# ELECTRICITY

## ELECTRICAL PROTECTIONS

**TRAINING MANUAL**
**Course EXP-MN-SE110**
**Revision 0**

# ELECTRICITY

## ELECTRICAL PROTECTIONS

## SUMMARY

# 1. OBJECTIVES

At the end of the course, the electrician (o going to be) must be able to

- Define types of protections in electrical distribution
- Identify physically any electrical device or material having protection functions, within a switchgear or MCC
- Select the appropriate electrical protection according to load
- Differentiate the different types of fuses
- Choose, determine, the required protection breakers and/or thermal relays
- Explain the use and functions of any type of protection relays used in electrical distribution
- Differentiate isolator, switch, contactor, relay, breaker and associate them appropriately in a schematic diagram
- Expose the different principles in earthing protection (RCD, PIM,…)
- Identify and select the proper lightning protection in an electrical (and low power domain) distribution
- Use this document as a reference booklet, coming back to it when required, adding notes, and…correcting it, if needed…

# 2. INTRODUCTION

## 2.1. THE ELECTRICAL PROTECTION ?

Subject to standardisation, in France with the C15-100 of UTE (Union Technique de l'Electricité), last edition 05.02.2002. This standard clearly identify and separate protection of personnel and protection of materials.

The electrical risk is at first physical: the **human body** accidentally in contact with voltage is conducting electrical current which can produce:

- Internal or external burns
- Muscular tetanization

Then, for the **materials**, the risks and consequences are mainly thermal: all electrical cables, features, apparatus…etc, allow a rated (and maximum) current. Excess current gives overheating (by Joule Law) which can cause deterioration and/or fire; short-circuit can be classified as a "speedy" overheating.

## 2.2. PROTECTION OF PERSONNEL

Risk is to be in contact with an electrical conductor either by **"direct contact"** or **"indirect contact"** through a defective insulation. Serious (and fatal) danger starts from a current of 500 mA during 10 ms through the human body. Intensity of current is related to skin surface and pressure in contact, health of victim, status of skin (callous or soft hands), wet or dry conditions,…etc.

Value of human body (ohmic) resistance is generally taken at (lowest) 2000 ohms. VLVS (Very Low Voltage Safety – TBTS in French) maximum value is limited at 50 volts (in AC, 50 Hz). This gives a current through the body (in case of direct contact) of 50 / 2000 = 25 mA under the value of risk.

Protection of personnel in electrical distribution is performed by using the RCD (Residual Current Detector) *or differential* method; system detecting a faulty current towards the ground and making and associated switch or breaker to trip (threshold being 30 mA). As complementary protections, all mobile (portable) tools and equipment's must be *double insulation* type, an equipotential ground wire has to be included in all distributions.

In this course, we shall see the RCD system but see as well the specific courses on this subject: *SE070 Ground and neutral* systems and *SE080 Electrical Safety*

## 2.3. PROTECTION OF MATERIAL

Risk on material comes generally from the deterioration of the insulation, itself caused by a too high current which can be even a short-circuit.

Permanent current measurement allows the detection of an "appearing" too high value and its interruption through switches and breakers (and fuses). Overheating of equipment is due to overcurrent, ambient conditions and some other parameters which can cause, at final, fire on electrical equipment

*Figure 1: Fire on a Power Transformer*

Such "accident" on Power Transformer has increased from 1% (of the installed units) in 2001 to 2% in 2008 (*status made beginning of 2008 from 2007 records).*

Do not think it is going to improve; we shall have more and more problems due simply to ageing material not being replaced and the general trend of "cost reduction"….. In our industry, we (apparently) still give priority to Safety, electrical distribution being well equipped.

However, I have already seen some signs of this 'cost reduction'" philosophy in electrical domain *(breakers not equipped with adjustable multiple trips inducing no selectivity in the plant – main breaker always tripping - as an example, among others…)*

**So, please, be alert with Electrical Protections**

## 2.4. TYPES OF ELECTRICAL PROTECTIONS

Once an electrical « problem » occurs, being detected, the nearly only one alternative is to open the faulty concerned circuitry. Consequently there are two categories of materials in electrical protection

- The fault detecting device
- The separation apparatus

We can even associate these two functions in one type of material, the breaker for example. Nevertheless breaker is not the only device used in the "protection chain", numerous other apparatus complement the electrical protections; we shall see the majority of them with:

- Fault Detection Relays in HV and LV
- Earth Fault Detection (RCD or Differential – Permanent Insulation Controller)
- Fuses, Fuses holders
- Isolators
- Contactors
- Switches
- Breakers
- Surge Protection (Lightning Protection)
- Busbars Protection – Homopolar Protections
- Protection integrated in a machine (or specific to a machine)
- Cathodic Protection
- *And what has been forgotten or put in an other course*

In this training program, 3 courses are more or less associated; this one EXP-MN-SE110 and *SE100 Electrical Networks* + *SE120 Electrical Panels (MCC & Switchgears)*; consequently, if you do not find “your subject” here, it is probably elsewhere…

# 3. PROTECTIVE RELAYS

## 3.1. FUNCTIONS OF PROTECTION AND THEIRS APPLICATIONS

Relays or multifunction devices fulfil the functions of protection. At the origin, the relays of protection used only one function and were analogue type.

Now, the technology is digital and then it is possible to conceive increasingly advanced functions and the same device generally carries out several functions.

This is why, we say rather multifunction devices.

The relays of protection are devices which verify permanently the electric network (current, voltage, frequency, power, impedances...) with predetermined thresholds and which make an automatic action (generally opening of a circuit breaker) or an alarm.

The role of the protection relays is to detect any abnormal phenomenon being able to occur on an electrical network such as short-circuit, variation of voltage, dysfunction of a machine, etc.

The relay can be:

**1)** Without auxiliary power supply (autonomous) when the necessary energy for its operation is taken directly from the supervised circuit. The actuator must be sensitive because the power taken on the circuit is weak;

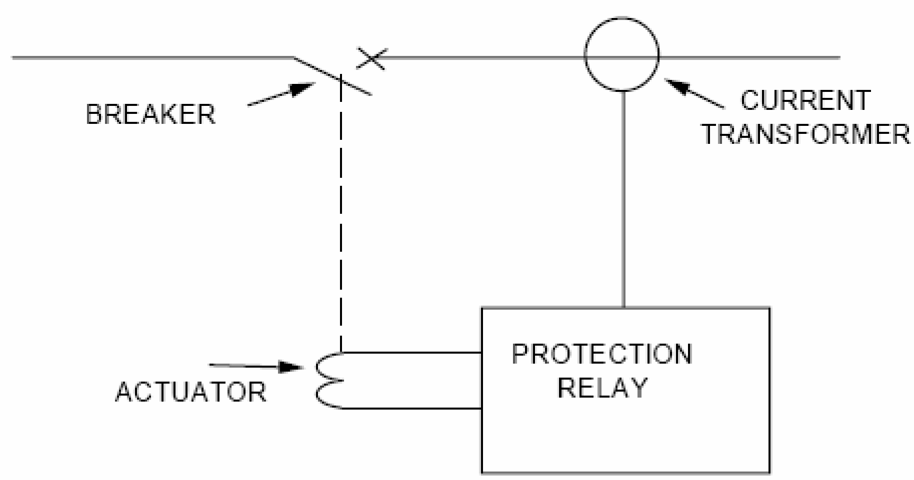



*Figure 2: Connection of an overcurrent relay without auxiliary power*

**2)** With auxiliary power supply when the necessary energy for its operation is taken from an auxiliary source of voltage (DC or AC) independent of the supervised circuit

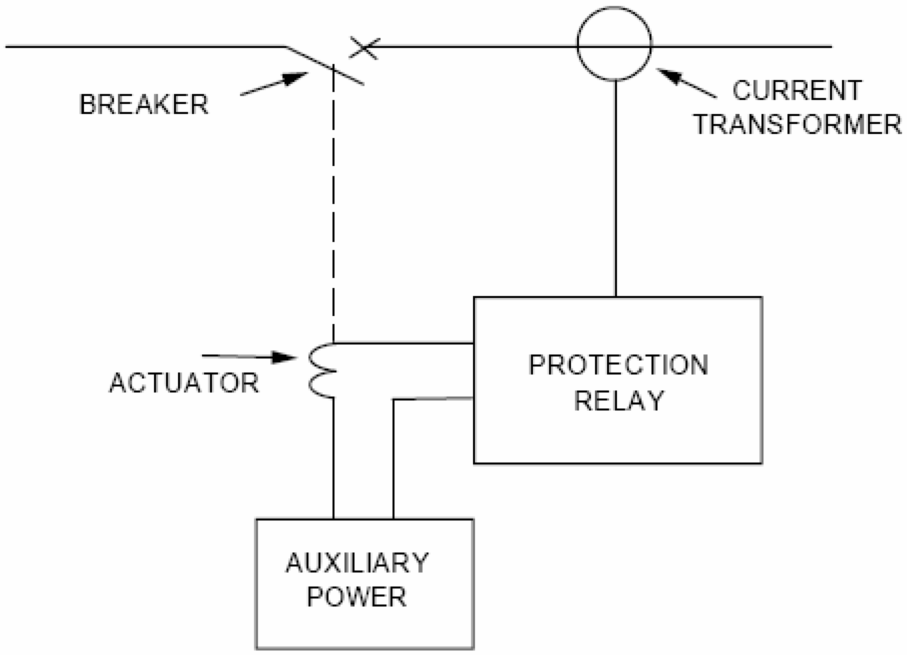



*Figure 3: Connection of an overcurrent relay with auxiliary power*

## 3.2. STANDARDISATION

All types of electrical faults have been “codified” with the ANSI code giving one reference number (+ letter), one symbol, for each.

### 3.2.1. ANSI Code

| Code | Protection |
|---|---|
| 27 | System undervoltage |
| 27D | Positive sequence undervoltage |
| 27R | Remanent undervoltage |
| 32P | True (active) reverse over power |
| 32Q<br>40R | Reactive over power / field loss |
| 37<br>37P<br>37Q | Phase under current/ Under power |
| 38<br>49T | Temperature monitoring (Pt 100) |
| 46 | Negative sequence unbalance |
| 47 | Phase rotation direction cheek |
| 48 | Excessive starting time |
| 49 | Thermal overload |
| 50 | Instantaneous phase overcurrent |
| 50N | Instantaneous earth fault |
| 51 | Time phase current |
| 51LR | Lock rotor |
| 51N | Time earth fault |
| 51V | Voltage restrained overcurrent |
| 59 | System overvoltage |
| 59N | Neutral voltage displacement |
| 64REF | Restricted earth fault |
| 66 | Starts per hour |

| | |
|---|---|
| **67** | Directional overcurrent – 1 phase |
| **67N** | Directional earth fault |
| **81** | Over frequency |
| | Under frequency |
| **87B** | Busbars differential |
| **87G** | Generator differential |
| **87M** | Motor differential |
| **87T** | Transformer differential |
| | **Control and monitoring** |
| **25** | Check synchronising |
| **26** | External thermal relay |
| **30** | Alarm |
| **34** | Local switchgear PLC |
| **55** | Out of step |
| **63** | Buchholz, detection of gas, pressure |
| **68** | Logic discrimination |
| **69** | Inhibit closing |
| **86** | Lockout relay |
| **74** | Trip circuit supervision, detection of plugged connectors |
| **79** | Recloser |

*Table 1: ANSI CODE*

### *3.2.2. Glossary*

**Phase overcurrent** (50 / 51)

Three phase connection and equipment protection against phase-to-phase faults. The following types of time delay settings are available: definite, standard inverse, very inverse and extremely inverse.

**Tank earth leakage** (50 / 51)

Quick, selective detection of earth leakage current in transformer primary and secondary windings. This is an additional overcurrent protection function. For it to be used the transformer tank must be insulated and a current sensor must be installed on the frame earthing connection.

**Neutral unbalance** (50 / 51)

Detection of unbalance current between the neutral points of star-connected capacitor banks; unbalance current indicates that components of one of the capacitors is damaged.

**Voltage restrained overcurrent** (50 / 51V)

Three phases' protection against alternator phase faults. Its characteristics are suitable for the weak current supplied by the alternator when short-circuit occurs.

**Earth fault** (50N / 51N)

Protection against earth faults. The following types of time delay settings are available: definite, standard inverse, very inverse and extremely inverse.

**Neutral** (50N / 51N) or **Sensitive earth fault** (50G / 51G)

Overload protection of neutral earthing impedance and sensitive overall network protection against earth faults. This is an additional earth fault protection function

**Directional overcurrent** (67)

Incomer protection, which provides quick, selective protection against upstream faults when there are several parallel transformer incomer in the network.

**Directional earth fault** (67N)

This protection has several uses:

- highly sensitive earth fault protection of transformer feeders supplied by long cables characterised by high capacitive current
- quick, selective detection of upstream earth faults when there are several parallel transformers in the network.

### Thermal overload (49)

Protection of equipment against thermal damage caused by overloads. Thermal overload is calculated according to a mathematical model, with 2 time constants, taking into account the effect of negative sequence current by means of an adjustable weighting coefficient:

- an adjustable setting to define motor warm state
- an adjustable tripping setting

### Negative sequence / unbalance (46)

Protection of equipment against overheating caused by an unbalanced power supply, phase inversion or phase break, and against low levels of overcurrent between 2 phases.

### Locked rotor / excessive starting time (48/51LR)

Protection of motors that are liable to start with overloads or insufficient supply voltage and/or drive loads that are liable to become locked (e.g.: crusher). It is an overcurrent protection that is only confirmed after a time delay, which corresponds to the normal start time.

### Starts per hour (66)

Protection against overheating caused by too frequent starts. Checking of:

- number of starts per hour
- number of consecutive warm starts (detected by the thermal overload protection)
- number of consecutive cold starts

The protection inhibits motor energising for a preset time period when the permissive limits are reached.

### Undercurrent (37)

Pump protection against the consequences of priming loss. This protection detects delayed undercurrent corresponding to motor no-load operation, which is typical of a loss of pump priming. Other relays: 37P (under active power) and 37Q (under reactive power)

**Undervoltage** (27)

Protection used either for automated functions (changeover, load shedding) or for the protection of several motors against undervoltage. This protection checks for undervoltage in each of the system voltages measured.

**Positive sequence undervoltage** (27D)

Protection which prevents motor malfunctioning due to insufficient or unbalanced supply voltage

**Remanent undervoltage** (27R)

Monitoring of the clearing of voltage sustained by rotating machines after the opening of the circuit. This protection is used with automatic changeover functions to prevent transient electrical and mechanical phenomena that are caused by fast re-supply of power to motors.

**Direction of rotation** (47)

Protection which prevents the changing of direction of motor rotation following a power supply modification

**Overvoltage** (59)

Protection against abnormally high voltage and checking that there is sufficient voltage for power supply changeover

**Neutral voltage displacement** (59N)

Detection of insulation faults in ungrounded systems by measurement of neutral voltage displacement. This protection is generally used for transformer incomer or busbars.

**Under frequency** (81)

Detection of variances with respect to the rated frequency, in order to maintain high quality power supply. This protection can be used for overall tripping or for load shedding

### **Over frequency** (81)

Protection against abnormally high frequency

### **Reverse true (active) power** (32P)

Protection of synchronous motors against operation as generators when driven by their load

### **Reactive overpower** (32Q / 40R)

Protection of synchronous drives against field loss, which causes over consumption of reactive power and leads to the loss of synchronism

### **Temperature monitoring by RTD** (38 / 49T)

Protection, which detects abnormal overheating of motors (bearings and/or windings), equipped with PT100 type platinum resistive temperature probes.

### **Motor differential** (87M)

Fast, sensitive motor protection against internal faults due to damaged insulation. The protection is based on the principle of percentage differentials, i.e. starting current restraint to sustain stability in spite of its high level of sensitivity

### **Synchronism check** (25)

Authorises the closing of the breaking device, only if the two circuits have voltage, frequency and phase gaps within the planned limits. The choice of an operating mode with voltage absent allows the generator to be coupled with a de-energised installation.

### **Restricted earth fault** (64REF)

A restricted earth fault protection is available on the secondary side of the protection. It is used to detect phase-to-earth faults in the transformer winding connected to the secondary side of the protection. It may be used when the secondary neutral point is earthed inside the protected zone.

## 3.2.3. Symbols

| Symbol - graphic | Code ANSI | Designation |
|---|---|---|
| $I>$ | 50<br>51 | Phase overcurrent |
| $I>$<br>$I>>$ | | Phase overcurrent with 2 settings |
| $I \leftarrow$ | 67 | Directional overcurrent<br>Phase directional |
| $I_N>$ | 50N<br>51N | Neutral earth fault |
| | 50 G<br>51G | Sensitive earth fault |
| $I_N\leftarrow$ | 67N | Directional earth fault |
| $\Delta I$<br>$\frac{\Delta I}{I}$ | 87M | Motor differential |
| | 87G | Generator differential |
| | 87B | Busbars differential |
| | 87N<br>87REF | Restrained earth differential |
| | 87T | Transformer differential |
| | 87L | Cable pilot wire differential |
| $I$ | 49 | Thermal overload |
| $T>$ | 38<br>49T | Temperature Protection |

| | | |
|---|---|---|
| *Ii>* | 46 | Negative sequence |
| | | Unbalance |
| | 51LR | Locked rotor |
| | 48 | Excessive starting tome |
| | 66 | Start per hour |
| *I<* | 37 | Undercurrent |
| *> f >* | 81 | Under frequency |
| | | Over frequency |
| *U<* | 27 | Undervoltage |
| *Vd<* | 27D | Positive sequence undervoltage |
| | 47 | Direction of rotation (phases) |
| *U>* | 59 | Overvoltage |
| *>U>* | 27 and 59 | Undervoltage and overvoltage |
| $U_N>$ | 59N | Neutral voltage displacement |
| $\frac{I}{U}>$ | 50V | Voltage restrained overcurrent |
| | 51V | |

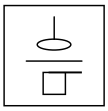
| | | |
|---|---|---|
| P← | 32P | Reverse true (active) power |
| Q← | 32Q | Reactive over power |
|  | | DGPT or Buchholz |
| CPI | | Earth fault detection<br>*(CPI = Contrôleur Permanent d'Isolement. PIM in English)* |

*Table 2: Symbols related to ANSI Code*

## 3.3. OVERCURRENT PROTECTION

**(Code ANSI 50 or 51)**

This protection has the function to detect the single-phase, two-phase or three-phase overcurrents (short circuit)

The protection is activated if one, two or three of the concerned currents exceed the setting corresponding to the threshold of adjustment.

This protection can be time lag; in this case it will be activated only if the controlled current exceeds the threshold adjustment during a time at least equal to the selected temporisation. This temporisation can be at independent time or dependent time.

### 3.3.1. Independent time protection

The temporisation is constant; the protection is independent of the value of the measured current.

The threshold of current and the temporisation are generally adjustable.

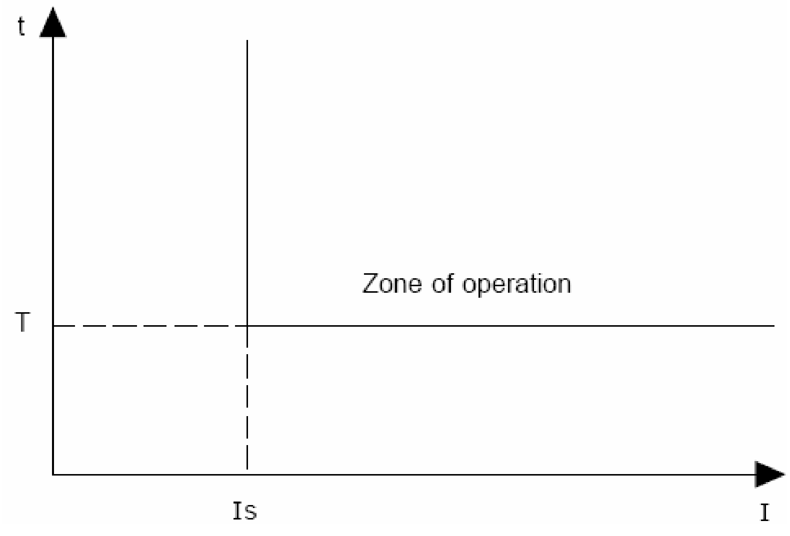



*Figure 4: Independent time protection*

**Is**: threshold of operation in current (threshold of current)

**T:** delay of the protection operation (temporisation)

### 3.3.2. Dependent time protection

The temporisation depends on the relationship between the measured current and the threshold of operation.

Higher is the current and weaker is the temporisation

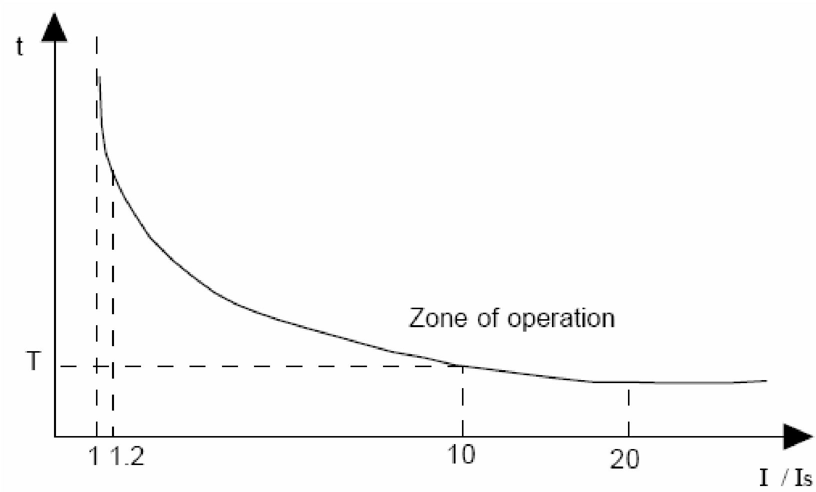



*Figure 5: Dependent time protection*

**Is:** threshold of operation in current corresponding at the vertical asymptote of the curve.

**T:** temporisation for 10 Is

The dependent time protection is defined by the standards CEI 255-3 and BS 142

They define several types of protection with dependent time, which are different following the slope from their curves: there will be protection with inverse, very inverse or extremely inverse time.

For example, the Sepam 2000 of Schneider proposes curves (see figure) for a temporisation set at 1 second, (temporisation of 1 second for I = 10 Is).

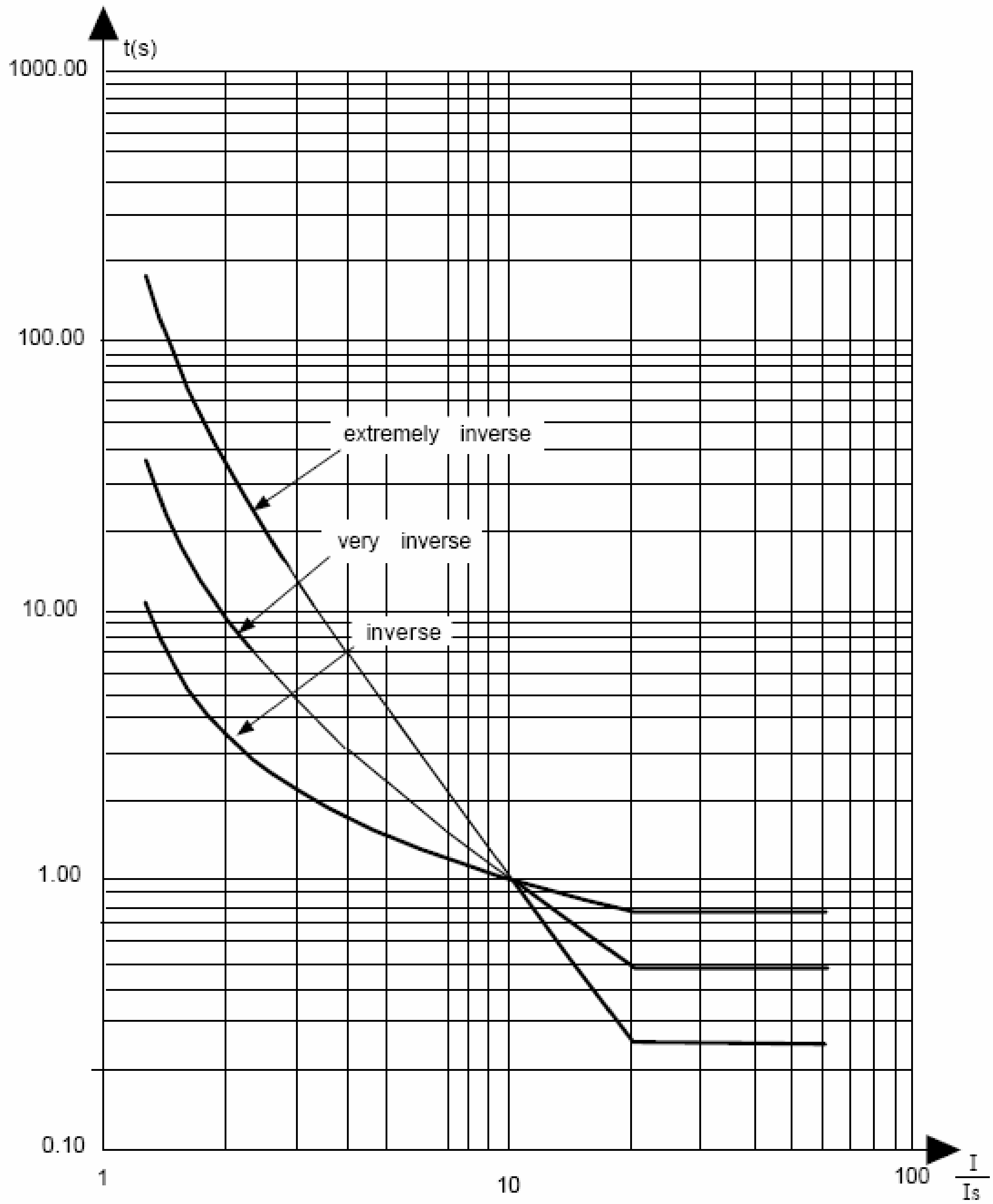



*Figure 6: Curves inverse, very inverse and extremely inverse with T = 1 s*

## 3.4. EARTH FAULT PROTECTION

**(Code ANSI 50N or 50G, 51N or 51G)**

This protection is used to detect the ground fault. The protection is activated if the residual current Irsd = I1 + I2 + I3 exceed the threshold of the adjustment for a time equal to the selected temporisation.

In the absence of ground fault, the sum of the three currents of the three phases is always zero.

The residual current gives the measurement of the current passing through the ground during the fault.

The protection can be independent or dependent time identically to the overcurrent phase protection (see previous paragraph and the figures).

The measurement of the residual current can be obtained in two manners: with one "current transformer" or with three current transformers

### 3.4.1. Measurement of residual current with one current transformer

**(Torus or toroid type)**

The three phases pass together through the CT

The secondary windings of the current transformer have a magnetic flux

$\Phi_{rsd} = \Phi_1 + \Phi_2 + \Phi_3$ (see figure). $\Phi_1$, $\Phi_2$ and $\Phi_3$ are proportional to the phase currents $I_1$, $I_2$ et $I_3$, $\Phi_{rsd}$ is then proportional to the residual current.

The earthing braid of the screen cables indicated on figure must pass back inside the torus, so that an internal fault of the cable (phase screen) is detected. If not, the short-circuit current circulates in the core of the cable and comes back by the screen, it is thus not detected by the torus.

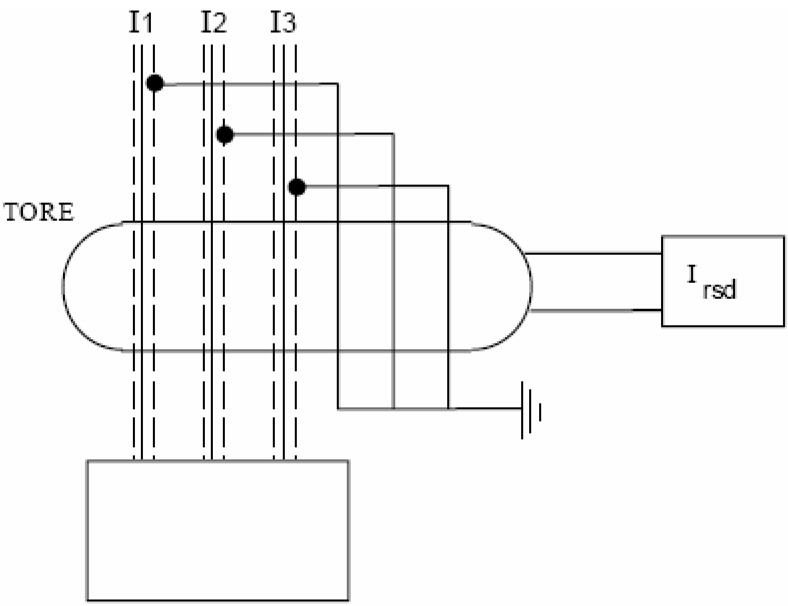



*Figure 7: Measure of the residual current by a torus*

### 3.4.2. Measure of the residual current with three current transformers

The three current transformers have neutrals and phases connected together as per the figure

*Minimal threshold of the adjustment*

There is a risk of a wrong activation of the protection due to an error of the residual current measurement, in particular in the presence of transient currents.

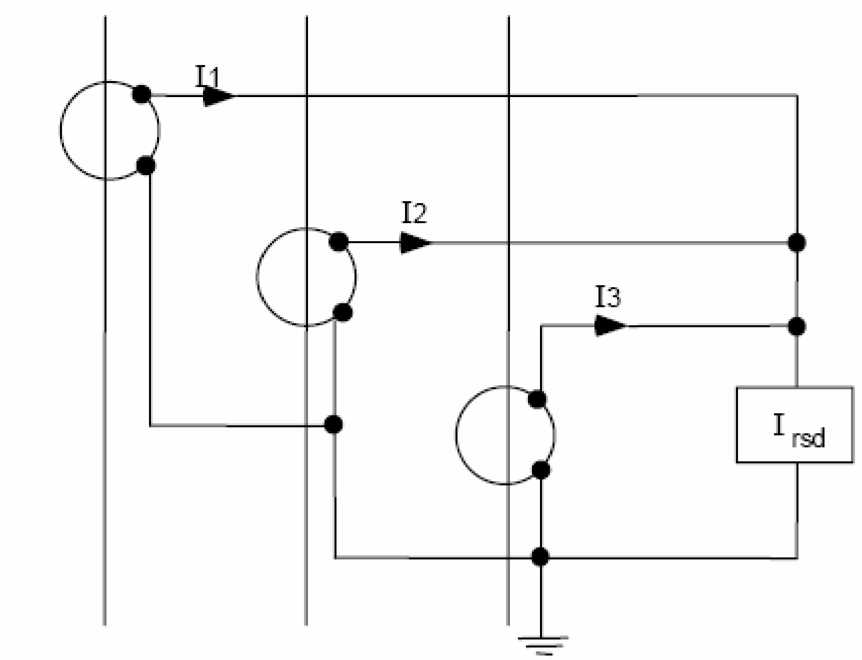



*Figure 8: Measure of the residual current with three current transformers*

In order to avoid this risk, the threshold of the protection adjustment must be higher to:

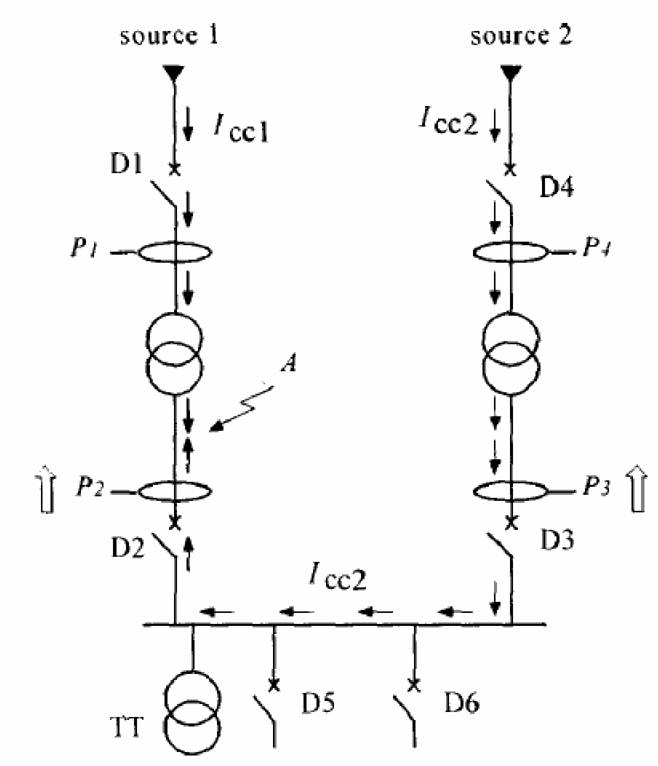
- Approximately 12 % of the nominal secondary current of the current transformers when the measure of Irsd is taken directly by a relay ;
- 1 A with a temporisation of 0.1 s, when the measure of the Irsd is taken through a torus *(detection with one current transformer on the “neutral” link)*.

## 3.5. DIRECTIONAL OVERCURRENT PROTECTION

**(Code ANSI 67)**

This protection has the function of an overcurrent defined in paragraph “overcurrent protection” associated with a detection of a "current flow direction".

To analyse its operation, we will show an example to use this protection.




Let us consider a set of busbars supplied by two power sources

<u>*Legend of the figure:*</u>
$P_1$, $P_4$ protections phase overcurrent
$P_2$, $P_3$ protections directional phase overcurrent
$I_{cc1}$ short-circuit current supplied with source 1
$I_{cc2}$ short-circuit current supplied with source 2

→ Flow of short-circuit current

⇑ Detection of the directional protection

When there is a fault in A, the two short-circuit currents $I_{cc1}$ and $I_{cc2}$ are established simultaneously. The four protections $P_1$, $P_2$, $P_3$ and $P_4$ are crossed by a short-circuit current.

*Figure 9: Set of busbars supplied by two sources*

However, to eliminate the fault without crossing the power supply of the outputs, only circuit breakers $D_1$ and $D_2$ must be tripped.

For that purpose, we install the protections of a directional phase overcurrent in $P_2$ and $P_3$.

The protection system behaves then like the following:

- The $P_3$ protection is not activated, because a current circulating in an opposite direction of its detection crosses it
- The $P_2$ protection is activated, because a current circulating in the direction of its detection crosses it. The protection opens the circuit breaker $D_2$, the current $I_{cc2}$ is switched off
- An inter-tripping system open $D_1$, the current $I_{cc1}$ is switched off
- The $P_4$ protection is not activated due to its time-lag.

The faulty section is thus insulated.

## 3.6. INDEPENDENT TIME DIRECTIONAL ZERO SEQUENCE OVERCURRENT PROTECTION

**(Code ANSI 67 N)**

This protection has the function of zero sequence overcurrent defined in paragraph “earth fault protection” associated with a detection of a "current flow direction".

**OPERATION**

The protection of the ground directional overcurrent is activated if there are the two following conditions during a time equal to the selected temporisation:

- Residual current is higher than the adjustment threshold
- Residual current phase compared to the residual voltage is in a gap, called "tripping area".

The current Irsd-A activate the protection while the current Irsd-B does not activate it.

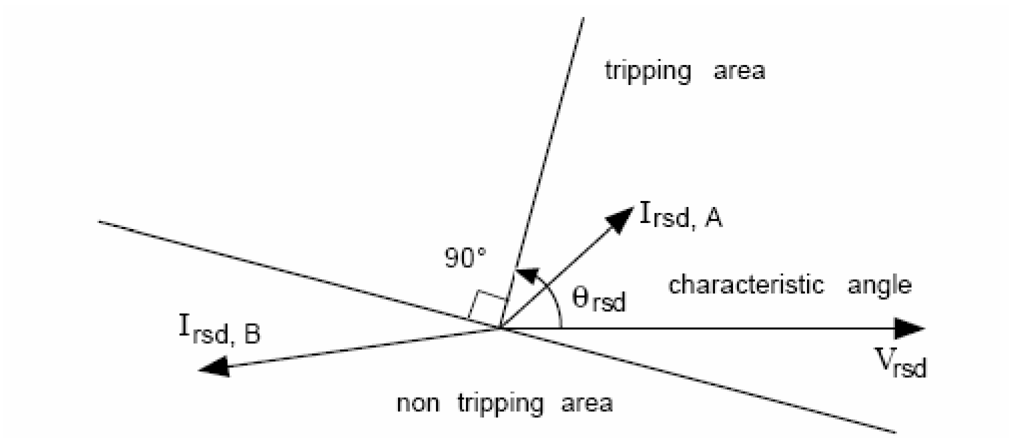



*Figure 10: Tripping area of the directional ground overcurrent protection*

## 3.7. DIFFERENTIAL GENERATOR PROTECTION

**(Code ANSI 87 G)**

The differential protection is in used for the generators, if the two terminals of each stator winding are accessible

The overcurrent for which protection must remain stable is the short-circuit current of the generator *(short-circuit inside the windings)*.

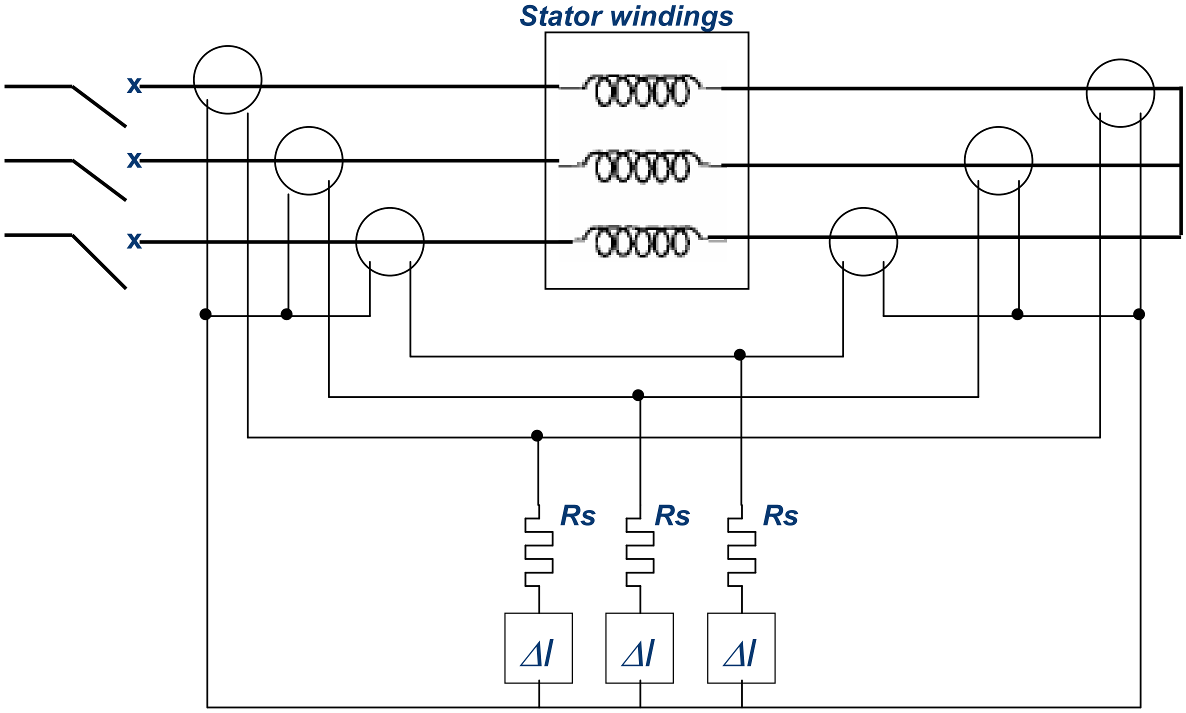



*Figure 11: Generator differential protection*

The operating time of the protection is almost instantaneous because the protection has no time lag.

The short-circuit current to be taken into account is thus the current during the period sub transient which is about 5 to 10 In

## 3.8. DIFFERENTIAL TRANSFORMER PROTECTION

**(Code ANSI 87 T)**

At first powering of the transformer, a differential current equal to the start-up current appears, its duration is of some tenths of second.

In order to avoid a strong deterioration of the transformer during an internal fault, the temporisation should not be higher than the duration of this current

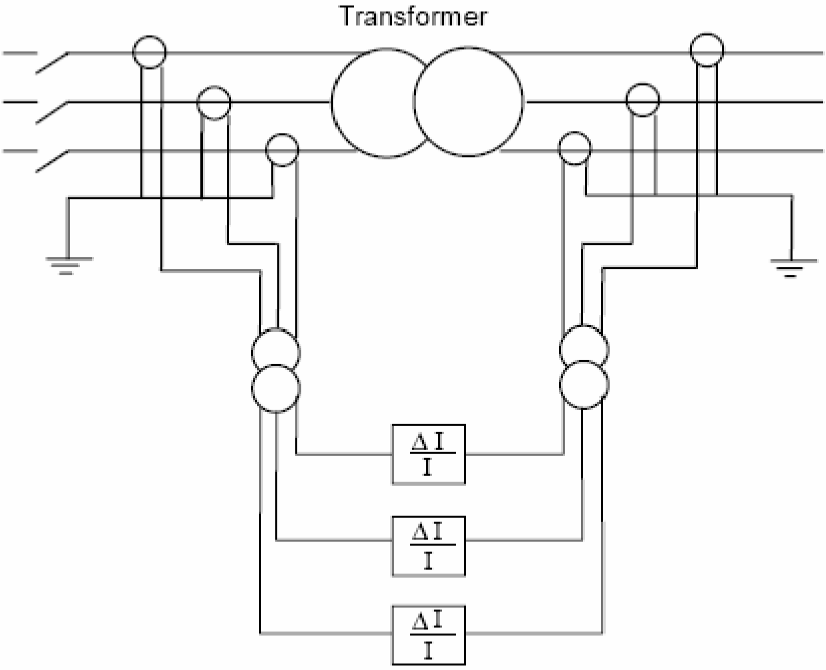
*The action of the tap changer during load (normal running) causes a differential current.*

The characteristics of the differential protection transformer are related to the characteristics of the transformers:

- Transformation ratio between the incoming current Ip, and the outgoing current Is,
- Coupling mode between the primary and the secondary (DZ1, YY0, DY6…..),

- Start-up current
- Permanent magnetising current.

### 3.8.1. Principle of operation




The differential protection of a transformer protects from the short-circuits between windings and spires from the same winding which correspond to short-circuits of two-phase or three-phase type.

*Figure 12: Diagram for a differential transformer protection*

If there is no earthing on the transformer, the differential protection can also be used to protect from the ground fault.

However, when the fault current is limited by impedance, it is often not possible to regulate the threshold of the current to a lower value than the limitation current.

The operation of the differential protection for transformer is very fast, approximately 30 ms, to avoid a deterioration of the transformer in the event of internal short-circuit.

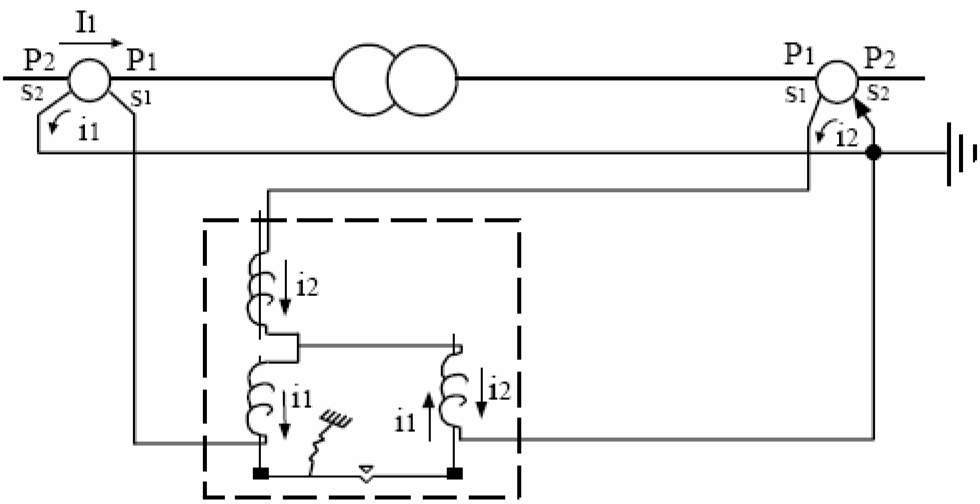



*Figure 13: Principle of a percentage relay for a transformer protection.*

In order to avoid the risks of inopportune trip for the strong fault currents of external origin to the protected zone, the differential protections for transformer are at percentage.

- In the first coil: current differential $i_1 - i_2 = i_m$

- In the second coil: $(i_1 + i_2) / 2 = i_a$

Operation of the relay when: $\mathbf{i_m = P\ \%\ x\ i_a}$

***Characteristics of protection***

They are due to:

a) The need to have current transformers of whose errors are similar, in spite of different currents and voltages.

b) The need to compensate the phase shift between primary-secondary from the transformer to be protected.

c) The variations of the ratio of the currents in the case of a transformer with a load tap changer

d) The magnetising current of the transformer at the start-up (in particular during the start-up to the zero passage of the voltage). The magnetising current contains a strong percentage of harmonic 2 (100 Hz).

### 3.8.2. Differential protection by a transformer (Torus homopolar)

Do not mix the above system with RCD (or differential in French language) detection. We shall see further in this course this “subject”, but nevertheless let’s see its basic function

The homopolar component of a three vectors system is obtained by the relation:

$$\overline{Vh} = (\overline{Va} + \overline{Vb} + \overline{Vc}) / \sqrt{3}$$

The tore homopolar determine directly the size of the homopolar vectors $3\ \overline{Vh}$

This torus measures the residual current Ir of an installation; they include the three cores of the phases.

In balanced mode, the sum of the magnetic fields of each current is null.

When a fault appears between the phase and the ground, the magnetic field resulting from the residual current Ir induces a voltage in the detection winding.

*Take care of the ground conductor (and the metallic armour) position through the torus….We see it again later but you may already discuss about that in course.*

*On the figure, cable is coming from the right, pass inside the torus and is stripped at "triangle" point, the 3 arrows being the 3 phases.*

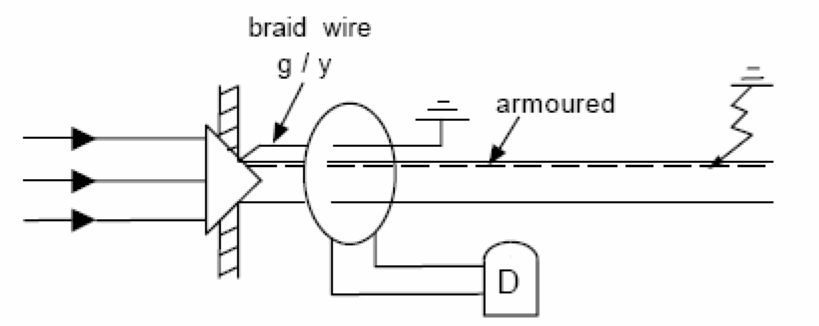



*Figure 14: Torus protection.*

## 3.9. THERMAL OVERLOAD PROTECTION

**(Code ANSI 49)**

The thermal overload protection is used to protect the machines (motor, generator, transformer...) against overloads.

To detect the existence of an overload, the thermal overload protection estimates the heating of the machine to be protected from the measurement of the current.

**Starting of motors and thermal overload protection:**

The thermal overload protection cannot be used against too long starting of motors. Indeed, the inrush current of a motor is very high (6 to 8 times the rated current). Its heating is roughly proportional to the square of the current; it is thus very fast at the starting.

During starting, the calorific contribution is not completely diffused in the motor.
Thus, the local heating on the level of windings and insulator can be excessive.
However, the thermal overload protection considers a total heat-storage capacity of the motor and an instantaneous calorific diffusion; it thus does not hold account of the local heating.

It results that thermal overload protection determines the heating caused by starting, but cannot protect the motor against a too long starting or a blocking of the rotor. There are besides specific protections for that (see in the following).

**Thermal image (49T)** is monitored inside the windings of a motor, generator, transformer with specific probes (RTD type) or switches

## 3.10. NEGATIVE SEQUENCE / UNBALANCE PROTECTION

**(Code ANSI 46)**

The protection at component inverse is used to protect the rotating machines (motors or generator) against unbalance of high current value, which may deteriorate them.

When the currents of the three phases are not balanced, it appears an “inverse component” of current.

The spinning field corresponding to the inverse component induces a double frequency current (rotor) which causes important Joule losses.

The overheating of a rotating machine by a permanent inverse component of low value (few percent) can be taken into account by an image thermal protection.
But, in the event of power supply on two phases only following by the fusion of a fuse or with the breakdown of a phase, the inverse component has a high value and can deteriorate the machine very fast; the thermal image protection is not quick enough

An inverse component protection protects the rotating machines against this type of anomaly.

**Adjustment indication for the motors**

Throughout starting, the motor absorbs an inverse component of current between 20 and 30 % of the rated current. To avoid inopportune release during starting, and to obtain satisfactory adjustments, it is necessary to use a protection at independent time with double threshold or a protection at dependent time.

