Advel Application Note – AAN2017.1

Sizing a MCB

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1. Introduction

One of the fundamental aspects in the construction of any industrial plant is the selection and positioning of the protection devices: these, in the event of overload or failure or need of maintenance, must be able to isolate a limited part of the system. This characteristic is defined "selectivity" of the system, and requires professionalism, experience, knowledge of regulations and industrial materials to be implemented correctly.

This document is intended to provide just some practical information and some examples only for the choice of circuit-breakers to be put upstream and/or downstream of power supplies/converters in a low voltage industrial plant.

2. Operation of a MCB

The magneto-thermic switch, or **MCB** (Figure 1) is an automatic device able to interrupt all the currents for which it has been designed. Compared to a simple fuse, the advantage is the ease of restoration (using a lever), as well as greater intervention precision.
In the magnetothermic switch, also improperly called 'automatic' circuit breaker, the opening of the circuit is determined by the action of two different tripping devices: one magnetic and one thermal.

The **thermal** switch opening takes place from the deformation of a bimetal lamina caused by the heat, caused by the Joule effect as the current increases. The deformation of the lamina determines the release of the spring, previously loaded manually.
When the current is very high, the opening takes place by **magnetic** means: a force is exerted on an iron core, by an electromagnet.

Substantially, therefore, the thermal opening takes place due to overload with respect to the expected current, and has response times is dependent on the current level (similar to a fuse), while the magnetic trip occurs when there is a short circuit and has very fast response times.

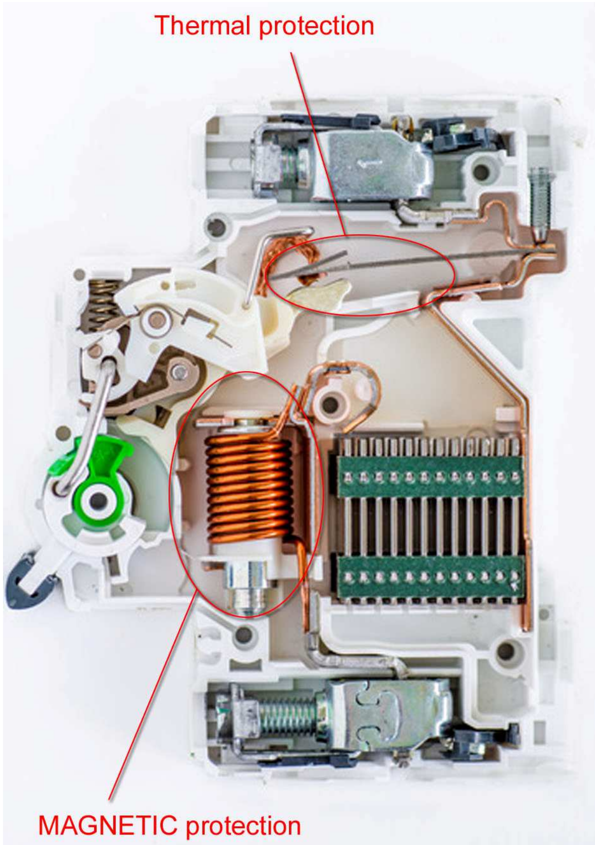


Figure1 *– The figure shows the two magnetic and temical protections inside a typical magneto-thermal switch.*

3. Parameters of a MCB

In general, in an electrical installation, the switch performs the following determining functions:
sectioning and protection of an electrical network against overloads (thermal function) and short circuits (magnetic function).
As far as earth fault protection is concerned, this is achieved by means of differential blocks that can also be mechanically associated to the

