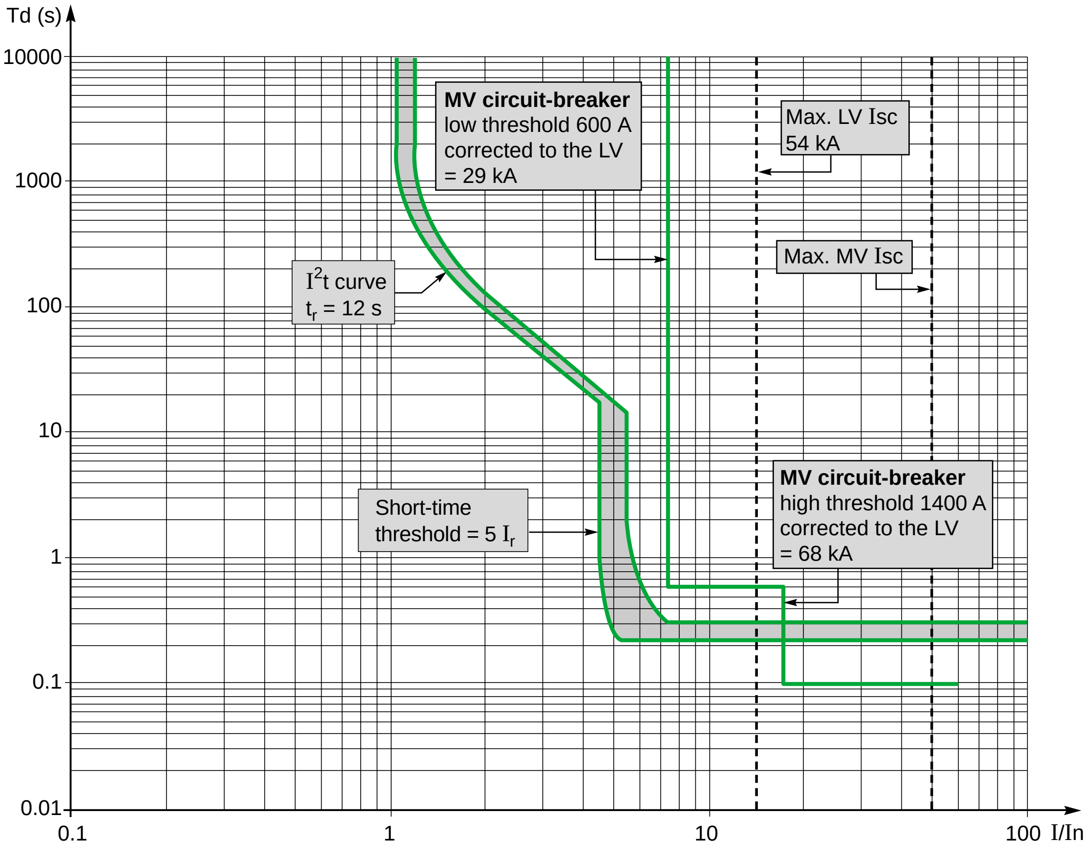


Fig. 24: Analysis of discrimination between LV circuit-breakers and MV protection of the transformer

the corresponding maximum value will equal I_r x threshold x tolerance, or 4000 x 5 x 1.1 = 22 kA, corresponding to 450 A for the MV incoming line. The first MV threshold can therefore be set at **600 A**.

To avoid interference with the short-time delay of 0.3 s, the delay associated with this first threshold is set for example at 0.6 s.

The second threshold should be higher than the above short-circuit current (1100 A), and lower than the short-circuit current upstream of the transformer. Assuming that the network has short-circuit power of 150 MVA, the corresponding current is 4 kA on the MV side. The second threshold can therefore be set at 1400 A.

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