**Adjustment indication for the generators**

We generally use a protection at time dependent with a threshold on adjustment of the component inverse fixed at 15 % of In
The activation time of the protection must be delayed a few seconds.

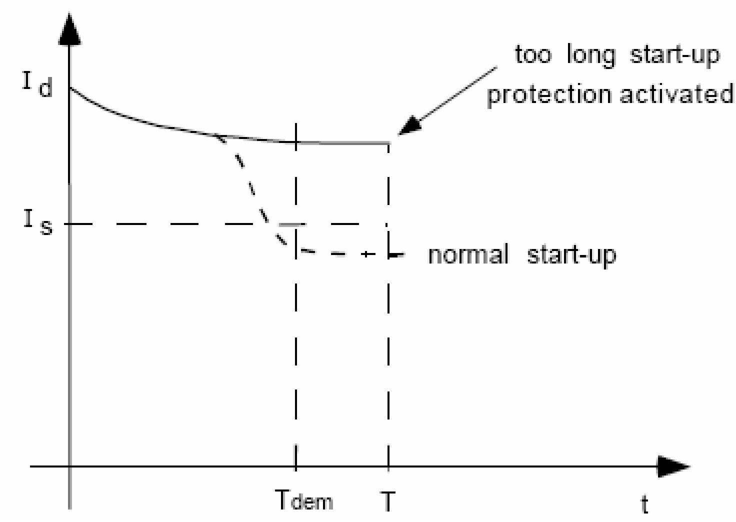
## 3.11. PROTECTION AGAINST EXCESSIVE STARTING TIME AND LOCKED ROTOR

**(Code ANSI 48 / 51 LR / 66)**

The principle is based on an overcurrent protection with independent time.

### 3.11.1. Too long start-up (code 48)

During a start-up, the protection is activated if the current of one of the three phases is higher than the threshold of current is during a time T (see figure).




This time T must be higher than the maximum value of the normal duration of starting. “Tdem”

The start-up origin can be detected in two manners:

- by the closing of the breaker information
- when the current exceeds a low threshold (for example 5 % of In).

*Figure 15: Case of a too long start-up*

***Id***: *inrush current of the motor with its associated starting system (autotransformer, star - delta, electronic starter...) if existing.*

### 3.11.2. Locked Rotor (code 51LR)

During starting, the protection is locked. In normal mode, the protection is activated if the current of one of the three phases is higher than the threshold current Is during a time higher than the temporisation Tb.

The figure shows the case of a locked rotor during a time higher than the set delay

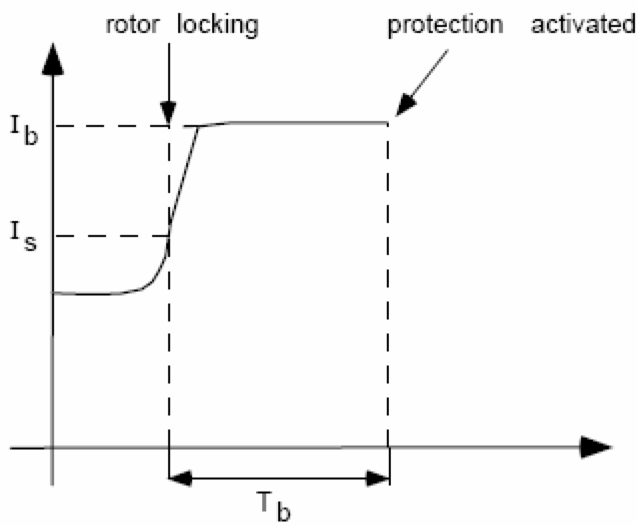



*Figure 16: Case of a locked rotor*

The current with a “rotor locking” Ib is equal to the inrush current of the motor without the starting system. Indeed, the starting system is short-circuited (or made inoperative) when the motor is on line.

### 3.11.3. Monitoring number of starts (code 66)

Too many start-ups can be due to:

- a faulty operation of a control system
- a manual action too frequent
- a series of restart on a fault.

The consequences are:

- an overheating,
- a succession of shocks on the couplings.

A protection monitors the number of start during a given time to protect the motor against too many demands for start, which may cause damage to the motor.

## 3.12. UNDERCURRENT PROTECTION

**(Code ANSI 37)**

This undercurrent protection is used to detect the air binding of a pump or the breakdown of a coupling (with the load). The suction pump air binding can be due to absence of liquid in the pump.

The air binding of a pump, or the breakdown of a coupling, involves a no-load of the motor, therefore a drop of the current. The undercurrent protection allows detecting the ***idle run*** of a motor.

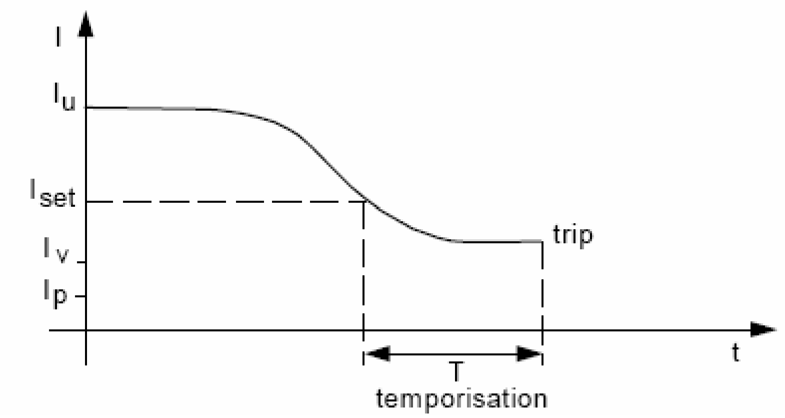



*Figure 17: Case of Motor no-load*

***Iu:** minimal current normally used by the user*
***Iv**: no-load current*
***Ip**: predetermined threshold for which the protection is inactive*

## 3.13. UNDERVOLTAGE PROTECTION

**(Code ANSI 27)**

The voltage drop can be due to:

- an overload of a network supplied with generators,
- a faulty operation of a transformer load tap changer or a voltage regulator of a generator

The consequences are an overheating of the motors:

- At the start-up, the starting torque and the maximum torque are proportional to the square of the voltage. A voltage drop involves a longer start-up time, therefore an overheating, and if the resistive torque is more important than the maximum torque, a locked rotor.
- In normal operation, the active power of the motor is: $Pa = \sqrt{3}.U.I.\cos\varphi$. If the voltage drops, the load being constant, the current increases in order to maintain the motor output (the value of the cosφ varies up to limited extend). Thus, for voltage variations which are not too important, we have: $Pa = \sqrt{3}.U.I.\cos\varphi$ = constant; the Joule losses are equal to 3 $RI^2$ and the heating increases.

The undervoltage protection allows protecting the motors against a voltage drop, which may deteriorate it by overheating.

The undervoltage protection can be used also to:

- control the operation of a voltage regulators,
- load shedding the non priority consumers during an overload,
- control the voltage before permutation of power supply.

## 3.14. OVERVOLTAGE PROTECTION

**(Code ANSI 59)**

The overvoltage protection allows protecting the receivers against a high voltage.

The overvoltage protection can also be used to:

- verify the presence of a sufficient voltage to transfer the power supply from another source. In this case the threshold is lower than Un,
- control the operation of the voltage regulators

The protection is activated if one voltage is higher than the threshold of the adjustment.

There is generally a time delay (temporisation) at constant time.

## 3.15. MINI AND MAXI FREQUENCY

**(Code ANSI 81)**

The variations of frequency for turbo-generators can be due to:

- an overload,
- a faulty operation of the frequency regulator.

The consequences are:

- a faulty operation of the synchronous devices (recorders, clock, …)
- an increase in the losses iron of the magnetic circuits of the machines; they are proportional to the square of the frequency,
- a variation of the motors speed which can involve damage to the installation

The minimum frequency protection detects an overload and initiates load shedding of the non-priority consumers in order to restore the rated frequency.

## 3.16. REACTIVE REVERSE POWER PROTECTION (LOSS OF EXCITATION)

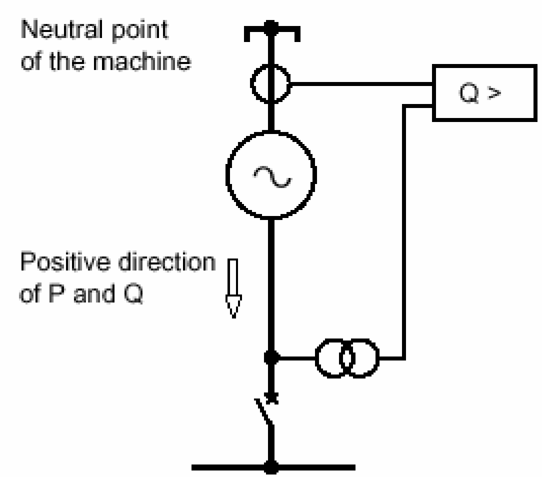
**(Code ANSI 32 Q and 40)**

This protection is used to detect the reactive reverse power (32Q) and/or field loss of the synchronous drives (40)

The break or the short-circuiting of the excitation coil of an alternator is a **serious fault**. It either causes the alternator to function as an asynchronous generator, or it stops the conversion of energy and causes an increase in speed.

The consequences are an overheating of the stator caused by the raise of reactive current and an overheating of the rotor being not designed for such induced currents. (*An important induced current circulates in the rotor and causes an overheating.(*

In normal conditions, D.C. current supplies the rotor (called inductor) to provide the "excitation" of the synchronous drives




The field loss can be due to a fault in the DC feeder or to a fault inside the rotor, (breakdown, short-circuit, etc).

When a field loss appears, the drive compensates the drop of the magnetising power of the rotor by absorbing reactive power on the network.
The reactive power of the machine is then negative.

*Figure 18: Protection against excitation losses by a reactive reverse power relay.*

## 3.17. ACTIVE REVERSE POWER PROTECTION

**(Code ANSI 32 P)**

This protection is used to detect an inversion of the sign of the active power in the absence of electric fault.

This protection is used in particular to:

- prevent the turbo-generators to receive energy from the network;
- protect a motor against an operation in generator when there is a power supply shutdown and when it is continuing to run by its load;

- protect a generator against an operation in motor which can deteriorate the driving engine.

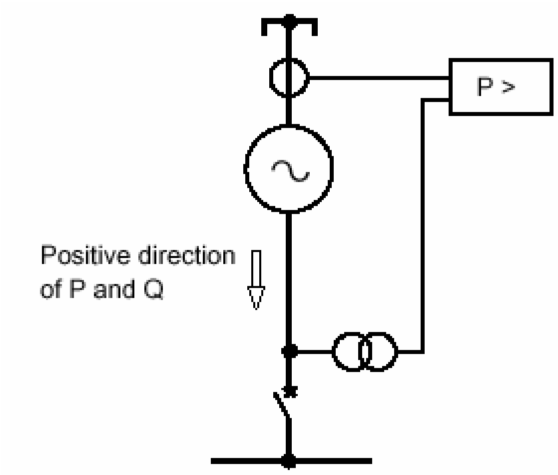
**Protection against the supply of active power by the network to the turbo-generators**

The reverse active power can be due to a power supply shutdown on the network, or to a faulty operation of the power regulators

The consequences are for example:

- an overload of the other turbo-generators
- a failing selectivity, if a fault appears after the inversion of the sign of the active power.

**Protection of the generators against an operation as a motor**




A generator set connected to a power network continues to turn synchronously even if the prime mover (diesel or turbine) is no longer energy supplied.

The alternator then functions as a synchronous motor. Operating in such a way may be detrimental to the prime mover.

*Figure 19: Detection of motor operation, by an active reverse power relay.*

## 3.18. SPECIFIC TRANSFORMER PROTECTIONS

### 3.18.1. Tank earth fault protection

**(Code ANSI 50 or 51)**

This protection protects a transformer against the internal fault between a winding and the ground.

This protection is recommended as soon as the power of the transformer reaches 5 MVA (However, it is installed on transformer with power far lower on our sites)

It is an overcurrent protection. This protection is installed on the earthing connection of the transformer body.

It requires isolating the tank of the transformer from the ground, so that the fault current crosses the protection (see figure).

This protection is selective, because it is sensitive only to the earth fault with the body of transformer

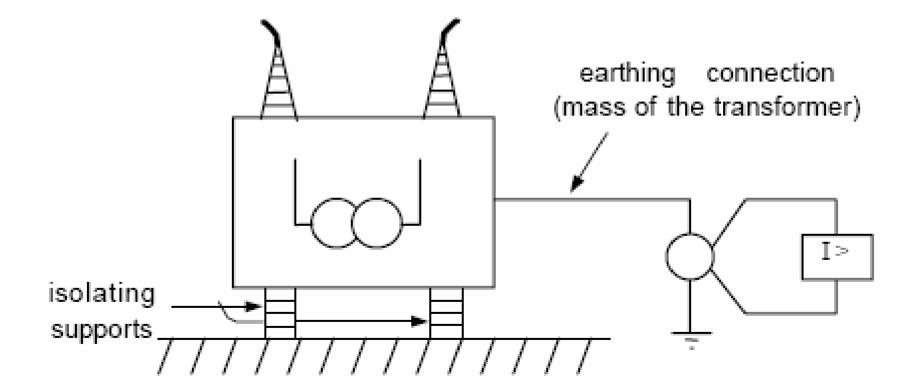



*Figure 20: Earth fault protection of a transformer's tank*

### 3.18.2. Protection by detection Gas, Pressure, Temperature (DGPT)

The DGPT is a safety device used (mainly) with the immersed transformers.

This device detects the anomalies within the dielectric liquid such as gas emission, rise in pressure or temperature, and causes the shutdown of the transformer.

**Gas Detection:**

The gas detection detects the internal short-circuit.
Indeed, for an immersed transformer, an internal short-circuit always causes, more or less, an important gaseous emission due to the decomposition of the dielectric and the action of the electric arc.

**Dielectric Drop Level Detection:**

This device can detect a failure (a crack) of the tank (body).

This detection has two functions:

- visualisation in the event of a weak dielectric drop level

- shutdown of the transformer in the event of important fall of the dielectric level.

The complement of filling of the transformer is normally (and easily) done through the higher part of this device

**Internal Overpressure inside the transformer:**

A pressostat (pressure switch) with an electrical contact controls the pressure.

This pressostat is preset at factory between 0 and 500 mbar (normal value 200 mbar or 3 PSI).

When there is a high internal short-circuit, it appears a gaseous emission which causes the activation of the pressostat in some tenths of a second.

**Abnormal Dielectric Temperature Detection:**

This detection is visual (thermometer from 0 to 120°C) and electric (1 or 2 thermostats).

These thermostats are independent, adjustable from 30 to 120°C (by step of 5 °C), one gives alarm (normal adjustment 90°C), the other shutdown the transformer (normal adjustment 100°C).

**Case of breathing Transformer:**

For the breathing transformers, the protection is done by a Buchholz relay.

For a small defect, the gaseous emission is collected in a high point of the relay; a too important accumulation causes an alarm.

For a serious defect, the gases produced in great quantity brutally drive back part of the oil of the tank towards the expansion tank

A float pulled by the oil flow gives the shutdown of the transformer.

## 3.19. APPLICATIONS

We have not seen all the possibilities, all the types of relays. A fault detection can be done by single function relay or multi-function relays regrouping “x” detecting.

We have not seen the calibration, the setting, the verification, the maintenance of such relays. The different manufacturers have their own procedures; Total sites have developed maintenance and verification procedures and/or sub contracting this to the concerned manufacturer or specialised engineers (*Apave, for example).*

We can just recommend you, to collect the operating and maintenance manuals for these protecting relays and schedule calibration/verification by maintenance team. In my opinion, it is the duty of a site electrician to know the operation and calibration of such equipment. The day one fail (rarely happening), you need to take initiative especially if you are on a remote site/area.

All least, you should know from this course, the principle of operation of the main protective relays, the rest needs site practice  and experience; However, see course MN-SE120 (Panels and switchgears) in which example of calibration is presented for CEE relays (old relays, but seen on numerous Total sites)

Use of current and voltage injection kits (calibration generators) is also in this course SE120

### 3.19.1. Thermal and magnetic relays

We see in detail those types of relays in the following chapters, but as, in low voltage, an electrician is nearly permanently "in contact" with thermal and magnetic relays, let's see at first, here, the general principles.

#### 3.19.1.1. Thermal Relay

In case of small power motors, which have a short starting time (4 to 5 seconds), the thermal relay is assembled in series in the circuit.

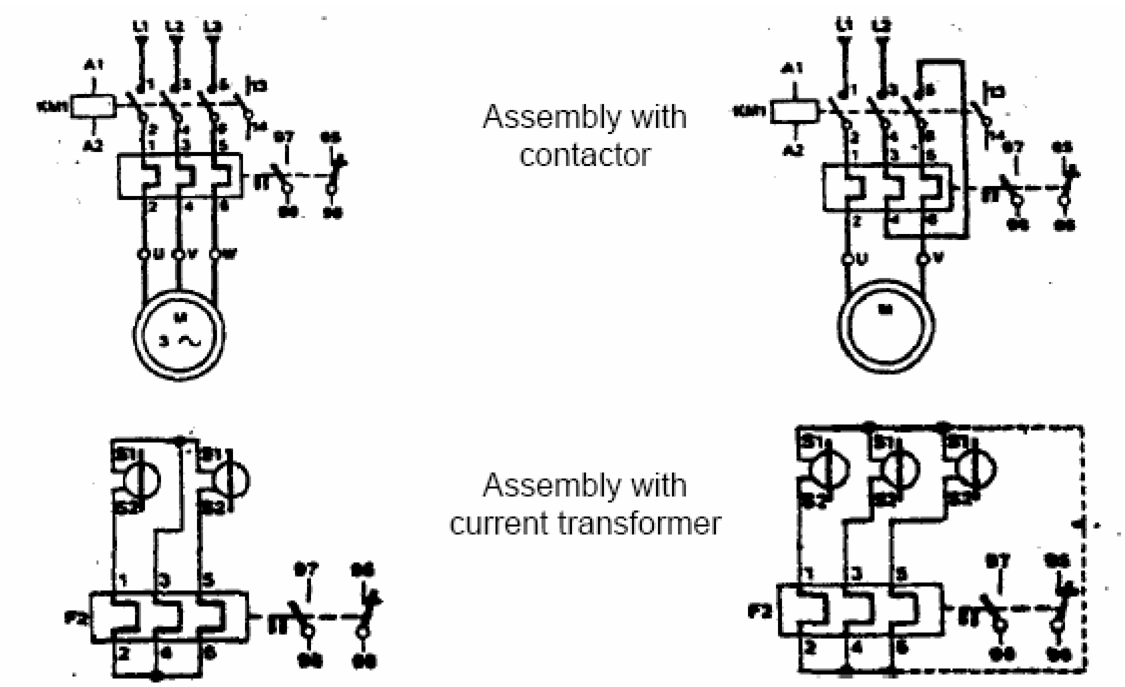



*Figure 21: Schematic diagrams with thermal relays*

This relay is crossed by the entire load current.

When motors are bigger or have a long starting time (ex: ventilation fan), we use a current transformer and the relay is crossed by a fraction of the load current.

### 3.19.1.2. Magnetic Relay (short-circuit protection)

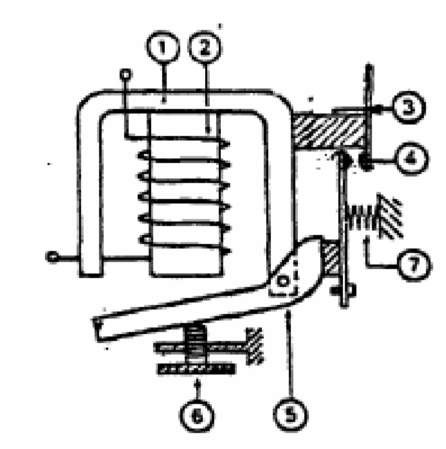
Protection against short-circuits in low voltage motors is done generally by aM fuses type.

Selectivity Precaution is done to check that the setting of the fuses is well adapted to the setting of the thermal relay, this to avoid the "fusion" of the thermal relay in event of short-circuit. This precaution to undergo only in case of thermal relay directly connected.

If the thermal relay is connected with current transformers, the saturation of the current transformers protects the thermal relay.

Protection against short-circuits can also be done by magnetic relays. The principle of these relays is as follows:

When an overcurrent occurs, the mobile frame (5) is attracted and closes the circuit by the contacts (3) (4) which in turn initiate the trip of the contactor (or breaker, or switch),




When the overcurrent disappears, the mobile frame (5) falls back.

This type of relay protects the circuits against the strong overcurrents, needing a fast opening of the circuit.

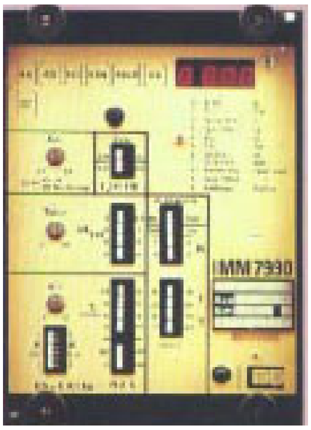
These relays act instantaneously (nearly – but nevertheless they are the fastest within the electromechanical protections) and especially in the event of short-circuit.

*Figure 22: Typical technology of a magnetic relay*

*Legend:*

*1 - Fixed magnetic circuit*
*2 - Large section of copper coil crossed by the overcurrent*
*3 - Fixed contact (operating the trip device)*
*4 - Mobile contact (operating the trip device)*
*5 - Mobile magnetic circuit*
*6 - Adjustable screw to regulate the "air-gap" proportional to the trip threshold*
*7 - Return spring*

### 3.19.2. Multi-function relays



For example the "Procom IMM 7990" of CEE which is still equipping panels on Total sites

This relay is for motor protection (LV or HV) and regroups the functions (ANSI codes): 49 / 46 / 51 / 51LR / 64 / 37 / 66.

*Figure 23: Front view of IMM7990 relay*

In the same range of relays, you will find:

- GMSx7002 (motor protection LV;HV) with functions 49 / 46 / 55 / 50 / 51LR / 59 / 24 / 27 / 31 / 32 / 59G / 64
- GMSx7001 (generator protection) with functions 49 / 46 / 40 / 21 / 59 / 24 / 27 / 81 / 31P / 32Q / 59N / 64

Of course protection, detection circuits are "supplied" from CT's and PT's

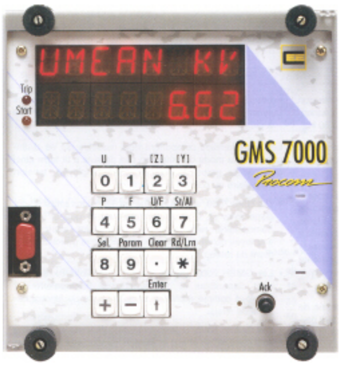



*Figure 24: Front view of IGM7000 relay*

The **GMS 7000** (from CEE) is an "intermediate" technology of the multi-functions relays but the ones which are now installed on sites have more and more performances like the 2 examples hereafter

The (Schneider) Sepam 20, 40, 80,… for Protections of incomer / feeder, Transformer, motor, busbars

*Figure 25: Sepam relays from Schneider*

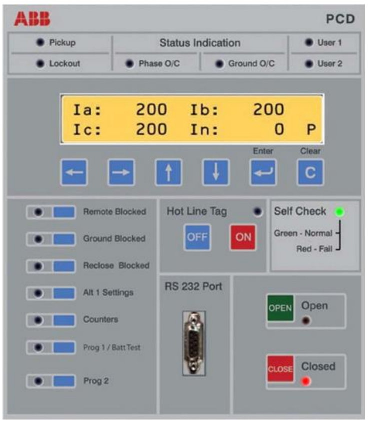



*Figure 26: ABB PCD Relay (Power Control Device)*

List of functions for this ABB relay

- Phase time over-current protection (51P)
- Phase instantaneous over-current protection (50P-1, 50P-2, 50P-3)
- Ground over-current protection (51N)
- Ground instantaneous over-current protection (50N-1, 50N-2, 50N-3)
- Negative sequence over-current protection (46)
- Phase and ground directional over-current protection (67P, 67N)
- Available with up to 38 recloser curves, nine ANSI curves, four IEC curves and three user programmable curves
- Multishot reclosing: each reclose step allows independent programming of protective functions (79-1, 79-2, 79-3, 79-4, 79-5)
- Reverse power detection and control (32P, 32N)
- Undervoltage and overvoltage control and alarm (27/59)
- Two independent steps for load shed, restoration and over frequency (81S, 81R, 81O)
- …/… and options….

All those digital relays are programmable (at distance through network or with local computer), have interface with all types of networks (fiber optic, RS232, ….) and are in permanent improvement. One model from one manufacturer can provide a technical manual of hundreds of pages, and you will understand…, we cannot reproduce even one (of those catalogue) here.

### 3.19.3. Applications for generator protection

Schematically, you will find this type of details showing all different protections for one piece of equipment, here a generator.

In training session, try to obtain such one line diagram and some details from the multi-function relays installed on your plant. *There could be as well combination of multi-function and (complementary) single function relays.*

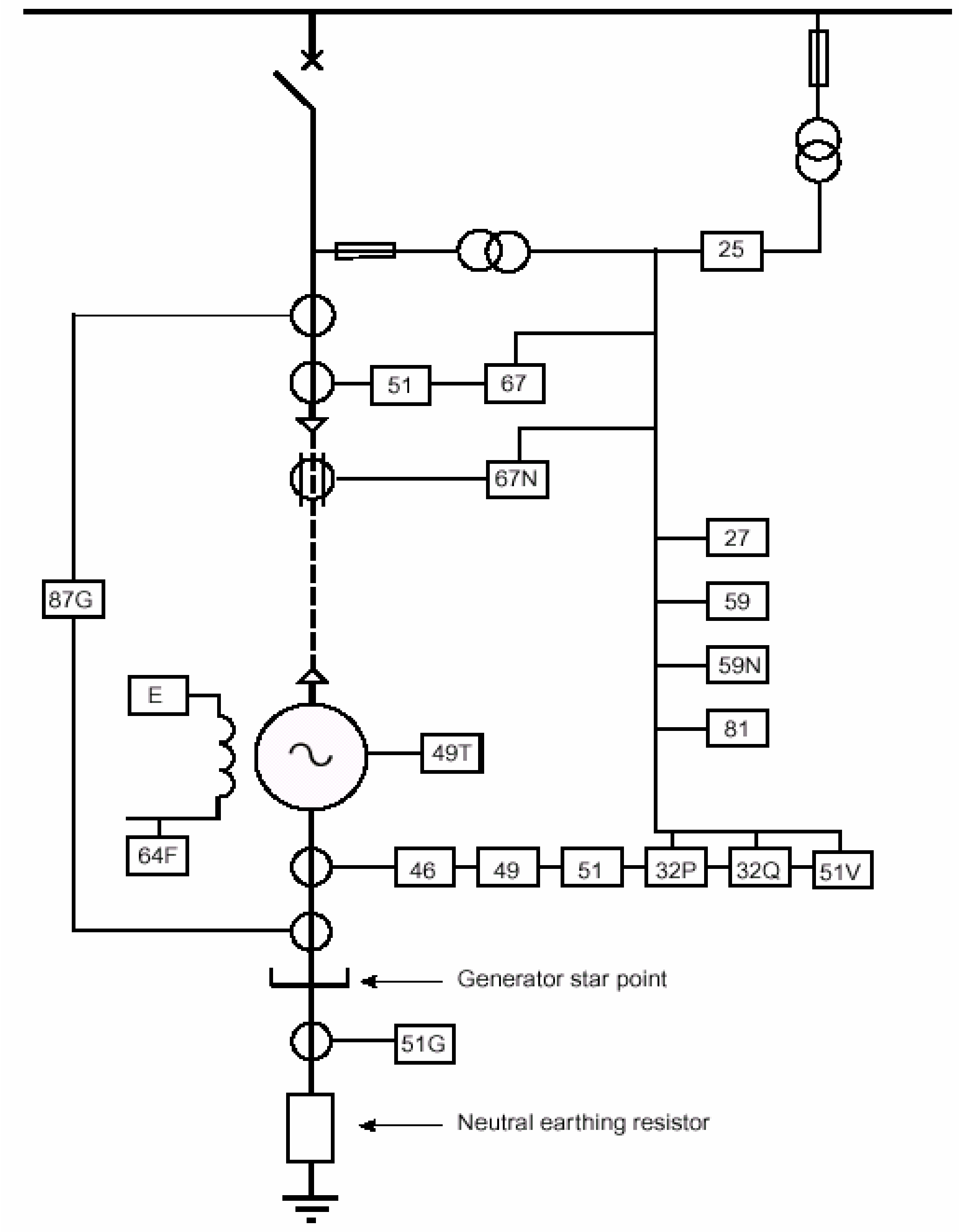



*Figure 27: Generator Protections examples*

Comments (review about correspondence between ANSI Code and meaning

## Protection functions connected to generator neutral current transformers

- 32P : reverse active power
- 32Q : reverse reactive power serving as loss of field (for generators above 1 MVA)

- 46 : negative sequence (for generators above 1 MVA)
- 49 : thermal image
- 51 : overcurrent
- 51G : earth fault
- 51V : voltage restrained overcurrent
- 87G : generator differential protection (for generators above 2 MVA)

(Note: 46,49, 32P and 32Q can also be connected to the line-side current transformers)

### Protection functions connected to voltage transformers

- 25 : synchronism-check (for parallel operation only)
- 27 : undervoltage
- 59 : overvoltage
- 81 : overfrequency and underfrequency

### Protection functions connected to line-side current transformers (for parallel operation only)

- 67 : directional overcurrent (not required if 87G is used)
- 67N : directional earth fault (on core balance CT for better sensitivity)

### Generator mechanical protection functions connected to sensors

- 49T : stator temperature (recommended for generators above 2 MVA)
- 49T : bearing temperature (recommended for generators above 8 MVA)
- 64F : rotor earth fault protection

For this example, generator can be considered as “well” protected… All protective functions can be done with single function relays (old trend) or (only) one multi-function relay (present trend).

See also course MN-SE100 (network) for protections of circuits supplied by generator / alternator

# 4. FUSES

From the principle of protection / detection, we proceed now with the technologies of the separating / breaking devices. Once a fault has been detected, analysed and processed, it arrives on the final element which opens the circuit, we start with the fuse.

## *4.1. CARTRIDGES gG AND aM. WHAT IS THE DIFFERENCE?*

Cartridges **gG** are for all overloads (low & high levels), and for protections against short circuits.

Cartridges **aM** protect against overload (generally high level) and against short circuits. They are calculated to ***withstand temporary overload***, such as the ***starting current of a motor.*** Consequently these cartridges must be associated with thermal protection systems

Standards (industrial use) say: ***gG*** have ***black*** indication marks , ***aM green****.* Other type equivalent to *gG* exist, depending manufacturers *gF, gL,…* their colours being, blue, red, balck,…

***Application:***

Hereafter is a one-line diagram for an example of electrical distribution protected by fuses. Do not think it is an unrealistic schematic, fuse protection is "coming back" replacing in turn the breaker which supplanted it few years ago; It is obviously for economical reason at first but also for the better breaking capacity of a fuse compared to a breaker (in same current/voltage conditions of course).

*We are sure a fuse is going to break in case of short-circuit and probably faster than a breaker (which could melt if not properly ranged).*
*I have even seen, nowadays, distribution protected by fuses + breaker.*

*Legend of the figure:*

***F1:*** *fuse aM 400 - secondary of transformer protection*
***F2: F3, F4****: gG 100 & 125 protection for main board distribution.*
***F5:*** *aM 160 in complement of breaker protection*
***F6:*** *aM 32 with contactor / thermal relay for motor protection (thermal & overload) 15 kW*
***F7:*** *gG 25 or lighting protection*
***F8:*** *gG 50 protection of electric oven 30 kW*
***F9:*** *aM 50 with contactor / thermal relay for motor protection (thermal & overload) 22 kW*
***F10, F11, F12:*** *gG 50, gG 6, gG 25 for other loads*

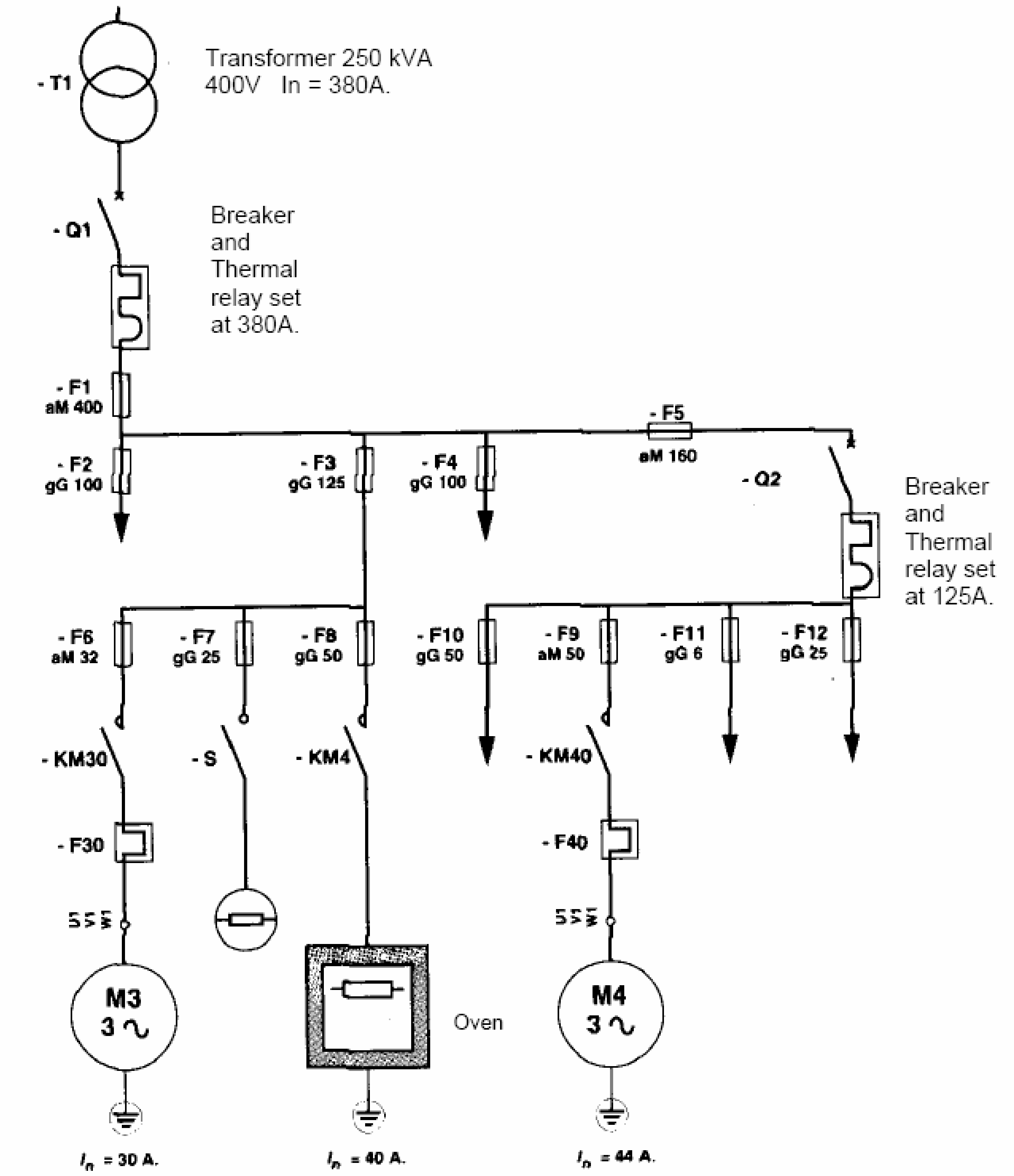



*Figure 28: Example of distribution protected by fuses*

## 4.2. QUESTIONS ABOUT FUSES

### 4.2.1. Nominal current In, nominal voltage

The nominal current (In) can go ***permanently through a fuse*** without neither overheating nor breaking.

The ***nominal voltage is the maximum voltage*** to be used with the fuse concerned.

### 4.2.2. A fuse cartridge consumes power?

Crossed by a current, a fuse cartridge has (slightly) the behaviour of a resistance and consume small power.

Standards are defining the limit of power consumption for each type / size / rating of cartridge.

### 4.2.3. What are conventional currents for "non-fusing" and for "fusing"?

Conventional current for "non-fusing" ($I_{nf}$ or $I_1$) is the ***specific current value, which can be withstood by the fuse cartridge during a specific time and this without blowing (or "fusing").***

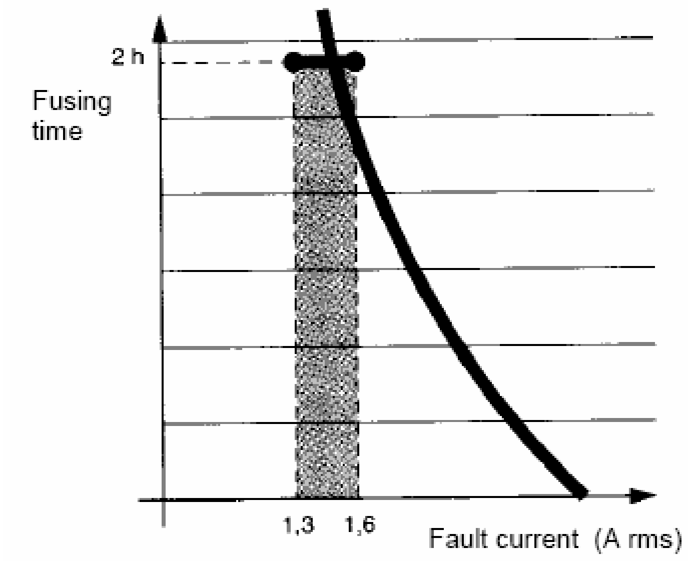
Conventional current for "fusing" ($I_f$ or $I_2$) is the *specific current value, which makes the fuse cartridge blow and this before a specific time.*

These values are typical as per the table for gG type (In = fuse 'nominal' current)

| Amperes rating | $I_{nf}$ current of "non-fusing | $I_f$ current of "fusing" | t = conventional time |
|---|---|---|---|
| In < 4A | 1.5 In | 2.1 In | 1 h |
| 5 to 10A | 1.5 In | 1.9 In | 1 h |
| 11 to 25A | 1.4 In | 1.75 In | 1 h |
| 26 to 63A | 1.3 In | 1.6 In | 1 h |
| 64 to 100A | 1.3 In | 1.6 In | 2 h |
| 101 to 160A | 1.2 In | 1.6 In | 2 h |
| 161 to 400A | 1.2 In | 1.6 In | 3 h |

*Table 3: Fusing and non-fusing conditions for a fuse*

<u>*Let's take an example:*</u>




With a fuse gG 100A we are in the range (from the table) of non-fusing = 1.3 In and fusing at 1.6 In this for a conventional time of 2 hours

It means that the 100 A rated fuse, being crossed permanently during 2 hours by a current of 130 A is not going to blow; It will blow (probably..) "a certain time" after the 2 hours

The same 100 A fuse is sure to blow before 2 hours if it is permanently crossed by a current of 160A

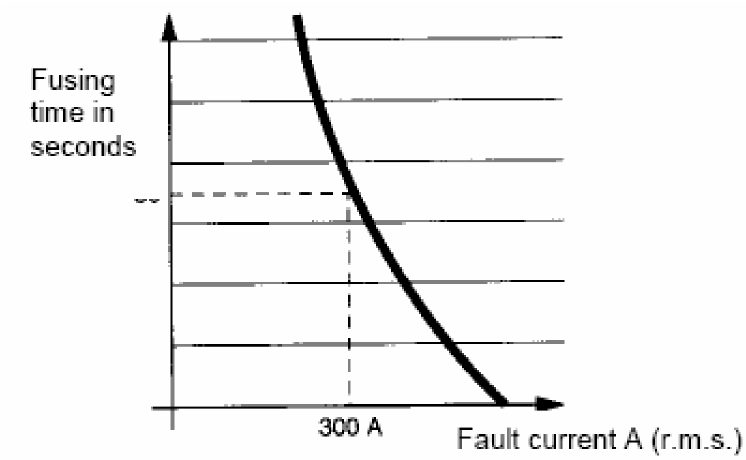
*Figure 29: Fuse typical blowing curve, example with Inf = 1.3 & If = 1.6*

### 4.2.4. What is "presumed" short circuit current?

It is the ***r.m.s. current*** which would appear in case of short circuit and without protection. Its peak value will increase when cos φ decreases (asymmetric short circuit).

### 4.2.5. What is a "working zone"?

The working time of a fuse cartridge can be established according to its current flowing through. This is the purpose of Standards, defining the working zone.




Let's take the same fuse, a cylindrical cartridge of 100 A dimensions 22 x 58 for which *an overload of 300A (permanently) will break the fuse in 30 s*

*Figure 30: Working zone curve of a fuse*

Knowledge of working zone characteristics is necessary to calculate selectivity within an electrical distribution.

### 4.2.6. Breaking capacity

The higher the breaking capacity of the fuse is, the higher faulty ***short circuit*** current can be "fused";

Fuses of *High Breaking Capacity* type are manufactured with up to 100 000A (r.m.s.) breaking capacity.

### 4.2.7. What is the limitation curve?

Limit of current becomes a variable value when it follows the current of a short circuit (different conditions of short circuit current, cos φ, …..)

Limitation curves (vendor data's) indicate the maximum current, which can be "limited" in the worst conditions (for the fuse).

Let's continue the example with "our" gG 100A cartridge

As example, a short circuit current of 10 000 A(r.m.s.) can reach a value 2.5 time greater (25 000 A in peak).

The cartridge gG 100 limits the first "shock" at 7000A, at one third of the maximum 'presumed' limit.

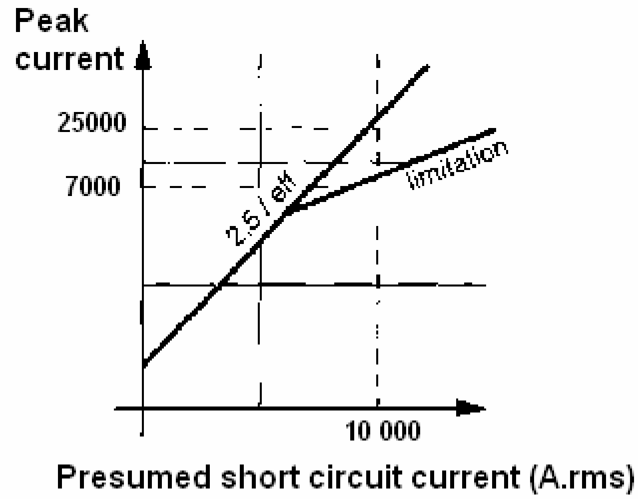



*Figure 31: Fuse limitation curve*

Destruction effects are reduced in the ratio of one tenth approximately (7000 / 250 000)²

* if the gG 100 cartridge limits the current at 15 000A peak, the limitation is 6% of the maximum presumed current

### 4.2.8. What is thermal constraint?

This is function of the thermal energy 'limited' by the cartridge when blowing. The energy developed by a short circuit can be expressed by the Joule formula:

$$R\int_0^t i^2\,dt = RI^2_{eff}\,t$$

When a short circuit occurs, the thermal constraint limited by the cartridge corresponds to this formula. Thermal constraint is in A² s (amperes² x seconds).

$$c = \int_0^t i^2 \, dt$$

### 4.2.9. Why limit the thermal constraint?

Energy developed during a short circuit if not limited can 'fuse' the whole electrical installation. 2 main parameters govern the thermal constraint:

- cos $\varphi$, the lower it is, the higher the energy is
- voltage, the higher it is, the higher the energy is

Fuse cartridges limit this energy.

*Example:*: short circuit asymmetric of 10 000$A_{rms}$ , 230V, cos $\varphi$ = 1. Without cartridge the first wave of thermal constraint can develop up to 4 000 000 A²sec;

A gG 100 (still our same example) will limit this thermal constraint at 90 000 A²sec, corresponding to 1.95% of the peak value of the first wave of presumed current.

### 4.2.10. Selectivity

When several fuse cartridges are installed in a "cascading" manner within an electrical installation, there will be correct ***selectivity if only the most downstream*** protecting device ***reacts*** when overload and / or short circuit occurs.

*Selectivity ratio is 2 for range under 16A & 1.6 for equal / above 16A gG type;*

| Upstream cartridge gG rating in Amp's | Downstream maximum rating in Amp's for correct selectivity | | Upstream cartridge aM rating in Amp's | Downstream maximum rating in Amp's for correct selectivity | |
|---|---|---|---|---|---|
| | aM | gG | | aM | gG |
| **2** | | | 2 | 1 | 1 |
| **4** | 1 | 1 | 4 | 2 | 4 |
| **6** | 2 | 2 | 6 | 2 | 6 |
| **8** | 2 | 2 | 8 | 4 | 8 |
| **10** | 2 | 4 | 10 | 6 | 10 |
| **12** | 2 | 4 | 12 | 6 | 12 |

| Upstream cartridge gG rating in Amp's | Downstream maximum rating in Amp's for correct selectivity | | Upstream cartridge aM rating in Amp's | Downstream maximum rating in Amp's for correct selectivity | |
|---|---|---|---|---|---|
| | aM | gG | | aM | gG |
| **16** | 4 | 6 | 16 | 10 | 16 |
| **20** | 6 | 10 | 20 | 12 | 20 |
| **25** | 8 | 16 | 25 | 12 | 25 |
| **32** | 10 | 20 | 32 | 20 | 32 |
| **36** | 12 | 20 | 36 | 20 | 32 |
| **40** | 12 | 25 | 40 | 25 | 32 |
| **50** | 16 | 32 | 50 | 25 | 40 |
| **63** | 20 | 40 | 63 | 40 | 50 |
| **80** | 25 | 50 | 80 | 50 | 63 |
| **100** | 36 | 63 | 100 | 63 | 80 |
| **125** | 40 | 80 | 125 | 80 | 100 |
| **160** | 63 | 100 | 160 | 100 | 125 |
| **200** | 80 | 125 | 200 | 125 | 160 |
| **250** | 125 | 160 | 250 | 160 | 160 |
| **315** | 125 | 200 | 315 | 200 | 200 |
| **400** | 160 | 250 | 400 | 250 | 250 |
| **500** | 200 | 315 | 500 | 315 | 315 |

*Table 4: Selectivity for fuses in cascade*

<u>Example</u>

Or how to use the table

With our gG 100A installed upstream, the maximum downstream value of fuse to install should be 36A in aM and 63A in gG to be sure to have “real” selectivity.
If I install downstream, for example, a 63A aM , my upstream gG 100A could blow before the downstream 63A aM; *It is said “could blow before” as a fuse is blowing within a range, and in these closed value (100A gG et 63A aM) no one can tell you which one will blow first….*

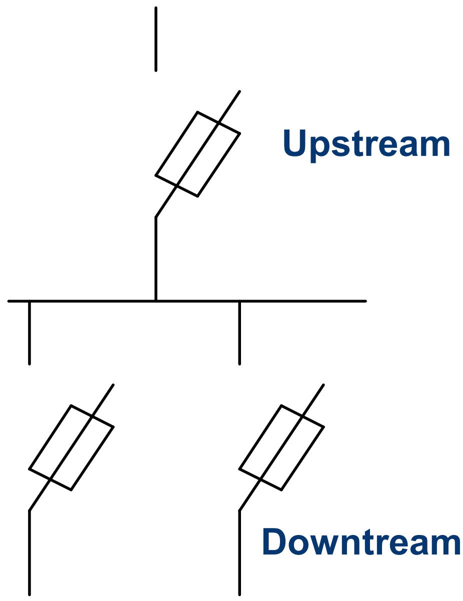



*Figure 32: Respect of selectivity with fuses*

#### 4.2.11. Difference between thermal constraints in arcing and pre-arcing

A fuse cartridge ***breaks in short circuit in 2 periods***: pre-arcing then arcing.

Thermal constraint in pre-arcing corresponds to the minimum energy required for the cartridge to arrive at its 'fusing' point; the knowledge of this thermal constraint is necessary to build correct selectivity in cascading electrical installation. The thermal constraint in pre-arcing is nearly a constant.

The thermal constraint in arcing corresponds to the energy limited between end of pre-arcing and the final circuit breaking.

## 4.3. SIZING - TECHNICAL CHARACTERISTICS

### 4.3.1. Replacement of a fuse

***Replacing*** of a faulty fuse always should be done by ***an identical one***, of same type (gG - aM), same size, same amperes rating, same nominal voltage, this to keep the original breaking capacity.

It is recommended to ***replace the full set of cartridges*** protecting the same device (***three phases and three fuses***) ***even if only one fuse is faulty***.