switches, but this argument comes out of the end of this document.
The choice of an MCB for the aforementioned functions depends on many parameters including the characteristics of the network on which it is installed, the continuity of service required, the different protection rules to be respected. The circuit breaker must have:
a **nominal voltage** greater than or equal to the voltage between the phases of the network;
a **nominal frequency** corresponding to the frequency of the network (and therefore there is a difference between MCB for AC or DC voltage);
the **thermal protection** of the circuit breaker must be greater than or equal to the rated operational current of the line (max load current) and must be less than or equal to the capacity of the connecting wires (and therefore in the event of overload the switch must intervene in times shorter than the overloads of the wiring cables);
the **breaking capacity** of the circuit breaker must be at least equal to the maximum short-circuit current that can occur (and therefore must not pass a specific energy higher than that which the cables can withstand: compare the I^2t characteristics of the circuit-breaker with the K^2S^2 allowable energy of the cable).
The cross-section and length of the system's wiring cables as well as the ambient temperature can also influence the selection of circuit breakers.

4. Intervention curves

First of all, it must be said that in the industrial field it is necessary to comply with the **EN60947-2** standard, which provides high breaking capacity and meets the safety needs of modern electrical systems in the production sector (therefore a more burdensome service), while for domestic installations the reference standard is **EN60898-1** (civil or tertiary sector).
The switches are classified according to precise characteristics of magnetic intervention:
curve **B**, curve **C**, curve **D**, curve **Z**, curve **K** and curve **MA**, as shown in Table 1.

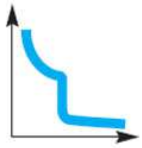
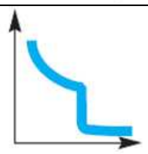
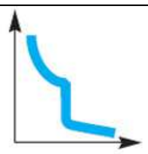
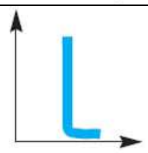
Curve type		Reference standards **EN 60947-2**	**EN 60898**	Typical applications
type **B**		(3,2 ÷ 4,8) I_n	(3 ÷ 5) I_n	*Protection for generators or people or for very long cable lines.* *Generally used with low inrush current circuits, or ohmic loads.* *Standard thermal protection.*
type **C**		(6,4 ÷ 9,6) I_n	(5 ÷ 10) I_n	*Protection for cables and systems that supply classic consumer devices (ohmic-inductive circuits with average inrush currents).* *Standard thermal protection.*
type **D**		(9,6 ÷ 14,4) I_n	(10 ÷ 14) I_n	*Protection for cables and systems that supply user equipment with high starting current (transformers, certain motors).* *Operating current $I_f = 1.3\ I_n$.* *Standard thermal protection.*
type **K**		(9,6 ÷ 14,4) I_n	-	*Protection for cables and systems that supply user equipment with high starting current (transformers, certain motors).* *Standard thermal protection.* *<u>NOTE</u>: with respect to curve D, the curve K MCB have an intervention current $I_f = 1.2\ I_n$.*
type **Z**		(2,4 ÷ 3,6) I_n	-	*Protection for electronic circuits.* *Standard thermal protection.*
type **MA**		(9,6 ÷ 14,4) I_n	-	*Motor protections.* *<u>Without</u> thermal protection.*

Table1 *– The table shows the magnetic tripping characteristics of the different types of circuit-breakers, with reference to current regulations, and the typical applications are indicated.*

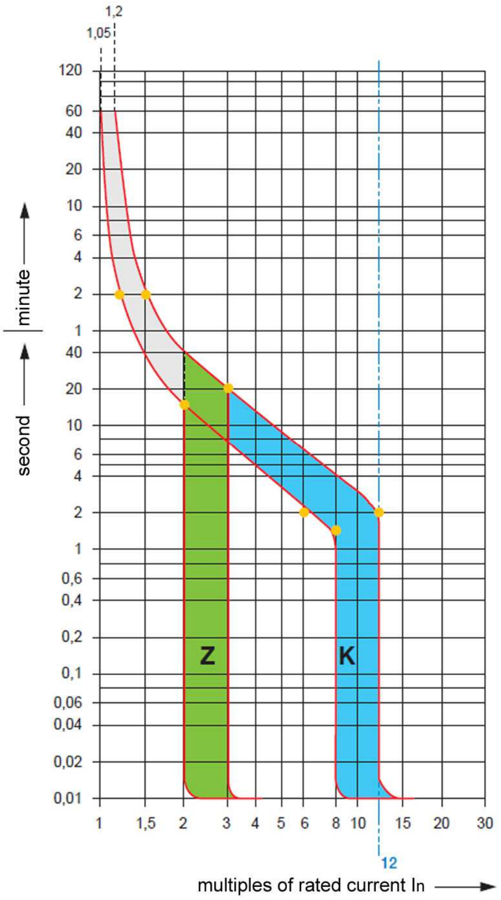


Figure2a *– Characteristic for magneto-thermal switches -Z and -K (EN60947)*

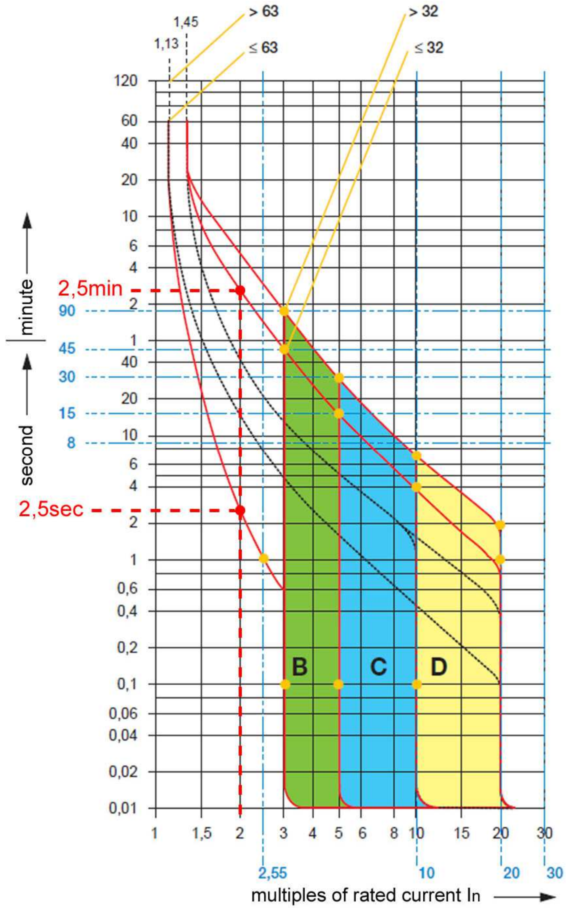


Figura2b *– Characteristic for magneto-thermal switches B, C and D (EN60898).*

Figures 2a and 2b show the typical tripping characteristics of the magneto-thermal switches.

Intervention bands are indicated in the graphs. For example for the curves B, C and D, the intervention zone is between 1.13In and 1.45In assuming an ambient temperature of 30°C (for higher temperatures the current values decrease by 6% for each increase of 10K of temperature).

Practical example:
*consider a **B10** MCB, that is a switch with a nominal operating current I_n = **10A** and curve **B** (suppose that T_{amb} = 30°C). If a current 20A (or 2xI_n) flows in that MCB, looking at the characteristics of Figure 2b, it is deduced that the circuit breaker will open thermally in a time ranging from 2.5 seconds to 2.5 minutes.*
If instead the current is > 30A (ie 3xI_n) the switch opens instantly magnetically ('instantly' means no less than 10msec about).

5. Input current of a power supply

Having to choose a MCB for input or output of a power supply, first of all it is necessary to know the main characteristics of the selected power supply.

A power supply is generally defined by the following main parameters:

$V_{in\text{-}rated}$
$P_{out\text{-}max}$
$V_{out\text{-}rated}$

The power supply, when is fully loaded, absorbs a maximum input current $I_{in\text{-}max}$, that can be calculated with the following formula:

$$I_{in-\max} = \frac{\left(\frac{P_{out-\max}}{\eta}\right)}{V_{in-\min}}$$

when:

η = efficiency of the power supply (typically the switching power supplies can have an efficiency ranging from 80% to 95%, depending on the technology of the power supply, the power cut, the input and output voltages, …);

$V_{in\text{-}min}$ = the minimum input voltage to which the power supply can operate (typically assuming a value $V_{in\text{-}rated}$ – 20%).