### 4.3.2. The different manufacturing's and Standards

#### 4.3.2.1. Fuses and fuse-holders Low Voltage

***Cylindrical fuses and holders – Domestic application***

Standard IEC 60269 and NF

General utilisation in all type of protections in domestic (residential) domain (class gF, gG)
Voltage 230 to 430 Vac – Current 2 to 32A

Available in sizes: 6x23, 8x23, 10x25, 8x31, 10x31, 10x38, 8x36 with or without fuse blown indication

Fuse holder available for all sizes for 1 pole and Ph + N

*Figure 33: Cylindrical domestic fuses*

### *Cylindrical fuses and holders – Industrial application*

Standard IEC 60269 and NF

General utilisation in all type of protections in industrial domain (class gG, black colour) and for motor (class aM, green colour)

Breaking capacity: 20 to 120 kA as per type

Voltage 400 to 690 Vac

*Figure 34: Cylindrical industrial fuses*

Available in sizes:  8x32, 10x38, 14x51, 22x58 mm with or without fuse blown indication

Fuse holder available for all sizes from 1 to 4 pole, fuse blown indicator, auxiliary contact…

### *Industrial fuses blade type*

Standard IEC 60269 and VDE 0636

General utilisation in all types of industrial protections (class gG, black) and for motors (class aM, green)

Breaking capacity: 120 kA

Voltage 400 to 690 Vac  - Current 4 to 1600A

*Figure 35: Industrial blade type fuses*

Available in sizes: C00(000), 00, 1, 2, 3 with or without fuse blown indication

### *Fuses Low Voltage D&DO*

Standard IEC 60269 and VDE 0636

*Figure 36: Fuses Low Voltage D&DO*

Breaking capacity 50 kA

Current 2 to 200A

Available in 7 sizes: DI, DII, DIII, DIV, D01, D02 & D03

Fuse holder for mounting in panels or grill and accessories (as above)

***British Standards (Low Voltage) Fuses***

Standards BS88, part 1, 2 and 6 - IEC 60269 part 1 and 2 certified ASTA

General utilisation in all type of protections - class gG

Voltage: 415, 550 & 660 Vac

Current 2 to 1250A

Fuses holder for all types of fuses

*Figure 37: British Standard fuses*

***Cylindrical fuses North American Standard***

Classed UL and certified CSA

Current: 100 mA to 1200 A

Voltage: 125 to 600 Vac

Sizes: miniature, class CC, class RK5, class J, class G

Modular fuse holder

*Figure 38: North American Standard fuses*

### *4.3.2.2. Quick acting fuses*

***Cylindrical IEC***

As per standards UL/CSA, IEC 60 269-4

Current 1 to 100A

Voltage 150 to 2000 Vac

Breaking capacity 200 kA

Sizes 6x32, 10x38, 14x51, 14x67, 21x51, 22x58, 20x127, 25x146

*Figure 39: Quick acting cylindrical IEC fuses*

***British Standards (quick acting)***

As per standard BS88 part 4, IEC 60 269-4

Current 6 to 710 A

Voltage 240 to 690 Vac

Breaking capacity 200 kA

With or without Visualisation fuse blown and micro-switch for remote indication

*Figure 40: Quick acting British Standards fuses*

***Quick acting square Body***

As per Standards EN, IEC 60 269-4, DIN 43653 and 43260, certified CSA

Current 10 to 7500 A

Voltage 660 to 3000 Vac

Breaking capacity 300 kA

Sizes 000, 00, 1, 2, 3, 4, 5

*Figure 41: Quick acting square Body fuses*

***Quick acting North American Standards***

As per Standard UL/CSA

Current 1 to 4000A

Voltage 130 to 1000 Vac and 130 to 800 Vdc

Size: standardised sizes do not exist for these fuses

*Figure 42: Quick acting North American Standards fuses*

### 4.3.2.3. High Voltage Fuses

***Voltage Transformers and Transformation auxiliaries***

As per Standards BS 2692-1 and IEC 60 282-1

Current 3.15 A

Voltage 1 to 36 kV

Use only on primary side of transformers

Figure 43: HV Transformer fuses

***HRC - DIn***

As per Standards DIN 43265, EN IEC 60 282-1, VDE 0670-4

Current 6.3 to 400 A

Voltage 3.6 to 36 kV

For all protections, motor protection

Figure 44: HV HRC-DIN fuse

***HRC-Oil (in breaker with oil)***

As per Standards IEC 282-2, BS 2692-1 and Standard ESI 12-8

Current : 6.3 to 2000 A

Voltage: 3.6 to 24 kV

Equipped with pyrotechnical striker

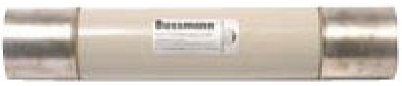


Figure 45: HV HRC-Oil type fuse

***HRC-Motor Starter***

As per Standards UL, IEC DIN 43625 and other British Standards

Current: 6.3 to 400 A

Voltage: 2.75 to 7.2 kV

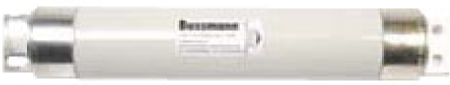


Figure 46: HV HRC-Motor Starter type fuse

***With this presentation of the different fuses available on the Market you have a general "Panel view" and you should not be surprised to discover some "strange manufacturing".***

***On our sites, with all the packages coming from all over the World, any kind of fuses can equip the electrical distribution/protection. If you have to replace a fuse and you do not have the original and same manufacturing equivalent, please, replace the complete fuse holder and all the "associated" fuses (case of tri phase), whatever the size of the fuse. Keep at least same ranking for current, voltage and mainly breaking capacity.***

### *4.3.3. The cylindrical cartridge*

Let's see hereafter the types of fuses mainly used on Total sites, and concerning the cylindrical cartridges as per European Standards.

Industrial type gG - black colour    Industrial type aM - green colour

| size | A | B | C | D |
|---|---|---|---|---|
| 8.5x31.5 mm | 8.5 | 31.5 | 6.3 | -- |
| 10x38 mm | 10 | 38 | 10 | |
| 14x51 mm | 14.3 | 51 | 13 | 7.5 |
| 22x58 mm | 22.2 | 58 | 16 | 7.5 |

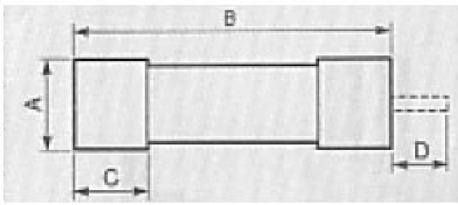
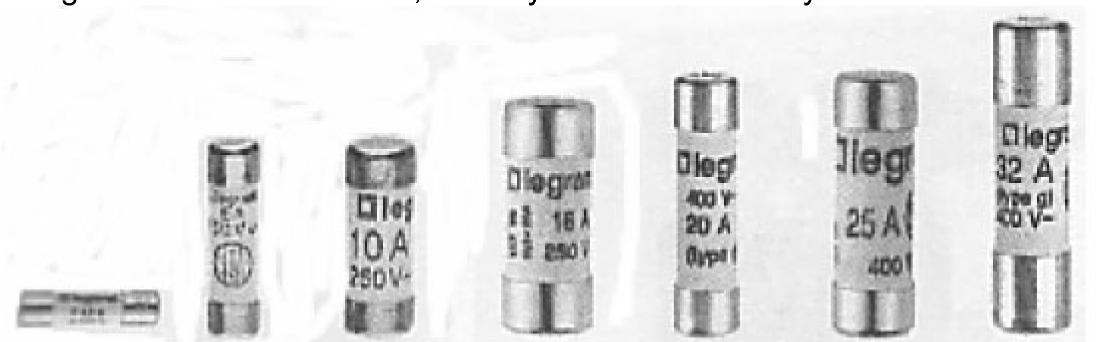



*Figure 47: Cylindrical fuses – IEC Standards – Industrial type*

Note that gG and aM look identical, the only differentiation is by the colour of the writing.



5x20    6.3x23    8.5x23    10.3x25.8    8.5x31.5    10.3x31.5    10.3x38

*Figure 48: Cylindrical fuses – IEC Standards – Domestic type – sizes in mm*

On site, you will probably find fuses from other Standards but also from the same IEC (industrial type) Standard but for domestic / residential fuses. There is no harm in using domestic fuses, they have the same functions but they have different sizes and could be also different in voltage rating and breaking capacity…

### 4.3.4. The industrial 'blade' type

Same as per cylindrical, let's see the typically used ones as per IEC Standards.


*Figure 49: Blade type fuses – gG and aM – with or without striker (fuse blown)*

And as per the cylindrical, without written indication, types gG and aM are identical in dimensions.

This type of cartridge is sized with "number" : 000 - 00 - 0 -1- 2 - 3 -4

***Dimensions of blade type***

| *Size* | Dimensions | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A mm | B mm | C mm | D1 mm | D2 mm | E mm | F mm | G mm | H mm | I mm | J mm | K mm | L mm | M mm | N mm |
| 00 | 78 | 44 | 52 | 30 | - | 46 | - | 2.5 | 15 | 6 | - | - | 59 | 10 | 14.5 |
| 0 | 125 | 62 | 67 | 36 | 39 | 46 | 14 | 2.5 | 15 | 6 | 15.5 | 14.5 | 59 | 10 | 14.5 |
| 1 | 135 | 64 | 74 | 47 | 47 | 52 | 14 | 3 | 21 | 6 | 16 | 14.5 | 64 | 10 | 14.5 |
| 2 | 150 | 64 | 74 | 50 | 50 | 60 | 14 | 3 | 28 | 6 | 19 | 14.5 | 72 | 10 | 14.5 |
| 3 | 150 | 61 | 75 | 70 | 64 | 75 | 14 | 2.5 | 36 | 6 | 23 | 14.5 | 88 | 10 | 18 |
| 4 | 200 | 61 | 78 | 90 | 77 | 107 | 14 | 2.5 | 60 | 8 | 27 | 14.5 | 119 | 10 | 23 |

*Table 5: Dimensions of blade type fuses*

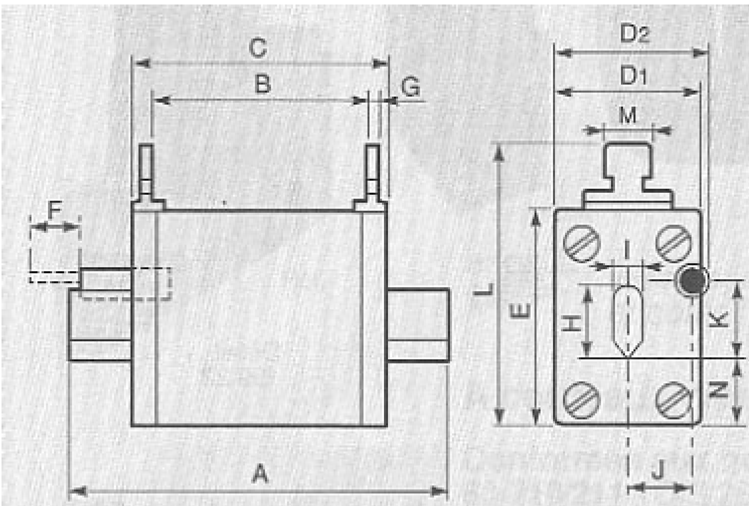



*Figure 50: Dimensions of blade type fuses*

## 4.4. RANGES – AMPERE RATING

We limit ourselves, here as well, with the IEC standards for cylindrical and blade type fuses.

Following table is a résumé of all sizes and types combined with amperes rating for domestic and industrial types in cylindrical and industrial blade type.

For example, you want a 100A gG size 22 x 58, no problem it is there, but above 125A, it does exist in 22 x 58 size. Do not search for a 10A, size '0', it neither does not exist. There is a "logic" progress and combination in sizes and amperes rating.

| dimension | type | Volt | Breaking Capacity (kA) | Rating or nominal current sizing | Form |
|---|---|---|---|---|---|
| **5 x 20** | F* | 250 | 1.5 | 0.2 / 0.5 / 0.63 / 1 / 1.25 / 1.6 / 2 / 3.15 / 5 / 6.3 / 10 | cyl. |
| **6.3 x 23** | Domestic | 250 | 6 | 2 / 4 / 6 | cyl. |
| **8.5 x 23** | Domestic | 250 | 6 | 2 / 4 / 6 / 10 | cyl. |
| **10.3 x 25.8** | Domestic | 250 | 6 | 6 / 10 / 16 | cyl. |
| **8.5 x 31.5** | Domestic | 400 | 20 | 0.5 / 1 / 2 / 4 / 6 / 8 / 10 / 12 / 16 / 20 | cyl. |
| | gG | 400 | 20 | 1 / 2 / 4 / 6 / 8 / 10 / 12 / 16 | |
| | aM | 400 | 20 | 1 / 2 / 4 / 6 / 8 / 10 | |
| **10.3 x 31.5** | Domestic | 400 | 20 | 16 / 20 / 25 | cyl. |

| dimension | type | Volt | Breaking Capacity (kA) | Rating or nominal current sizing | Form |
|---|---|---|---|---|---|
| **10 x 38** | Domestic | 400 | 20 | 32 | cyl. |
| | gG | 500 | 100 | 0.5 / 1 / 2 / 4 / 6 / 8 / 10 / 12 / 16 / 20 / 25 | |
| | aM | 500 | 100 | 0.25 / 0.50 / 1 / 2 / 4 / 6 / 8 / 10 / 12 / 16 / 20 / 25 | |
| **14 x 51** | gG | 500 | 100 | 2 / 4 / 6 / 10 / 16 / 20 / 25 / 32 / 40 / 50 | cyl. |
| | aM | 500 | 100 | 1 / 2 / 4 / 6 / 8 / 10 / 12 / 16 / 20 / 25 / 32 / 40 / 45 / 50 | |
| **22 x 58** | gG | 500 | 100 | 4 / 6 / 10 / 16 / 20 / 25 / 32 / 40 / 50 / 63 / 80 / 100 / 125 | cyl. |
| | aM | 500 | 100 | 16 / 20 / 25 / 32 / 40 / 50 / 63 / 80 / 100 / 125 | |
| **00** | gG/gL | 500 | 120 | 25 / 32 / 35 / 40 / 50 / 63 / 80 / 100 / 125 / 160 | blade |
| | aM | 500 | 120 | 25 / 32 / 40 / 50 / 63 / 80 / 100 / 125 | |
| **0** | gG/gL | 500 | 120 | 64 / 80 / 100 / 125 / 160 / 200 | blade |
| | aM | 500 | 120 | 63 / 80 / 100 / 125 / 160 | |
| **1** | gG/gL<br>aM | 500 | 120 | 125 / 160 / 200 / 250 | blade |
| **2** | gG/gL<br>aM | 500 | 120 | 200 / 250 /315 / 400 | blade |
| **3** | gG/gL<br>aM | 500 | 120 | 500 / 630 | blade |
| **4** | gG/gL<br>aM | 500 | 120 | 630 / 800 / 1000 / 1250 | blade |

** F type: quick acting fuse in glass or ceramic*

*Table 6: Dimensions and amperes rating gG, aM types in IEC Standards*

## 4.5. CURVES

The fuse responds characteristically to a standardised (pre-determines) curve

***Remark: Curves given here in this paragraph as example for gG cylindrical type. For the other types, any manufacturer catalogue will provide the required data's***

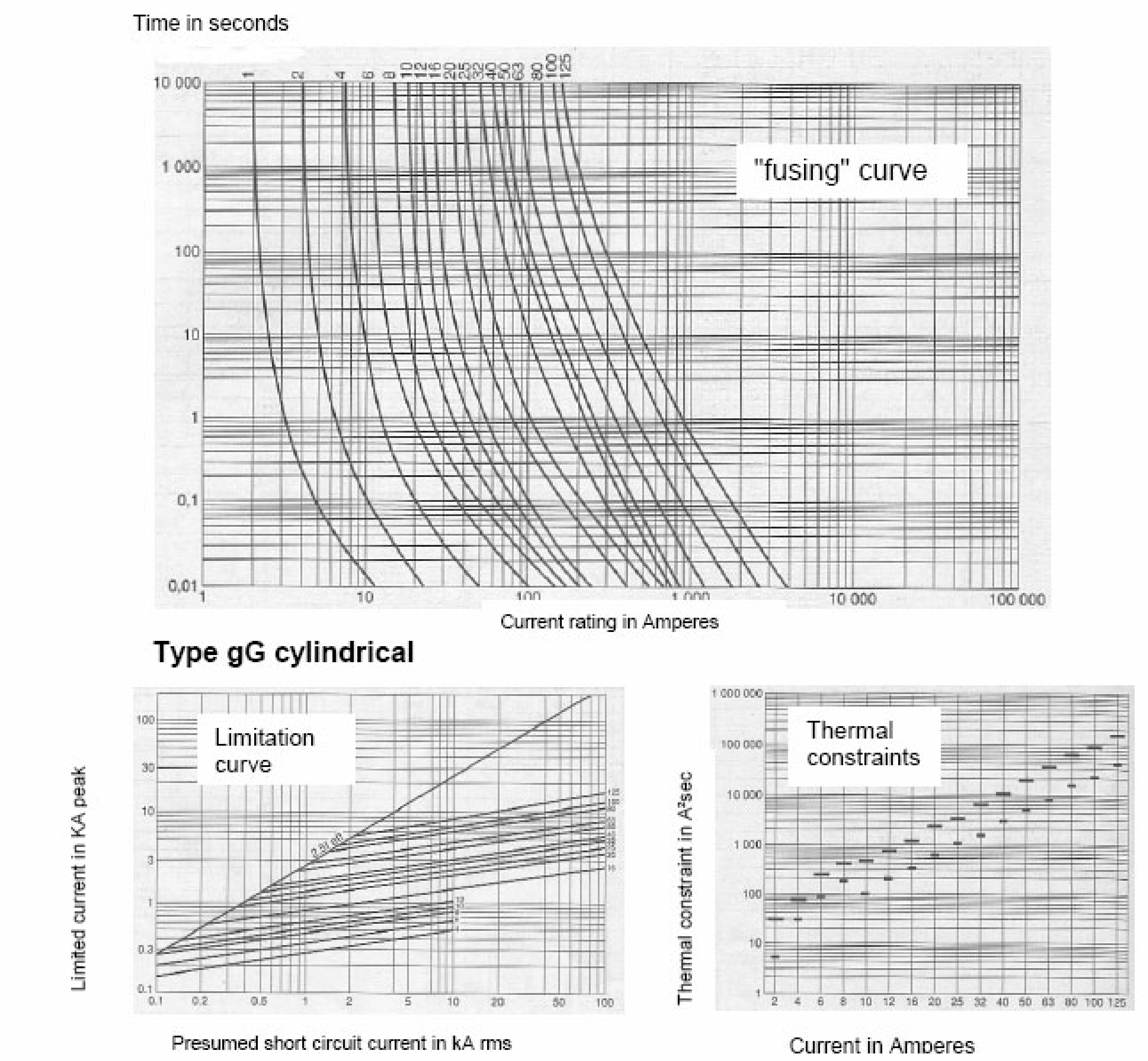



*Figure 51: Typical response curves for gG cylindrical fuses*

<u>*As complementary information:*</u> consumption in *Watts* for the same gG type

Values indicated are the consumption for the nominal current (rating)

| Cartridge / rating (A) | 1 | 2 | 4 | 6 | 8 | 10 | 12 | 16 | 20 | 25 | 32 | 40 | 50 | 63 | 80 | 100 | 125 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **8.5 x 31.5** | O.4 | O.6 | 0.7 | 1 | 1.2 | 1.2 | 1.2 | 1.9 | | | | | | | | | |
| **10 x 38** | 0.27 | 0.50 | 0.90 | 1.05 | 1.30 | 1.35 | 1.45 | 2.20 | 2.50 | 3.50 | | | | | | | |
| **14 x 51** | | 0.80 | 0.90 | 1.40 | | 2 | | 2.60 | 3.10 | 3.50 | 3.50 | 3.70 | 4.60 | | | | |
| **22 x 58** | | | 1.50 | 1.60 | | 1.90 | | 3 | 2.90 | 3.90 | 3.60 | 3.90 | 5.30 | 5.30 | 8 | 8 | 11 |

*Figure 52: Watt consumption for gG type cylindrical at rated current*

## 4.6. THE ACCESSORIES

### 4.6.1. Fuse holder for cylindrical type cartridge

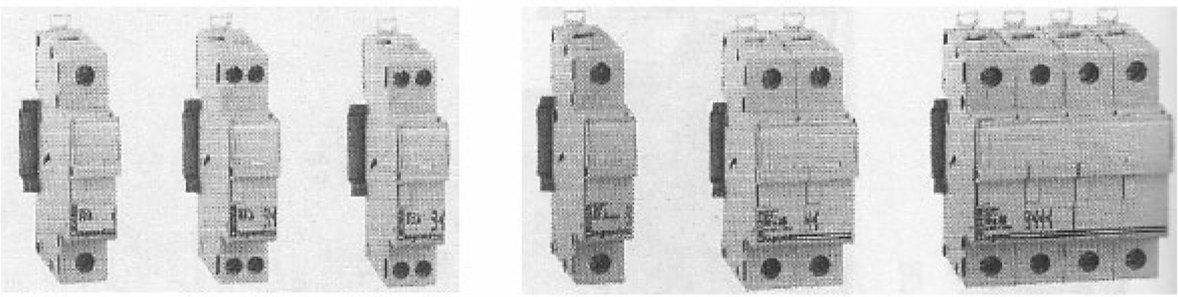
The fuse holder opens the electrical circuit, according to the number of poles it is designed for; 1, 2, 3 or 4 poles. From one phase to 3 phases + neutral.

**Important: in electrical distribution, the neutral pole is (generally) not protected. The neutral can be opened in same time than the phase (or the 3 phase), but in the fuse holder, the neutral pole *is not a fuse*.**
*See course EXP-MN-SE070 "Ground and neutral systems" explaining neutral philosophy and where and where to protect the neutral..*

The "***Neutral cartridge***" is ***just a cylinder*** sized identically to the "normal" cartridge
In mm: 8.5x31;5 / 10x38 / 14x51 / 22x58

*Figure 53: Neutral cartridge cylindrical type as a "fuse"*

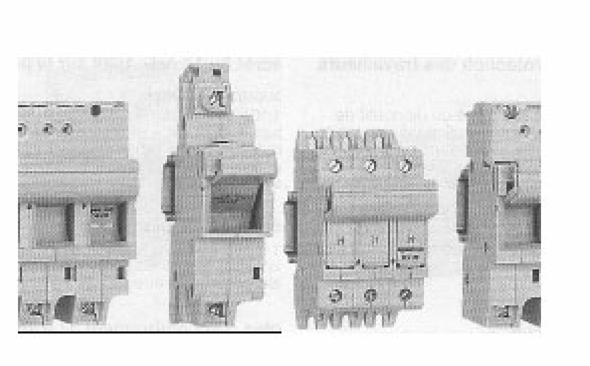
*Fuse holders domestic type*



Mono | Ph + N | Ph + N | Mono | Bi (2 Ph) | 3 Ph + N

*Figure 54: Fuse holders domestic type*

<u>*Fuse holder (industrial) with protection on connections*</u>



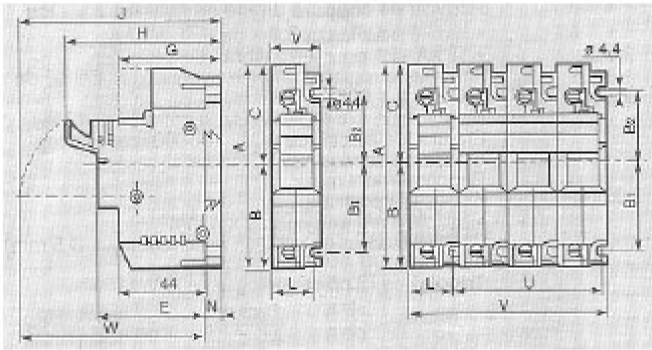
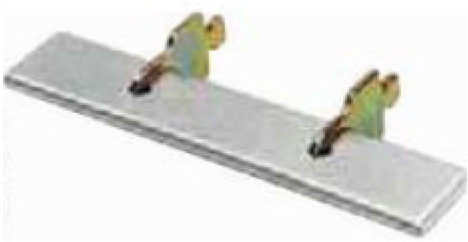


*Figure 55: Fuse holders industrial type*

Industrial holders *"have to be different"* compared to the domestic ones. They are in mono, bi, tri tetra, sized according to the type fuse (10x38, 22x51,…..)

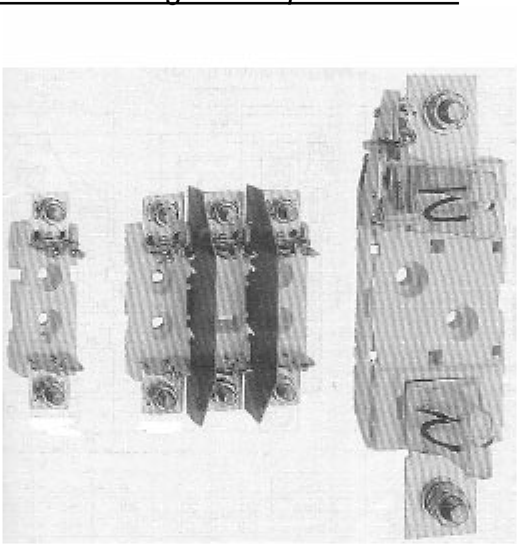
### 4.6.2. Fuse holder for blade type cartridge



**Same remark about the neutral:** neutral is "linked" with a rectangular shape bar

*Figure 56: Neutral cartridge blade type as a "fuse"*

<u>*Holder for cartridges 00 up to 4 sizes:*</u>



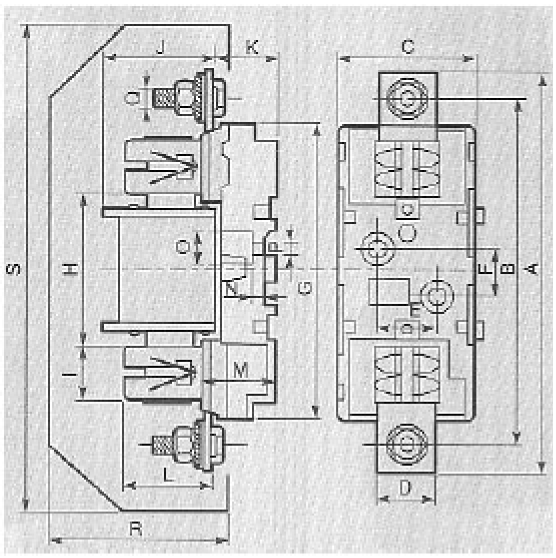


*Figure 57: Fuse holders blade type*

They exist in mono or tri. Two versions only, there is (officially) no bipolar assembly for this type of cartridge

*Accessories to remove this cartridge: the handle*

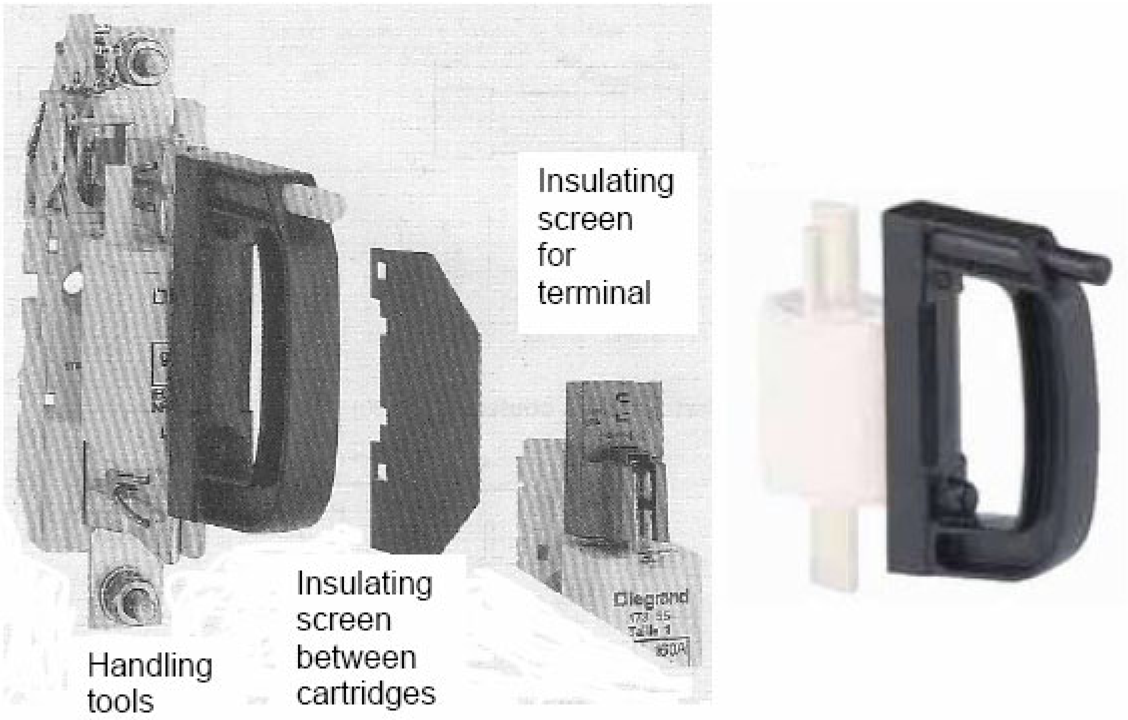



Figure 58: Handle to remove or insert a blade fuse

### 4.6.3. Additional devices on fuses holders / fuses carriers

All types of cartridge (cylindrical or blade type - LV and HV) can be equipped with ***blowing indicator*** "light" or striker pin

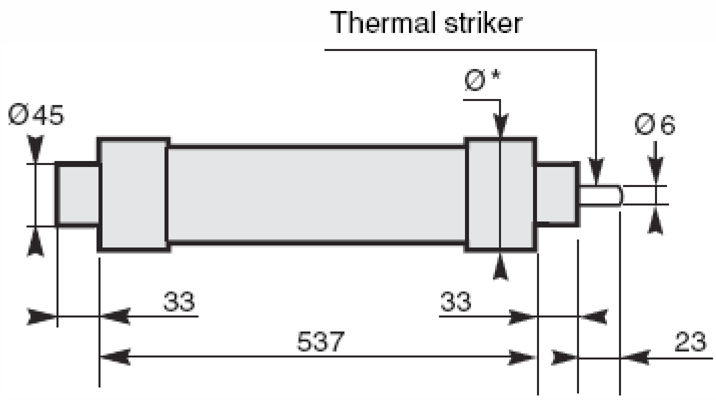



Figure 59: Striker pin on HV Fuse

The striker pin of the fuse (in blown condition) can also activates a ***micro-switch*** which in turn relay the signal towards the tripping system.

In industrial distribution, heavy duty fuse carrier are used, equipped with all the required accessories

***Specific power fuse holder:***

Picture of the GK1 series of fuse holder isolator from Schneider-Telemecanique shows tri or tetra “isolator” (sectionneur in French) which can be equipped with micro switch activated by striker pins of fuses. Isolator has no breaking capacity and must be actuated off- load

They are designed to be operated with external handle (can be frontal in some version)

*Figure 60: Power fuse holder – Isolator series GK1 of Schneider/Télémécanique*

Picture of the GS1 series of fuse isolator is a switch version. Switch means breaking capacity, this device can be actuated with load (up to its designed capacity)

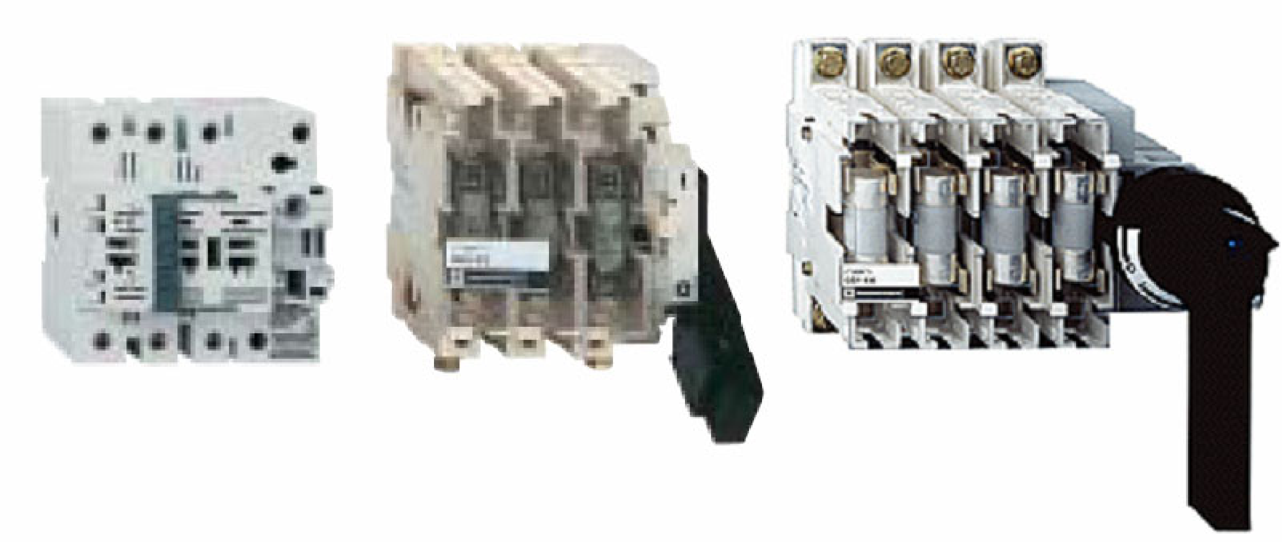


*Figure 61: Power fuse holder –Switch series GK1 of Schneider/Télémécanique*

# 5. LOW VOLTAGE RELAYS – CONTACTOR

## 5.1. GENERAL TERMS

A ***contactor*** is a switch operated by an automatic electrical accessory (coil), opening and closing the circuit on a power circuit, this on 1 phase or phase + neutral, 3 phases, 3 phases + neutral (also 6 phases)

*Figure 62: Schneider Télémécanique Contactor Ref: LC1 D 3200E7*

The figure represents a Télémécanique contactor 3 poles 50/60 Hz service - rating 32 Amps with control circuit 48V AC

A ***control relay*** is a switch operated by an automatic electrical accessory (coil), opening and closing the circuit on a control circuit. Number of breaking contacts can be from 1 to xx contacts.

*Figure 63: Schneider Télémécanique Relays and accessories*

The figure represents:

On the left: a Télémécanique auxiliary relay instantaneous CA2 DN22 M5 with coil 22OV 50 Hz equipped with 2 x N/O and 2 x N/C contacts

In the middle: side instantaneous additional Contact LA8 DN20 2 x N/O contacts

On the right: Miniature plug-in relay RXN41G11P7 Télémécanique equipped with 4 contacts N/O. Coil 230V 50/60 Hz

For these types of relays, the term ***contactor is for power circuit*** and the term ***relay*** (alone) ***is for control circuit***

A ***thermal relay*** is a device actuating auxiliary contacts or a mechanical trip system, when over current is flowing through during a certain time


*Figure 64: Schneider Télémécanique Thermal Relay*

The figure represents a Télémécanique Thermal Overload Relay LR9D5569 class 20. Protection range 90…….150 Amps

To be associated with contactor type D115 to D150 or more exactly, “plugged” under a contactor, the 3 upper connecting pins are sized to fit the under connections of a contactor.

## 5.2. CONTACTORS

### 5.2.1. Definitions and comments

#### Altitude

The rarefied atmosphere at high altitude reduces the dielectric strength of the air and hence the rated operational voltage of the contactor. It also reduces the cooling effect of the air and hence the rated operational current of the contactor (unless the temperature drops at the same time).

No de-rating is necessary up to 3000 m.

De-rating factors to be applied above this altitude for main pole operational voltage and current (a.c. supply) are as follows.

| Altitude | 3500m | 4000m | 4500m | 5000m |
|---|---|---|---|---|
| **Rated operational voltage** | 0.90 | 0.80 | 0.70 | 0.60 |
| **Rated operational current** | 0.92 | 0.90 | 0.88 | 0.86 |

*Table 7: De-rating factors to apply to contactors according to altitude*

#### Ambient air temperature

The temperature of the air surrounding the device measured near to the device. The operating characteristics are given:

- with no restriction for temperatures between - 5 and + 55 °C,
- with restrictions, if necessary, for temperatures between - 50 and + 70 °C.

### Rated operational current (Ie)

This is defined taking into account the rated operational voltage, operating rate and duty, utilization category and ambient temperature around the device.

### Rated conventional thermal current (Ith = conventional thermal current in free air)

That is he current which a closed contactor can sustain for a minimum of 8 hours without its temperature rise exceeding the limits given in the standards. (IEC standards)

### Permissible short time rating

That is the current which a closed contactor can sustain for a short time after a period of no load, without dangerous overheating.

### Rated operational voltage (Ue)

This is the voltage value which, in conjunction with the rated operational current, determines the use of the contactor or starter, and on which the corresponding tests and the utilisation category are based. For 3-phase circuits it is expressed as the voltage between phases. Apart from exceptional cases such as rotor short-circuiting, the rated operational voltage Ue is less than or equal to the rated insulation voltage Ui.

### Rated control circuit voltage (Uc)

That is the rated value of the control circuit voltage, on which the operating characteristics are based. For a.c. applications, the values are given for a near sinusoidal waveform (less than 5% total harmonic distortion).

### Rated insulation voltage (Ui)

This is the voltage value used to define the insulation characteristics of a device and referred to in dielectric tests determining leakage paths and creepage distances.

As the specifications are not identical for all standards, the rated value given for each of them is not necessarily the same.

### Rated impulse withstand voltage (Uimp)

This is the peak value of a voltage surge which the device is able to withstand without breaking down.

### Rated operational power (expressed in kW)

This is the rated power of the standard motor which can be switched by the contactor, at the stated operational voltage.

### Rated breaking capacity (*)

This is the current value which the contactor can break in accordance with the breaking conditions specified in the IEC standard.

This is the maximum fault-current the contactor can successfully interrupt without being damaged for a resistive load

### Rated making capacity (*)

This is the current value which the contactor can make in accordance with the making conditions specified in the IEC standard.

This is the maximum fault-current the contactor can successfully interrupt without being damaged for a resistive + reactive load.

Making capacity = breaking capacity x k
K being a factor function of the cos. Phi of the installation

(*): For a.c. applications, the breaking and making capacities are expressed by the rms. value of the symmetrical component of the short-circuit current. Taking into account the maximum asymmetry which may exist in the circuit, the contacts therefore have to withstand a peak asymmetrical current (making capacity) which may be twice to three time the rms. symmetrical component (breaking capacity).

### On-load factor (m)

This is the ratio between the time the current flows (t) and the duration of the cycle (T)

$$m = \frac{t}{T}$$

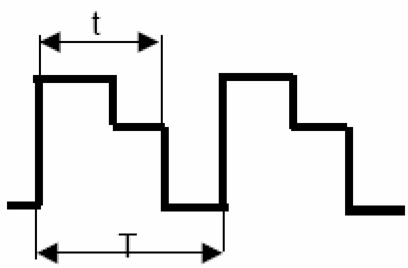



Figure 65: On load Factor

Cycle duration (T): duration of current flow + time at zero current

### Pole impedance

The impedance of one pole is the sum of the impedance of all the circuit components between the input terminal and the output terminal. The impedance comprises a resistive component (R) and an inductive component (X = L$\omega$). The total impedance therefore depends on the frequency and is normally given for 50 Hz. This average value is given for the pole at its rated operational current.

### *Electrical durability*

This is the average number of on-load operating cycles which the main pole contacts can perform without maintenance.

The electrical durability depends on the utilisation category, the rated operational current and the rated operational voltage.

### *Mechanical durability*

This is the average number of no-load operating cycles (i.e. with zero current flow through the main poles) which the contactor can perform without mechanical failure

**As you can see, we have a lot of factors to consider when choosing, installing a contactor. It is not a simple piece of equipment we can take from a shelf. *As for breaker, I have seen "electricians" wondering why their newly installed contactor (or breaker) is melting… And it is not finished, let's see some other selection factors***

## *5.2.2. Utilisation Categories*

***According to the utilisation, a specific type of contactor must be used.***

*When requested to replace a contactor, refer to the following categories of utilisation*

The standard utilization categories define the current values which the contactor must be able to make or break

.
These values depend on:

- the type of load being switched: squirrel cage or slip ring motor, resistors,…
- the conditions under which making or breaking takes place: motor stalled, starting or running, reversing, plugging.

#### 5.2.2.1. A.C. applications

**Category AC-1**

This category applies to all types of **a.c. load** with a ***power factor equal to or greater than 0.95 (cos. φ ⁄0.95).***

Application examples***: heating***, distribution.

**Category AC-2**

This category applies to starting, plugging and inching of ***slip ring motors.***

On closing, the contactor makes the ***starting current, which is about 2.5 times*** the rated current of the motor.

On opening, it must break the starting current, at a voltage less than or equal to the mains supply voltage.

**Category AC-3**

This category applies ***to squirrel cage motors with breaking during normal running of the motor.***

On ***closing,*** the contactor makes the starting ***current, which is about 5 to 7 times*** the rated current of the motor.

On ***opening, it breaks the rated current*** drawn by the motor; at this point, the voltage at the contactor terminals is about 20% of the mains supply voltage. Breaking is light.

Application examples: all standard ***squirrel cage motors: lifts, escalators,*** conveyor belts, bucket elevators, ***compressors, pumps,*** mixers, ***air conditioning*** units, etc... .

**Categories AC-4 and AC-2**

These cover applications with plugging and inching of squirrel cage and slip ring motors.

The contactor ***closes at a current peak which may be as high as 5 or 7 times*** the rated motor current.

On ***opening*** it ***breaks this same current*** at a voltage which is higher, the lower the motor speed. This voltage can be the same as the mains voltage. Breaking is severe

Application examples: printing machines, wire drawing machines, ***cranes*** and ***hoists***, metallurgy industry.

### *5.2.2.2. D.C. applications*

#### *Category DC-1*

This category applies to all types of D.C. load with a time constant (L/R) of less than or equal to 1 ms.

#### *Category DC-3*

This category applies to starting, counter-current braking and inching of shunt motors.
Time constant ≤ 2 ms.

On closing, the contactor ***makes the starting current,*** which is about ***2.5 times the rated motor current***.

On ***opening, the contactor must be able to break 2.5 times the starting*** current at a ***voltage which is less than or equal to the mains voltage.*** The slower the motor speed, and therefore the lower its back e.m.f., the higher this voltage.

Breaking is “difficult”.

#### *Category DC-5*

This category applies to starting, counter-current braking and inching of series wound motors.
Time constant ≤ 7.5 ms.

On closing, the contactor makes a starting current peak which may be as high as 2.5 times the rated motor current. On opening, the contactor breaks this same current ***at a voltage which is higher,*** the lower the motor speed. This voltage can be the same as the main voltage.

Breaking is “severe”.

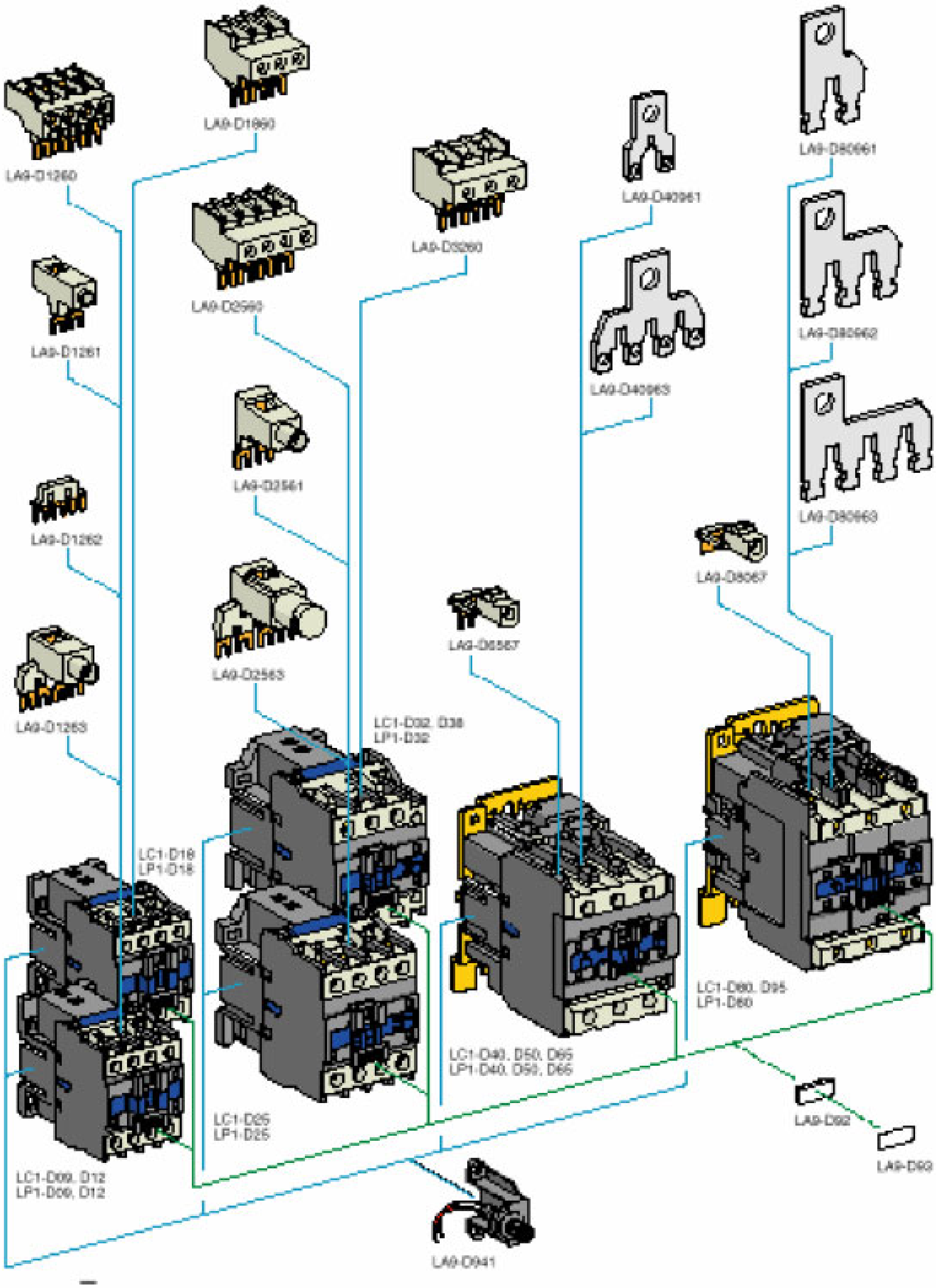



*Figure 66: Contactor's general parts constitution (Télémécanique material)*

### 5.2.3. Résumé choice of contactor

- ***Number of poles***
- ***Type of voltage***
- ***Rated current - range of contactor***
- ***Starting current - category of contactor***
- ***Coil voltage***
- ***Auxiliaries contacts***

## 5.3. AUXILIARY RELAYS

For control purpose, they can be of many types and for many applications.

### 5.3.1. Common criteria

- ***Coil voltage***: AC or DC from 6V up to 440V
- ***Amperes rating of contacts,*** for mA with miniature relays (on printed circuits) to several amperes for contactor control relays
- Plug-in type: requires a base sockets
- Rail mounted
- Plate mounted
- Number of contacts and type ***(N/O: normally open - N/C: normally closed***)
- Additional features: some relays can be added extra instantaneous contacts, time delay,…
- Consumption of relays (miniature ones far less than others)
- Type of connections for wire: pin, lug, screw, clip,…..
- …etc…

### 5.3.2. Different types

- Instantaneous relays: actuated when power is on the coil,
- Latched relay: one pulse on the coil changes its status, open or close; the following pulse re-changes status …and so on… *(télérupteur in French)*
- Time delay relay, delay "ON": at time of powering the coil, the delay is started. At end of set timing, the contact closes, if power is cut during the "on" timing, it is equivalent to a reset
- Time delay relay, delay "OFF": at time of de-powering the coil, the delay is started. Same remark as for "on"
- …etc…

***Example of Relays***

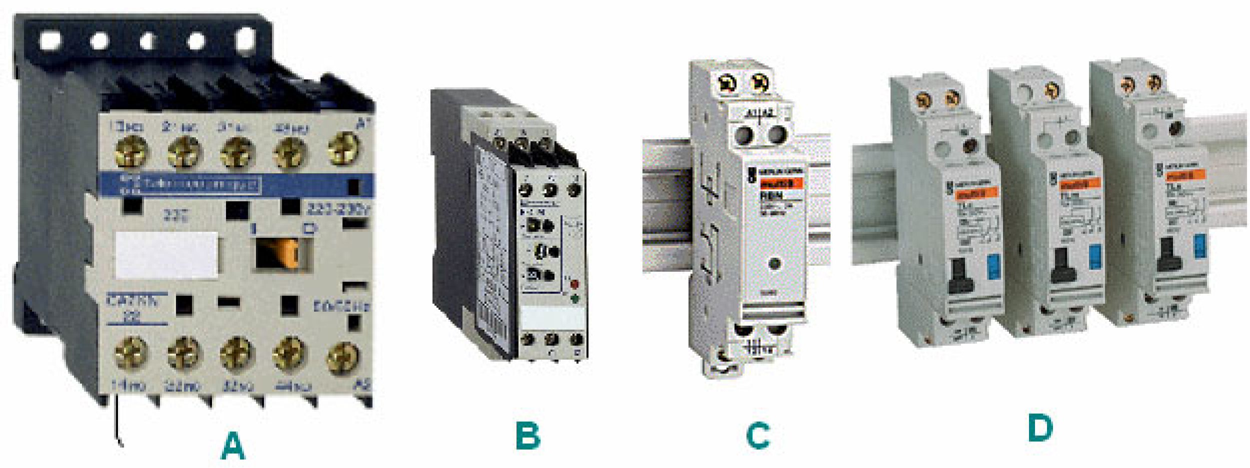



*Figure 67: Panel of auxiliary Relays*

Relay ‘A’: Télémécanique auxiliary relay CA2KN40E7 - screw clamp connections with LA2KT2E, timer 0-30sec. Delay "on" - 4 contacts N/O - Coil 48V AC 50 Hz

Relay ‘B’: Télémécanique:   Solid state relay RE 4 MY13BU output timing relay "off" delay Adjustment range 0.05 sec; to 300 hrs  - 2 contacts N/O or N/C - Coil 110 6 240VAC

Relays ‘C’ & ‘D’: Latched relay of Schneider / Merlin-Gerin. Generally used in lighting distribution either domestic or industrial.