Having to choose a precautionary value, we can consider:

$$I_{in-\max} = \frac{\left(\frac{P_{out-\max}}{0{,}8}\right)}{V_{in-nom} - 20\%}$$

Based on this value, the rated operating current I_n of the input MCB for the power supply can be defined (I_n = the highest current that can circulate continuously at a given reference ambient temperature) which must be ≥ $I_{in\text{-}max}$.
The type of MCB curve depends instead on the insertion current, or **Inrush** current of the power supply.

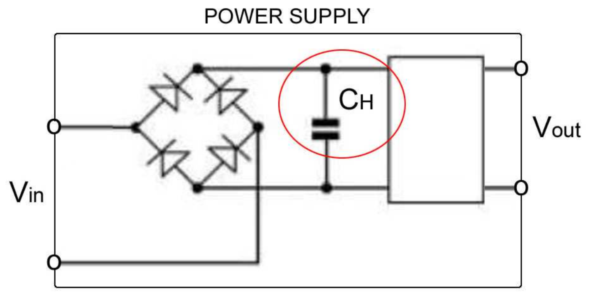


Figure2 *– Qualitative diagram of an AC/DC power supply, with highlighted the Hold-Up capacitor, C_H.*

Each AC/DC power supply has inside a certain number of capacitors at its input, the so-called Hold-Up capacitors, C_H in Figure 2, which, having to be charged, when the power supply is turned on they require a classic current peak: this is called Inrush current (analogous speech also for DC/DC power supplies).
All power supplies present an Inrush current limiting circuit, which prevents it from reaching very high values ... however not all Inrush current limiting circuits have the same performance. For example, in low power models (<500W) this circuit is almost always made by simple NTCs (we do not go into the technical details in question) and therefore the peak of the Inrush current depends a lot on the working environment temperature.
For example, a power supply with an NTC for limiting the Inrush current, at the first power on (cold power on) can present $I_{inrush} = 3 \div 5\ I_{in\text{-}max}$. However, the power supply warms up during operation, and therefore if it is switched off and immediately switched on again (not allowing the internal NTC to cool down), it will present a value of I_{inrush} much higher than the cold power on, up to 10 $I_{in\text{-}max}$.
Unfortunately the datasheets of power supplies never indicate how the Inrush circuit is realized, for this reason for the input of the power supplies it is always advisable to use a switch with characteristic curve of type D.

6. Output current of a power supply

A power supply unit can continuously output a maximum $I_{out\text{-}max}$ current defined on the datasheet. If not specified, this value can be calculated with the simple formula:

$$I_{out-\max} = \frac{P_{out-\max}}{V_{out}}$$

Some power supplies, equipped with "power boost" technology, can supply a current even greater than $I_{out\text{-}max}$, but for a short time.
For example:

$I_{out\text{-}boost} = I_{out\text{-}max}$+50% for 200msec
or $I_{out\text{-}boost} = I_{out\text{-}max}$+100% for 100msec

Also in this case the parameter is defined by the manufacturer's datasheet, however the $I_{out\text{-}boost}$ is so short that it is typically not able to open, by thermal means, an automatic circuit breaker. For example, in Figure 2b we have seen that a curve B type MCB opens in thermal mode in at least 2.5 seconds if a $2xI_n$ current flows therein, regardless of the characteristic curve.

When choosing a magneto-thermic switch for the output of a power supply, the **short-circuit current** $I_{out\text{-}cc}$ must be considered: how much current a power supply is able to deliver if its output is put in short circuit?