## 5.4. OVERLOAD RELAYS

### 5.4.1. Principles and types

Or Thermal Relays which are systematically associated with contactors; here in the figure, some examples of thermal relays from Schneider / Télémécanique


*Figure 68: Panel of Thermal Relays*

*Relay 'A': Series LR2-K - range 0.11 to 12 A - for unbalanced load*
*Relay 'B': Series LRD – range 0.1 to 140 A – for phases balanced load*
*Relay 'C': Electronic Relay - Series LR9-D – range 60 to 150 A – motor protection*
*Relay 'D': Electronic Relay - Series LR9-F – range 30 to 630 A – motor protection*

In the past, magnetic relay system was associated with thermal relay to have a "magneto-thermal" relay. These combined functions are nowadays more the duty of a breaker and/or a motor protective breaker/contactor device (series GV2 for Schneider or PKZ for Moeller)

Electromechanical relays (tags A & B) operates through thermal dilatation of a bimetal device actuating a micro switch

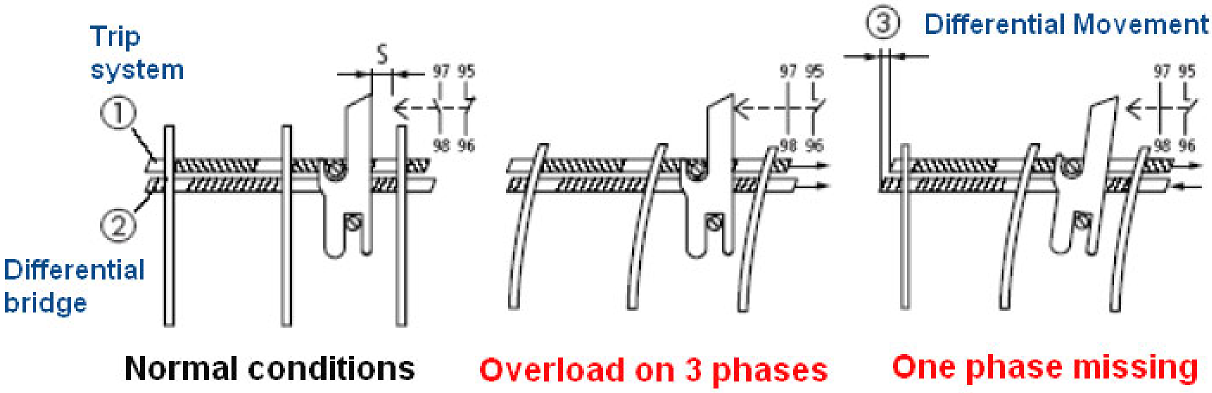



*Figure 69: Principle of electromechanical Thermal Relay*

Concerning Electronic relays they operate indirectly analysing temperature function of current. Generally a complementary protection by survey of receptor temperature is used, integrating one or several thermistors in the body of the same receptor (winding of motor, casing of heater,…). This double "*temperature protection"* can be done with same relay or two separate ones.

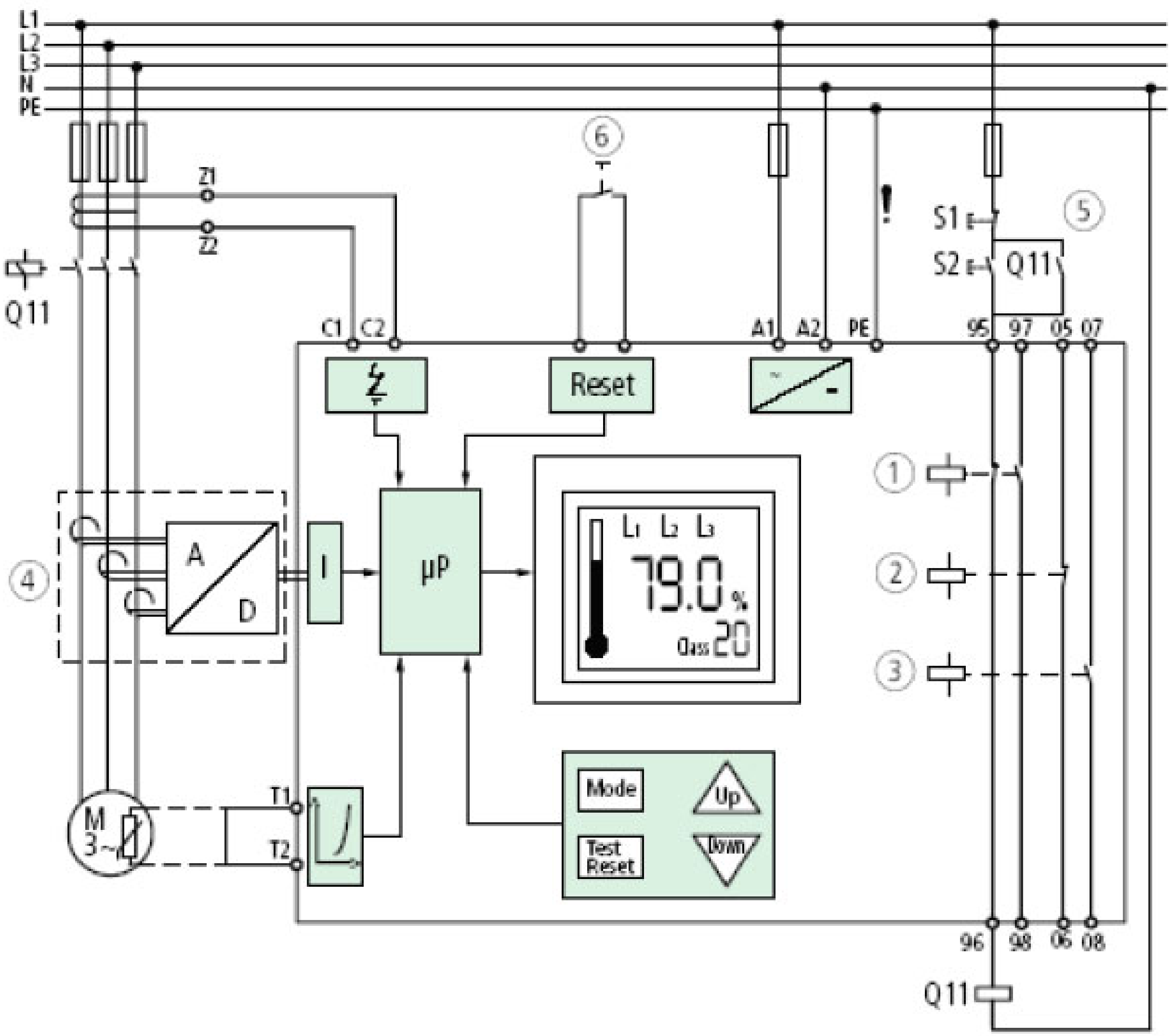



*Figure 70: Principle of electronic Thermal Relay + Thermistor – Relay ZEV of Moeller*

*Legend of the figure:*
*1 - Fault*
*2 - Trip 1*
*3 - Trip 2*
*4 - Thermal sensor same type as C& D on the previous figure*
*5 - Start / Stop / self maintained*
*6 - Reset*

The figure for *principle of electronic thermal relay"* is from the manufacturer Moeller who can cover the protection for phase current from 1 to 820 A.

### 5.4.2. Criterion's definitions for thermal relay

We come back to the typical (electromechanical) thermal relay which is still equipping our sites and still promised for future applications in small (and medium) power range. *I have not seen yet so many electronic thermal relay on Total sites; protection is done rather by breaker or multi-functions relays.*

*Figure 71: Typical Thermal relay of Schneider*

Thermal relay LT2D1510

***Tripping class: 20*** (long starting) – *see next paragraph*

Thermal protection ***setting : 4…..6***

Mounting beneath contactor DO9….D32

Relay type: compensated and differential

Reset type: manual or auto

Trip indication: with
Frequency (Hz): ***AC or DC***
Number of poles: 3
Number of contact N/O: 1 - N/C: 1

Relay LR2D1 equipped with reset function LA7 D305

Thermal protection setting is as per the "nominal" current of the load, corresponding to the current taken at 100% of load.

*Example: pump motor 3Ph, 400V (between phases), 9 kW, cos phi = 0.9,*

*I = 9000 / 400 x 1.732 x 0.9 = 14.4 Amp's*

*Thermal relay will be in the range 12-18 adjustable LR2 D1321*

***Caution:*** relay has to protect the equipment, motor and pump.

At full load the load takes *(supposedly)* only ***7 kW.***
It means that At 9 kW, the pump (not the motor) has "already» a problem
Protection must be adapted for 7 kW, which is the ***Nominal load, at 11.2A.***

### 5.4.3. Tripping class of a thermal relay

It defines the 'delay' for the tripping

**Class 10:** between 2 and 10 seconds

**Class 20:** between 6 and 20 seconds

It is the response time of the device, typical curves being produced by vendor, and to be referred to when performing test / calibration of thermal relays

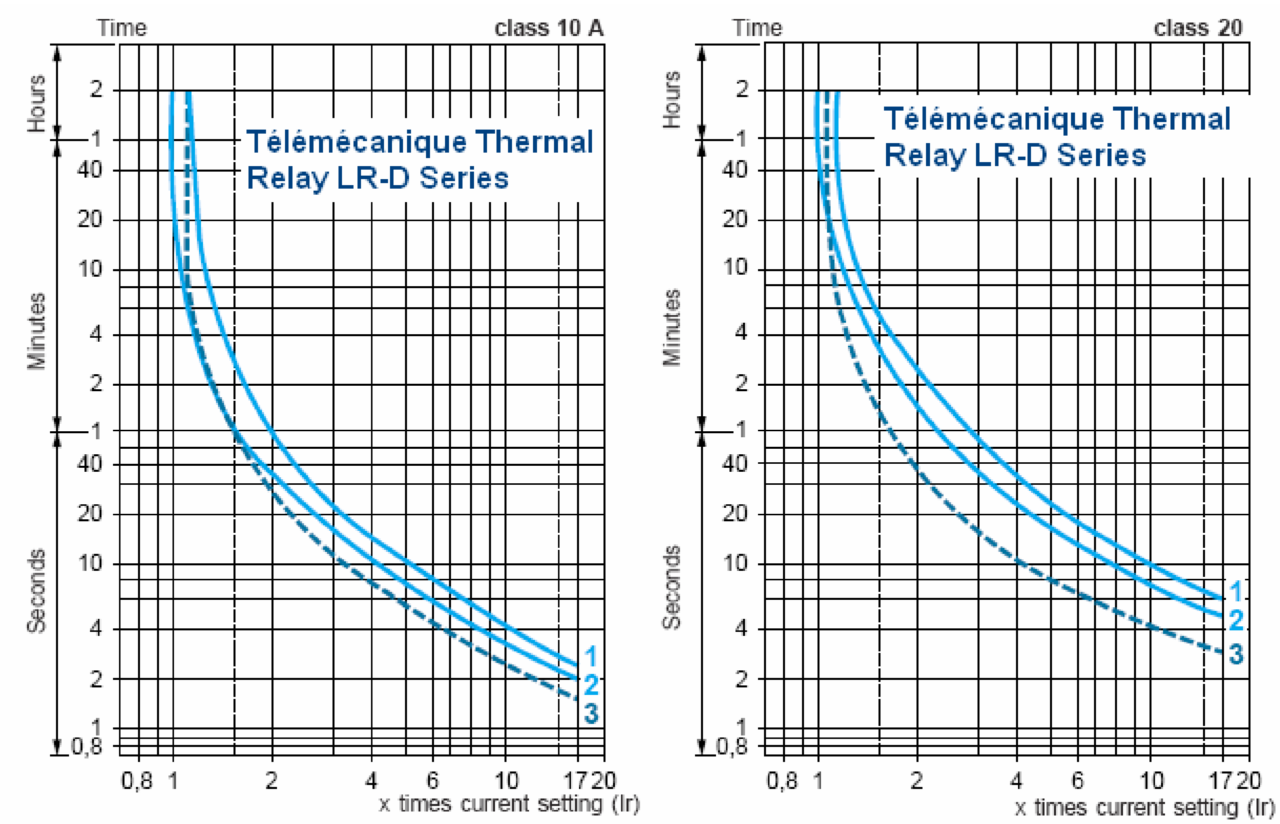



*Figure 72: Tripping curves for Class 10 and 20 of Schneider LR2-D thermal relay*

**1** *Balanced operation, 3-phase, from cold state.*
**2** *Balanced operation, 2-phase, from cold state.*
**3** *Balanced operation, 3-phase, after a long period at the set current (hot state).*

Example: for a relay set at 20A, class, with a permanent load current of 20 A it takes 20 minutes to reach the “tripping zone”. With a current of 40A it takes 40 to 60 mn to reach the same zone
With the same set at 20A, for a class 20 relay, with 40 A load, it takes 1.5 to 2.5 minutes to trip

Note that the curves 3 (hot state) are nearly identical in both classes.

Other tripping curve is shown with the Schneider / Télémécanique LR9-F series. All manufacturers have (more or less) same types of curves

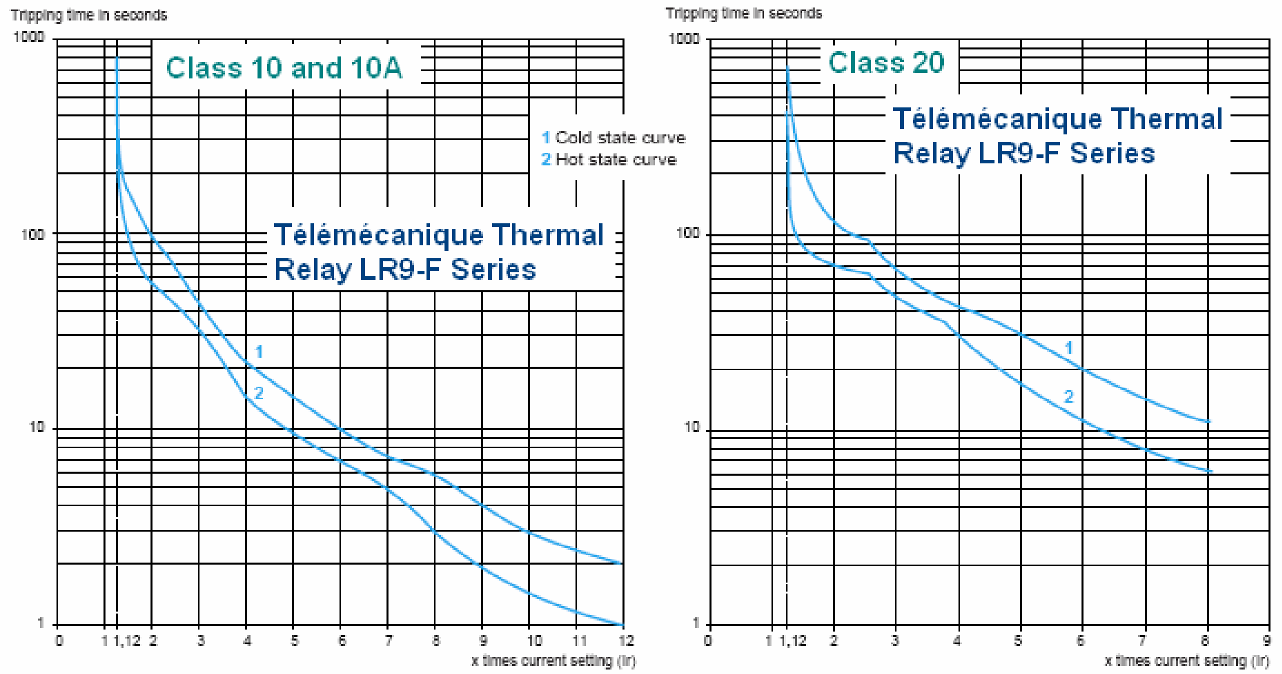



*Figure 73: Tripping curves for Class 10 and 20 of Schneider LR9-F thermal relay*

For electronic "thermal relay", more classes can be preset on the device

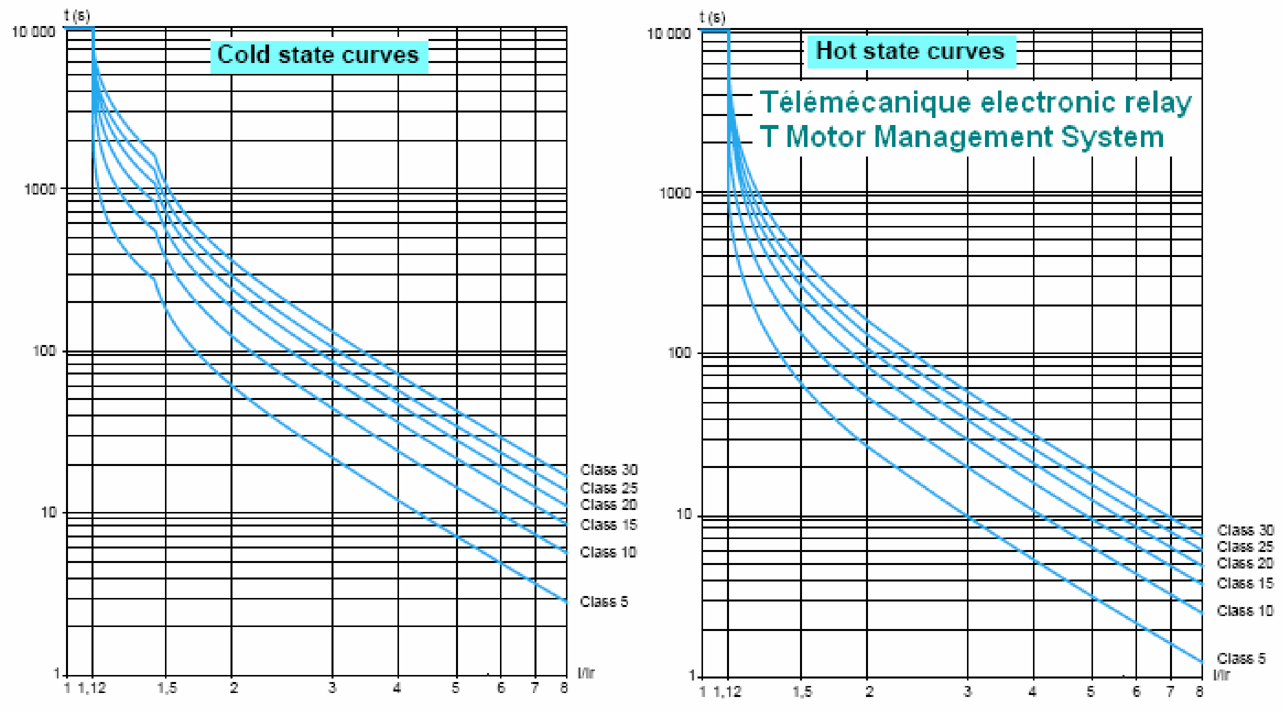
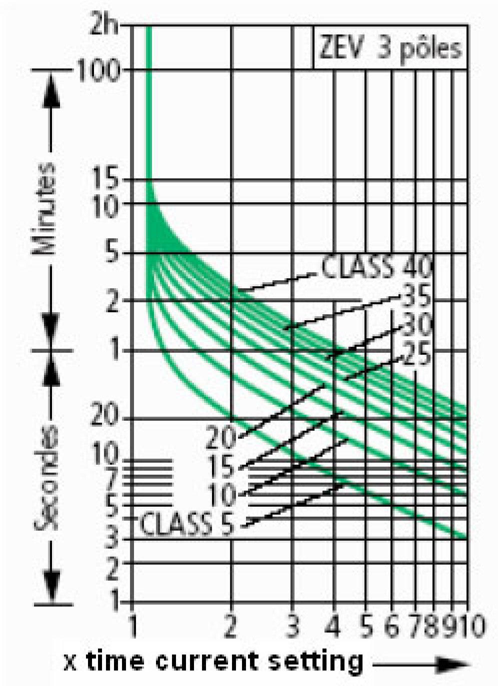



*Figure 74: Tripping curves for Schneider electronic thermal relay*

Schneider / Télémécanique relay offers 6 classes of adjustment (class 5 to class 30)




Other example is given with the curves of the ZEV relay from Moeller

*Figure 75: Curve of electronic "thermal relay' type ZEV of Moeller*

In this manufacturing, 8 classes are available, from 5 to 40

This curves are established for cold state

In hot state, all indicated tripping times drop by about 15%

## 5.4.4. Current transformer operated thermal overload relays

Used when the current is greater than 200 A and/or when:

- with FUSES / CONTACTORS / OVER LOAD assembly, the breaking of high over current must be ensured by fuses only (not by relays with magnetic tripping).
- with PLUG-IN CONTROL CENTRES and similar equipment, the CT's mounted on the fixed part are calibrated for each output current, while each tray has the same low-rated relay.
- with LONG STARTING TIMES (more than 7 seconds for an average current of 5 In, a relay would trip directly.

CT's with a low "saturation index" are used in order to increase the time up to about 30 seconds. Beyond this, normal CT's are used, the secondary being short-circuited for a time equal to the starting time less the tripping time of the relays.

When the sole function of the relay is to provide overload protection for a motor (or balanced circuit) with 3-phase supply without neutral, supply of the relay by 2 CT's is normal and conserves all the relay characteristics, including tripping in the event of phase failure (differential).

### *5.4.5. Protection by thermal relay must be associated with fuses protection*

If a breaker is installed upstream of the contactor/relay, fuses are not required, but

It would be a double protection (in series) as breaker has thermal protection devices systematically included by construction (and definition).

***Remind:***

3 poles thermal protection relays are for motors and circuits protection, against overload, phase loss, long starting time, locked rotor too long.

They are :

- Ambient compensated (-15°C to + 55°C)
- Differential (phase loss)
- With manual or automatic reset
- With trip indicator
- Directly or separately mounted with contactor

Association contactor and thermal relay is called ***'discontactor'***

### *5.4.6. Association fuses / contactor / thermal relays*

Those 3 devices are non dissociable when protecting a load (except when there is a breaker as said above, but breaker is not designed to associated with thermal relay)

Hereafter is a table for Schneider / Télémécanique material ranking sizes of fuses + sizes of contactors + size of relays; If you have different manufacturer, just change references of material, main aim here is to give you the correct sizing of fuses with the gap of adjustment for the thermal relay

| | Relay adjustment | Associated fuses | | | Contactor ref | Relay Ref |
|---|---|---|---|---|---|---|
| | | aM | gG | BS88 | | |
| **Class 10A** | 0.10…0.16A | 0.25A | 2A. | - | LC1-D09…D38 | LRD-01 |
| | 0.15…0.25A | 0.5A | 2A | - | LC1-D09…D38 | LRD-02 |
| | 0.25…0.40A | 1A | 2A | - | LC1-D09…D38 | LRD-03 |
| | 0.40…0.63A | 1A | 1.6A | - | LC1-D09…D38 | LRD-04 |
| | 0.63…1A | 2A | 4A | - | LC1-D09…D38 | LRD-05 |
| | 1A…1.7A | 2A | 4A | 6A | LC1-D09…D38 | LRD-06 |
| | 1.6…2.5A | 4A | 6A | 10A | LC1-D09…D38 | LRD-07 |

| | Relay adjustment | Associated fuses | | | Contactor ref | Relay Ref |
|---|---|---|---|---|---|---|
| | | aM | gG | BS88 | | |
| | 2.5…4A | 6A | 10A | 16A | LC1-D09…D38 | LRD-08 |
| | 4…6A | 8A | 16A | 16A | LC1-D09…D38 | LRD-10 |
| | 5.5…8A | 12A | 20A | 20A | LC1-D09…D38 | LRD-12 |
| | 7…10A | 12A | 20A | 20A | LC1-D09…D38 | LRD-14 |
| | 9…13A | 16A | 25A | 25A | LC1-D12…D38 | LRD-16 |
| | 12…18A | 20A | 35A | 32A | LC1-D18…D38 | LRD-21 |
| | 16…24A | 25A | 50A | 50A | LC1-D25…D38 | LRD-22 |
| | 23…32A | 40A | 63A | 63A | LC1-D25…D38 | LRD-32 |
| | 30…38A | 50A | 80A | 80A | LC1-D32 & D38 | LRD-35 |
| | 17…25A | 25A | 50A | 50A | LC1-D40…D95 | LRD-3322 |
| | 23…32A | 40A | 63A | 63A | LC1-D40…D95 | LRD-3353 |
| | 30…40A | 40A | 100 | 80A | LC1-D40…D95 | LRD-3355 |
| | 37…50A | 63A | 100A | 100A | LC1-D40…D95 | LRD-3357 |
| | 48…65A | 63A | 100A | 100A | LC1-D40…D95 | LRD-3359 |
| | 55…70A | 80A | 125A | 125A | LC1-D40…D95 | LRD-3361 |
| | 63…80A | 80A | 125A | 125A | LC1-D65 & D95 | LRD-3363 |
| | 80…104A | 100A | 160A | 160A | LC1-D80 & D95 | LRD-3365 |
| | 80…104A | 125A | 200A | 160A | LC1-D115 & D150 | LRD-4365 |
| | 95…120A | 125A | 200A | 200A | LC1-D115 & D150 | LRD-4367 |
| | 110…140A | 160A | 250A | 200A | LC1-D150 | LRD-4369 |
| **Class 20A** | 6A | 10A | 16A | - | LC1-D09…D32 | LRD-1508 |
| | 4…6A | 8A | 16A | 16 | LC1-D09…D32 | LRD-1510 |
| | 5.5…8A | 12A | 20A | 20A | LC1-D09…D32 | LRD-1512 |
| | 7…10A | 16A | 20A | 25A | LC1-D09…D32 | LRD-1514 |
| | 9…13A | 16A | 25A | 25A | LC1-D09…D32 | LRD-1516 |
| | 12…18A | 25A | 35A | 40A | LC1-D18…D32 | LRD-1521 |
| | 17…25A | 32A | 50A | 50A | LC1-D25 & D32 | LRD-1522 |
| | 23…28A | 40A | 63A | 63A | LC1-D25 & D32 | LRD-1530 |
| | 25…32A | 40A | 63A | 63A | LC1-D25 & D32 | LRD-1532 |
| | 17…25A | 32A | 50A | 50A | LC1-D40…D95 | LR2-D3522 |
| | 23…32A | 40A | 63A | 63A | LC1-D40…D95 | LR2-D3553 |
| | 30…40A | 50A | 100A | 80A | LC1-D40…D95 | LR2-D3555 |
| | 37…50A | 63A | 100A | 100A | LC1-D50…D95 | LR2-D3557 |
| | 48…65A | 802A | 125A | 100A | LC1-D50…D95 | LR2-D3559 |
| | 55…70A | 100A | 125A | 125A | LC1-D65…D95 | LR2-D3561 |
| | 63…80A | 100A | 160A | 125A | LC1-D80 & D95 | LR2-D3563 |

*Table 8: Association Fuse / contactor/thermal relay for series LRD & LR2 of Schneider*

*Thermal relays LR9 series (Schneider / Télémécanique)*

| Relay adjustment in Amp's | Associated fuses in Amp's | | With contactor type | Reference Relay | | Alarm equipped Cl 10 or 20 |
|---|---|---|---|---|---|---|
| | aM | gG | | Class 10 | Class 20 | |
| 60…100 | 100 | 160 | D115 & D1560 | LR9-D5367 | LR9-D5567 | - |
| 90…150 | 160 | 250 | D115 & D1560 | LR9-D5369 | LR9-F5569 | - |
| 30…50 | 50 | 80 | F115…F185 | LR9-F5357 | LR9-F5557 | LR9-F57 |
| 48…80 | 80 | 125 | F115…F185 | LR9-F5363 | LR9-F5563 | LR9-F63 |
| 60…100 | 100 | 200 | F115…F185 | LR9-F5367 | LR9-F5567 | LR9-F67 |
| 90…150 | 160 | 250 | F115…F185 | LR9-F5369 | LR9-F5569 | LR9-F69 |
| 132…220 | 250 | 315 | F185…F400 | LR9-F5371 | LR9-F5571 | LR9-F71 |
| 200…330 | 400 | 500 | F225…F500 | LR9-F7375 | LR9-F7575 | LR9-F75 |
| 300…500 | 500 | 800 | F225…F500 | LR9-F7379 | LR9-F7579 | LR9-F79 |
| 380…630 | 630 | 800 | F400…F800 | LR9-F7381 | LR9-F7581 | LR9-F81 |

*Table 9: Association Fuse / contactor/thermal relay for series LR9 of Schneider*

And now you are ready to assemble not only fuses/contactor/relay but also all the other accessories.

See the figure showing all the possible components for a Schneider / Télémécanique thermal relay

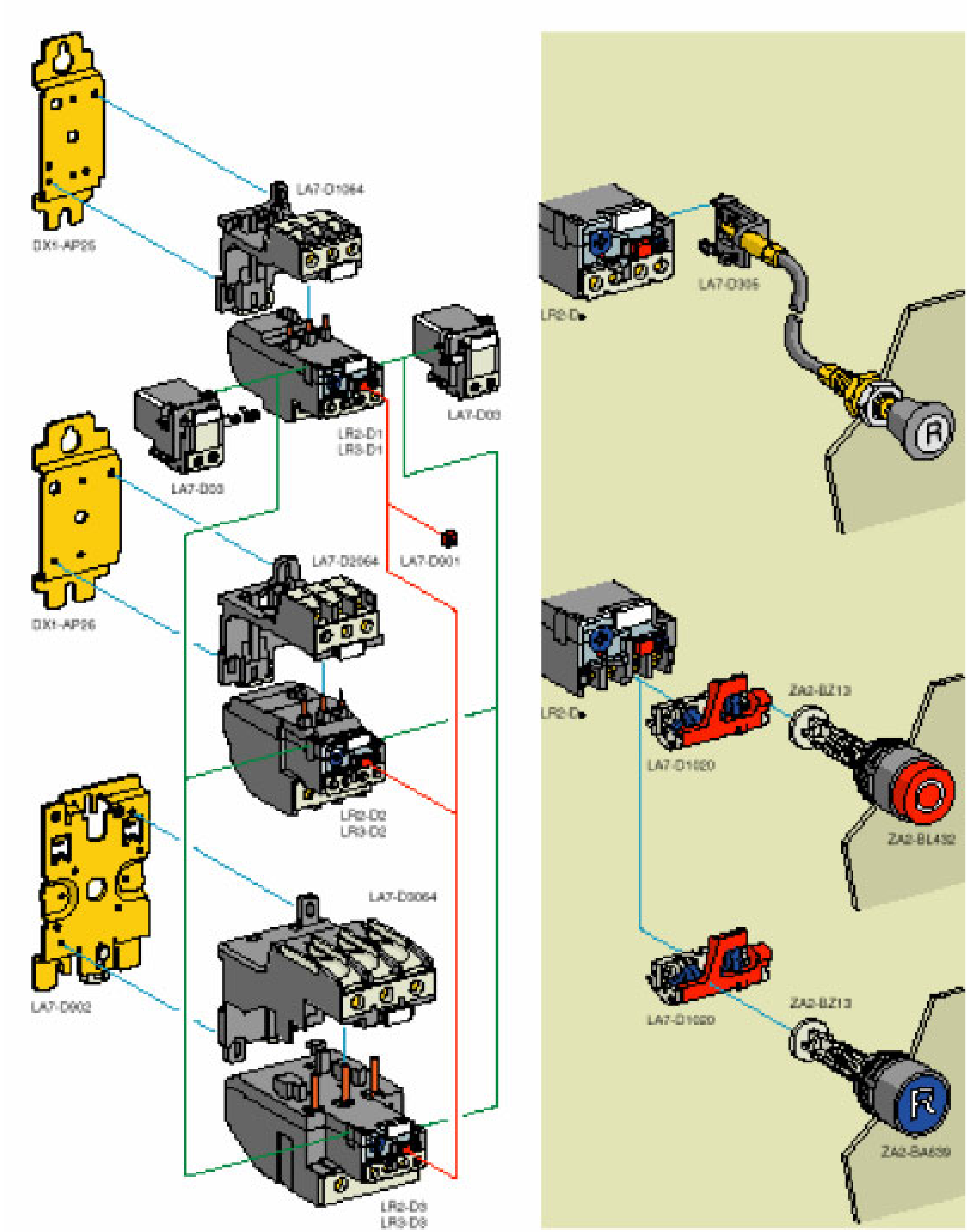



*Figure 76: Contactor + thermal relay + accessories example*

# 6. BREAKER - SWITCH

***Title is "Breaker – Switch" as I saw numerous electricians (all nationalities…) mixing those 2 devices, it is why we start by differentiating them.***

***I worked (on industrial sites) as well with French electricians, at least the old (fashioned) ones, speaking about breakers and taking references upon principles, technologies, characteristics, etc.., only within one (well known) French manufacturer range of materials.***

***They were unable to speak (really) about general principles of breakers and unable to select, compare the working characteristics of other made breakers. (note: I am French myself…)***

***It has improved now, with young generation of electricians, and also because different manufacturers are equipping the electrical distribution panels on Total sites (ABB, Alstom, GE, Schneider, Siemens, etc…)***

## 6.1. DIFFERENCE BREAKER - SWITCH

To switch on the light at home or at your office, you use, close to the entrance door, a switch. You do not call it a breaker and you are right.

But on front of a lighting distribution panel, you can have "separation devices" switching on and off lighting circuits and being either switch or breaker and looking alike!

On a Power distribution panel - it is mandatory - you must a power separation device generally a power switch actuated manually or remotely.

*On Total sites, a power distribution panel is always protected by a (general) breaker, but a power switch would be sufficient, as per Standards…*

So, at first we can say: ***breaker and switch have in common the opening / closing of a circuit <u>under load</u>*** . We'll discuss here only about power switches

### 6.1.1. The Power Switch

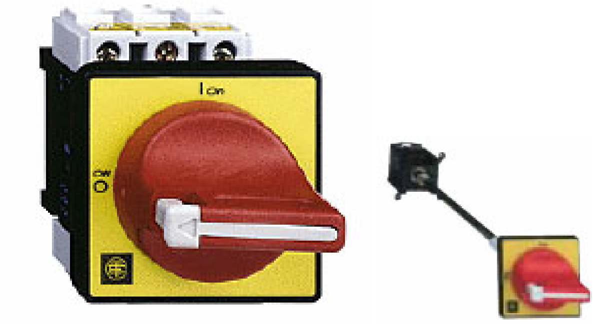
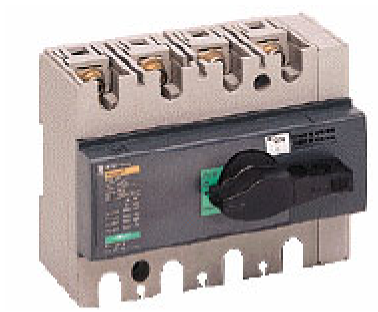
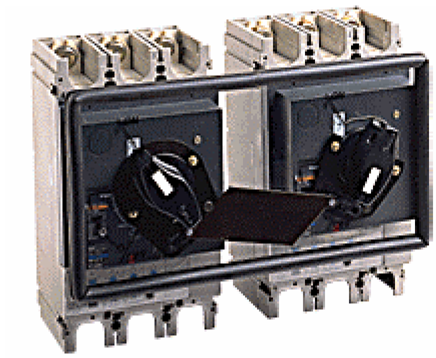
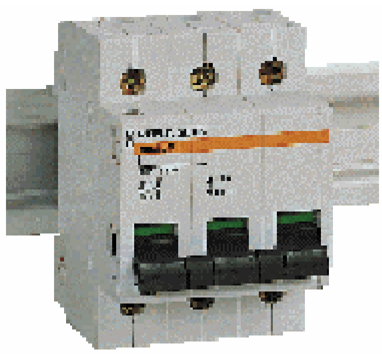
| | |
|---|---|
| <br>Fuse-break switch for 14x51 cartridges 3x50 Amp<br>Already seen in fuses chapter.<br>Rating 100 Amp. | <br>"Emergency" switch “disconnector” 3 or 4 poles<br>Range 12 to 175 Amp.<br>Local panel mounted (generally “Padlockable” |
| <br>"Interpact" Merlin Gérin INS 40 to 160<br>Conventional thermal current 40A up to 160A<br>Making capacity: 15 kA peak with switch only, 75 kA peak with upstream protection via circuit breaker | <br>Change-over non-automatic switch<br>Made with base of INS 160 |
| <br>Modular type Power switch mounted inside a distribution panel | <br>Switch NS100: *"breaker"* without thermal-magnetic device<br>This Power switch can be installed in MCC (TGBT) as general protection or individual circuit protection |
| **We are not breakers, we are switches** | |

*Table 10: Panel of Power Switches*

Power switches are devices able to break the rated current being operated manually or by control on/off actuator.

They have the same characteristics than the breakers concerning:

- rated voltage
- rated current (nominal current)
- breaking capacity
- …etc…

They can be equipped with auxiliary contacts, tripping coil (depending type of switch) and other devices as per he breakers, but they do not have automatic trip by thermal and / or magnetic overcurrent

### 6.1.2. Breaker Vs Switch

***A breaker is a switch equipped with thermal or thermal + magnetic devices making it to operate automatically and open circuit in case of overcurrent (it is called circuit-breaker)***

***A switch can be an "originally" breaker in which we have removed the automatic thermal-magnetic trip systems***

*Of course, it depends the design; in the table of this paragraph only the last 2 switches have the "physical manufacturing" to receive thermal magnetic elements able to "transform" in breaker*

*Figure 77: Two switches and two breakers*

The picture represents breakers/switches in modular and moulded versions. They are of same design / manufacturing, it is just a matter of equipping differently the internals to have either breaker or switch.

*(On figure in modular, we have a Schneider breaker and an ABB switch, do not argue, the picture is only to show the principle)*

## 6.2. WORKING PRINCIPLE OF A BREAKER

On front face of circuit breakers (most of them) you see this symbol, once you have understood what it means, once you can explain the 3 main characteristics represented by this figure, the circuit breaker has no more secret for you….;

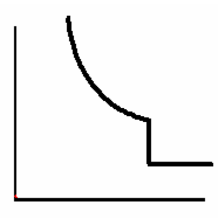


*Figure 78: The working principle symbol of a breaker*

### 6.2.1. Circuit breaker specifications:

*A* ***circuit breaker*** *is an electromechanical device capable of establishing, withstanding and interrupting a current in an electric circuit, even in the case of overloading and short circuits.*

A **circuit breaker** protects the installation against **thermal** overloads and against **short circuits**. It must also be capable of interrupting the circuit whatever the current flowing through it, up to its ultimate **breaking capacity** $I_{sc}$ which can be up to a few tens of kilo-amperes.

***The multi-pole version is capable of simultaneously making, monitoring and interrupting (breaking) the three phases of a three-phase supply, even if the fault is only on one phase.***

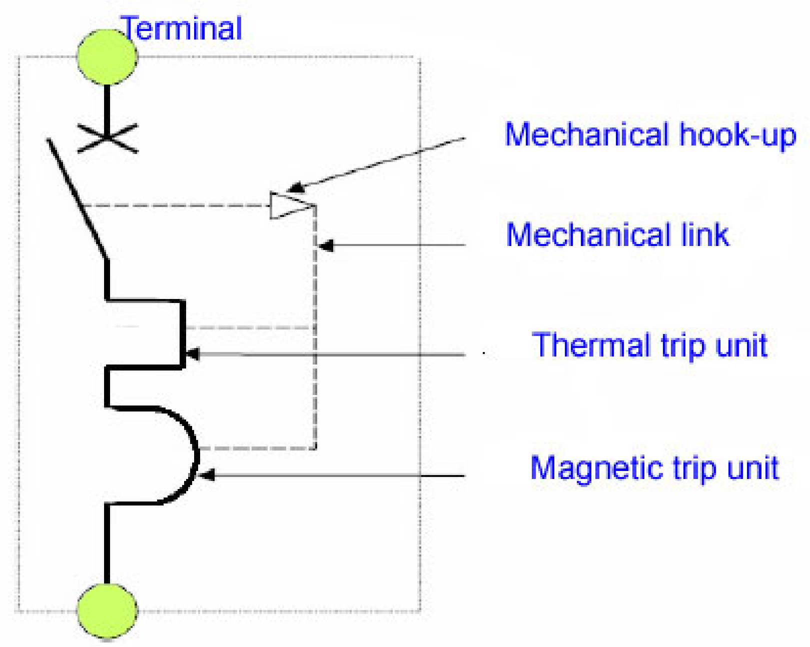



*Figure 79: Thermal trip unit and magnetic trip unit*

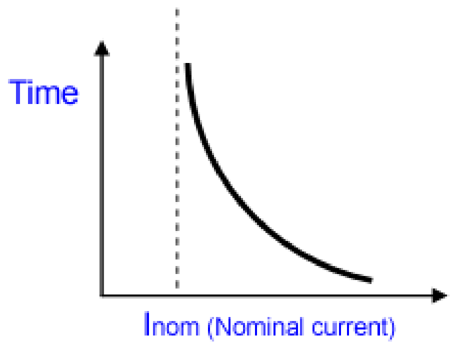
It contains **two types of trip units**:

**A thermal trip unit,** which operates the device after a certain time if there is an overload.

**A magnetic trip unit**, which trips immediately if there is a short circuit *(with however a slight delay due to time response of the electromechanical system*.

It contains also a mechanical links system; see paragraph "*technology of a breaker*"

### 6.2.1.1. Thermal trip unit




The thermal trip unit acts like a fuse, it requires a "warm-up" time to trip at its nominal (rated) current (Inom), characteristic value.

The higher the current the faster it trips.

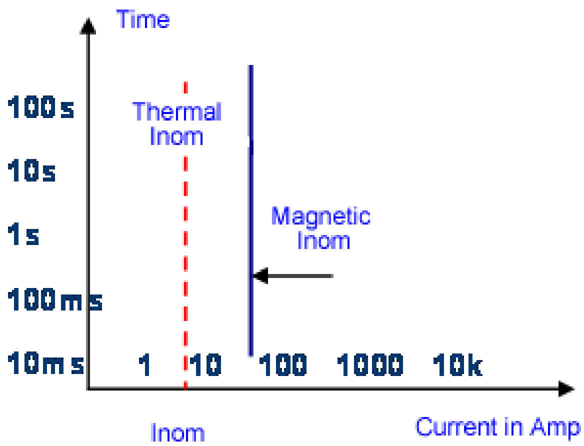
*Figure 80: Logarithmic scale for the time and current of a thermal trip unit;*

### 6.2.1.2. Magnetic trip unit

A magnetic trip unit acts (almost) instantaneously, it protects against starting currents which are too high or which suddenly become too high (rotor blocked) and, of course, against short circuits.

The circuit breaker trips after a few tens of ms due to mechanical inertia.

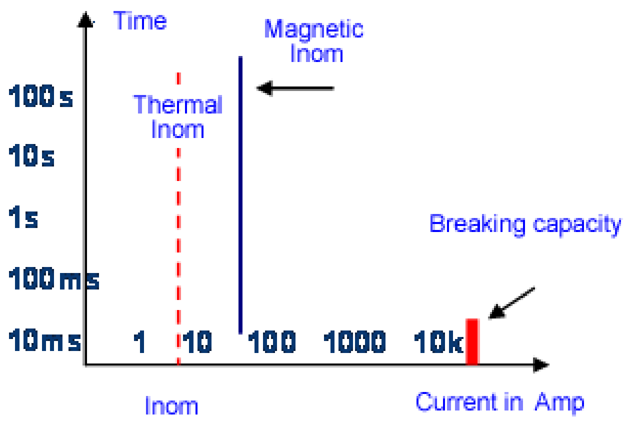
*Figure 81: Graph of the time and current of a magnetic trip unit*




### 6.2.1.3. Breaking capacity

It must be associated with the thermal and magnetic functions. It is the device's capacity to hold a very high current (the kiloamps of a short circuit) for a few tens of milliseconds, until the magnetic trip operates after a delay due to the inertia.

*Figure 82: Breaking capacity*



Already mentioned with the fuses: a short circuit current (Icc) is established in a few tens of milliseconds.

And **by associating these 3 functions,** we obtain the tripping curve of a magneto-thermal (or thermal-magnetic) circuit breaker:

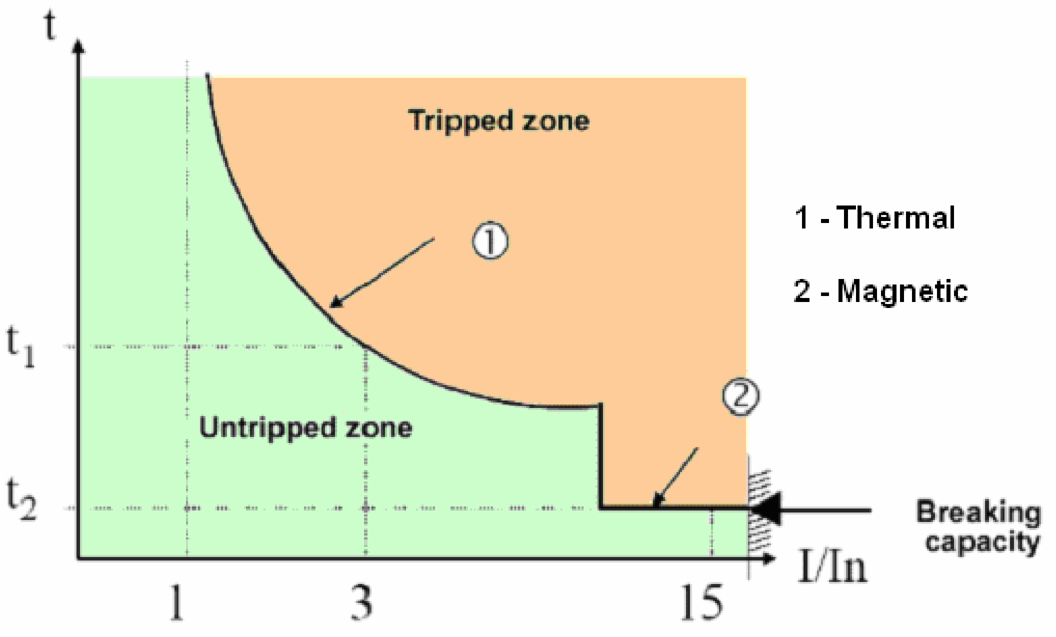



*Figure 83: Thermal magnetic circuit breaker tripping curve*

*And this the “sign” or symbol appearing on front plate of a circuit breaker*

### 6.2.2. Why do we need such curve

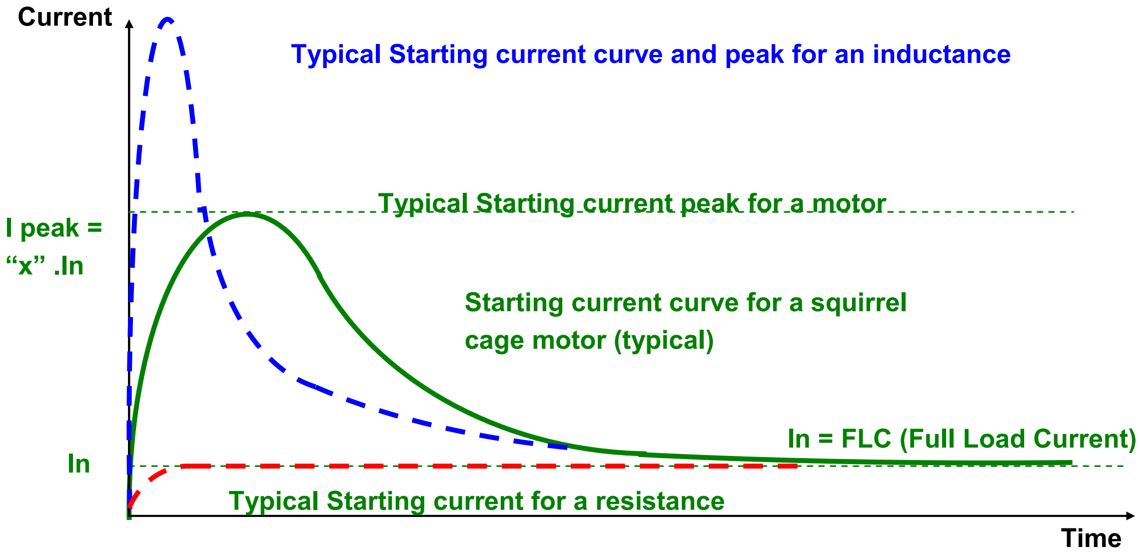



*Figure 84: Typical starting curves*

Here is the typical starting curve of a motor (green curve). *A resistive load (heater) would have no peak at start and an inductive load (transformer) a more pronounce peak.*

A slight “problem”, the curves are not in correct position, time and current axis have to be reversed. No problem, we just do it and superpose the motor starting curves and the breaker characteristics.