Consider the qualitative circuit of Figure 3, in which the various R_{WIRING} resistances are also indicated in addition to the LOAD.
$R_{contact}$ is the resistance present in the connection between a cable to an apparatus, by clamp (sliding or screw) or welding or faston ... it can be assumed that this resistance is about 20mΩ (typical value).
The R_{WIRING} resistance is given by the sum of the connection cable resistance (R_{WIRE}) and the 4 contact resistors (4 x $R_{contact}$).
Definitely:

R_{WIRING} = 4 x 20mΩ + R_{WIRE}

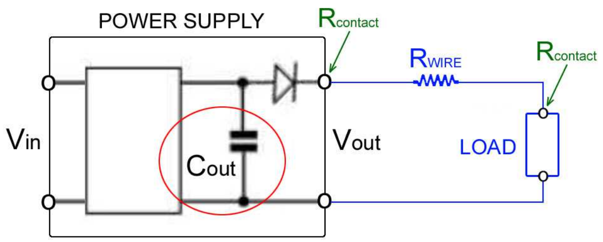


Figure3 *– Qualitative diagram of a power supply, with a LOAD. The various wiring resistances are also highlighted.*

Assume that the LOAD goes in short-circuit: a good quality power supply can withstand a short-circuit condition at the output for a long time, and deliver a current

$I_{out\text{-}cc} = I_{out\text{-}max}$ + 30÷50% (typical).

However, before reaching this value, the output current of the power supply has an initial current peak $I_{out\text{-}pk}$: in fact, looking at Figure 3, when LOAD goes in short circuit, obviously the output capacitor C_{out} of the power supply is discharged very quickly.

$$I_{out-pk} = \frac{V_{out}}{R_{WIRING}}$$

Let's try to realize the R_{WIRING} value by giving an example.

Quick example:

- power supply with $V_{out-rated}$ = 24VDC
- LOAD 1mt far from the power supply (and therefore the length of the wire is L_{WIRE} = 2mt in total)
- load current = 10A → wire with $A_{WIRE} = 2{,}5mm^2$ (in order to have the typical current density of $4A/mm^2$ for the wire)

In this case, considering the resistivity of the copper (about **$\varphi_{copper} = 0{,}018\Omega mm^2/m$**), we can calculate:

$$R_{WIRE} = \frac{0{,}018 \times L_{WIRE}}{A_{WIRE}} = \frac{0{,}018 \times 2mt}{2{,}5mm^2} = 0{,}0144\Omega$$

$R_{contact} \cong 0{,}02\Omega$ (typical value)

→ $R_{WIRING} = R_{WIRE} + 4R_{contact} \cong 0{,}095\Omega$

Therefore, by putting the output of the power supply in short circuit, there is a first current peak equal to:

$$I_{out-pk} = \frac{V_{out}}{R_{WIRING}} = \frac{24V}{0{,}095\Omega} = 252A$$

The example just done serves to understand the order of magnitude of the value that the current peak I_{out-pk} can reach.
However, this peak of current decays very quickly: in fact it is the discharge current for C_{out}, the drop happens with time constant RC = R_{WIRE} x C_{out}.
Figure 4 shows the trend of the short-circuit current of a power supply in which the output is short-circuited at time t_0.

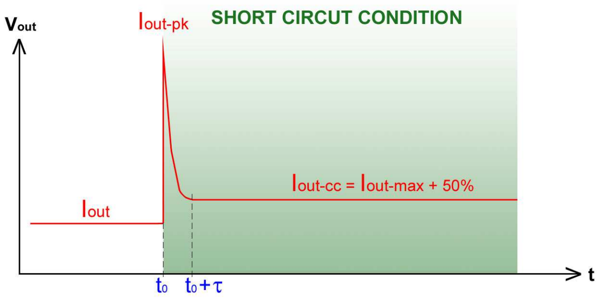


Figure4 *– Output current trend of a power supply short-circuited on the output*

As we can see, the descent time of the short-circuit current, called τ in Figure 4, depends on the wiring parameters, as well as on the characteristics of the power supply, as well as on the type of fault of the LOAD (not always dealing with a <u>net</u> short circuit).
It can be assumed that within a relatively short time (a few msec) C_{out} has already been discharged and therefore that the short circuit current has already reached the steady state value, which is $I_{out-cc} = I_{out-max}$ + 30÷50% as said before (and dependind no longer from C_{out}, but from how much the power supply can stay in this condition).

<u>NOTE</u>: this peak current, given its very short duration, must not come into play with regard to the sizing of the wiring cables, but it is good that is present (also because required by the **EN60204-1** Machine Directive): this peak allows a possible magneto-thermic switch to open (naturally magnetically).

<u>NOTE</u>: as the length of the connection cables increases, the R_{WIRE} takes on increasingly higher values. It follows that the peak of the short-circuit current is lowered as the length of the connecting cables increases, ie with the increase of R_{WIRE}.
This is the reason why, in Table 1, it has been indicated that the curve B MCB are suitable for "*very long cable lines* ".

7. AC or DC MCB

Magneto-thermic switches in AC or DC voltage/current mode work in the same way. However, as it is easy to understand, is less difficult interrupting an alternating current (which has periodic zero transitions, as showed in Figure 5) than a continuous current, in which a greater magnitude of the **electric arc** that is created inside the switch.

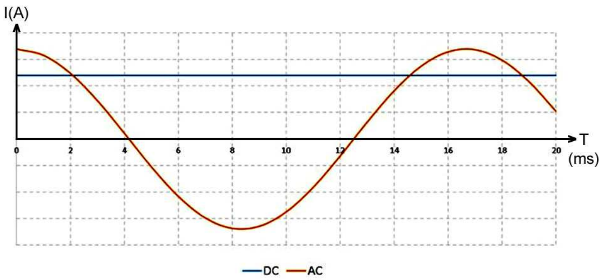


Figure5 *– Comparison between alternating and continuous current.*

Therefore, once the rated operating current I_n and the curve of the MCB have been decided, care should always be taken if this is suitable for working in alternating and/or continuous operation.
Moreover, in continuous operation, it is sometimes sufficient to interrupt only one phase, while in an alternate regime it is always necessary to interrupt both phases.

Now it is useful to make a practical example of calculation.

8. EXAMPLE

Suppose you have an AC/DC power supply with the following characteristics:

$V_{in\text{-}rated}$ = 115VAC_50Hz
$P_{out\text{-}max}$ = 1000W
$V_{out\text{-}rated}$ = 110VDC

Suppose you want to put two magneto-thermic switches: one in input and one in output (system in Figure 6).

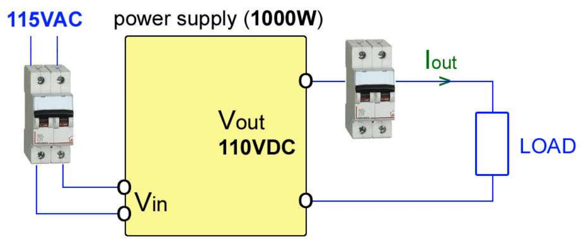


Figure6 *– AC/DC System with n.2 MCB, for input and output.*

Input MCB:

$$I_{in-\max} = \frac{\left(\frac{P_{out-\max}}{0{,}8}\right)}{V_{in-nom} - 20\%} = \frac{\frac{1000W}{0{,}8}}{115VAC - 20\%} = 13{,}6A_{RMS}$$

→ a **D15** automatic switch can be used (which is suitable for tolerating very high Inrush currents) bipolar.

However if, for example, the wiring cable between the 115VAC network and the power supply is very long, let's suppose distance = 100mt, would you choose another MCB?