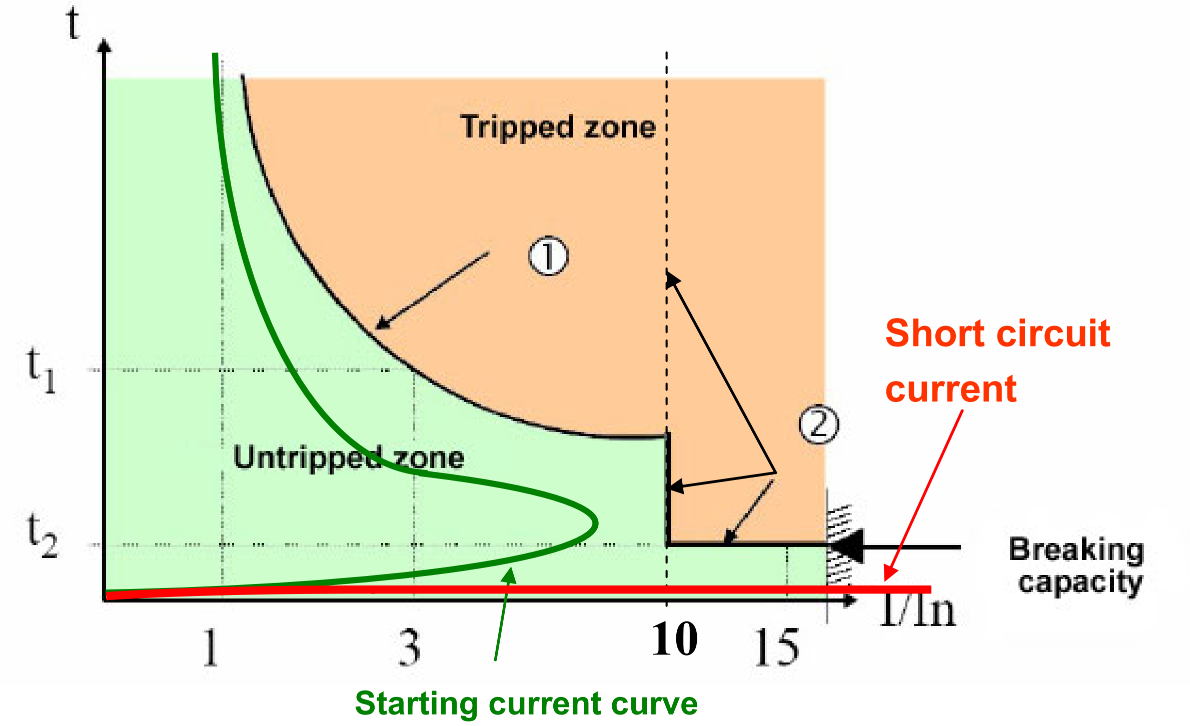



*Figure 85: Typical starting curve of a motor and breaker protections*

<u>Protections scheme:</u> *comments on the figure “typical starting curve of motor and breaker protection”*

In normal conditions, at start, the motor current follows its green starting curve, it is protected by the magnetic device ② (set at 10 times In) against too high starting current.

The thermal trip ① is taking over, if still in normal condition, protecting against permanent overload (normally set at 1.15 In)

If during start, at time t1, the current is at 3In, the thermal trip actuates, protecting against too long start

If at closure of the circuit, there is a short-circuit, the breaker must be able to hold the short-circuit current up to time t2 and then break this same short-circuit current being actuated by the magnetic trip ②. If in normal running, there is a short-circuit, this same magnetic device actuates also the trip. *(It is why magnetic device is also called short-circuit protection).*

***Remark: on the figure, the short-circuit current (red curve) establishes itself instantaneously (matter of microseconds), going above the breaking capacity value of the breaker. Breaker is going to melt!***

Breaking capacity is an important characteristic of any breaker. Short-circuit current is function of the power sources capacities and installation configuration; it is calculated at design time and must appears on drawings (at least the one-line diagram). See course EXP-MN-SE100 “Electrical Network” on that subject

Now for choice for choice of magnetic and thermal trips values, behaviour of load is the main selection criterion. Those trip settings (which can be delayed) are also function of the electrical distribution characteristics when there are “cascading” protections. *(See course MN-SE100 as well for selectivity protection)*

## 6.3. CHOICE OF LOW VOLTAGE CIRCUIT-BREAKER

It will be chosen according to its ***performances***

A circuit breaker's performances ensure its suitability in a given installation and at a specific point of an installation.

Electrical installations require the use of many circuit-breaker (at installation origin,…..at line cross-section changes,….near certain loads….) with highly varying performances.

**The choice will be done according to:**

- Rated voltage
- Type of breaker
- Rated current In
- Overload or high transient current
- Breaking capacity

### 6.3.1. Rated voltage

- DC voltage
- AC voltage 24V up to 690 Volts

### 6.3.2. Type of breaker

The types of breaker are:

- ***modular type*** , up to 100 / 125 Amp's *(depending the manufacturer)*
- ***moulded*** *(compact)* up to 630 / 8OO Amp's *(depending the manufacturer)*
- ***heavy duty*** *or "High Breaking Capacity" (the Masterpact of Schneider / Merlin-Gérin)*, 800 to 6300 Amp's (nearly all manufacturers have now the same range)

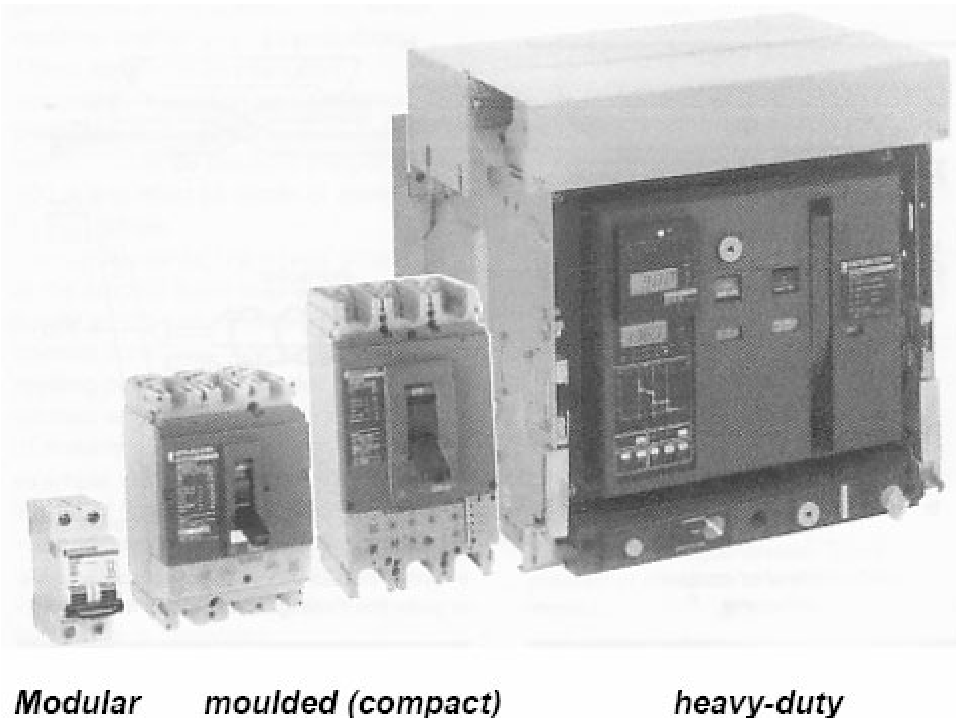



Figure 86: The 3 types or categories of breakers

This design "classification" is identical for all manufacturers *(figure here shows Schneider range of breakers).*

Principle of detection, actuation is different in each category (we see it in the following).

***A small current to protect does not point systematically towards a "small breaker" like a modular one****. (I saw this "reaction" many times….)*

### 6.3.3. Rated current In

This is the ***thermal protection*** of the load: (In being the ***"nominal" current*** of this same load. This type of protection is called for the breaker **Ir or Ith** and can be from few amperes up to 6300A.

The ***thermal element*** is

On ***modular: fixed.*** Example on C 80 type it can be from 1 A up to 63A as a permanently determined value (4 or 6, 8, 10, 16, etc…) which cannot be adjusted

On ***moulded*** type: example the NS160 can be equipped with ***different thermal*** of 16, 25, 32, 40, 50, 63; 80, 100, 125 amperes, each range being adjustable from 0.8 to 1 of the chosen thermal value.
It is not because it is called NS 160 (Schneider reference), that it can be only 160 amperes, this value being the maximum which could be used.

Same for ***heavy-duty*** breakers, they have different range of maximum setting (0.8, 1.6, 2, 2.5, 3.2,….. up to 6.3kA) in which a thermal device has to be installed and adjusted between 0.8 and 1 In

*See pictures on next paragraph with the magnetic protection*

### 6.3.4. Overload or high transient current

This is the ***magnetic protection called Im***.

A load (like a motor or a transformer) can take high current during a short period at time of closing, (up to 20 times the normal In). The magnetic protection *Im* is the device to "accept" this (transient) overload.

#### 6.3.4.1. Thermal + magnetic protection for Modular type breakers

For ***modular type breaker*** the value of ***Im*** is (generally) ***not adjustable***, the type of "permanent" Im setting being given by the **curve type.**

type ***'A'*** or ***'Z'***: 2 to 3 times the nominal rated In thermal current (2.5 times)

***'B':*** 3 to 5 times In (4 times as average)

***'C':*** 5 to 10 times In (7,5 Times as average)

***'D':*** 10 to 20 times In (15 times as average)

***'K':*** 10 to 14.5 times In

***This standard (A, B, C, D, K, Z) is general for all worldwide manufacturers, accepted as unified Standard and applicable for all made modular type***
*Merlin Gérin references, L, M, U, …etc, are obsolete, not used in last manufacturing's.*

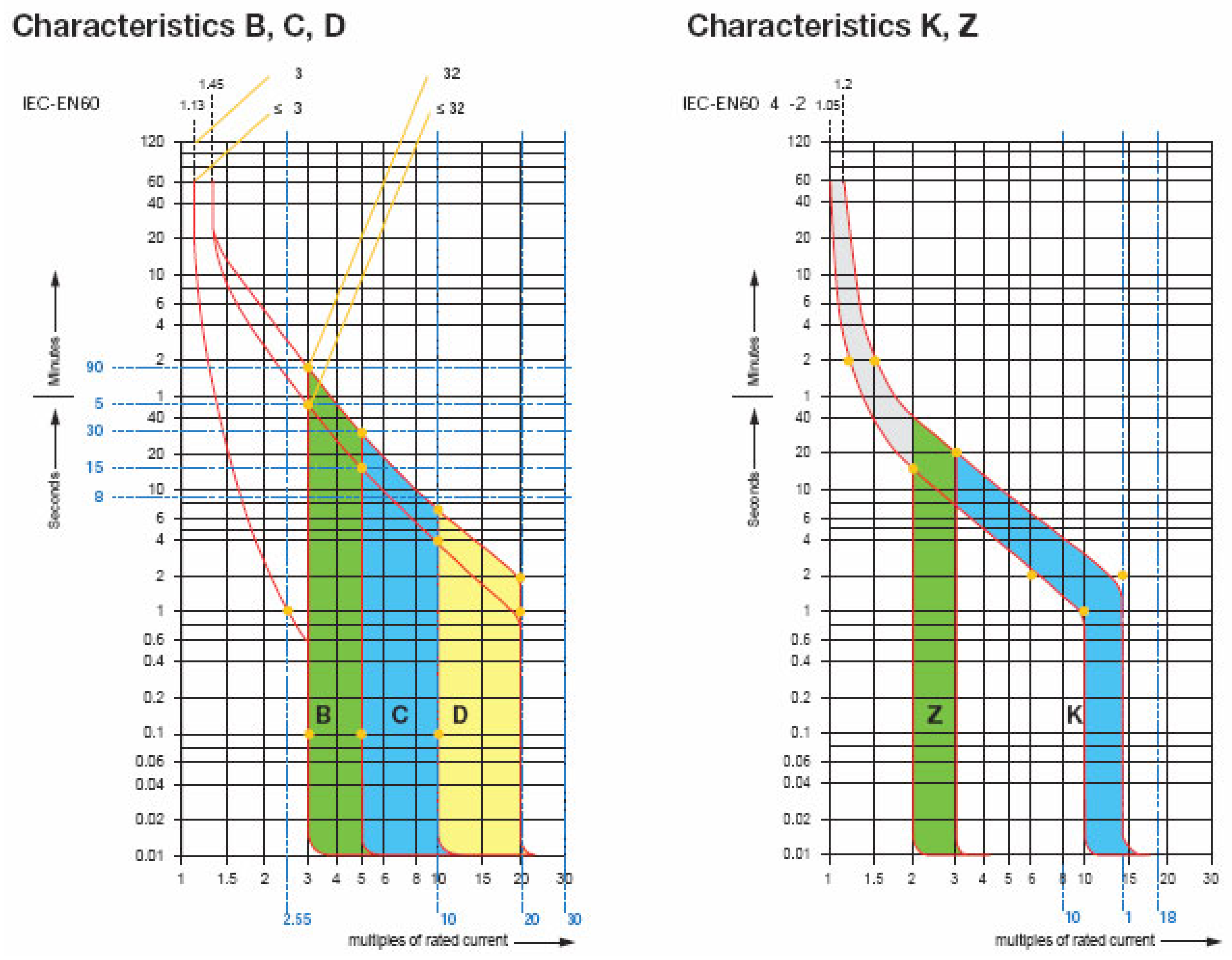



*Figure 87: Typical magnetic ranges for modular breakers – from ABB catalogue*

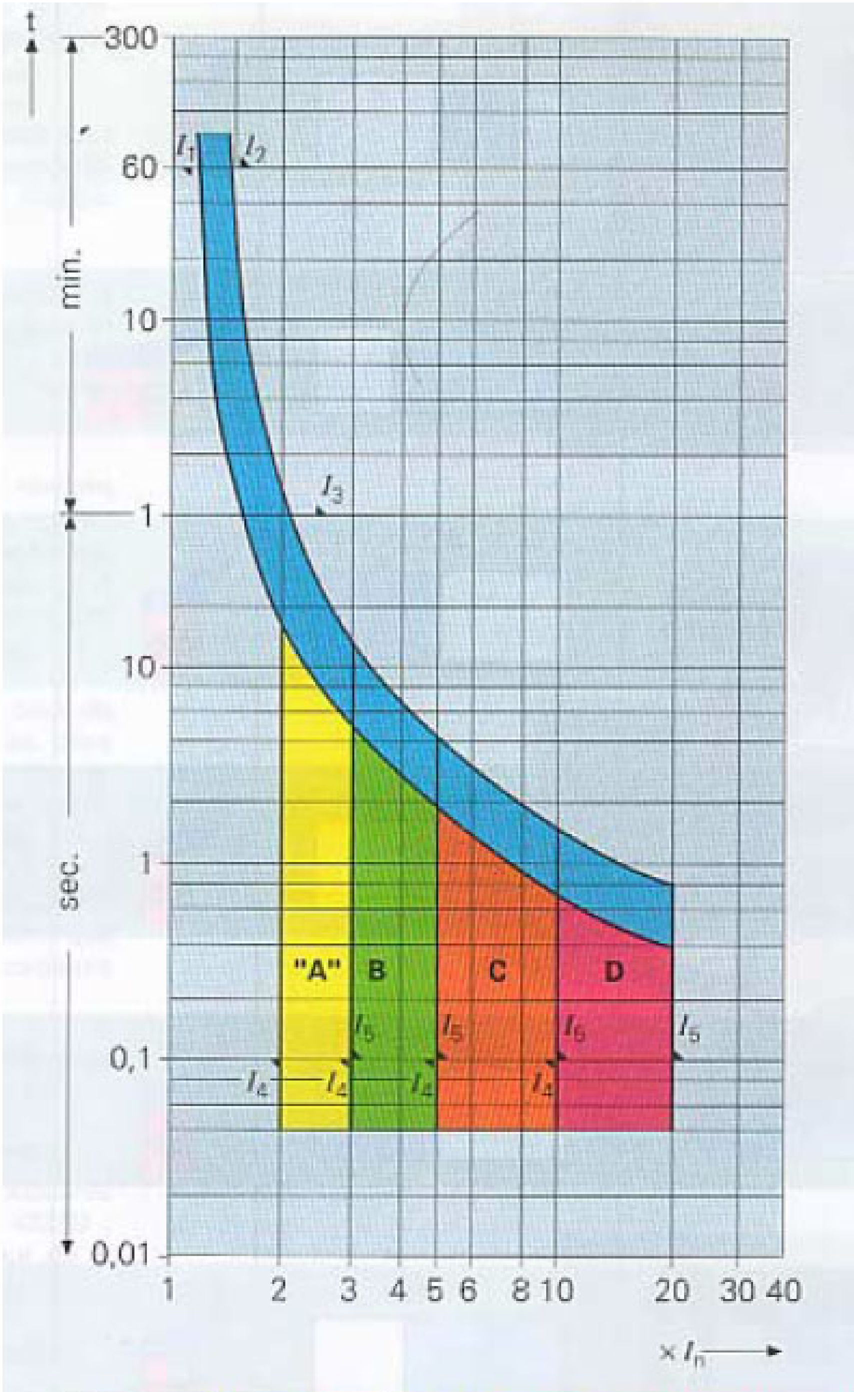
If I want to protect a motor with this type of breaker, motor taking 5 ***In*** at start, I shall choose a 'C' curve

If I want to protect a lighting distribution equipped with incandescent lamps and having no peak current at start, I need only a curve 'A' or 'Z'. However, if the lighting installation is made of luminescent tubes, it can take more than 10 times ***In***, the curve to choose is 'D' or 'K'

Concerning ***In***, it is the rated load current, which is protected by the thermal element, set at ***Ith*** which is between ***I1 = 1.13*** and ***I2 = 1.45*** In (see table under Siemens curves.

***Ith*** cannot be at a "rigorous" value, it is like for thermal relays and fuses depending its cold state and hot state

***Im***, magnetic thermal trip is not a fixed value as well, it is ***In*** multiplied by, for example 'C' curve, the lower value 5 and upper value 10 depending reaction time and also heat state of the thermal element.




| | | A | B | C | D |
|---|---|---|---|---|---|
| T | $I_1$ (t ≥ 1h) | $1{,}13 \times I_n$ | $1{,}13 \times I_n$ | $1{,}13 \times I_n$ | $1{,}13 \times I_n$ |
| | $I_2$ (t < 1h) | $1{,}45 \times I_n$ | $1{,}45 \times I_n$ | $1{,}45 \times I_n$ | $1{,}45 \times I_n$ |
| m | $I_4$ (t ≥ 0,1s) | $2 \times I_n$ | $3 \times I_n$ | $5 \times I_n$ | $10 \times I_n$ |
| | $I_5$ (t < 0,1s) | $3 \times I_n$ | $5 \times I_n$ | $10 \times I_n$ | $20 \times I_n$ |

*Figure 88: Typical magnetic ranges for modular breakers – from Siemens catalogue*

### 6.3.4.2. Thermal + magnetic protection for Moulded type breakers

For ***moulded type***, the value of *Im* is either pre-set at ordering or adjustable with a built-in device, setting being (as average) 6 to 10 times the In of the breaker.

The Schneider/Merlin Gérin circuit breakers series Compact NSxxx (NS80 to NS3200) may be equipped with thermal-magnetic (TM) or electronic (STR22SE) trip units.

*Figure 89: Typical moulded circuit breaker*

All trip units may be installed on all circuit breakers (according to size, corresponding to amperes ranges. On picture it is size of NS100, NS160 andNS250, types N, H and L).
However a mechanical mismatch feature prevents installation of a trip unit on a circuit breaker with a lower rating.

Type represented: NS160N 3 poles, fixed setting of magnetic current.

#### *Fixed magnetic trip (with thermal adjustment)*

This is the part which is fitted under the “switch” section.

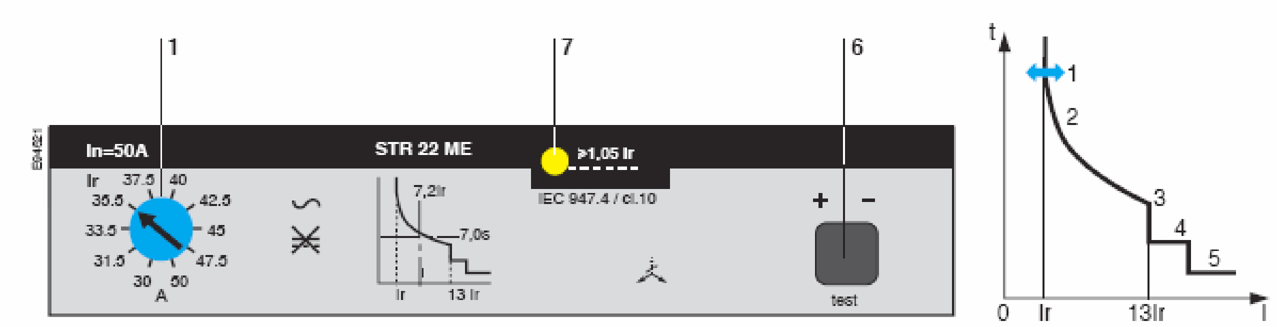



*Figure 90: Merlin Gérin thermal magnetic with fixed magnetic trip STR22ME*

<u>*Legend of the curve:*</u>
***1*** *long-time threshold*
***2*** *tripping class 10 as defined by IEC 60947-4 (same as for thermal relay under contactor)*
***3*** *short-time pick-up*
***4*** *short-time tripping delay (see next paragraph for delays and multi setting*
***5*** *instantaneous pick-up*
***6*** *test connector*
***7*** *percent load indication*

Figure shows a trip unit which can be installed on Series NS100, NS160, and NS250 (Merlin Gérin). The thermal trip is adjustable between 30 and 50A, the magnetic trip is fixed at 13 times ***Ir***. This value of Ir being the adjusted value: ***Ir = Ith = In x k*** (k being the adjustment 0.6 to 1 here)

***Thermal Magnetic adjustable*** - Example is NS250, thermal trip at 250A

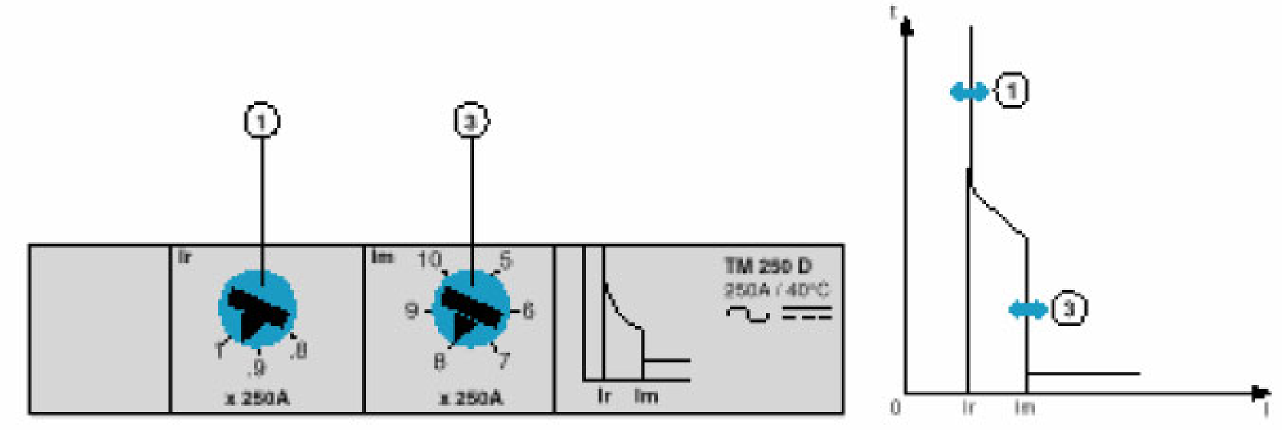



*Figure 91: Merlin Gérin thermal magnetic trip both adjustable trip STR-TMD*

*Legend:*
**1** Adjustment thermal is between 250 x 0.8 = 200A and 250 x 1 = 250A
**3** Adjustment magnetic 5 to 10 times the set thermal value Ir

*If I install a thermal unit of 160A (the "smallest" one I can install is 20A), the thermal can be adjusted between 128 an 160A, magnetic trip5 to 10 times the adjusted Ir.*

***Thermal Magnetic adjustable higher range***

Example is STR43ME to install on NS400 or NS630

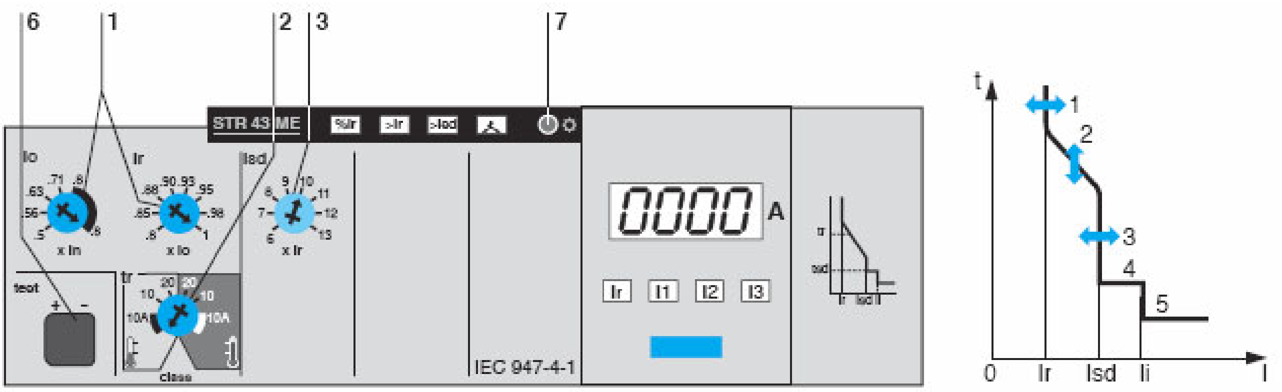



*Figure 92: Merlin Gérin thermal magnetic trip both adjustable trip STR2TMD*

*Legend / example:*
**1** long-time threshold - Io base setting (5 settings from 0.5 - 0.8) and Ir fine adjustment (8 settings from 0.8 - 1)
**2** tripping class (as per thermal relays)
**3** short-time pick-up (adjustable 6 to 13 Ir)
**4** short-time tripping delay (fixed setting at 4s ±10 %
**5** instantaneous pick-up (safety magnetic trip, fixed setting at maximum range)
**6** test connector
**7** percent load indication

Other manufacturers use the same principles.

### 6.3.4.3. Thermal + magnetic protection for Heavy-duty type breakers

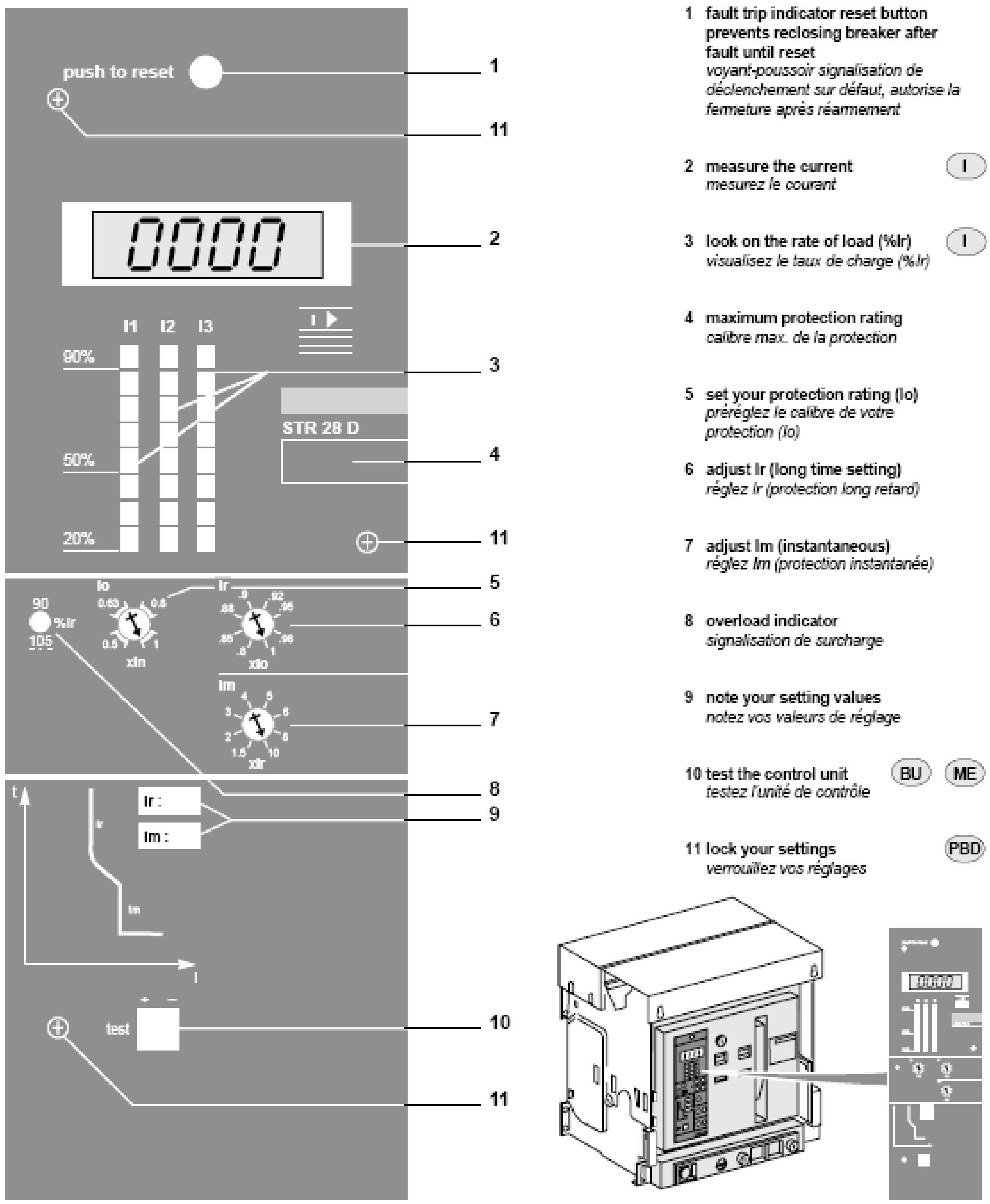
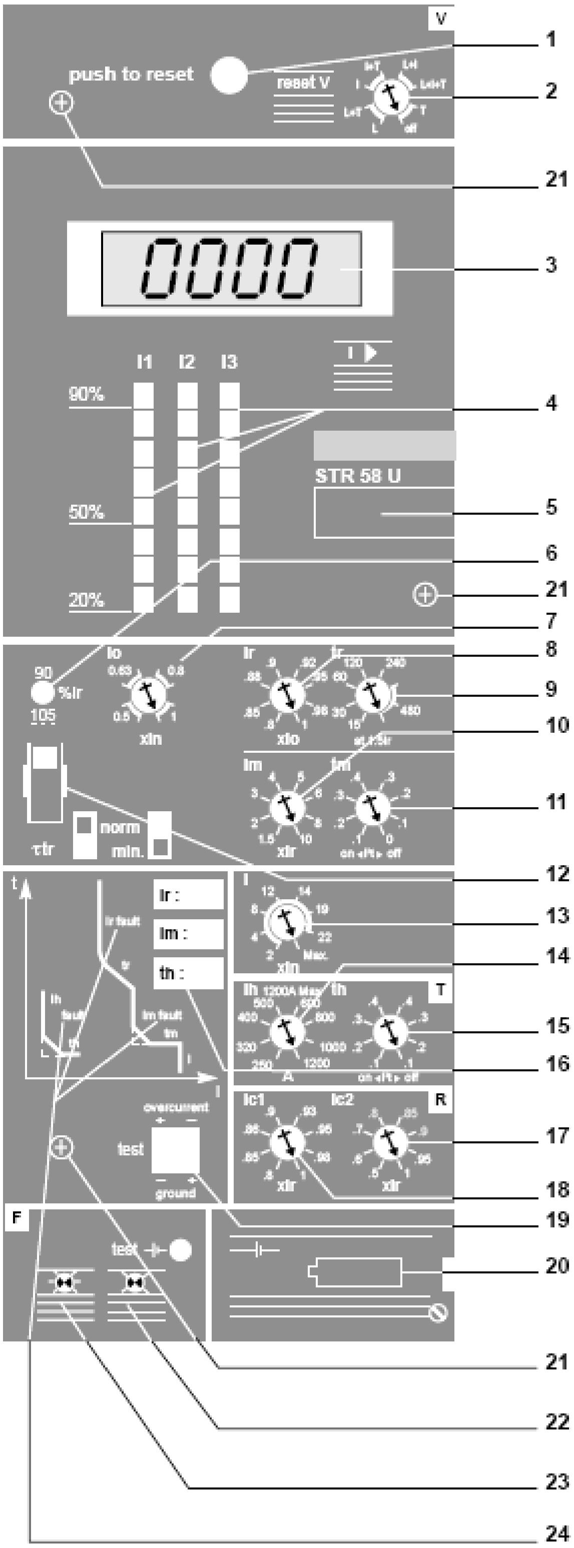



*Figure 93: Typical thermal magnetic on heavy duty breaker – Masterpact with STR28D*

Heavy duty breakers can be equipped with “simple” thermal magnetic trip unit as per the lower range breakers; setting is just higher in amperes. They can protect a distribution panel placed at head of it or a single load of high power.




1 fault trip indicator reset button prevents reclosing breaker after fault until reset
*voyant-poussoir signalisation de déclenchement sur défaut, autorise la fermeture après réarmement*

2 select the remote indicated fault trip (FV)
*sélectionnez le défaut signalé à distance*

3 measure the current (I)
*mesurez le courant*

4 look on the rate of load (%Ir) (I)
*visualisez le taux de charge (%Ir)*

5 maximum protection rating
*calibre max. de la protection*

6 overload indicator (ALR)
*signalisation de surcharge*

7 set your protection rating (Io)
*préréglez le calibre de votre protection (Io)*

8 adjust Ir (long time setting)
*réglez Ir (protection long retard)*

9 adjust tr (long time delay)
*réglez tr (constante de temps long retard)*

10 adjust Im (short time setting)
*réglez Im (protection court retard)*

11 adjust tm (short time delay)
*réglez tm (temps court retard)*

12 decrease thermal memory after tripping
*limitez la mémoire thermique après déclenchement*

13 adjust I (instantaneous)
*réglez I (instantané)*

14 adjust Ih (earth protection) (T) (W)
*réglez Ih (protection terre)*

15 adjust th (earth protection delay) (T) (W)
*réglez th (temps protection terre)*

16 note your setting values
*notez vos valeurs de réglage*

17 adjust Ic2 (load monitoring) (R)
*réglez Ic2 (contrôle de charge)*

18 adjust Ic1 (load monitoring) (R)
*réglez Ic1 (contrôle de charge)*

19 test the control unit (BU) (ME)
*testez l'unité de contrôle*

20 save fault trip indicator (PIL)
*sauvegardez la signalisation de défaut*

21 lock your settings (PBD)
*verrouillez vos réglages*

22 clear fault trip indicator and or check battery level (F)+(PIL)
*effacez la signalisation du dernier défaut et / ou contrôlez l'état de votre pile*

23 look for the latest fault trip indicator (F)+(PIL)
*réactivez la signalisation du dernier défaut*

24 fault trip indicator (F)
*signalisation des défauts*

*Figure 94: Typical thermal magnetic on heavy duty breaker – Masterpact with STR58U*

This type of breaker is when there is need for Selectivity - see course SE100 -. There is one thermal trip (with possibility of time delay) and several magnetic trips adjustable in “x times Ir” and time of “neutralisation”. Some manufacturers present up to 6 magnetic trips on the same unit. They can combine also earth protection (RCD system), see chapter earth protection

In the course, if you can get vendor document (type/manufacturer of material installed on site), and/or the device itself, make practice on how to adjust and to what it corresponds.

### 6.3.5. Breaking Capacity

The breaker must be able ***to open*** 'its' protected circuit ***even if a short circuit occurs downstream.***

The ***maximum possible short-circuit has to be calculated*** within an electrical distribution, it is part of the engineering duty .

On electrical drawings; commonly the ***one line distribution diagram***, the Isc (short-circuit current) is shown (written) at each level of installation (for each distribution panel, MCC, Switchgear,…) being calculated in kA (kilo-amperes).

Each type of breaker (modular-moulded-heavy duty) has on its characteristics the indication of ***breaking capacity*** (the maximum current it can withstand).

For Merlin Gérin breakers, the breaking capacity value is represented by the letter associated with the type: ***A, N, H, L, LH***, LH being the one with the highest breaking capacity
*C60N, NS160H, NS 250H,…etc…*

For other manufacturers, it is matter of references

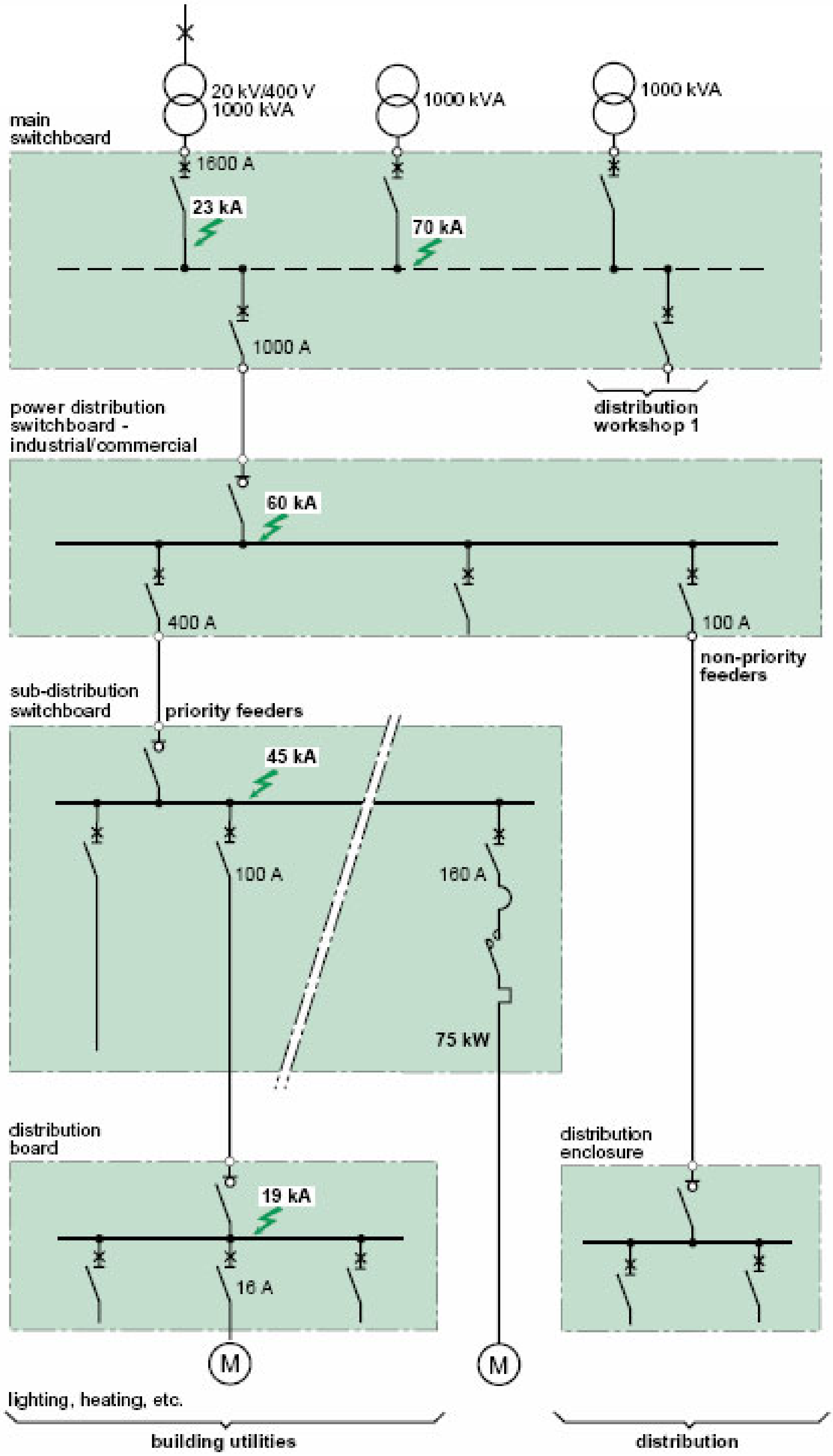



*Figure 95: Typical one-line diagram with Isc indication*

### 6.3.6. Other features

Not detailed in the present booklet, they are

- Timing adjustment for Ith (or Ir or In) & Im
- Auxiliary contact
- Trip contact
- Tripping coil
- Differential (only for modular in a "block" mode)
- The ***making capacity:***
- ***Tripping coil: MX or MN***

***Making capacity*** = Breaking capacity x (times) K *K being a coefficient function of reactance of the downstream circuit K= 1 with resistance and k>1 in general*

***Breaking capacity*** *can be related to the* **rms** *value of the short circuit current, when* ***making capacity*** *corresponds to the peak possible value of the same Isc.*

***MX coil:*** tripping device needing voltage to energise

***MN coil*** tripping device permanently energised, actuating breaker when its supply is opened

***Example : Ordering a breaker*** *(material Merlin Gérin)*

a) *C60H 3 poles 30A, curve B* is a ***minimum requirement*** *for the definition*

It means: a breaker for 3 phases, type modular C60 of Merlin Gérin, breaking capacity H (corresponding to 10 kA), thermal element at 30 Amperes, magnetic element set 4 times 30 Amp. = 120 A (curve B)

b) *NS 250L, 4 poles, protection 3x100 Amp, equipped TM,D*:

It means a breaker type NS 250, breaking capacity 25 kA (L), equipped on the 3 phase by a thermal 100A, neutral non-protected. Magnetic adjustable 5 to 10 times by TM-D system.

*If you can obtain catalogues from different manufactures, make exercises in courses, choosing one reference and asking to get the equivalent from the others made, it is surprising the diversity of result you can get……… (You can get it now easily on the net, choose the pages related to concerned references only)*

## 6.4. FUNCTION AND TECHNOLOGY OF LV CIRCUIT BREAKER

We have defined 3 types of circuit breakers, let' see how they "work" and where to install in a distribution. We therefore go the "traditional" one-line diagram with (always now) the indications of short-circuit current (course SE100)

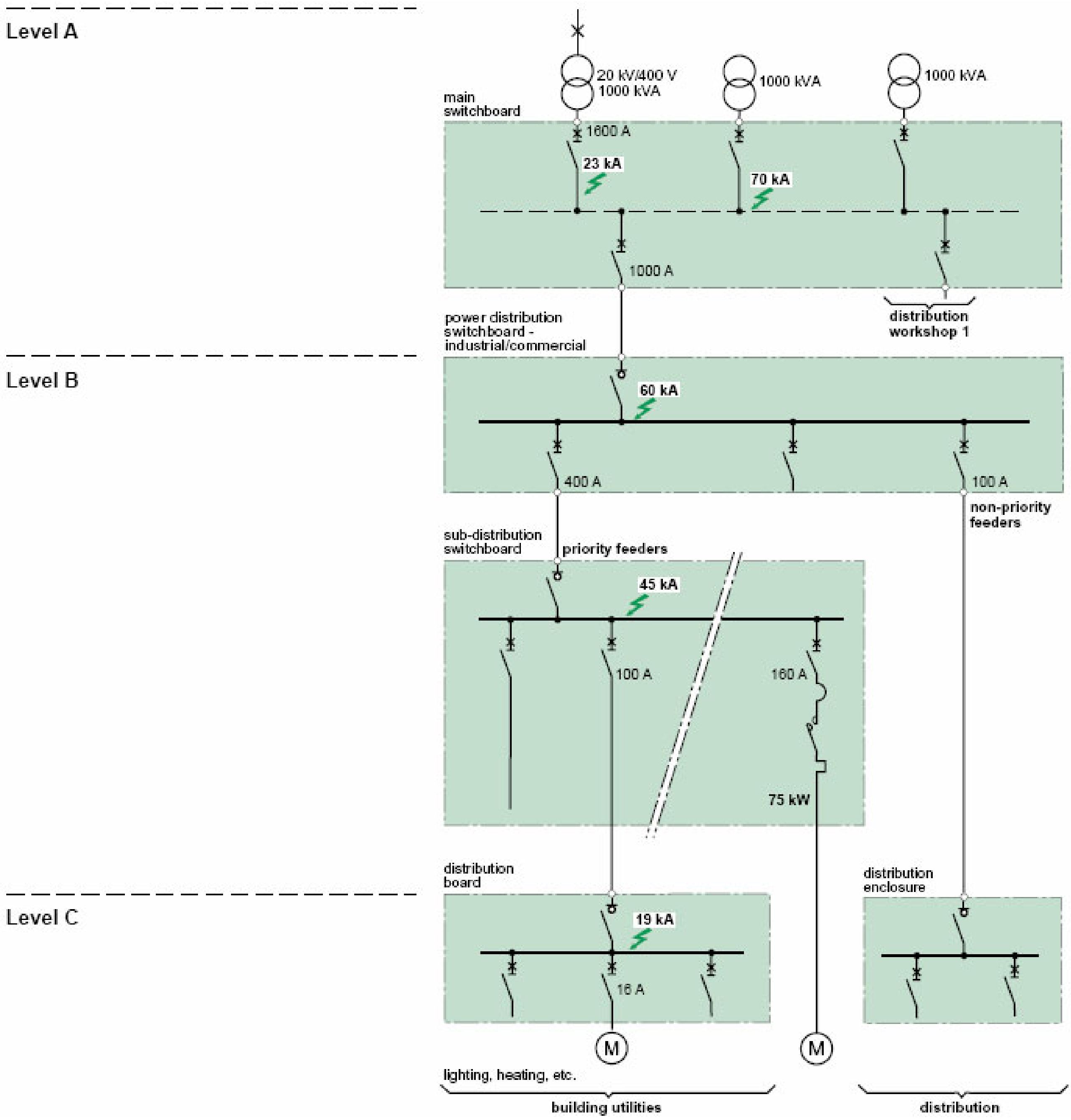



*Figure 96: Simplified diagram of a standard installation covering most of the cases observed in practice.*

Installations of the different type of breakers are (roughly) defined in three levels: A, B, C, each of the three levels of the installation has specific availability and safety needs.

### 6.4.1. Reminders of standard-related electrical data

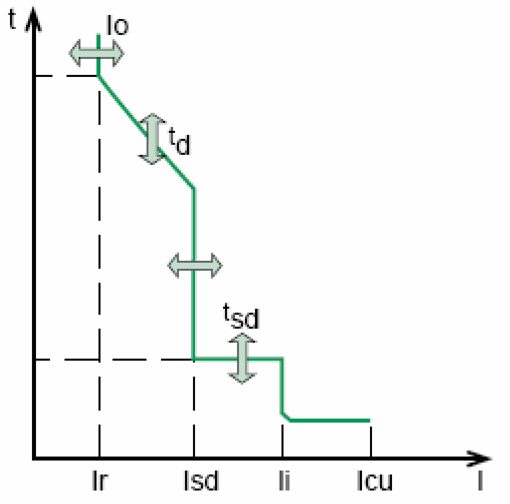
But first, prior to go to breakers (again), we (re)define the terms

We have already seen terms, letters; we see them again for well understanding of acronyms / abbreviations

We start with a résumé table

| | | |
|---|---|---|
| Voltage data | **Ue**<br>**Ui**<br>**Uimp** | Rated operational voltage<br>Rated insulation voltage<br>Rated impulse withstand voltage |
| Current data | **In**<br>**Ith**<br>**Ithe**<br>**Iu** | Rated operational current<br>Conventional free air thermal current<br>Conventional enclosed thermal current<br>Rated uninterrupted source |
| Short circuit data | **Icm**<br>**Icu**<br>**Ics**<br>**Icw** | Rated short circuit making capacity<br>Rated ultimate short circuit breaking capacity<br>Rated service breaking capacity<br>Rated short time withstand current |
| Trip unit data | **Ir**<br>**1.05 x Ir**<br>**1.30 x Ir**<br>**Ii**<br>**Isd** | Adjustable overload setting current<br>Conventional non-tripping current<br>Conventional tripping current<br>Instantaneous tripping setting current<br>Short time tripping setting current |

*Table 11: Acronyms used with breakers*




The setting data are given by the tripping curves.