Some calculation must be done:
being an $I_{in\text{-}max}$ = 13.6A → a cable with section A_{WIRE} = 4mm^2 must be chosen (so as to ensure a current density on the cable not exceeding 4A/mm^2, typical value).
Distance between mains and power supply 100mt → cable length L_{WIRE} = 2 x 100mt = 200mt in total.
The resistance of the cable is given by:

$$R_{WIRE} = \frac{\rho_{copper} \times L_{WIRE}}{A_{WIRE}} = \frac{0{,}018 \times 200mt}{4mm^2} = 0{,}9\Omega$$

then we must consider the total contact resistance (as explained in the example of the previous paragraph):

$R_{contact} \cong 0{,}08\Omega$ (typical)

It can therefore be said that surely:

$$I_{inrush} < \frac{115VAC}{R_{WIRE} + R_{contact}} = \frac{115VAC}{0{,}9\Omega + 0{,}08\Omega} = 118A$$

In reality, thanks to the Inrush current limiting circuit inside the power supply, the I_{inrush} will stay certainly below 118A.

Considering that:

int. **C10** → magnetic intervention 75 ÷ 150A
int. **D10** → magnetic intervention 150 ÷ 300A

it would be certainly more correct to use a **C10** MCB, since I_{inrush} <118A.

Output MCB:

$$I_{out-\max} = \frac{P_{out-\max}}{V_{out}} = \frac{1000W}{110VDC} = 9{,}1A_{DC}$$

→ it can be used a **B10** or a **C10** or a **D10** MCB, that must be suitable for 110VDC voltage at least.

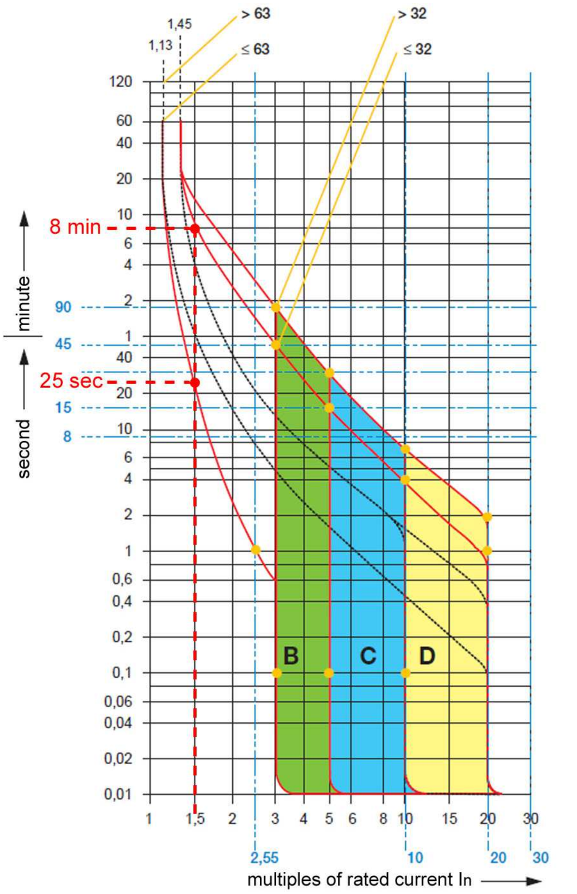


Figura 7 *– Characteristic curves for B, C and D MCBs. Thermal tripping times are showed for an overload of 1,5I_n.*

For example, the magneto-thermal switches **S202MB10**, **S202MC10** and **MCB60161** have the following characteristics:

product code	S202MB10	S202MC10	C60N
manufacturer	ABB	ABB	Schneider El.
series	S200	S200	C60N
I_n	10A	10A	10A
I_{cu}	10kA	10kA	10kA
Curve type	B	C	D
voltage ca	400VAC	400VAC	240VAC
voltage cc	125VDC	125VDC	125VDC

It should be noted that, and this is always valid, the magneto-thermal circuit breakers, with the same rated current I_n, have the same area relative to the thermal intervention regardless of whether the characteristic curve is B, C or D.