These curves contain some areas limited by the following currents

*Figure 97: The breaker tripping curve*

### Rated operational current (In)

In (in A rms) = maximum uninterrupted current withstand at a given ambient temperature without abnormal temperature rise.
E.g. 125 A at 40 °C

### Adjustable overload setting current (Ir)

Ir (in A rms) is a function of In. Ir characterises overload protection.

For operation in overload, the conventional non-tripping currents Ind and tripping currents Id are:

- Ind = 1.05 Ir,
- Id = 1.30 Ir.

Id is given for a conventional tripping time.

For a current greater than Id, tripping by thermal effect will take place according to an inverse time curve. Ir is known as Long Time Protection (LTP).

### Short time tripping setting current (Isd)

Isd (in kA rms) is a function of Ir. Isd characterises short-circuit protection.

The circuit breaker opens according to the short time tripping curve:

- either with a time delay tsd,
- or with constant I2t,
- or instantaneously (similar to instantaneous protection).

Isd is known as Short Time Protection or Im.

### Instantaneous tripping setting current (Ii)

Ii (in kA) is given as a function of In. It characterises the instantaneous short-circuit protection for all circuit-breaker categories. For high overcurrents (short-circuits) greater than the Ii threshold, the circuit-breaker must immediately break the fault current.

This protection device can be disabled according to the technology and type of circuit-breaker (particularly B category circuit-breakers).

### Rated short-circuit making capacity (*defined for a specific voltage rating Ue.*) (Icm)

Icm (peak kA) is the maximum value of the asymmetrical short-circuit current that the circuit-breaker can make and break. For a circuit-breaker, the stress to be managed is greatest on closing on a short-circuit.

### Rated ultimate breaking capacity (*defined for a specific voltage rating Ue.*) (Icu)

Icu (kA rms) is the maximum short-circuit current value that the circuit-breaker can break. It is verified according to a sequence of standardised tests. After this sequence, the circuit-breaker must not be dangerous. This characteristic is defined for a specific voltage rating Ue.

### Rated service breaking capacity (*defined for a specific voltage rating Ue.*) (Ics)

Ics (kA rms) is given by the manufacturer and is expressed as a % of Icu. This performance is very important as it gives the ability of a circuit-breaker to provide totally normal operation once it has broken this short-circuit current three times. The higher Ics, the more effective the circuit-breaker.

### Rated short time withstand current (*defined for a specific voltage rating Ue.*) (Icw)

Defined for B category circuit-breakers
Icw (kA rms) is the maximum short-circuit current that the circuit-breaker can withstand for a short period of time (0.05 to 1 s) without its properties being affected.

This performance is verified during the standardised test sequence.

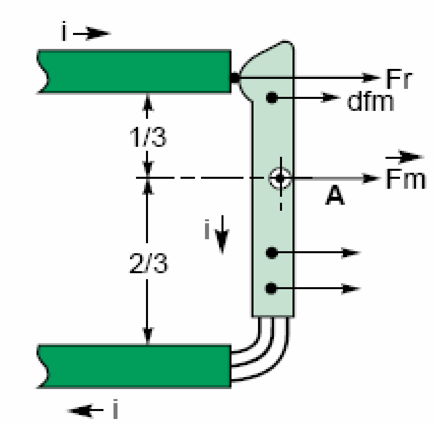
## *6.4.2. Level A: the Main Switchboard (MSB)*

This unit is the key to the entire electrical power distribution: availability of supply is essential in this part of the installation.

***Short-circuit currents are high due to:***

- the proximity of the LV sources,
- amply sized busbars for conveying high currents.

***This is the area of the power circuit-breakers, the heavy-duty ones***




These circuit-breakers are designed for high current electrical distribution:

- they are normally installed in the MSBs to protect high current incomers and feeders;
- they must remain closed in event of short-circuits so as to let the downstream circuit-breaker eliminate the faults. Their operation is normally time-delayed.

*Figure 98: Own current compensation diagram*

Contact pressure is proportional to I2 in the loop.

Fm: magnetic Force.  Fr: repulsive Force

Electro Dynamic Withstand (EDW) and high thermal withstand characterised by a short time withstand current Icw are essential.

EDW is designed to be as great as possible by an own current compensation effect.

***Main data of these circuit-breakers:***

- of industrial type, meeting standard BSEN 60947-2,
- with a high breaking capacity Icu from 40 to 150 kA,
- with a nominal rating of 1000 to more than 5000 A,
- category B:

  - with a high Icw from 40 kA to 100 kA — 1 s

  - With a high electro-dynamic withstand (EDW),
- with a stored energy operating mechanism allowing source coupling.

Continuity of supply is ensured by total discrimination:

- upstream with the protection fuses of the HV/LV transformer (*),
- downstream with all the feeders (time discrimination). – See course SE100

***Example with Masterpact NW:*** *(last technology)*

Breaking capacity up to 200 kA/400 V for the UL range, Thermal withstand of 37 kA/400 V,

Important limiting capacity (NW L1 assumed Isc = 390 kA to 380/415 V, limited Isc = 170 kA).

Specific technologies used:

- Selective pole like the other switchgear in order to reach a thermal withstand of 30 kA/400 V,
- Automatic unlatching of the circuit breaker operating mechanism to produce ultra fast tripping.
- Use of a U-shaped current loop to increase the repulsion force.
- Use of a magnetic U around the fixed pole to concentrate field lines and project the arc in the arc chute, early on, quickly and high.

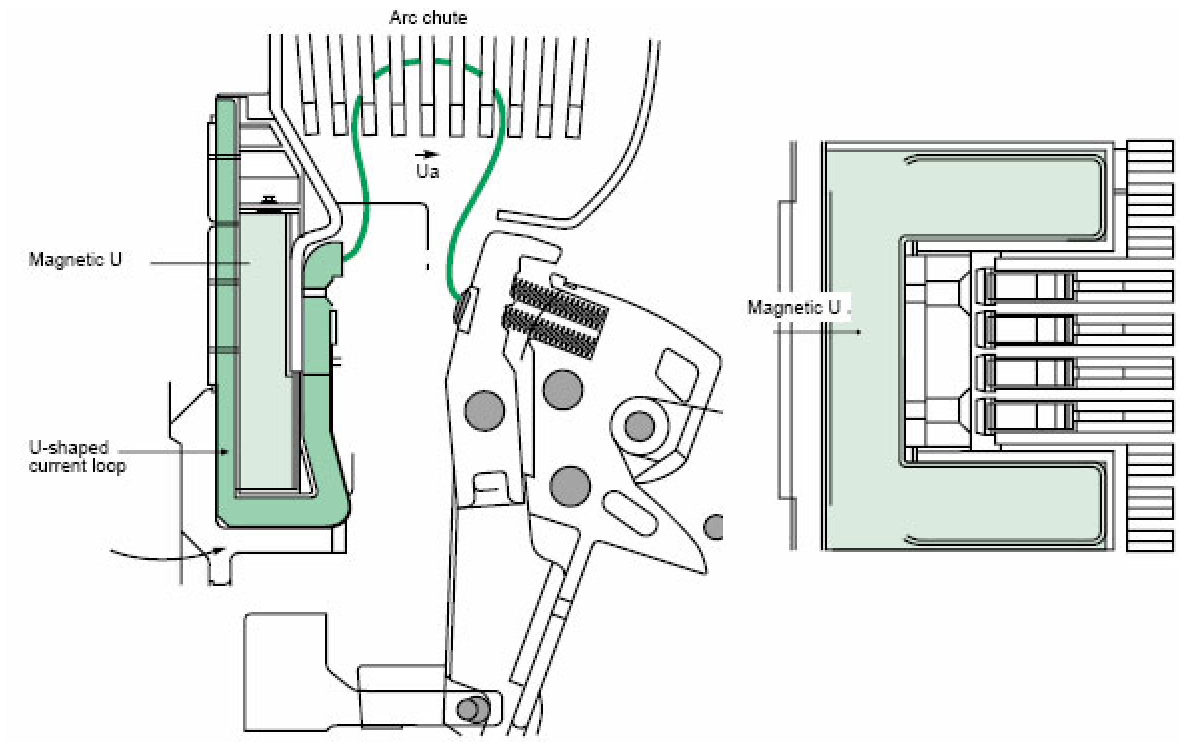



*Figure 99: Technology of power breaker masterpact type NW*

On a high short-circuit, the poles open very slightly and the magnetic U then projects the arc in the arc chutes. The fault current is diverted. The automatic unlatching of the circuit breaker operating mechanism then quickly opens the circuit-breaker.

This performance meets the limitation needs of fault currents while at the same time guaranteeing an unmatched level of discrimination of 37 kA for this circuit-breaker type.

To enhance breaking performance and obtain a high short-circuit current limitation on devices theoretically not very limiting, a trip unit is used, not based on the instantaneous value of the current but on a drift whose peculiarity is not to trip on the first fault current half wave. When a short-circuit current appears, the downstream circuit-breaker opens as soon as the fault current is greater than its tripping threshold and eliminates the fault in less than one half-wave.

### 6.4.3. Level B: the sub-distribution boards

These boards belong to the intermediate part of the installation:

- distribution is via conductors (BBT or cables) with optimised sizing,
- sources are still relatively close: short-circuit currents can reach 100 kA,
- the need for continuity of supply is still very great.

Protection devices must consequently limit stresses and be perfectly coordinated with upstream and downstream LV distribution.

***This is the area of the moulded case circuit-breakers***

These circuit-breakers must open and break the current as quickly as possible. The main need is to avoid as far as possible stresses at cable and connection level and even at load level. For this purpose, repulsion at contact level must be encouraged in order to eliminate the fault even as the current is rising.

The possible diagrams are:

- with a single repulsion loop,
- with double repulsion
- with an extractor, a magnetic core pushing or pulling the moving contact.

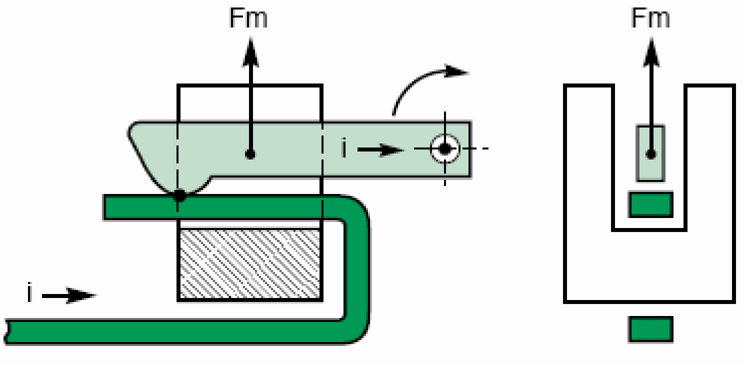



*Figure 100: Example of a repulsion diagram Fm = magnetic force*

The repulsion effects can be enhanced by implementation of magnetic circuits:

- with effects proportional to the current square (U-shaped attracting or expulsion circuit),
- with effects proportional to the current slope (di/dt) and thus particularly effective for high currents (Isc).

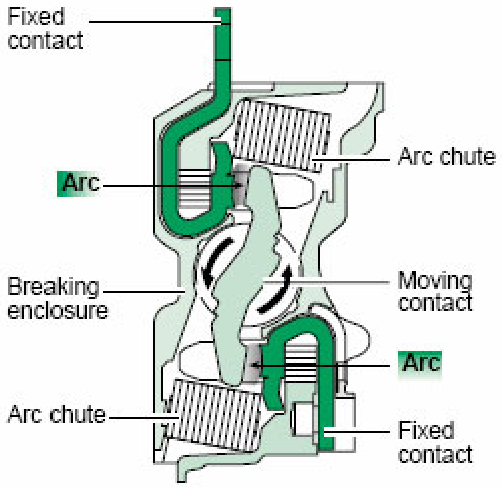
***Main data of the moulded case circuit-breakers:***

- of industrial type, meeting standard BSEN 60947-2,
- with a high breaking capacity (36 to 150 kA),
- with a nominal rating from 100 A to 1600 A,
- category B for high rating circuit-breakers (> 630 A),
- category A for lower rating circuit-breakers (< 630 A),
- with fast closing and opening and with three operating positions (ON/OFF/ Tripped).

Continuity of supply is ensured by discrimination:

- partial, possibly, to supply non-priority feeders,
- total for downstream distribution requiring high energy availability.

This range of circuit breakers (100 to 800A) implements an innovating technique: **roto-active breaking.**



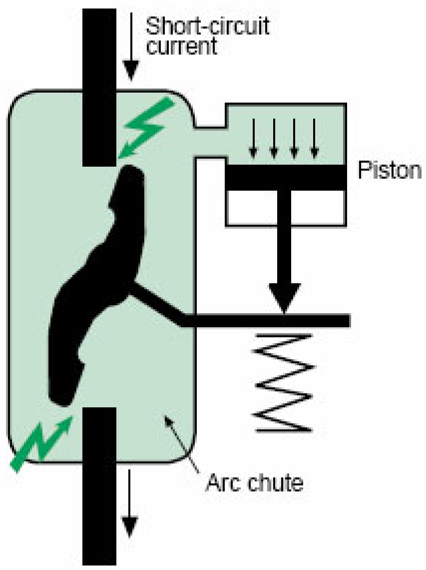




*Figure 101: Roto-active breaking: repulsion of contacts (left) - tripping by pressure(right)*

This high current limiting technique uses a new tripping energy, pressure, resulting from arc energy.

Its operation is described below:

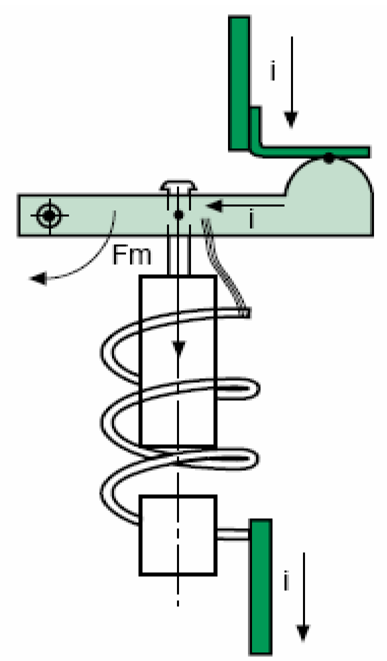
- Each circuit-breaker pole has an enclosure in which a rotating contact generates, by electromagnetic repulsion, two serial arcs on occurrence of the short-circuit current.
- A piston and spring device uses the pressure from arc energy to cause — beyond a certain threshold (roughly 35 In) — a reflex tripping, roughly 3 ms after contact repulsion.
- Up to this threshold, pressure is not sufficient to cause tripping and arc impedance limits the short-circuit current.
- Beyond this threshold, breaking is very quick (1 ms) and limits still further the short-circuit current.

### 6.4.4. Level C: Final distribution

The protection devices are placed directly upstream of the loads: discrimination with the higher level protection devices must be provided.

A weak short-circuit current (a few kA) characterises this level.

***This is the area of the Miniature Circuit-breaker***




These circuit-breakers are designed to protect final loads.

The purpose is to limit stresses on cables, connections and loads.

The technologies for the miniature circuit-breakers, mainly used at this installation level, prevent such stresses from occurring.

In miniature circuit-breakers, limitation partly depends on the magnetic actuator. Once the mechanism has been released, it will strike the moving contact making it move at a high speed very early on. Arc voltage thus develops very quickly at a very early stage. For small rating circuit-breakers, specific pole impedance contributes to limitation.

*Figure 102: Miniature circuit breaker main technology*

The miniature circuit-breaker is ideal for domestic use and for the protection of auxiliaries; it then conforms to standard BSEN 60898.

On the other hand, if it is designed for industrial use, it must meet standard BS EN 60947 - 2.

**Main data of these circuit-breakers:**

- a breaking capacity to match needs (i.e. Below 10 kA on average but 50 kA at maximum),
- a nominal rating of 0.5 to 125 A according to the loads to be supplied,
- normally intended for domestic applications: conform to standard BSEN 60898 and industrial lighting distribution.

The protection devices installed must provide: (as these devices are handled by non-specialist users).

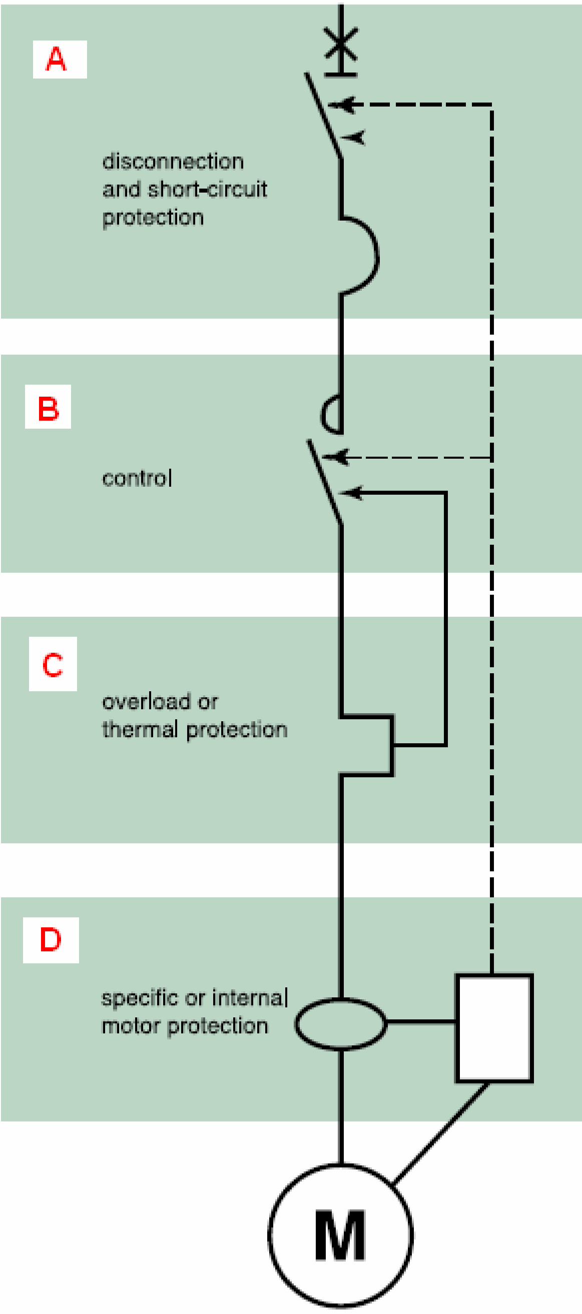
- current limitation,
- operating convenience,
- absolute safety,

## 6.5. APPLICATION – MOTOR PROTECTION

We have seen (nearly) al components to protect a load; let's see an application with a motor protection reminding functions of the different devices and proposing a test to prove efficiency of protection.

Concerning selectivity, discrimination, coordination of cascading protections, see courses EXPè-MN-SE100

### 6.5.1. Protection functions




A circuit supplying a motor may include one, two, three or four switchgear or control gear devices fulfilling one or more functions.

**When a number of devices are used, they must be coordinated to ensure optimum operation of the motor.**

Protection of a motor circuit involves a number of parameters that depend on:

- the application (type of machine driven, operating safety, starting frequency, etc.)
- the level of service continuity imposed by the load or the application
- the applicable standards to ensure protection of life and property.

The necessary electrical functions are of very different natures:

- protection (motor-dedicated for overloads)
- control (generally with high endurance levels)
- isolation

*Figure 103: Example of protection for a motor protection*

We see in detail, the functions A to D of the figure (see previous chapters/ paragraphs for more details)

***A1) Disconnection***: Isolate a motor circuit prior to maintenance operations.

***A2) Short-circuit protection:*** Protect the starter and the cables against major overcurrents (> 10 In).

This type of protection is provided (here) by a circuit breaker, differencing:

- **Impedant short-circuit (10 < I < 50 In),** deterioration of motor-winding insulation is the primary cause.
- **Short-circuit (I > 50 In),** this type of fault is relatively rare. A possible cause may be a connection error during maintenance.

***B) Control:***

Start and stop the motor, and, if applicable:

- gradual acceleration
- speed control.

***C) Overload protection:***

Protect the starter and the cables against minor over currents (< 10 In).

Thermal relays provide protection against this type of fault. They may be:

- integrated in the short-circuit protective device
- separate.

An **overload (I < 10 In)** may be caused by:

- an electrical problem, for instance on the mains (loss of a phase, voltage outside tolerances, etc.)
- a mechanical problem, for instance excessive torque due to abnormally high demands by the process or motor damage (bearing vibrations, etc.).

A further consequence of these two origins is excessively long starting.

***D) Additional specific protection:***

- Limitative fault protection (while the motor is running)
- Preventive fault protection (monitoring of motor insulation with motor off).

**Protection against insulation faults** may be provided by:

- a residual current device (RCD)
- an insulation monitoring device (IMD).

See in following chapter

### 6.5.2. The different test currents

The motor protection drawn in above paragraph should fulfil the following test conditions

**“ Ic” , “ r” and “ Iq” test currents**

The standard requires three fault-current tests to check that the switchgear and control gear operates correctly under overload and short-circuit conditions.

#### 6.5.2.1. “ Ic” current (overload I < 10 In)

The thermal relay provides protection against this type of fault, up to the Ic value (a function of Im or Isd) defined by the manufacturer.

IEC standard 60947-4-1 stipulates two tests that must be carried out to guarantee coordination between the thermal relay and the short-circuit protective device:

- at 0.75 Ic, only the thermal relay reacts
- at 1.25 Ic, the short-circuit protective device reacts.

Following the tests at 0.75 and 1.25 Ic, the trip characteristics of the thermal relay must be unchanged.

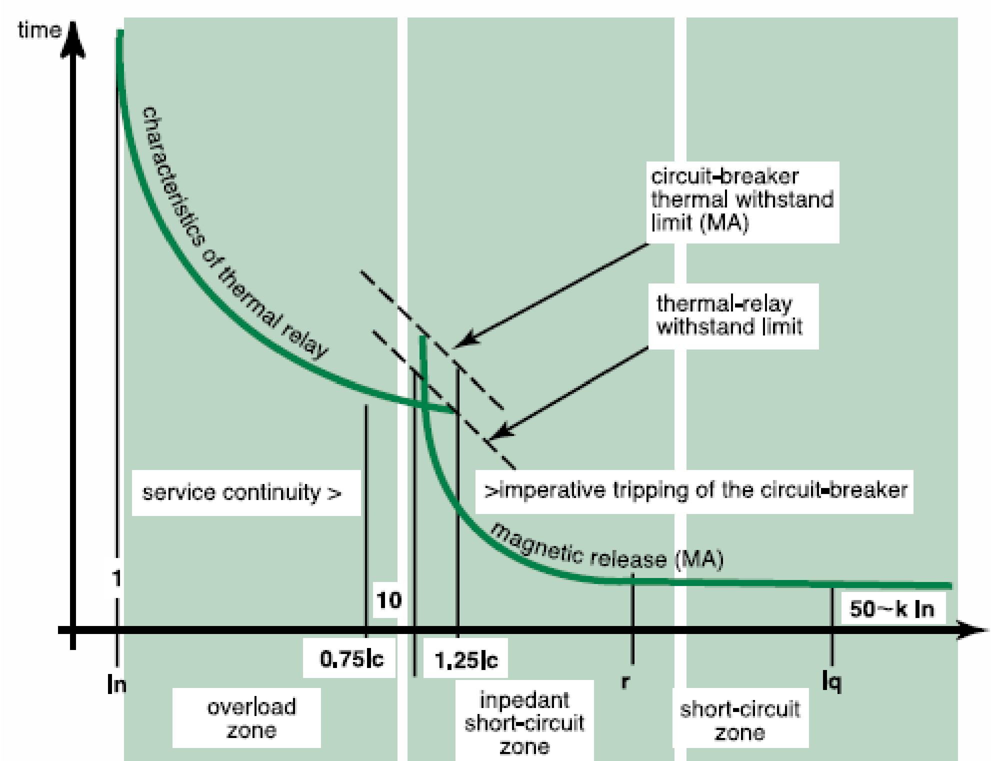



*Figure 104: Response time and coordination for typical motor protection*

### *6.5.2.2. "r" current (Impedant short-circuit 10< I < 50 In)*

The primary cause of this type of fault is the deterioration of insulation. IEC standard 60947-4-1 defines an intermediate short-circuit current "r". This test current is used to check that the protective device provides protection against impedant short-circuits.

There must be no modification in the original characteristics of the contactor and the thermal relay following the test.

The circuit breaker must trip in 10 ms for a fault current ≥ 15 In, with however a maximum current according to the range of protection as per hereunder

| **Operational current Ie (AC3*) of the motor (in A)** | **"r" current (in kA)** |
|---|---|
| Ie ≤ 16 | 1 |
| 16 < Ie ≤ 63 | 3 |
| 63 < Ie ≤125 | 5 |
| 125 < Ie ≤ 315 | 10 |
| 315 < Ie < 630 | 18 |

**see contactor paragraph)***)**

#### 6.5.2.3. "Iq" current (short-circuit I > 50 In)

This type of fault is relatively rare. A possible cause may be a connection error during maintenance.

Short-circuit protection is provided by devices that open quickly.

IEC standard 60947-4-1 defines the "Iq" current as generally • 50 kA.

The "Iq" current is used to check the coordination of the switchgear and control gear installed on a motor supply circuit.

Following this test under extreme conditions, all the coordinated switchgear and control gear must remain operational.

## 6.6. HIGH VOLTAGE CIRCUIT BREAKER

This type of equipment needs as well maintenance. Do not "forget" it on your site.

For equipment of HV cubicles, see course EXP-MN-SE120 where we see (among other equipment) the principles of all separating devices associated with "their" cubicles.

- Isolator mainly used for earthing connection
- Switch used in HV loops interconnections
- Breaker for direct protection of HV motor, transformer, generator,….

Here we just see the breaker *which could be called "discontactor" when it is an association of a power switch (or contactor) with fuses.* Current and voltage "problems" are detected by CTs and PTs, then through relays (or multi-function relay) to actuate the "contactor".

The HV breakers installed on Total sites are of withdrawable type and breaking in air or in gas (SF6). *I never saw other types.*

Different manufacturers equip sites; let's choose the Merlin Gerin device, like for the figure in this paragraph. Some cubicles provide space for 2 breakers vertically arranged.

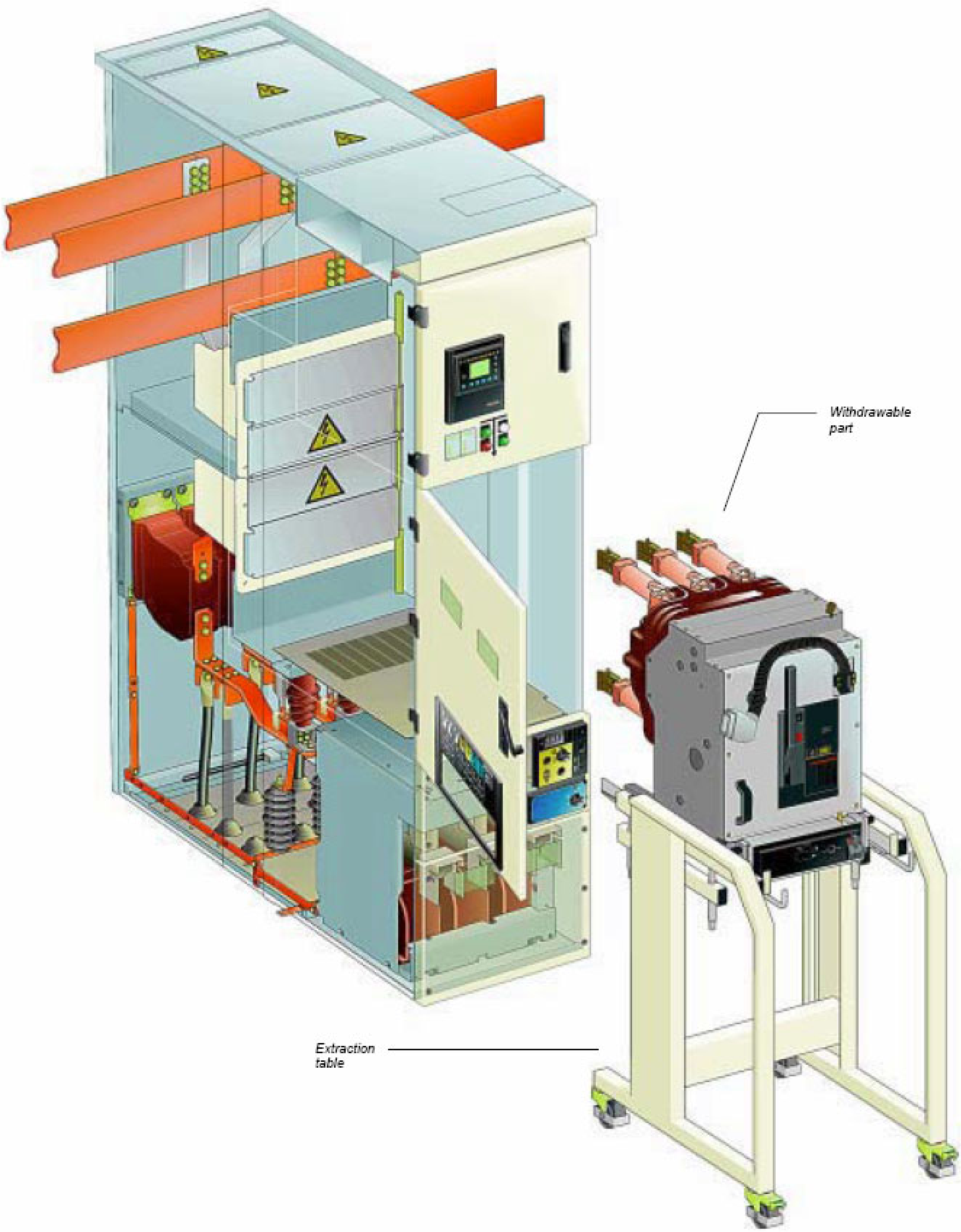
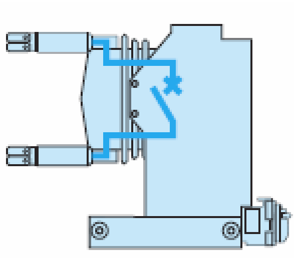



*Figure 105: The withdrawable HV breaker and its cubicle (Merlin Gerin)*

### 6.6.1. The withdrawable device

It is in our case the breaker, but you can equip the cubicle with other type of device.

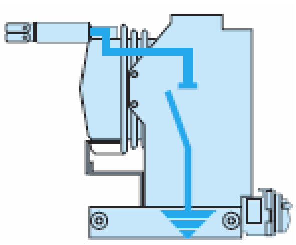
**Circuit breaker**



A circuit breaker is a safety device enabling switching and protection of electrical distribution networks. Installed in the cubicle, it protects all components situated downstream during a short circuit.

*Figure 106: The withdrawable breaker*

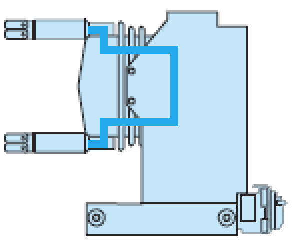
**Earthing truck**



The earthing truck is a safety feature which allows the cubicle busbar to be earthed.
It is installed instead of the circuit breaker and has lots of interlock possibilities.

*Figure 107: The withdrawable earthing truck*

**Disconnector truck**



The disconnector truck enables the upper and lower part of the cubicle to be short-circuited.
It is installed instead of the circuit breaker and has the same interlock possibilities.

*Figure 108: The withdrawable disconnector truck*

**Power and control connections**

The withdrawable breaker has power connections with “slide-in” blade type connectors and control connections with a multi pins socket.

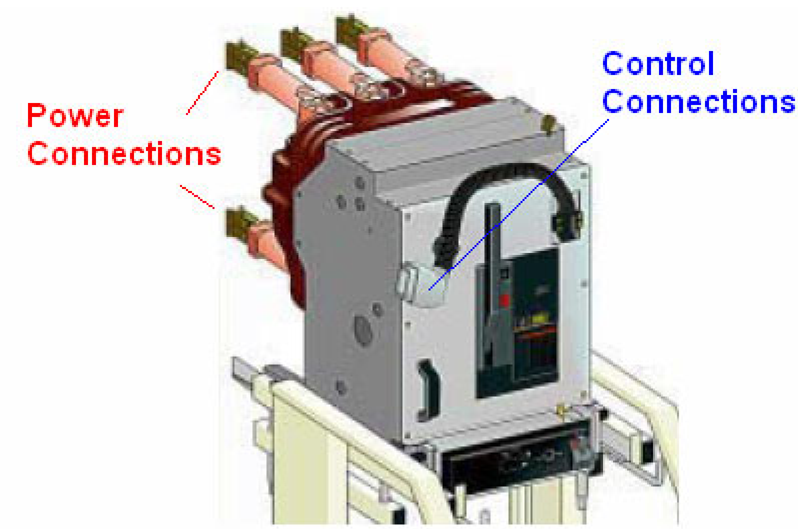



*Figure 109: Withdrawable breaker power and control connections*

Note: after racking-off and before racking-in, always check the status of the connections, seeking for either cracks/holes of material deposit due to arcing. Clean the contact surface with soft file or emery cloth and if in real bad status, replace the connectors. *But if you perform this last operation you will have to check as well the female part of the connectors, as soon as possible.*

**Racking positions:**

Normally, 3 positions could be available

- **In place:** drawer just racked in cubicle, control socket connected, nothing operational
- **In test:** a further in racking-in the drawer, all control circuits are operational, breaker can be operated on/off but not switching on/off the main power, the power connectors being not in “final” contacts;
- **In operation**: ready to power on/off (and protect) the load

### *6.6.2. Self-expansion HV breaking*

Breaking is based on the principle of self-expansion in SF6.

The 3 main poles are contained in an insulating enclosure of the sealed system type, which requires no filling during the service life of the device (in conformity with standard IEC 62271-100).*

This gas-tight enclosure is filled with SF6 at a low relative pressure of 0.15 Mpa (1.5 bars).

Low pressure filling ensures reliable gas tightness.

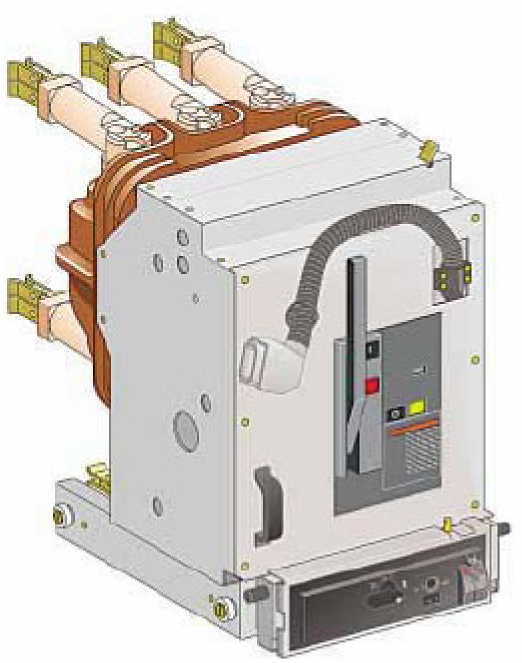


*Figure 110: The LF series HV circuit breaker of Merlin Gerin (7.2 to 7.5 kV)*

*SF6 is a gas filling nearly all types of HV circuit breakers and is used by all manufactures.*

*Some of them propose a regular check of SF6 pressure with possibility of refilling.*

*Please check the maintenance manual of your equipment, there is (probably) a specific procedure about SF6 “management.*

### 6.6.2.1. Principle of the self-expansion breaking technique

This technique is the result of a large amount of experience in SF6 technology and significant research effort.

It combines the rotating arc technique (see in the following) with thermal expansion to create the conditions to cool and extinguish the arc.

This enables the control mechanism energy to be reduced as well as arc contact erosion; mechanical and electrical endurance is therefore increased.

The operating sequence in a self-expansion breaking chamber whose moving part is actuated by the mechanical control is as follows:

- Fig. A: the circuit breaker is closed;
- Fig. B: on opening of the main contacts (a), the current is transferred to the breaking circuit (b);
- Fig. C: on separation of the arcing contacts, an electrical arc appears in the expansion chamber (c); the arc rotates under the effect of the magnetic field created by the coil (d) which has the breaking current running through it; the overpressure produced by the increase in gas temperature in the gas expansion chamber (c) causes gas flow which blows the arc within the tubular arcing contact (e), thus causing it to extinguish when the current passes to zero;
- Fig. D: circuit breaker open.

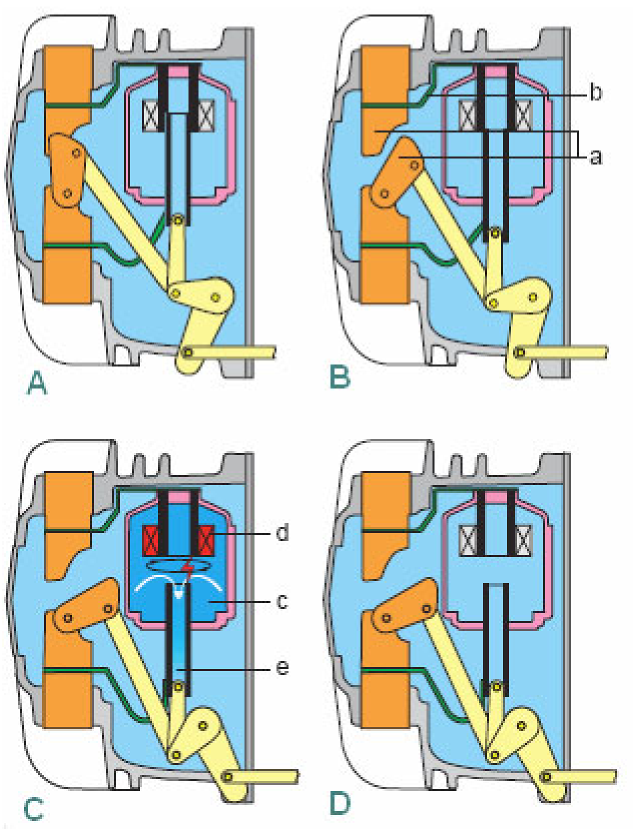



*Figure 111: Self expansion breaking technique for LF breaker of Merlin Gerin*

### 6.6.2.2. Operating mechanism (LF breaker of Merlin Gerin)

LF range circuit breakers are actuated by an “RI” operating mechanism that ensures a switching device closing and opening rate that is independent of the operator.

This operating mechanism, which is always motorised, can perform remote control functions and enables fast reclosing cycles.

**The RI operating mechanism includes:**

- a spring system that stores the energy needed to close and open the breaker;
- a manual spring charging system;
- an electrical motor-operated spring charging device that automatically recharges the mechanism as soon as the contacts close (recharging time < 15 s);
- two mechanical push buttons for opening and closing, accessible with the cubicle door open (circuit breaker in test position). For control with the door closed (circuit breaker racked in):
  - Circuit breaker opening by controlling the propulsion device,
  - circuit breaker closing optional.
- an electrical closing system comprising a closing release for remote control and an anti-pumping relay;
- an electrical opening system comprising one or more opening releases of the following type:
  - single or double shunt,
  - undervoltage.
- an operation counter;
- an “operating mechanism charged” indication contact (M3);
- an spring charging limit switch contact (M1-M2);
- a black-white mechanical “open-closed” position indicator;
- a multi-pin connector to isolate auxiliary circuits in the “racked out” position.

#### 6.6.2.3. Auxiliary contacts, equipment and diagram (LF breaker)

The RI operating mechanism is equipped with a block of 14 auxiliary contacts including:

- 1 changeover contact for the electrical operating mechanism;
- 1 changeover contact for indication;
- 1 contact for the shunt release.

The number of available contacts depends on the position

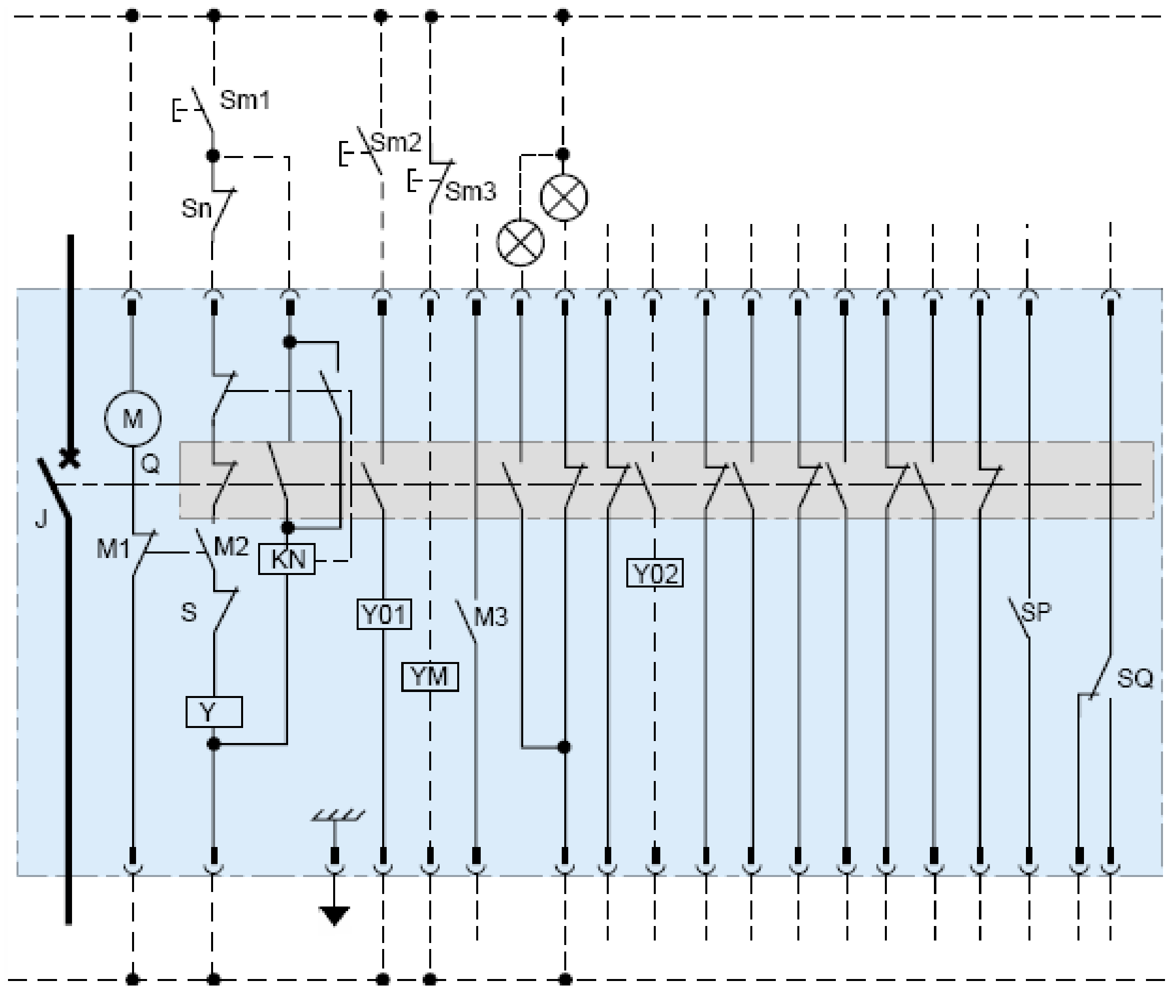



*Figure 112: RI circuit breaker operating mechanism* -f HV breaker LF series of M.G.

***J:*** *Circuit breaker*
***KN:*** *Anti-pumping relay*
***M:*** *Spring charging motor*
***M1-M2:*** *End of charging contacts*
***M3:*** *Operating mechanism charged indication*
***QF:*** *Circuit breaker auxiliary circuits*
***SE:*** *Latched tripping contact*
***Sm1:*** *Closing push button (external)*
***Sm2:*** *Opening push button for shunt trip release (external)*
***Sm3:*** *Opening push button for undervoltage release (external)*
***Sn:*** *Closing disabling contact (external)*
***SP:*** *Pressure switch contact*
***SQ:*** *Device ready to operate contact*
***YF:*** *Closing release*
***Y01-Y02:*** *Shunt opening release*
***YM:*** *Undervoltage opening release*

### 6.6.3. Puffer breaking technique.

#### 6.6.3.1. Presentation

They are the SF series range circuit breakers (of Merlin Gerin) with rated voltage values of 24 kV.

They work on the basis of the “puffer” type principle in SF6, which is used as a breaking and insulating medium.

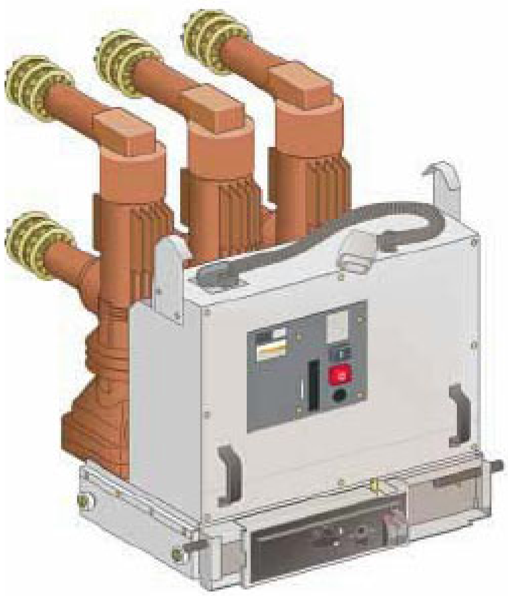


*Figure 113: The SF series HV circuit breaker of Merlin Gerin (up to 24 kV)*

Each of the 3 poles has an independent insulating enclosure which forms a filled pressure system in compliance with IEC standard 62271-100.

Each pole forms a gas-tight unit filled with low pressure SF6 at low relative pressure of 0.05 to 0.35 MPa (0.5 to 3.5 bars) according to the performance level required.

No filling is required during the equipment’s life. *(Same remark as in the previous paragraph for the self-expansion breaker)*

According to the performance levels, it is possible to optionally equip SF6 circuit breakers with a pressure switch to act on an alarm in the case of a pressure drop.*(this comment is from the manufacturer manual, it proves that topping of SF6 gas is not an optional event….)*

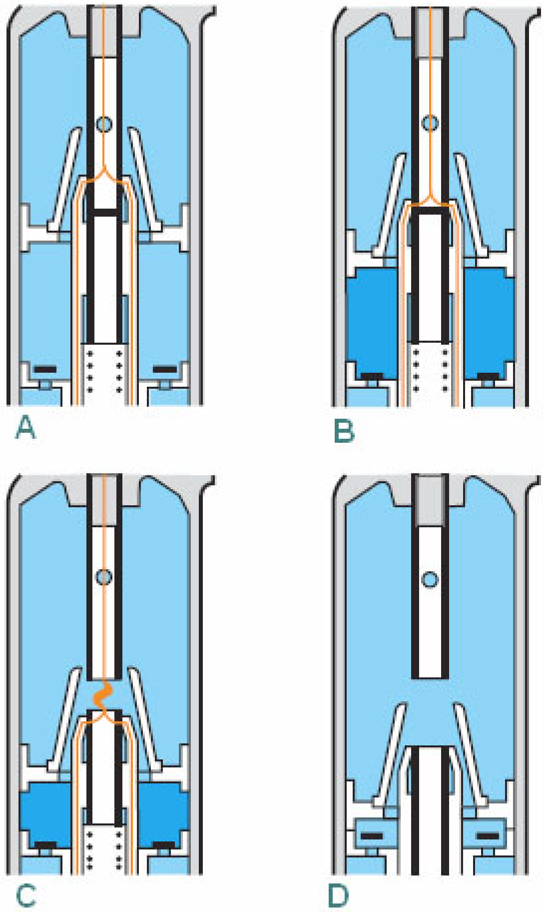
SF6 range circuit breakers are actuated by a GMH type spring mechanism.

#### 6.6.3.2. Principle of the puffer breaking technique.

Part **A** or the figure: The main contacts and arcing contacts are initially closed

Part **B** or the figure: **Pre-compression**

When the contacts begin to open, the piston slightly compresses the SF6 gas in the pressure chamber.




Part **C** or the figure: **Arcing period**

The arc appears between the arcing contacts.

The piston continues its downward movement.

A small quantity of gas, directed by the insulating nozzle is injected across the arc.

For the breaking of low currents, the arc is cooled by forced convection.

However, for high currents, thermal expansion causes the hot gases to move towards the cooler parts of the pole unit.

The distance between the two arcing contacts becomes sufficient for the current to be broken when it reaches the zero point, due to the dielectric properties of the SF6.

*Figure 114: Principle of the puffer breaking technique (SF series of Merlin Gerin)*

Part **D** or the figure: **Sweeping overstroke**

The moving parts finish their movement and the injection of cold gas continues until the contacts are completely open.

### 6.6.3.3. Operating mechanism (SF series breaker of Merlin Gerin)

SF range circuit breakers are actuated by a GMH operating mechanism that ensures a switching device closing and opening rate that is independent of the operator.

This operating mechanism, always motorised, enables remote operation and fast reclosing cycles.

**The GMH operating mechanism includes:**

- a spring system that stores the energy needed to close and open the breaker;
- a manual spring charging system;
- an electrical motor spring charging device that automatically recharges the mechanism as soon as the contacts close (recharging time < 15 s);

- two mechanical push buttons for opening and closing, accessible with the cubicle door open (circuit breaker in test position);
- an electrical closing system comprising a closing release for remote control and an anti-pumping relay;

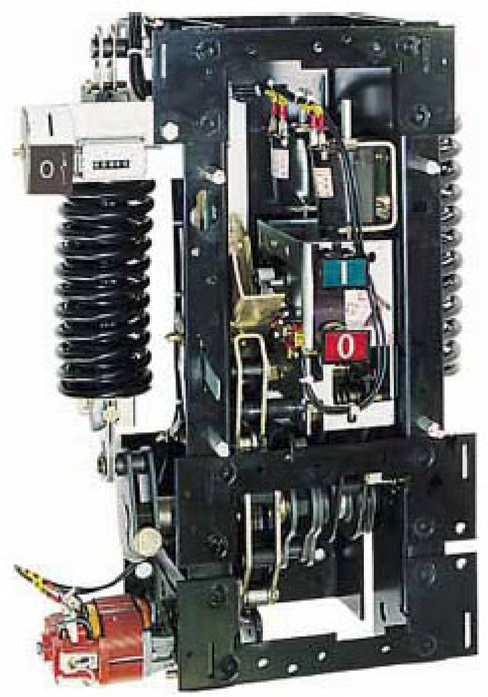


*Figure 115: Operating mechanism GMH of SF series*

- an electrical opening system comprising one or more opening releases of the following type:
  - shunt,
  - undervoltage.
- an operation counter;
- an optional "operating mechanism charged" indication contact;
- an end of charging contact;
- a black-white mechanical "open-closed" position indicator;
- a multi-pin connector to isolate auxiliary circuits in the "racked out" position.

### 6.6.3.4. Auxiliary contacts, equipment and diagram (SF breaker)

The GMH operating mechanism is equipped with a block of 14 auxiliary contacts including:

- 1 changeover contact for the electrical operating mechanism;
- 1 changeover contact for indication;
- 1 contact for the shunt release.

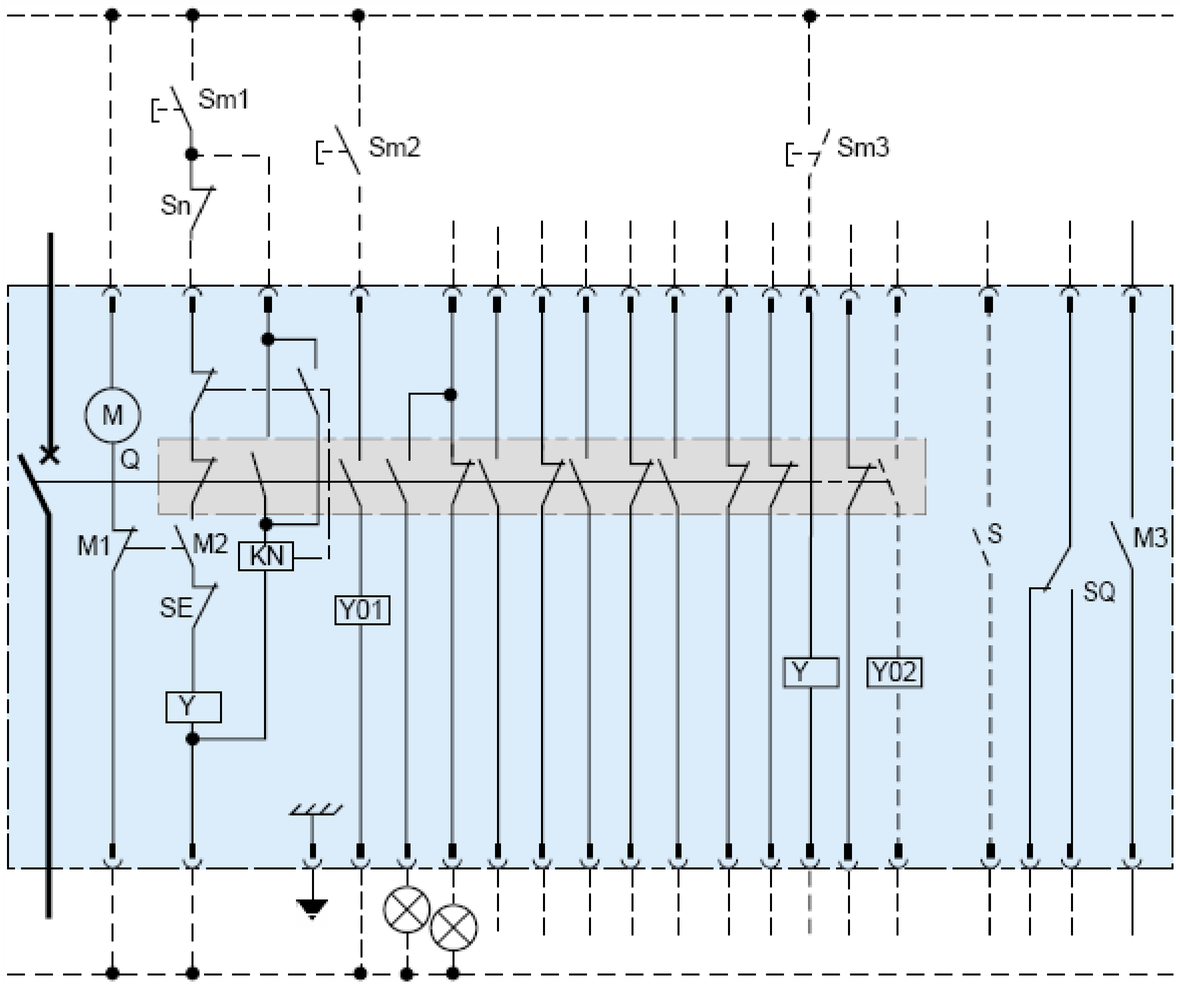



*Figure 116: GMH circuit breaker diagram – SF series breaker of M.G.*

***J:*** *Circuit breaker*
***M:*** *Spring charging motor*
***YF:*** *Closing release*
***M1-M2:*** *End of charging contact*
***QF:*** *Auxiliary circuit breaker contacts*
***KN:*** *Anti-pumping relay*
***SE:*** *Latched release contact*
***Y01-Y02:*** *Shunt opening releases*
***YM:*** *Undervoltage opening release*
***M3:*** *Operating mechanism charged contact*
***SP:*** *Pressure switch contact*
***SQ:*** *Device ready to operate contact*
***Sm1:*** *Closing push button (external)*
***Sm2: Opening*** *push button for shunt releases (external)*
***Sm3:*** *Opening push button for undervoltage releases (external)*
***Sn:*** *Closing disabling contact (external)*

## 6.6.4. Rollarc contactor (Merlin Gerin)

### 6.6.4.1. Description

- three main poles located in the pressurised enclosure;
- electromagnetic operating mechanism with:
  - magnetic latching for Rollarc 400,
  - mechanical latching for Rollarc 400D.

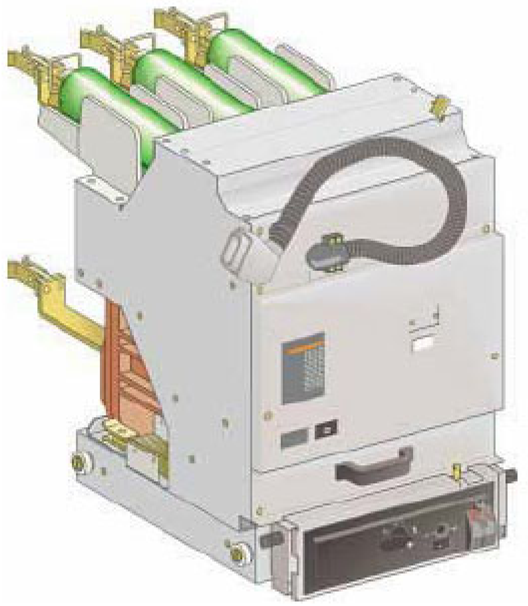


Figure 117: Rollarc contactor of Merlin Gerin

- upstream and downstream terminals for power circuit connections;
- pressure switch equipped with a NO contact for continuous monitoring of SF6;
- mechanical interlocking of the contactor in the open position to prevent racking in or out with the contacts closed;
- 3 HPC fuses with striker pin and auxiliary contact to trip the contactor.

### 6.6.4.2. Principle

The Rollarc contactor uses rotating arc breaking in SF6 gas. A magnetic field causes the arc to rotate between the arcing contacts; the field is created by the passage of the arc through a blow-out coil

The rotation movement cools the arc by forced convention.

The arc rotation rate depends on the current to be broken.

The energy required to extinguish the arc is supplied by the electrical system.

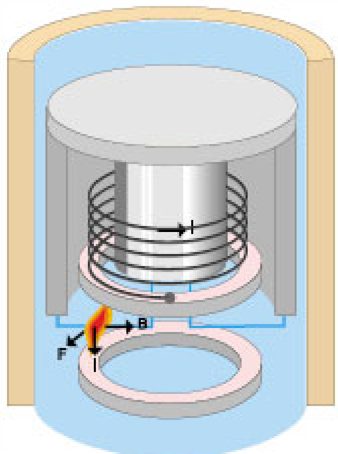



Figure 118: Rollarc contactor principle

The operating mechanism is simple and economical.

Modulation of the rotation rate ensures soft breaking without any dangerous overvoltage or current chopping.

The Rollarc has a high breaking capacity and may be used without a time delay in combination with fuses.

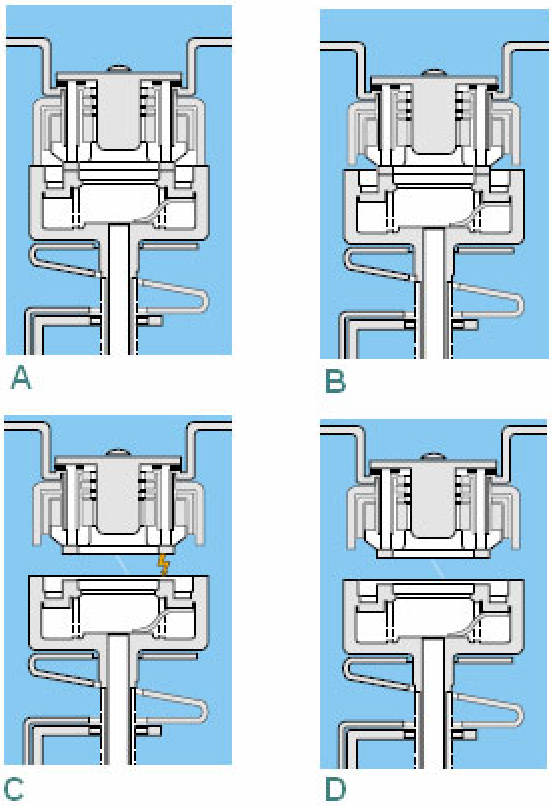
### 6.6.4.3. Contactor operation

Part **A** of figure: at the beginning of the opening operation, the main contacts and arcing contacts are closed

Part **B** of figure: the main circuit is interrupted by the separation of the main contacts

The arcing contacts are still closed.

The arcing contacts separate shortly after the main contacts.




The arc that is created is subjected to the electromagnetic field produced by the coil, which is proportional to the current to be interrupted.

Part **C** of figure: the arc rotates rapidly, driven by the electromagnetic force and is cooled by forced convection (arcing period,).

Due to the phase-shift between the current and the magnetic field, this force is still significant around the current zero point.

Part **D** of figure: at the zero point, the gap between the two arcing rings recovers its original dielectric strength due to the intrinsic properties of SF6 (contactor open).

*Figure 119: Contactor operation*

### 6.6.4.4. Fuses

The fuses used are of the **FUSARC CF** or **FERRAZ** type (Standard IEC 60282.1 and DIN 43625) with high breaking capacity.

Substantial fault current limitation reduces the electrodynamic stresses on the load-side components (contactor, cables, CT, etc).

A “blown fuse” device is used to open the three poles of the contactor; only one fuse blown is enough to actuate the mechanism.

Fuses characteristics (current and voltage) as per the network and the load

### *6.6.4.5. Auxiliaries diagram*

***FU1 :*** *MV fuses*
***FUBT :*** *LV fuse*
***K1 :*** *R400 AC MV contactor*
***P61:*** *Operation counter*
***S61:*** *Locking contact activated by the pre-trip push button and during racking in/out operations*
***SQ1:*** *Contactor limit switch*
***X20:*** *LV connecter, 42 pins + earth*
***X51:*** *Control plate*
***X61:*** *Contactor terminal block*
***XAP:*** *Instantaneous auxiliary relay*
***XE:*** *Instantaneous auxiliary control relay*
***XU:*** *0.6 s time delay auxiliary relay*
***YD:*** *Shunt trip coil*
***YF:*** *Closing coils*
***YM:*** *Latching coil*
***S4:*** *Trip button*

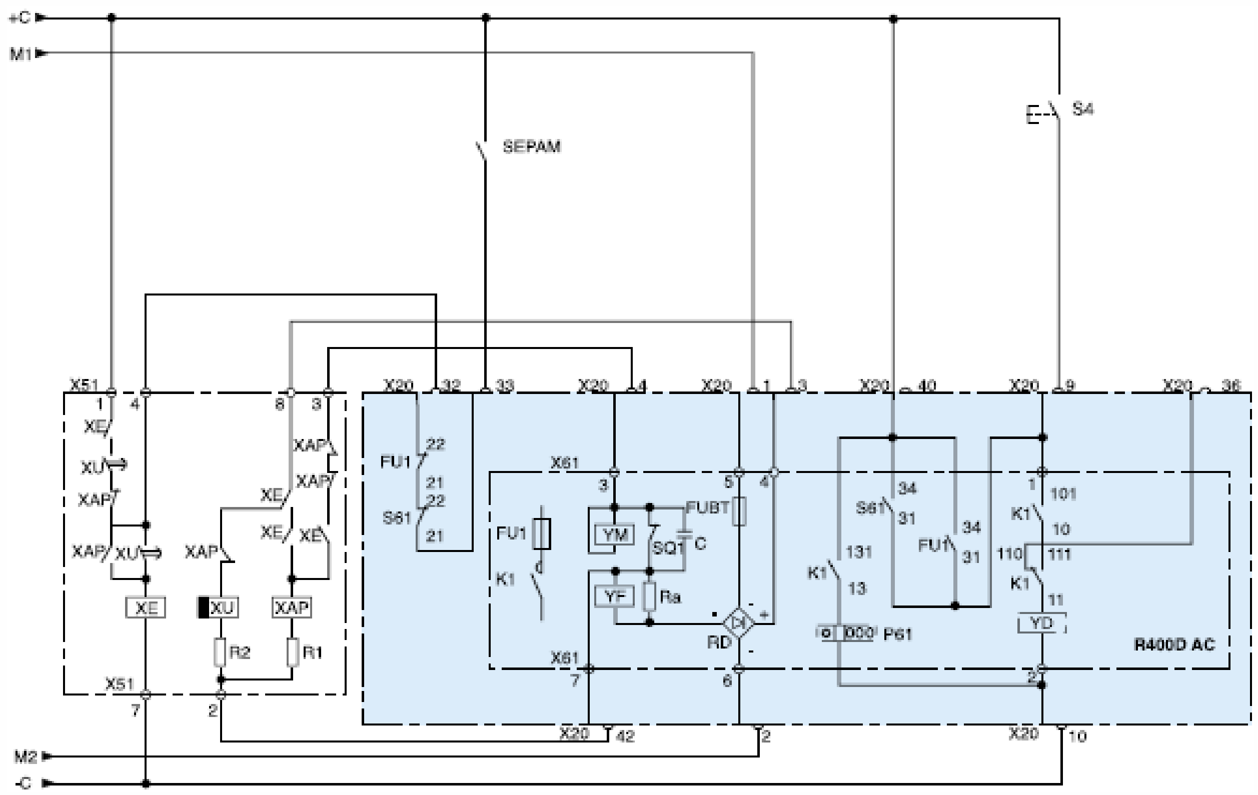



*Figure 120: Rollarc contactor control diagram - model 400D of M.G*

# 7. EARTHING PROTECTION

## 7.1. RCD OR DIFFERENTIAL PROTECTION

RCD stands for Residual Current Detection

It is the system which measures a "residual" fault current and which, when this current becomes "dangerous", indicates the fault or triggers a disconnection device.

### 7.1.1. Principle of RCD protection

Here is some ***theory*** to understand the principle,

#### 7.1.1.1. Measuring current

We have a two-pole power supply with a load (Ph + N or 2 phases, these are identical for this principle) and we take current measurement with a clamp ampere meter (or with a CT and a multimeter)

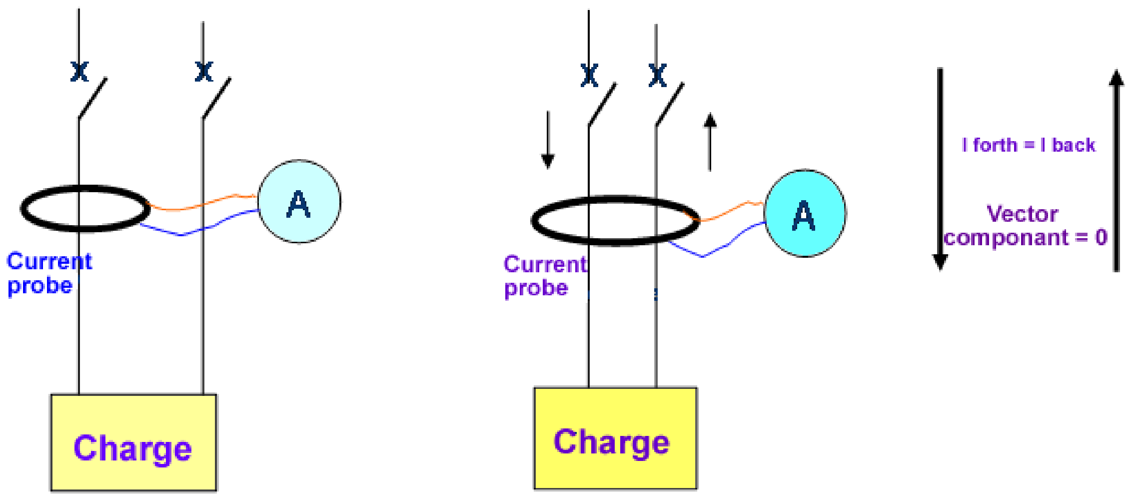



*Figure 121: Current measurement with a clamp meter*

***On the left***, I take a current measurement, the ammeter indicates a value (circuit breaker closed, of course), indication is identical on both wires.

***On the right,*** I place the clamp on the 2 conductors; the current measured is zero since at the same measurement instant 't' the 2 currents cancel each other out, one in one direction and the return in the other direction.

### 7.1.1.2. Measuring residual current

Let's give up the CT type clamp meter and let's use a specific toroid (or torus), having still the principle of a CT (Current Transformer), but able to detect / measure a very small current on its secondary winding *(a fault current or a residual current)*

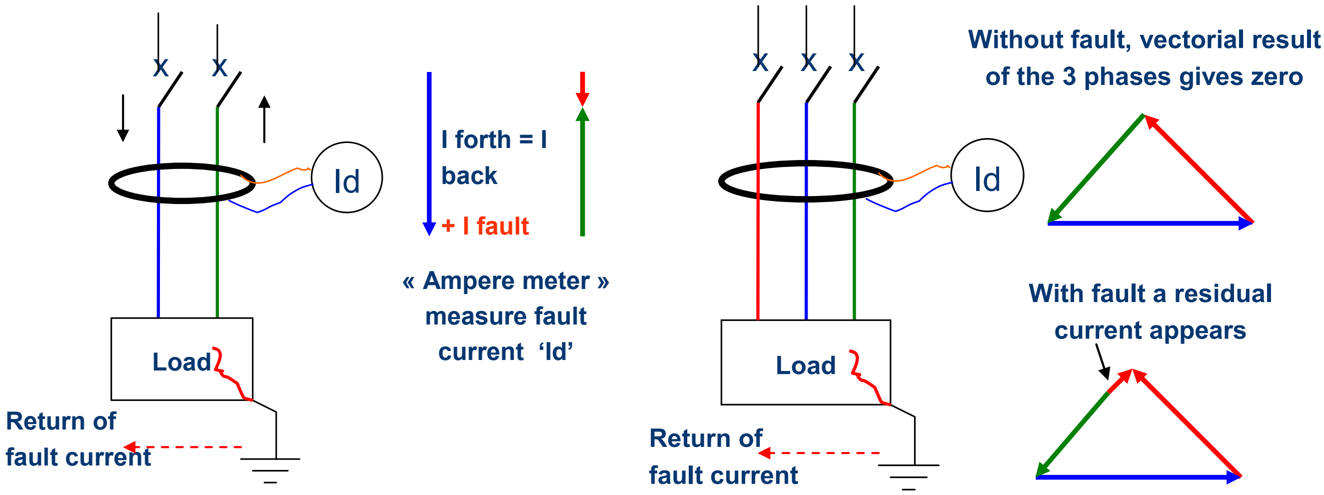



*Figure 122: Measuring a fault current*

With an earth fault, part of the current returns to the source via the ground and the earthing distribution system

With a two-pole supply, the return current is less than the supplied current, but the "detector" now measures the equivalent of the leakage fault, it measured the difference, it is a differential detector, or a residual current detector. (RCD)

With three-phase, and when no fault is present, the components of the 3 currents are equal to zero (try this using a clamp-on ammeter on a cable); as soon as a fault appears, it is measured by the "differential detector".

## 7.1.2. RCD associated with trip separating device

Meaning breaker (or switch) and RCD unit form one device.

It can be done with modular and moulded type of breakers (or switch)

### 7.1.2.1. The RCD + Breaker (switch) block

Within this group, we differentiate the ***inseparable device***; it is the RCD breaker (or switch) or the differential breaker

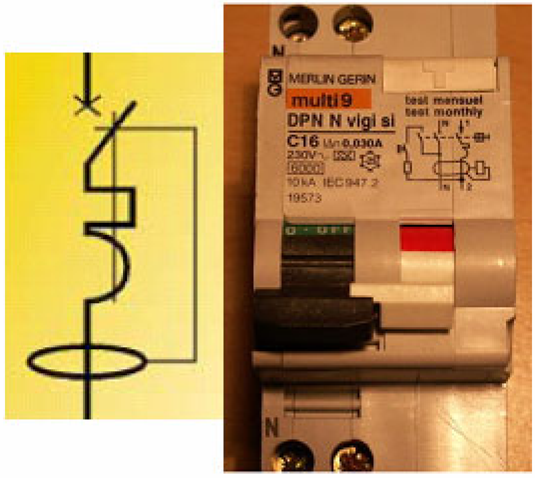



*Figure 123: Example of one block Breaker + RCD and its symbol (for one phase)*

**Figure represents a Differential circuit breaker** preassembled *(DPN Vigi of Merlin Gerin)*

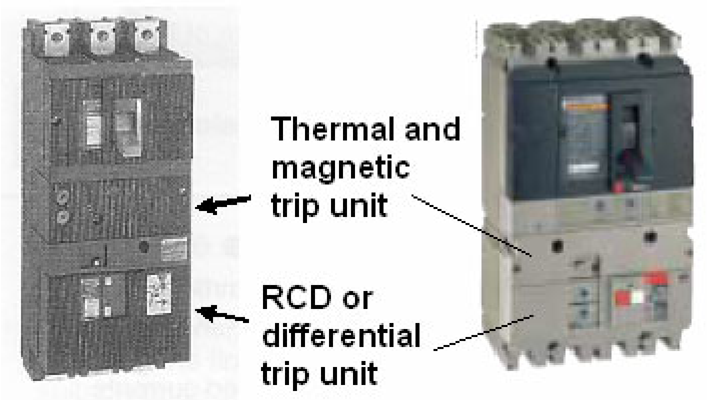
*<u>Specifications of this DPN Vigi:</u>*

2 poles: Phase and Neutral - *Phase with thermal-magnetic protection* - Thermal at 16 A *Magnetic at?? (Function of curve, B, C or D for Merlin Gerin, written on the side of breaker with a sticker, generally for MG made – within the reference for other manufacturers)* - Neutral not protected (normal) - *Service voltage: 230V* - Breaking capacity: 10 kA – "*Differential*" *30 mA*

### 7.1.2.2. The Breaker (or switch) + RCD in separate block

In this group we have the RCD breaker (or switch) made by ***association of an RCD block and the breaker*** (or switch) itself

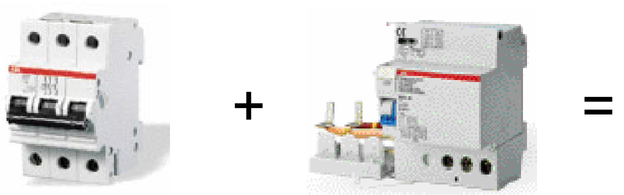
See the figures, examples of association which can be done for modular and moulded type



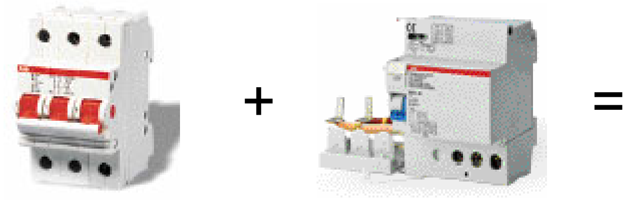

With moulded type, the RCD block is mounted under the breaker or switch

*Figure 124: Moulded breaker + RCD block*

Figure represents an old fashioned "Compact" of Merlin gerin and the new version of Compact NS250 both equipped with a block "vigi"




'ABB' Differential **Circuit breaker**
3 poles, the power unit is for the thermal and magnetic protection, the add-on unit is available with a 30 or 300mA differential.



'ABB' Differential **Switch**
At least 'ABB' makes the switch a different colour… It is only the differential unit which automatically trips the switch.

*Figure 125: ABB differential circuit breaker and differential switch*

Same for Merlin-Gerin equipment with 2, 3 or 4 poles.

*Figure 126: Merlin-Gerin circuit breaker + bloc "vigi"*

At this point, I have few personal remarks:

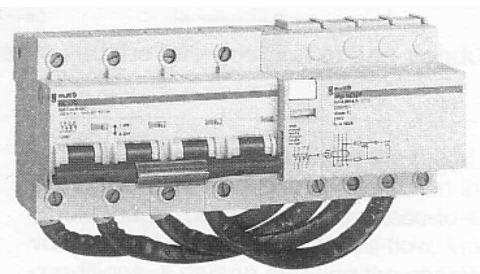
1 - For the French people, stop to say "vigi" when speaking of RCD,. Vigi is a brand name of Merlin Gerin, understood only by French electricians using the same material M.G.

2 – The term "Compact" is also a brand name of Merlin Gerin. However it is used by some other manufacturers when naming the moulded type of breakers (or switch), but the term "moulded" is the one internationally understood.

3 – May be, you noticed that systematically, the word "switch" is associated (under brackets) with "breaker" in this paragraph about RCD's. It is because I realised that (many) industrial electricians think that the RCD can be associated only with breakers. In lighting and domestic distribution, you find at head of protection a switch equipped with a RCD, then the sub-protection by breakers; and it is "as per standard".

### 7.1.2.3. Range of RCD blocks

***The differential units associated with the modular devices have fixed residual current trip thresholds, 2 values (*):***



- ***30mA***
- ***300mA***

*Figure 127: Differential unit 4 poles (1)*

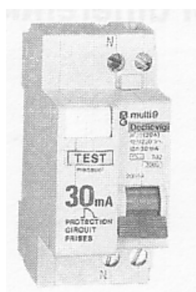


*Figure 128: Differential unit 2 poles(2)*

* They are the 2 major protections in domestic and industrial distributions (see course EXP-MN-SE 180 “Electrical Safety”)

**30 mA** is systematically for sockets protections and specific applications

**300 mA** is for lighting and industrial equipment protections

Other fixed settings are however available (for –nearly- all manufacturers):

**10 mA**, bathroom, wet areas protections

**100 mA** increased safety in lighting distribution

**500 mA** for domestic applications

**1 A, 2A, 3A** when there is a selectivity requirement (see course EXP-MN-SE100 ‘Electrical Networks”)

***RCD Selective type (modular)***

No time delay in majority of this devices, but some manufacturing’s propose a “selective RDC” which means having a set time delay in reaction

It is a protection against the effects of sinusoidal alternating, direct pulsating and pulsating DC or smooth DC earth fault currents with an intentional tripping delay, which permits to realize the selectivity with downstream instantaneous devices; (Time delay = ?, see manufacturers manuals)

In all types of manufacturings, the fault is detected through a toroid. Its secondary coil, once having “enough” energy (with the set tripping current) energises a tripping coil which in turn mechanically trips the breaker / switch. For modular type, side mounted,

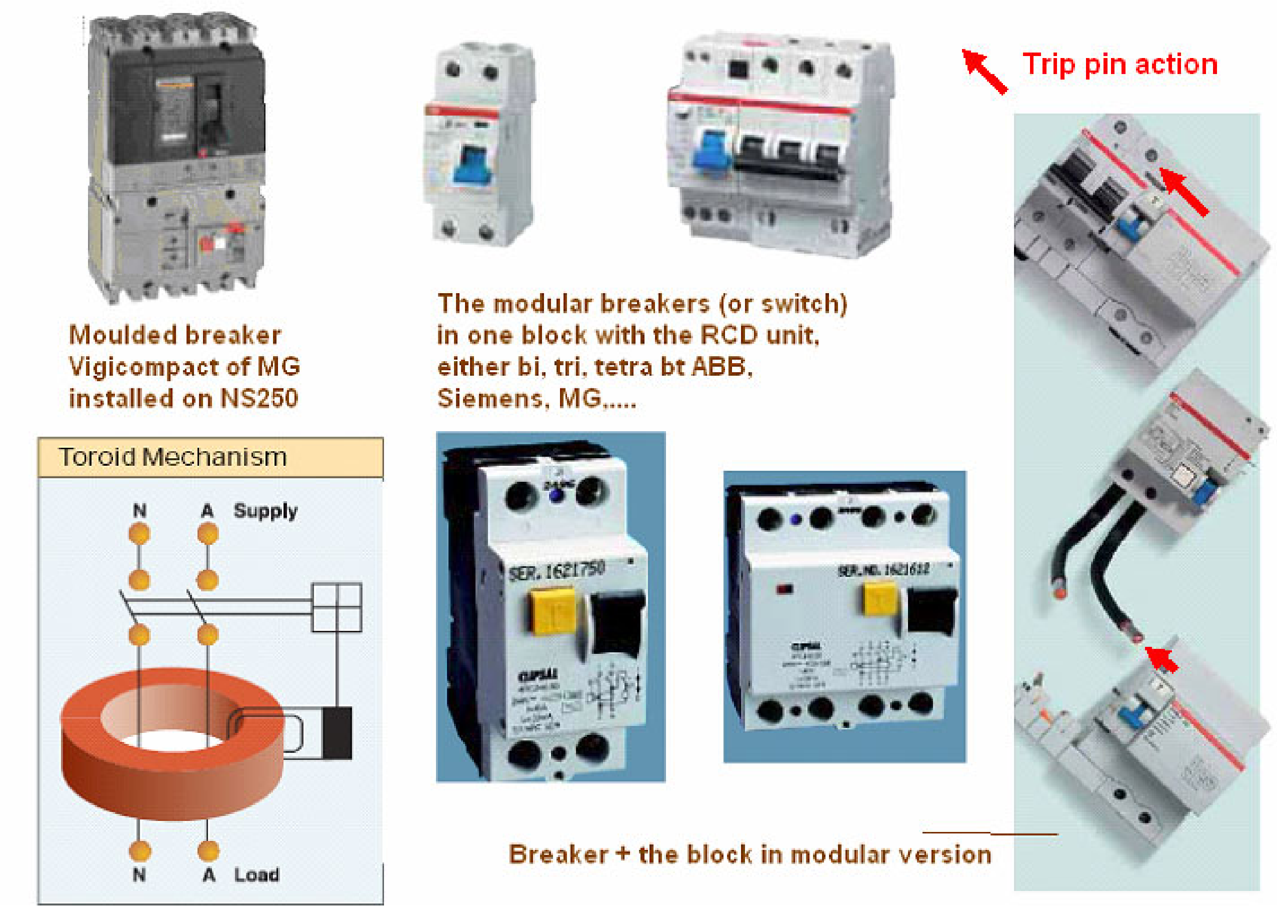



*Figure 129: Panel of breakers and RCDs associated*

***The differential units associated with the moulded devices have residual current trip thresholds values adjustable in value and time***

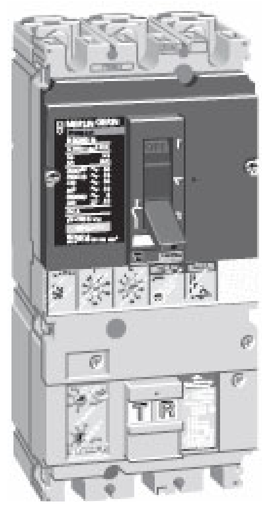


*Figure 130: NS250 Merlin Gerin equipped with RCD block*

For the example here, block RCD (Vigi for MG…) the possible adjustments are:

**Sensitivity IΔn** (A) Adjustable
0.03 - 0.3 - 1 - 3 - 10

**Time delay** (ms) Adjustable
0 - 60 - 150 - 310

### 7.1.3. Toroid and RCD relay

#### 7.1.3.1. Principle

There is no difference in the principle of operation; it just requires separates pieces of equipment

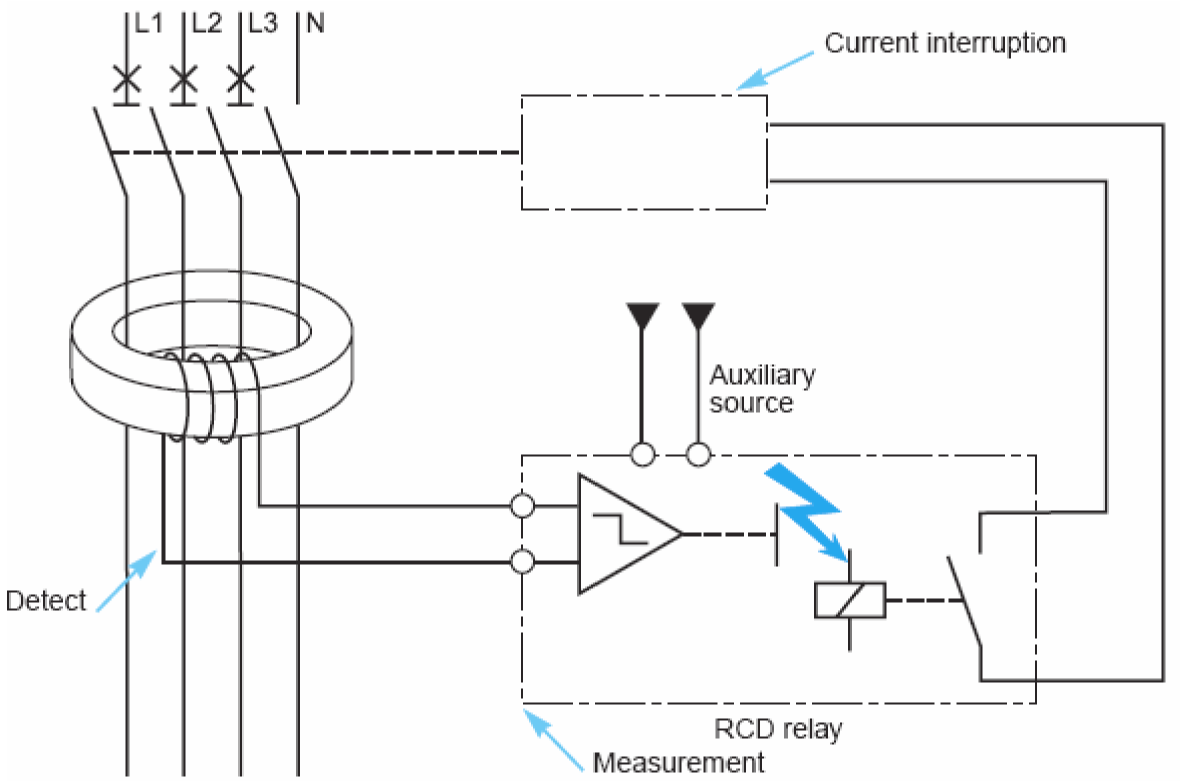



*Figure 131: RCD operating principle with separate toroid*

This system of RCDs implements:

- A  toroid (or torus) installed downstream the breaker, protected power cable passing through
- an electronic (RCD)  relay supplied by an auxiliary source
- a link (cable) between secondary of toroid and RCD rellay
- a tripping device (current interruption) part of the breaker (or switch) connected on the output trip contact of the RCD relay (either NO or NF)

When there is no insulation fault, the vector sum of the currents flowing in the live conductors is equal to zero.

If an insulation fault occurs, the sum is no longer equal to zero and the fault current creates in the toroid a magnetic field which generates a current on the secondary winding.

This current is monitored by a measurement circuit and, if it overruns the set threshold for a time greater than the set intentional time delay, the relay orders the current-breaking device to open.

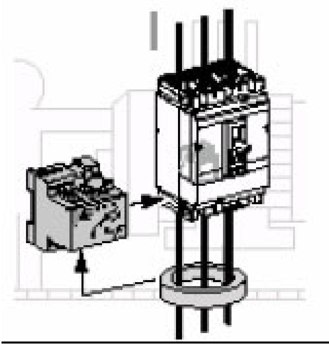


*Figure 132: Example of "Compact" circuit breaker with separate toroidal differential current detector*

The Heavy duty (or power type) circuit breaker range is systematically equipped with separate torus type current transformers for RCD protection.

### 7.1.3.2. Type of materials

*Figure 133: Closed Torus, "openable" torus and RCD "Vigirex" (Merlin Gerin) relays connected to the torus secondary*

Figure shows a set of torus and typical RCD relays, manufacturer Merlin Gerin, other manufacturers have same devices, same ranges.

Note that diameter of torus is only function of the cable diameter and a torus (being not a CT) is self protected (by construction) against overcurrent.

### 7.1.3.3. Range – Sensitivity levels

Electronic relays offer wide setting ranges for the sensitivity and the time delay.
The installation standards characterise the required RCD sensitivity depending on the need for protection (course SE100).

| High sensitivity | Medium sensitivity | Low sensitivity |
|---|---|---|
| 30 mA | 100 mA to 3 A | > 10 A |

*Table 12: Sensitivity depending on the different needs*

### 7.1.3.4. RCD operating / non-operating current

The standards indicate the preferred values for the residual operating current settings.

Operating current **IΔn in A**: 0.006 – 0.01 – 0.03 – 0.1 – 0.3 – 0.5 – 1 – 3 – 10 – 30.

To take into account the tolerances (temperature, dispersion of components, etc.), the standards indicate that an RCD device set to an IΔn value must:

- **not operate** for all fault currents y IΔn/2
- **operate** for all fault currents u IΔn.

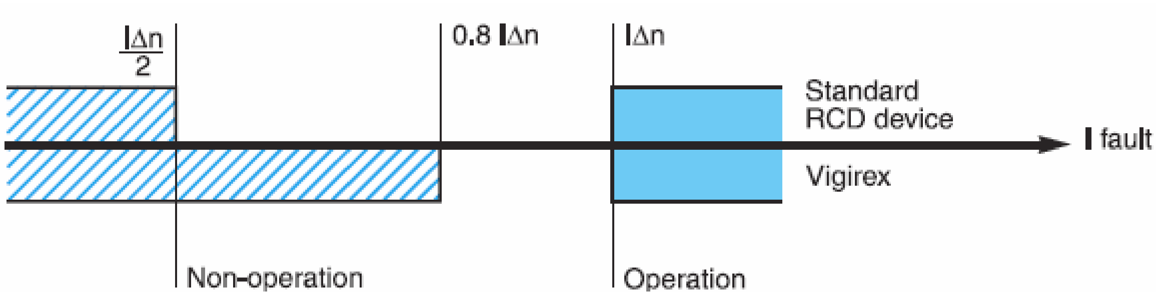



*Figure 134: Example of operability for a RCD type “vigirex” of Merlin Gerin*

The technologies employed for Vigirex devices guarantee dependable non-operation up to 0.8 IΔn.

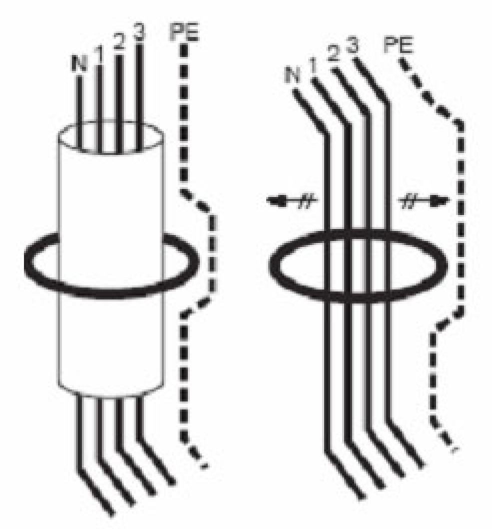
Standard IEC 60947-2 allows manufacturers to indicate the level of non-operation if it differs from the general rule.

Nearly all type of RCD separate relay have a complementary time delay adjustment of the trip threshold (this for selectivity). Time 0.01 to 10 s.

### *7.1.3.5. Cable passing through the toroidal current torus*

***"Torus" and not "transformer"***

The fault current returns to the source via earth and takes the path of least resistance, i.e. the earth conductor in the power supply cable.




If we no longer pass the earth cable along the side of the torus but through it, the fault component also passes via this same torus and no current is detected since all the currents cancel each other out.

For the connection at the level of the racks in the 'MCC', the construction makes provision for toroidal current transformers in the cable trunk. The power cable must be sufficiently bared beforehand to be able to pass the earth conductor along the side (and connect it to the earth busbar).

*Figure 135: Cable passing through the toroidal current transformer – earth wire apart*

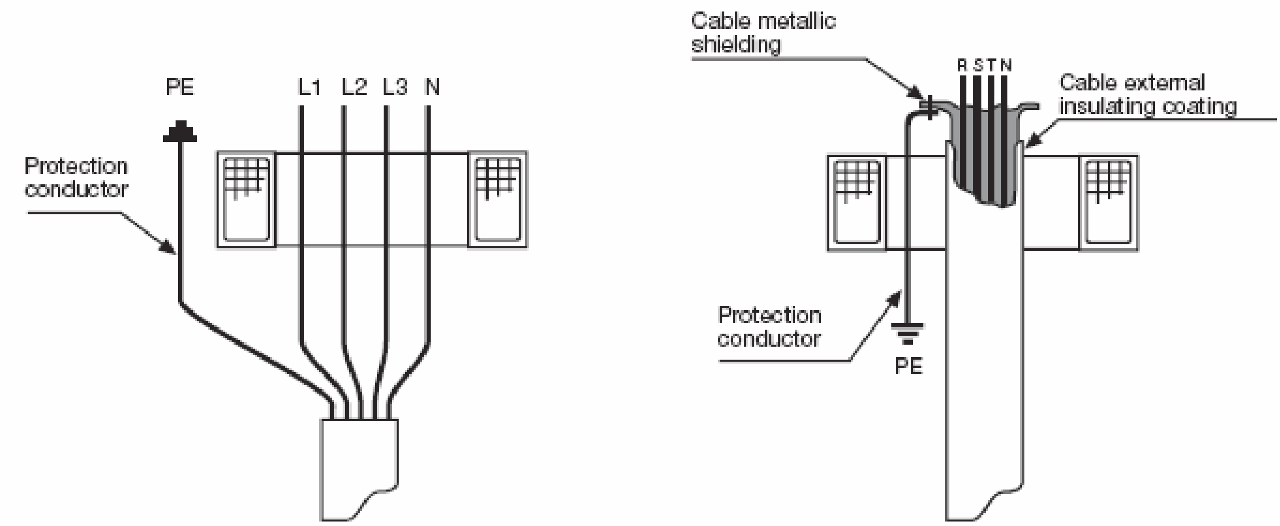



*Figure 136: Normal (left) and accepted (right) cable configuration through a torus*

Nevertheless, if for a "good reason" (torus too far), phases and earth wires pass together inside the torus, you manage to pass back the earth wire through the torus, cancelling so the earth current if any

## 7.1.4. Example of protection using RCDs

See the diagram which is referenced with Merlin Gerin material

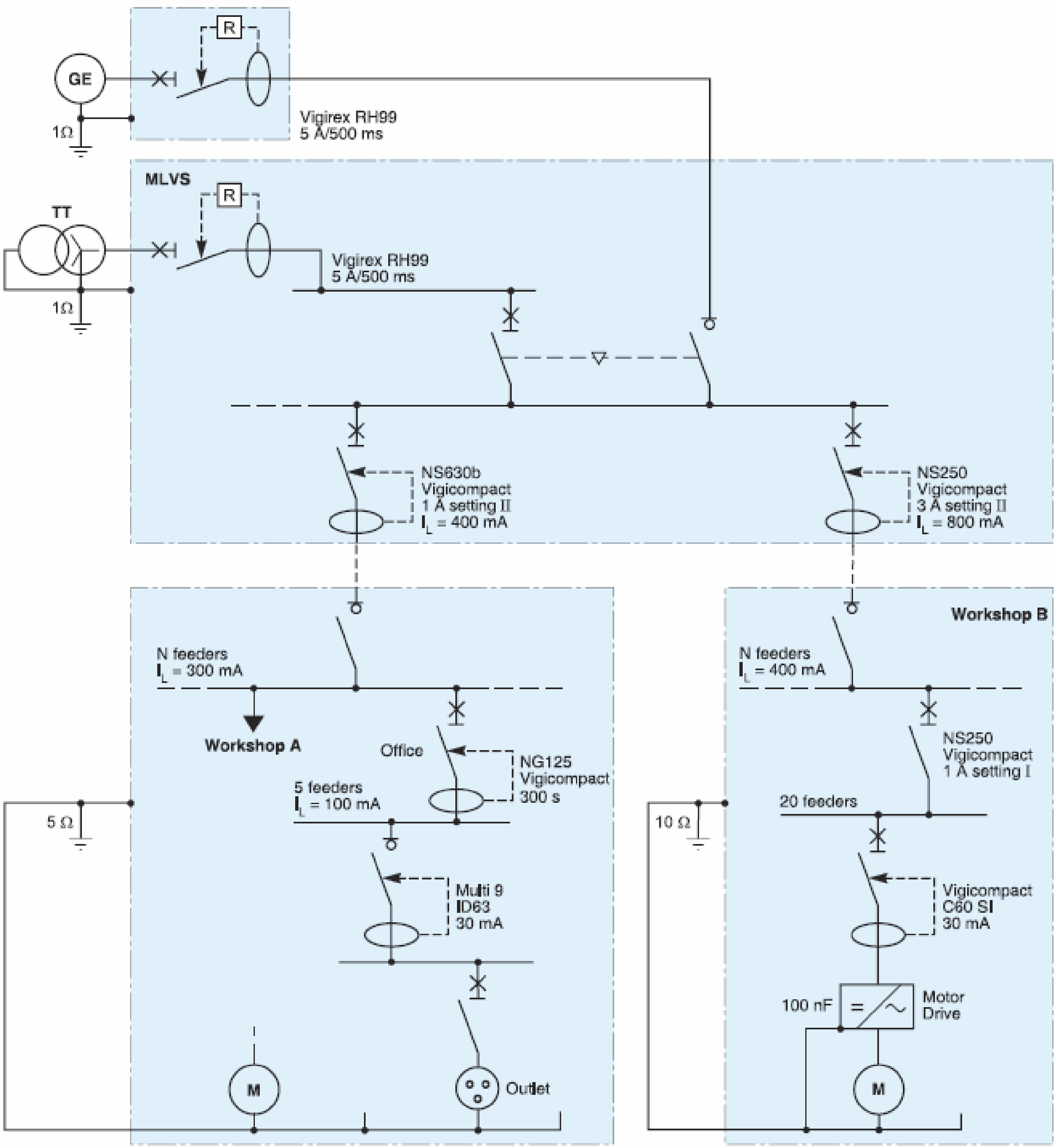



*Figure 137: Example of selective protections (with discrimination)*

***Vigirex:*** toroid + separate adjustable relay setting and time) tripping breaker / contactor / switch through control circuit

***Vigicompact***: RCD block associated physically and mechanically with the tripping device (breaker). Depending the type of RCD block, it is adjustable or not in setting and time.