In this example we can assume that, in the output short-circuit condition, the power supply can deliver the current:

$$I_{out-cc} = I_{out-\max} + 50\% = 15A \text{ about.}$$

In this condition the three MCBs open in a time between 25sec and 8min (as shown in Figure 7).
However, if the short circuit is net and takes place suddenly, there will be a very high current peak I_{out-pk} :

if $30A<I_{out-pk}<50A$ → MCB **B10** opens magnetically
int. **C10** does not open magnetically (but opens thermally within 8 min.)
int. **D10** does not open magnetically (but opens thermally within 8 min.)

if $50A<I_{out-pk}<100A$ → MCB **B10** opens magnetically
MCB **C10** opens magnetically
MCB **D10** does not open magnetically (but opens thermally within 8 min.)

if $I_{out-pk}> 100A$ → MCB **B10** opens magnetically
MCB **C10** opens magnetically
MCB **D10** opens magnetically

As already said above, the current peak I_{out-pk} is function of the wiring (section and length of the wires, type of connections, ...), of the characteristics of the power supply (C_{out}) and even of the type of short circuit.
Therefore using a curve switch B, C or D depends on these parameters, as well as on the customer's need:
if the customer will use the switch simply as a disconnecting device, it is more than just a classic C10 switch.
If, on the other hand, the LOAD has a very high starting current (or inrush current), a D10 switch should be chosen.
If the customer wants to be protected as much as possible from the short-circuit currents, or if the wiring cables are very long, a B10 type MCB have to be chosen.

Since it is a direct voltage, it is also possible to use unipolar magnetothermal switches.

9. THE FUSES

It is right to mention the fuses: there are various types fuses (rapid, ultra-fast, slow, ...) but qualitatively have the intervention characteristic curve shown in Figure 8: the opening is as quickly as the greater the current that exceeds the their nominal value, similar to the magneto-thermal switches in the thermal tripping area.

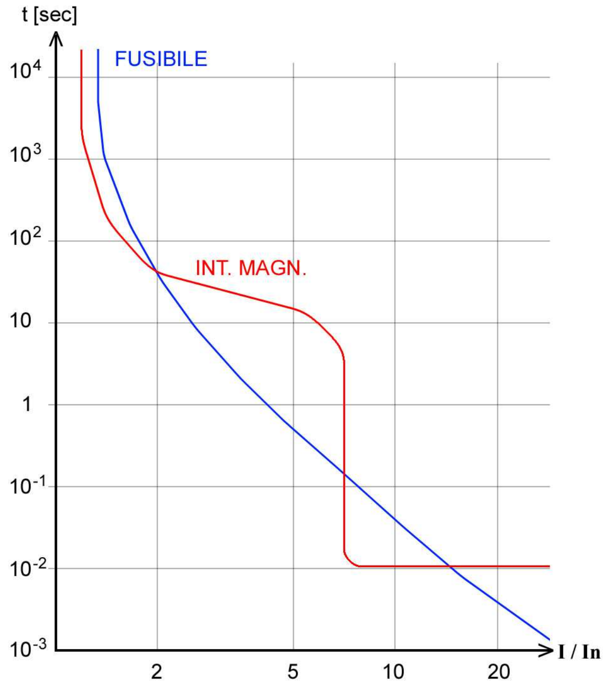


Figure 8 *– Typical trippng characteristic of a fuse (in blue) compared to the typical characteristic of a magneto-thermic switch (in red).*

It should be noted that the circuit breakers can not open in less than about 10msec (magnetic opening), while the fuses can open faster. For this reason, in cases where the presumed short-circuit currents reach very high values, it may be convenient to use a combination of fuses and magneto-thermic switches.

Finally, the fuse, although it requires recovery times much higher than those of MCBs, allows a simple and safe selectivity, has a very high breaking capacity, moreover, besides ensuring excellent reliability, it is very cheap.

9. CONCLUSIONS

A very general overview has been made about the operation and characteristics of the thermal-magnetic circuit breakers, and finally a real example of sizing and selection of two switches for input and output of an industrial power supply was made.
It is deduced that the choice of MCBs depends not only on the characteristics of the power supply, but also on the load associated with it, the wiring of the system and the specific needs of the customer.

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