This diagram represents “selectivity” (with discrimination) at different level of distribution in an electrical installation. Seen mainly in course MN-SE100

***Using circuit breakers + differential units (on Total sites)***

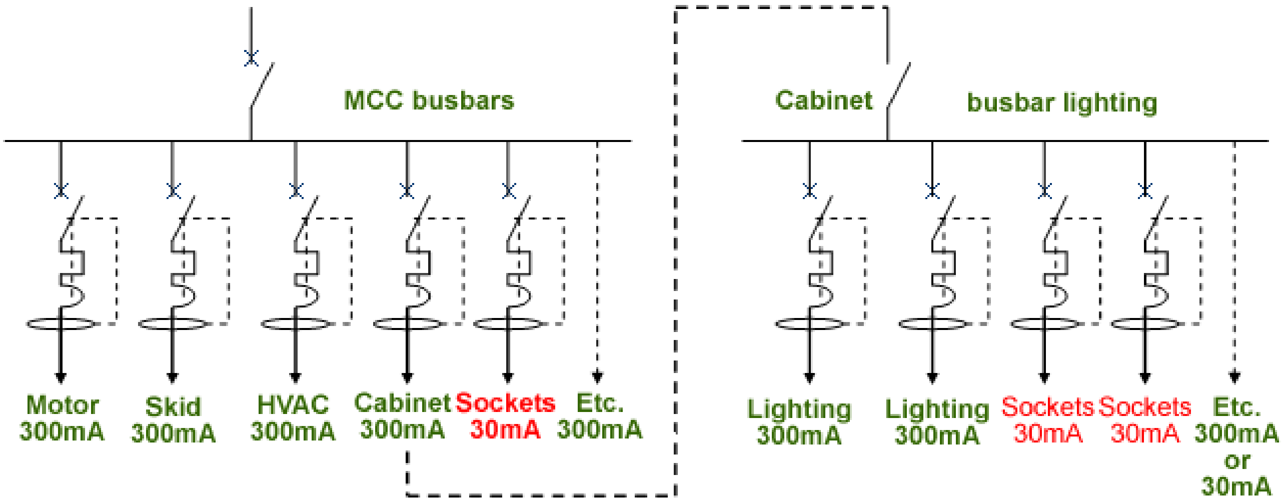



*Figure 138: Using circuit breakers + differential units*

The outgoing lines from the MCC supplying a user have a **300mA** differential protection except for the **power sockets** (and special applications) which have a **30mA** protection whatever the size of the power socket.

For the lighting sub-distribution, the lighting supply circuits have a **300 mA** protection; the **power sockets** have a **30mA** protection.

For a power supply connected in cascade, the selectivity is important; the upstream protection must have a higher threshold or a time-delay system. For example, the above diagram is "Incorrect". For the lighting cabinet protection the MCC differential protection will be 500 mA to 1A or 300mA with a delay of 0.5 to 1sec.

## 7.2. P.I.M.

Permanent Insulation Monitor

It monitors the LV distribution network from the energy source (generator or transformer).

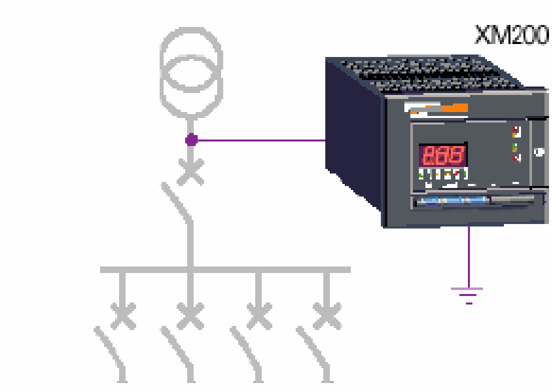



*Figure 139: Insulation monitor type XM200 of Merlin Gerin.*

One of the most commonly used in France and on the sites is Merlin Gérin's "Vigilohm" which is available in various versions. Other manufacturers offer equivalent equipment under another name but the term "Vigilohm" is firmly established with French electricians and when you hear it you will know that they are talking about the PIM (Permanent Insulation Monitor).

### 7.2.1. Principle of operation

The first PIMs generated a DC voltage (they still exist). However, low frequency AC is now used with a generated "special" format.

The device is connected between the distribution and earth. The current generated is superimposed on the network current and flows through the "insulations" to return to its source, the PIM (it cannot go elsewhere). The result of which is an "artificial" earth leakage current.

The PIM measures this specific (own) return current and establishes the resistance (or insulation) value for the network concerned. This is the indication (permanent) which you see on the meter.

A relay switches and the fault LED comes on when insulation drops below the threshold preset by the user.

### 7.2.2. Connection possibilities

Figure represents the different connections methods according to distribution configuration (Neutral distributed or not, neutral impedant or not connected to earth)

The PIM represented is a TRH22A, model from Merlin Gerin, The “Cardew” is the surge protection device specific term (of Merlin Gerin) for surge protection of transformers

The PIM is preferably connected on neutral when this one is available (impedant or not connected to earth). Otherwise the PIM can be connected directly on a phase or through an artificial neutral (neutral non distributed or directly connected to earth).

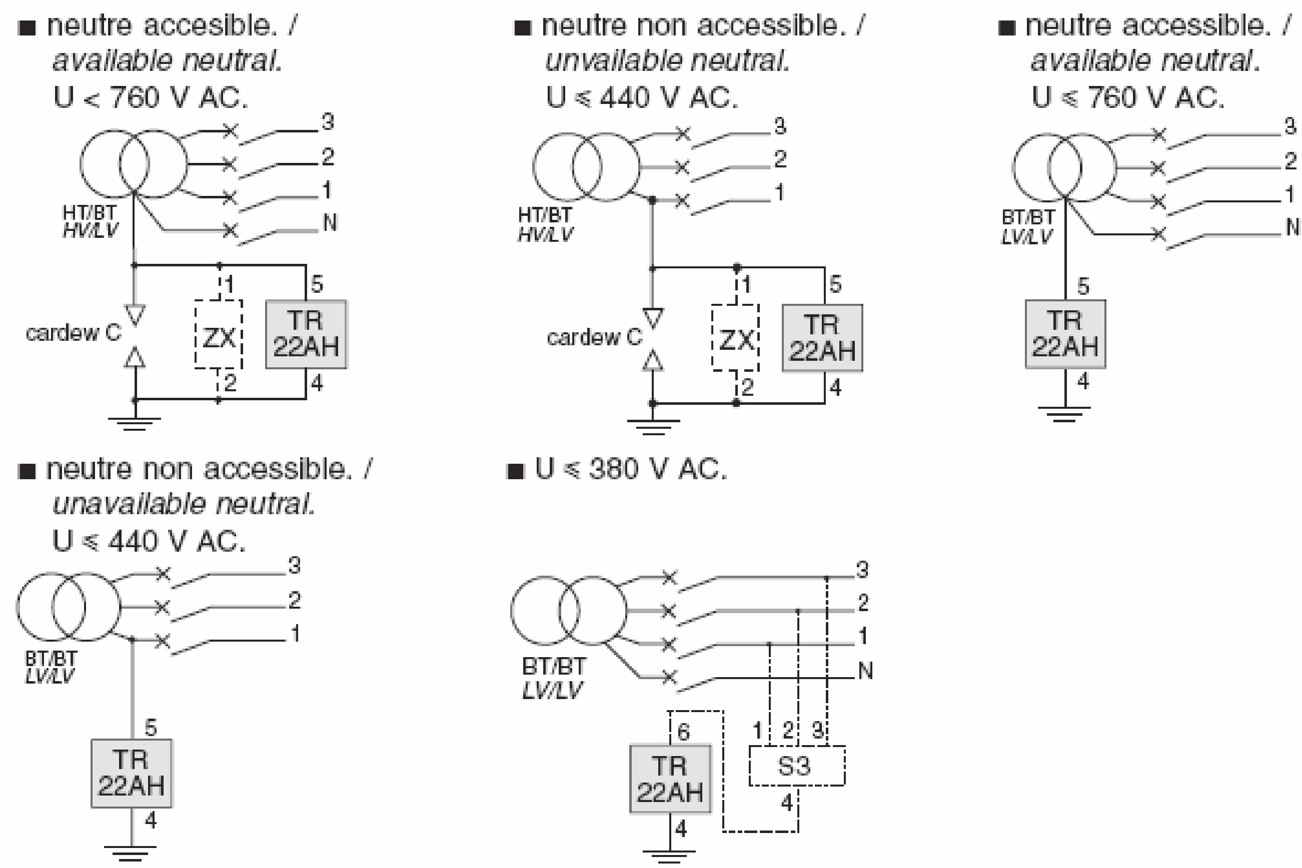



*Figure 140: Connections possibilities as per distribution configuration*

*About neutral systems, please see course EXP-MN-SE070*

### 7.2.3. Detection of fault

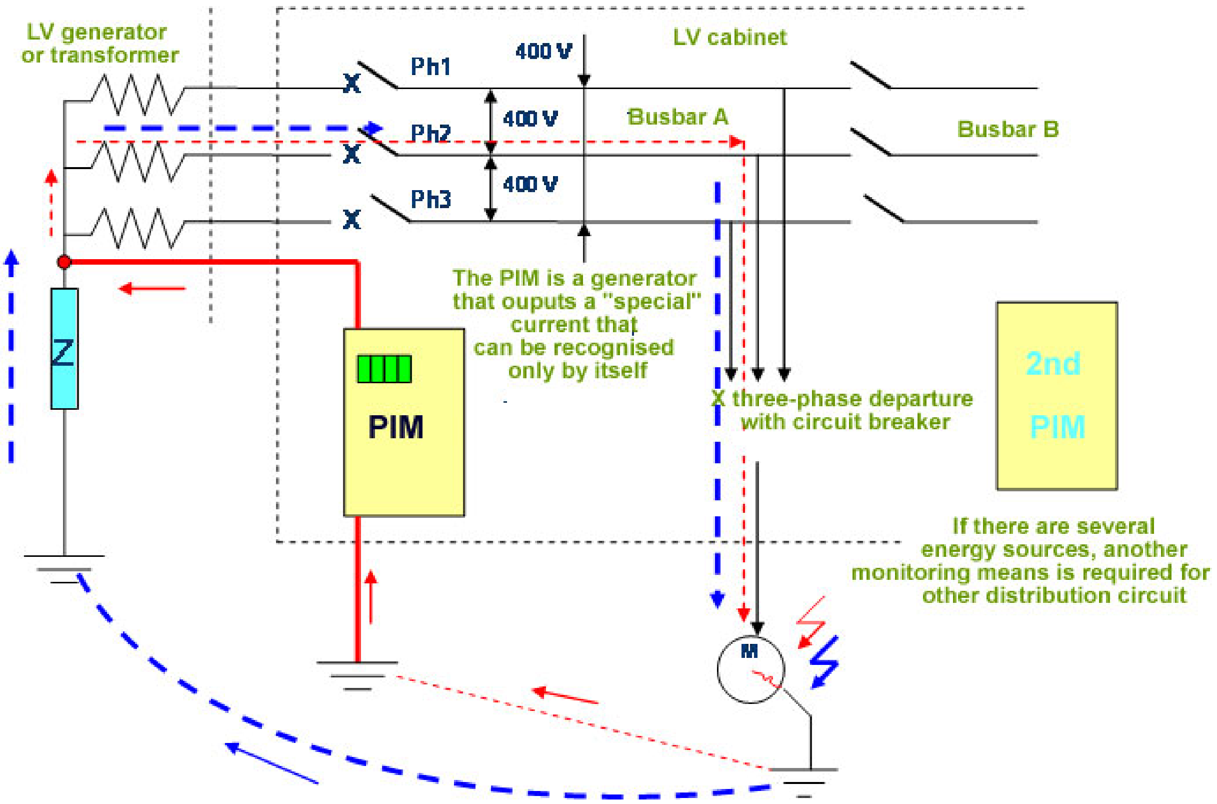



*Figure 141: PIM connection / operating principle in an IT arrangement*

***Important point:***

When a LV distribution panel includes several separated busbar, there should be as many PIM as there are busbars, each PIM working independently on its section.

When the Tie-in breaker (or switch) is closed between two busbars, only one PIM must be in operation otherwise there are interferences between the two. *But if they are of different types, generating different form of current, they can work in parallel.*

In "normal" operation the PIM measures the network's resistance with all the insulating resistances in parallel and indicates a high resistance (for a low (leakage) current).

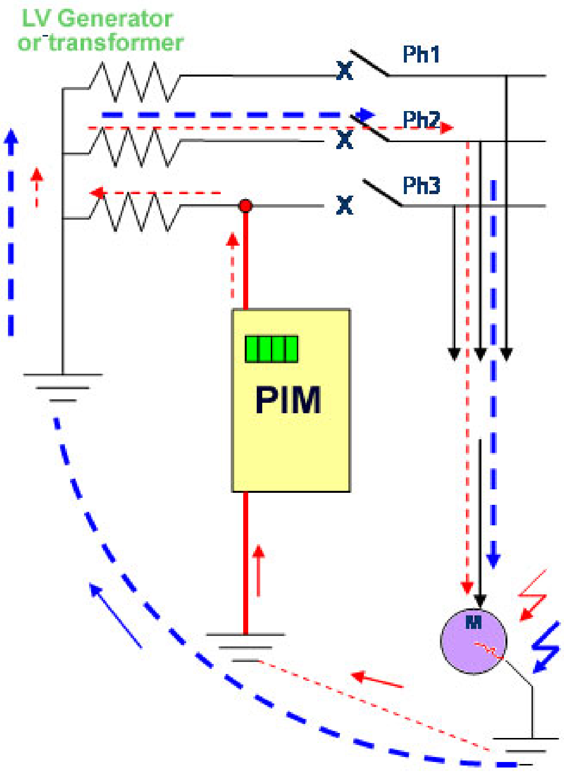



*Figure 142: PIM connected directly on a phase*

A fault appears (blue circuit), in parallel (red circuit), the PIM sends "its" current via the faulty resistance, the PIM current increases, the measured resistance decreases, and at the pre-selected threshold, the PIM emits an alarm and/or a trip signal.

***Advantage of PIM:***
Permanent indication of the network insulation status

***Inconvenient of PIM:***
It is a simple resistance measurement of a complete installation, there is no indication telling from where is coming the fault

System has one first threshold giving an alarm and second one supposed to trip the concerned distribution as insulation becomes dangerous.

***This is the theory as in practice the trip and even the alarm are non-operational on an ageing installation***

I have always seen, on all sites, without exception (Total and all other industries), as long as the insulation is “correct”, no problem, we have a reasonable indication on the PIM.

But as soon as we are in alarm range, the PIM either becomes blank or indicates the magic “9999” value (on the digital ones). The electrician has disconnected it, not willing to seek for an earth fault which can takes hours and hours (sometimes days and days) to be discovered. The same electrician very often has not the correct tools to perform the search….

<u>*Other point*</u>: nearly only France uses the IT system and consequently the PIM survey (as it is a common habit to connect a PIM on this configuration). On the new designed LV distribution panel on Total sites, all (going out) circuits and cables are protected by RCD. This means that the PIM is not mandatory (as per standard) and becomes a gadget (however useful gadget, it is always interesting to know the value of general insulation);

Nevertheless, the PIM is asked to be installed as key safety device….., and same reaction for site electricians, they disconnect it when it reaches low insulation value. On the other hand, the RCD makes the concerned circuit to be tripped and it is never bypassed by the electricians…..

*Figure 143: Panel of PIM device from Merlin Gerin and Socomec*

### 7.2.4. Localising the fault

On site, when the PIM no longer indicates Mega Ohms but changes to kilo Ohms, there is (serious) cause for concern.

If it is a large network, a large number of small fault currents in parallel generate a large "leakage", we must look for the largest faults where the insulation resistance is at its lowest.

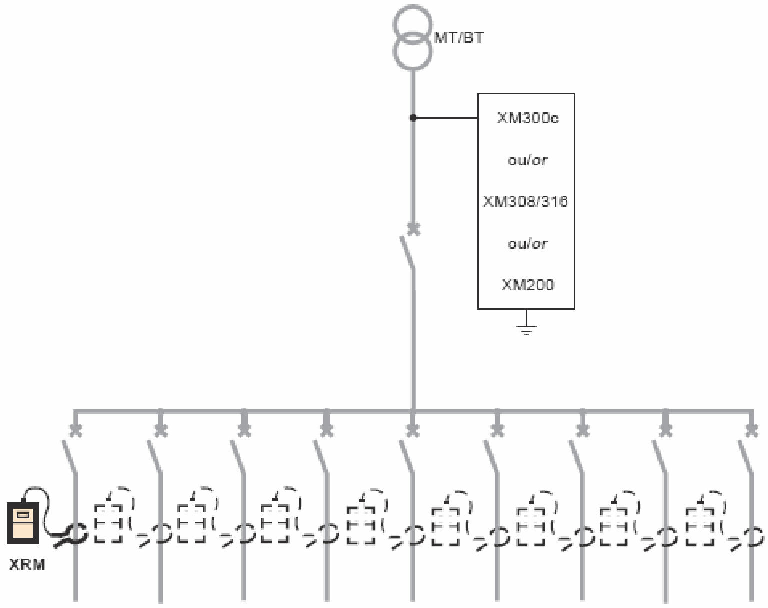



Figure 144: Troubleshooting for a low insulation detected by PIM

When there is an insulation fault the electrician often does not know where to start looking. He has no excuse if the installation is equipped with for example a XM200 of Merlin Gerin (or equivalent) and if he has a detection kit.

He picks up his clamp on current probes, the meter, and off he goes... The probes are not clamp-on ammeter probes; this is not a differential system.

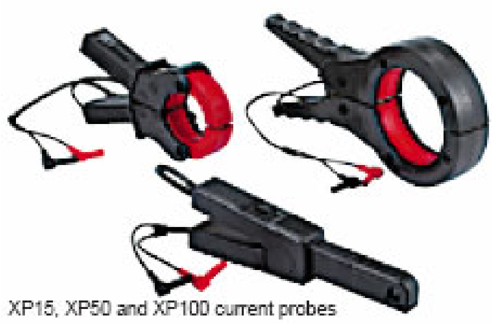
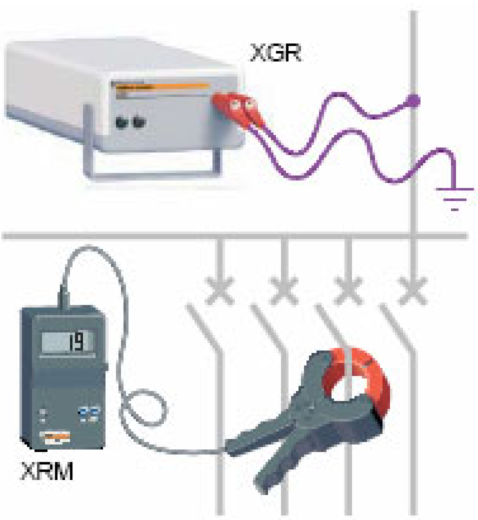



Figure 145: Different types of clamp on probes

We can place a probe on one phase, on several phases, on the complete cable, without any problems, the different probes are for the different wire and cable diameters.




The specific generated (by XM200) alternative signal is passing inside the faulty loops and can be detected by the clamp on probes, measuring only this “specific generated” signal / current.

And if the installation does not have a PIM or a "Vigilohm", if it is another type of device, you just have to create your own PIM using a portable generator, which you connect between one phase and earth (the other device must obviously be disconnected), and you look for the fault current.

Figure 146: Troubleshooting kit

The troubleshooting is thus very fast, no more hours or even days wasted on searching. This troubleshooting kit does not cost very much, why do without it!

Other manufacturers also offer troubleshooting kits, so suggest that the electrician obtain one if he does not already have it.

The monitoring and fault finding by PIM also works for a DC distribution system (instrumentation distribution for example) since this PIM generates an alternating current

## 7.3. HV BUSBAR HOMOPOLAR PROTECTION

***Homopolar protection*** is a term very often used when talking about the "HV substation" but it is very often incorrectly interpreted...*Equivalent to "zero sequence" protection code 67N*

The homopolar protection is the protection of the HV busbars, of a group of cubicles against earth faults inside the cubicles themselves.

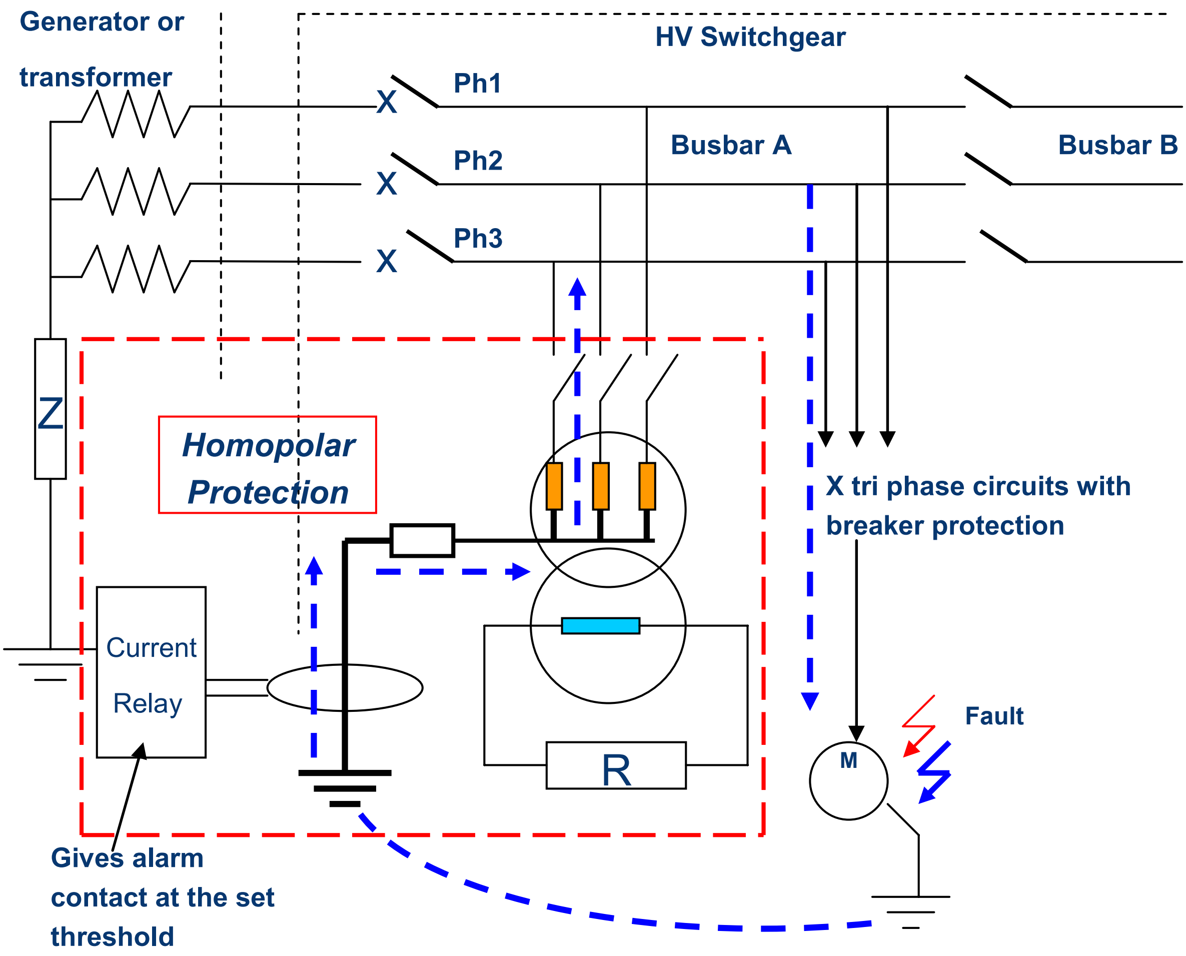



*Figure 147: Principle of homopolar protection on HV switchgear*

If there is an earth fault, there must be a system to detect it, and if the fault is too great, the installation must trip.

An "artificial neutral" must be created which can be done using resistors (mainly used in LV) but in this case, in HV, a "***homopolar transformer"*** is used with the neutral of its primary windings connected to earth (through impedance for current limiting). This transformer's secondary winding is "loaded" to the minimum with a resistor.

A busbar fault current will return to the generator (or transformer) via the neutral and the homopolar transformer windings, a CT detects this current, transmits it to a threshold relay which in turn transmits an alarm and trips.

Same remark as for PIM (in LV) for a multi busbars panel.

Each independent section of a busbar must have its homopolar transformer and associated protection devices.; As soon as busbars are tied-in, only one protection has to be in service, the other(s) one(s) to be disabled.

# 8. SURGE / LIGHTNING PROTECTION

In the “old time”, lighting protection was limited to striking rods installed on roof of a building, driving the lightning current towards earth through specific conductor and earth electrodes system

Then, it was realised that lightning was creating induction in the cables, and it was decided to protect installation at its source at level of transformers (*the Cardew for French people)* and that was the only protection for an electrical distribution.

Nowadays, after numerous destructions due to lightning in installations, surge protections are installed at different levels of distributions and with all type of voltages. Telephone, computer , telesystems, instrumentation,…etc have their own surge protections, all type of cables (power, coaxial, fibre-optic, ….) have their own type of protections.

## 8.1. THE LIGHTNING PHENOMENA

Prior to present the surge protection devices, it is worth explaining why we need such equipment. We pass over the formation of a lightning storm; we just admit that we have strikes which can destroy “our” electrical materials

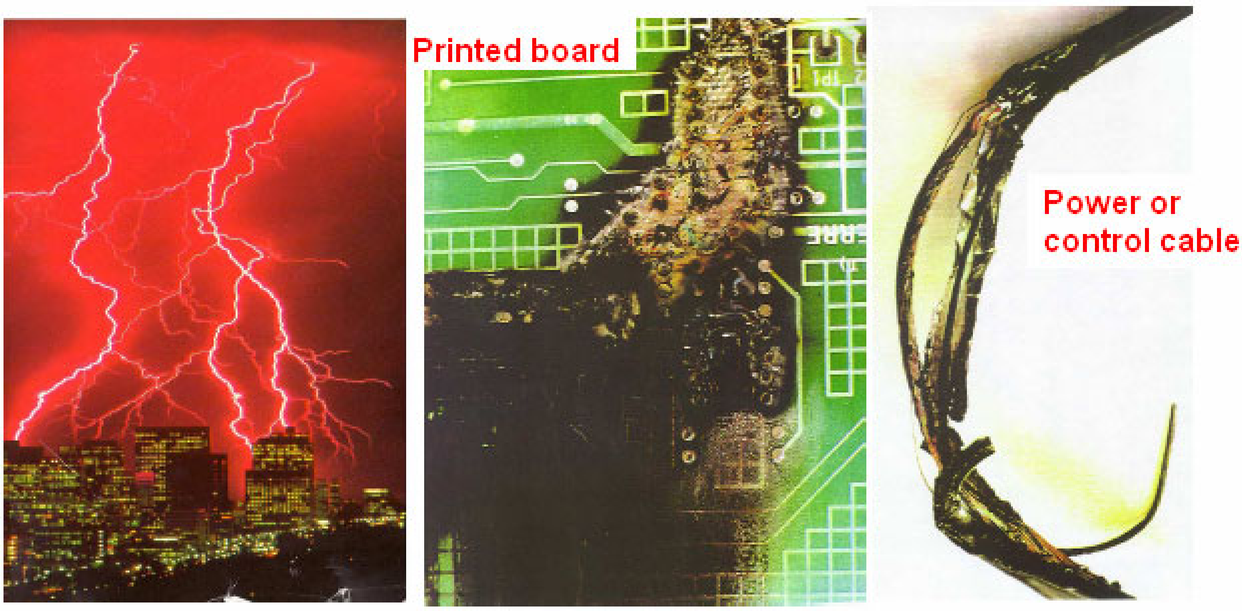



*Figure 148: Lightning strikes and examples of “localised” effects*

This picture represents only a partial effect, it can be generalised to a complete installation and end in a building fire.

In 1986, in France, I was in charge to rebuild the complete telephone and computer networks, in a (big) factory. Hundreds of computers and telephones (and cables) were out of order, all the dispatching panels were "burned", part of electrical distribution was also out. Only one lightning strike was the cause of this, the lightning current being canalised along the main cable trays of telephone and computers distribution.

I can assure you, that now the factory is equipped with surge protection at all levels, and in all different distributions (power + lighting + instrumentation + computer + telephone, +…)

In 1998/99, in Myanmar, Kanbok site, lightning stroked again…. Site was supposed to be well equipped against such problems. In my opinion, it was not! I had the experience of France (in 1986), working with one "real" specialist who was rebuilding the lightning protections installed by others and after unhappy events caused by incomplete lightning protections installations.

The ***first protection is the ground network*** specific for lightning, and a "serious and severe" ground network with numerous interconnections, itself interconnected with the earth lightning network. Separate ground network (instrumentation, telephone, telecommunication,…) is an aberration when protection against lightning strikes is involved. What can do a wire of 10 mm² cross-section of a "specific" telesystem earth network *(even when "well" equipped with surge protection)* when it has to drive 30 000 A (*30 kA is an average value, it can be a lot higher)* issued from a strike; instead the current will spread into the frames and cables of the same telesystem installation and destroy it mainly through induction phenomena.

Let's take an example with instrumentation cables distribution

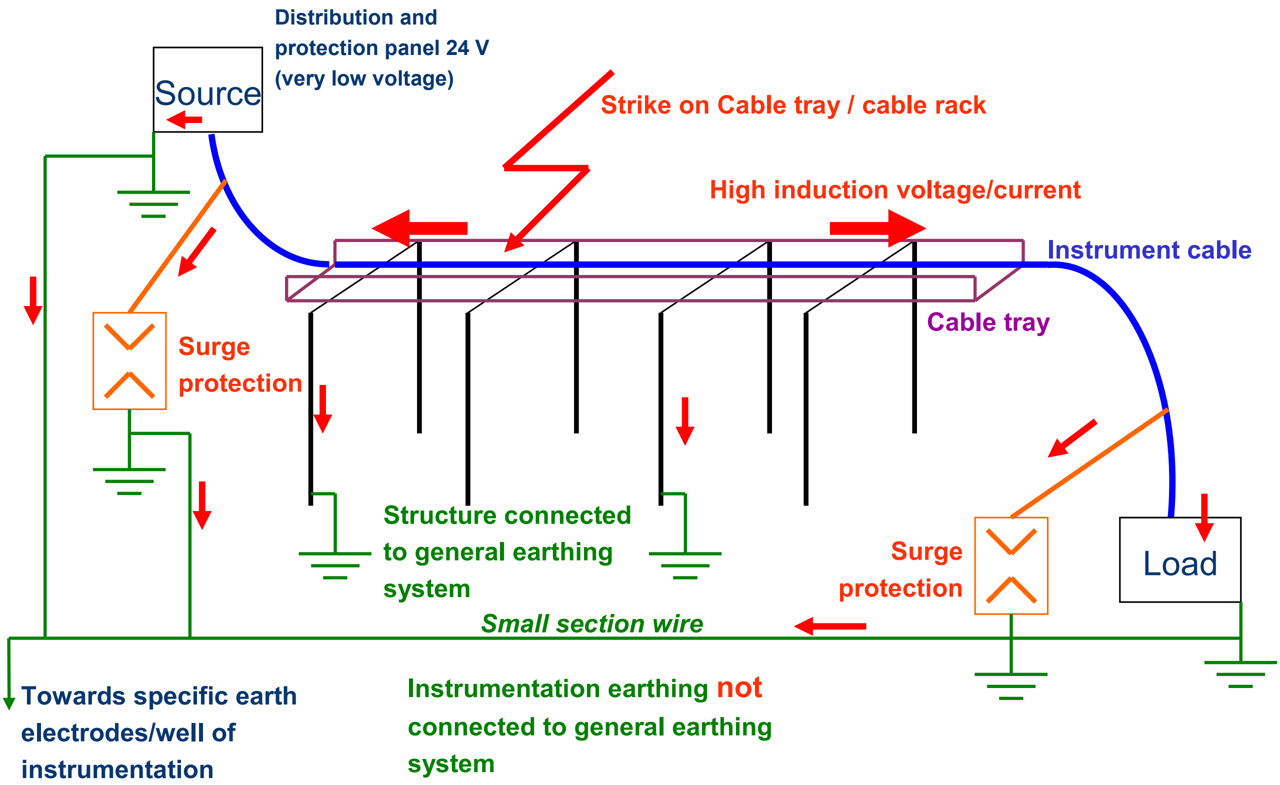



*Figure 149: Example of earthing + surge protection*

Cables are laid on a metallic cable tray, each one being well protected with surge protections devices (*we see them in the following*) at each end (*in reality, on site, one end is protected…)*

When a strike occurs, it spreads alongside the cable trays, in the structure (*cable tray having to be looped to ground!);* the current will seek its way towards the ground. Induction has already done its effects in the cables and high voltage (inducing high current) appears at each ends of (blue) cable.

The surge protection devices react, driving important currents towards earth. Normally it works without problem protecting the load and source. But if the lightning current find resistance in the ground wire (too small section), there will be still high voltage at load and source level, enough to destroy them….

***Conclusion:***

Prior to install surge protections, have a "strong" earthing system able to drive at any point of the installation / distribution, unexpected high current towards ground.. It means all earthing "different" systems have to be interconnected with proper wires sections!

***The surge protection devices presented hereafter are useless without a good earthing / ground installation. See GS ELE 051 - Paragraph 3.7***

**See course EXP-MN-SE070 "ground and neutral systems" detailing the lightning earthing protection system.**

The typical answer for those who are not willing to interconnect "their" ground system is: *"when it is interconnected we get harmonics and interferences back in our distribution through the earth system…"* My answer is: of course, because the ground network (in our sites) is always insufficient….

*I am convinced, I worked as electrician, instrument, and telesystem technician, I had the opportunity to be trained in lightning protection with serious specialist, I saw several consequences of lightning in installation, being able to analyse the cause which was always an insufficient ground network. Now, for those willing to have separate ground networks (the other side), they are convinced as well , let's stay on our positions …*

Offshore, it is different, any lightning strike spreads immediately in the structure.

### 8.1.1. Current of a typical lightning strike

The peak value of the lightning current varies from few tens kA to hundred kA, for the negative descendant lightning strikes. It can reach several hundreds kA for the positive ascendant thunderbolts.

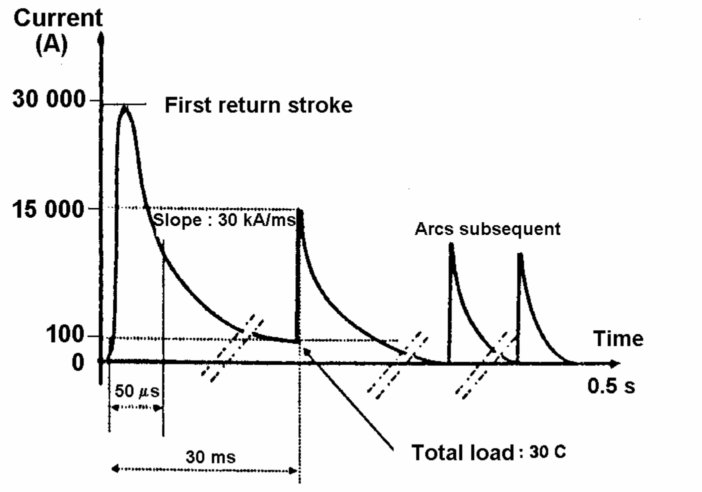



*Figure 150: Typical wave form of a negative average lightning strike*

The form of the typical discharge (negative descendant current cloud-ground) explains the blinking aspect of the negative flash (the most common).

**Amplitude of lightning strikes**

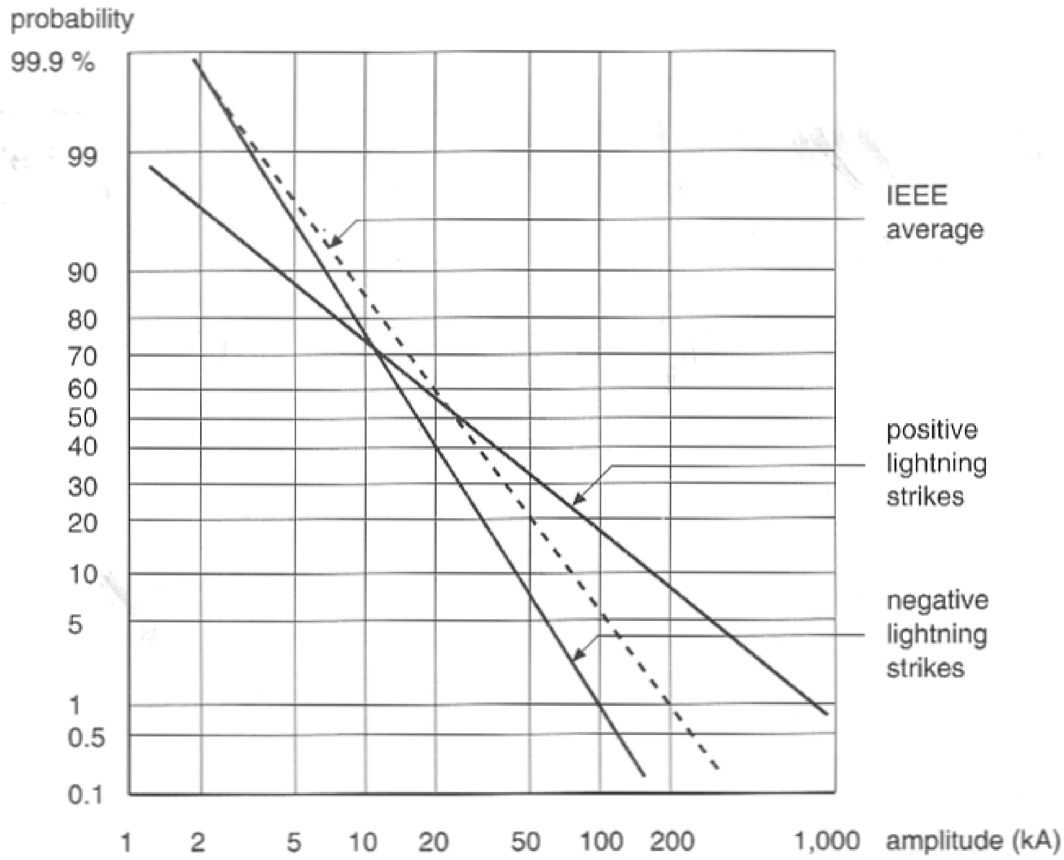



*Figure 151: Experimental statistical distribution of positive & negative strikes as function of amplitude*

_Analyse of the curves_

- Amplitude of positive lightning strike currents can reach great values, above 150 kA in 10% of the cases
- Amplitude of negative lightning strike current is smaller, 10% of their values are about 50 kA
- The average values of positive strikes are around 25 kA (in 50% of the cases)
- The average values of negative strikes are around 18 kA.

**Note: these statistics are valid worldwide

### 8.1.2. Energy of a lightning strike

Subject is to calculate the energy dissipated by a strike is height of arc is 5 km, electric static field before discharge is E = 10 kV / m and total charge is 50 Coulombs.

**Solution:**
A cumulonimbus acts as a capacitance. The voltage between the cloud and the ground equals the product of electric field E by the height of the arc

U = E.h = 10000 x 5000 = 50 MV

The discharging capacitance is C = Q / U = 5O / 50 000 000 = 1 μF

Energy stored in a capacitance is W = 0.5 C.U² = 1.25 x $10^9$ joules.

Energy is around 1 Giga joules, representing about 300 kWh, principally dissipated in electromagnetic field. This is a relatively 'small' energy compared to human electrical consumption.

***About the "idea" of using the lightning energy***

Taking an example, France is stroked 1.5 millions time a year, with 3.15.$10^7$ seconds per year, one strike happens every 20 seconds as average.

Supposing being able to "canalise" all strikes and with a value of W = 1.$10^9$ joules per strike

**P = W /T = 1 x $10^9$ / 20 = 50 MW value ridiculously small…**

****In a lightning there is an enormous instantaneous energy (in a range of 1 million of MW) but effective (or average) power and energy are low.***

### 8.1.3. How a lightning strike is initiated

Consider the "system" cloud-ground as a "big" capacitance, charged in Millions of Volts ready to arc

Consider now this huge potential at the centre of a sphere, radius of this sphere function of the charge, the more potential, the biggest the radius.

This "center" is searching in space its opposite potential towards which it will strike, it will somewhere at the ground level

If it is a mountain, a high building, a striking rod; the discharge will go preferably through this "easiest" and closest way. You can understand why striking rods are pointing towards the clouds on the highest parts of the buildings (or on a mast), it is to be in the radius of the discharging range.

Seeing the figure, you can realise that big radius, meaning high potential and high current would be catch by the striking rods on a well covered plant. But paradoxically, a low energy sphere can find its way through the external protections and strike anywhere, a low current lightning strike (few kA) has more chance to cause damage than a bigger one!
The external protection (rods) catches about 80% of the strikes, it cannot be perfect at 100%, it is why we need surge protection on electrically distributed circuits

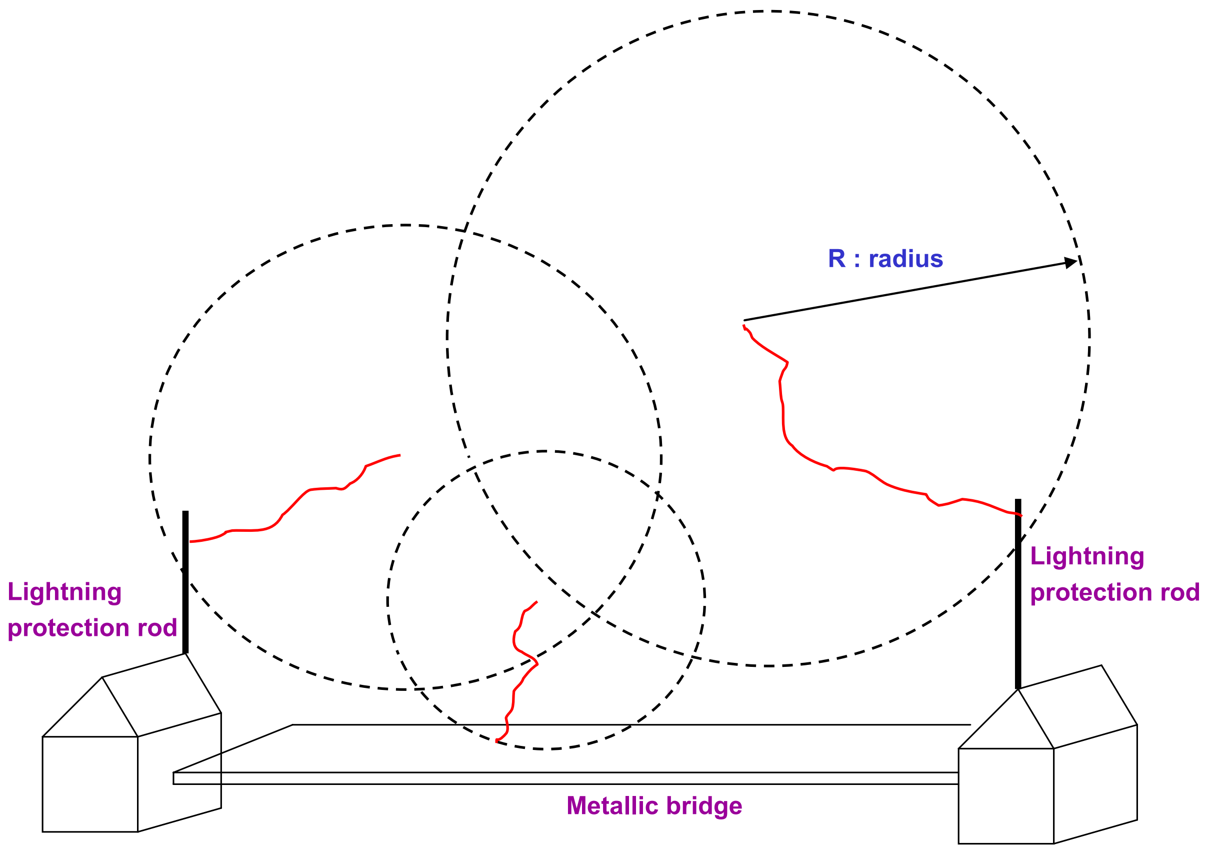



*Figure 152: Relation between lightning energies and possibilities of strikes*

## 8.2. SURGE ARRESTORS - GENERALITIES

**As a general guide, all cables / lines of power, data communication, signals, telephone, video, etc which enter or leave a building should be protected.**

*In fact, any kind of communicating or interconnecting cable having a sufficient length outside a protected building and being laid either on a rack or under the ground is subject to induced voltage / current due to a lightning strike on the same rack or on the ground even if those elements are well interconnected within the earthing network.*

*Each type of cable and each type of signal transmitted have their own adapted type of electrical surge protection.*

### 8.2.1. When and where to protect

Transient overvoltages are conducted into the sensitive circuitry of electronic equipment on power and data communication, signal and telephone lines. Protection is recommended for:

- all cables which enter or leave the building (except fibre optic)
- the power supply local to important equipment
- electronic equipment outside the main building(s).

#### 8.2.1.1. Protect incoming and outgoing electrical services

Lightning strikes between clouds or between cloud and ground (and objects upon it) can cause transient overvoltages to be coupled on to electrical cables, and hence into the sensitive electronic equipment connected to them.

To protect the electronic equipment inside a building, all cables that enter or leave the building must be protected. (Cables leaving the building can also provide a route back into the building for transient overvoltages.)

For each building protect incoming/outgoing:

- mains power supplies (including UPS supplies)
- data communication and local area network cables
- signal, control, instrumentation and alarm lines
- CCTV, satellite, TV and antenna cables

- telephone and telemetry lines.

Each one of these systems requires a specific surge protection

#### *8.2.1.2. Protect the power supply locally for important equipment*

In addition to installing protection on the mains power supply as it enters / leaves the building, protection should also be installed locally for important equipment. Protection at the main LV (low voltage) incomer(s) is necessary to prevent large transients from entering the building's power distribution system, where they could have far-reaching effects.

However, where the cable run to equipment exceeds, say, 20 metres, transient overvoltages may appear on the mains after the protector at the main LV incomer. These transients can result from:

- the electrical switching of large inductive loads within the building
- a lightning strike to the building - as lightning currents flow through down conductors transient overvoltages can be induced on to nearby power cables
- the natural inductance and capacitance of long cable runs, 'amplifying' the voltage 'let-through' the protector at the main LV incomer.

Additionally, local protection guards against the possibility of a supply which enters/leaves the building being overlooked and left unprotected.

(Note: Data communication, signal and telephone lines are not usually exposed to switching transients and, owing to the protection afforded by their generally good cable screening, do not normally require additional local protection.)

#### *8.2.1.3. Protect electronic equipment outside the building*

On-site or field-based electronic equipment with mains power, data communication, video, signal or telephone line inputs will need to be protected against transient overvoltages. It may be helpful to think of each equipment cabinet or cubicle as a separate building with incoming/outgoing cables to be protected.

### *8.2.2. How to get effective protection*

In order to provide effective protection, a transient overvoltage protector must:

- be compatible with the system it is protecting

- survive repeated transients
- not leave the user unprotected, at the end of its life
- have a low 'let-through' voltage, for all combinations of conductors, and
- be properly installed.

#### 8.2.2.1. Compatibility

The protector must not interfere with the system's normal operation:

- Mains power supply protectors should not disrupt the normal power supply or cause high leakage currents to earth,
- Protectors for data communication, signal and telephone lines should not impair or restrict the systems data or signal transmission.

#### 8.2.2.2. Survival

It is vital that the protector is capable of surviving the worst case transients expected at its intended installation point. Transient overvoltages caused by the secondary effects of lightning are unlikely to have currents exceeding 10kA. More importantly, since lightning is a multiple event, the protector must be able to withstand repeated transient overvoltages.

#### 8.2.2.3. Let-through voltage

The larger the transient overvoltage reaching the electronic equipment, the greater the risk of interference, physical damage and hence system downtime. Consequently, the transient overvoltage let through the protector should be as low as possible and certainly lower than the level at which interference or component degradation may occur.

Transient overvoltages can exist between any pair of conductors:

- phase to neutral, phase to earth and neutral to earth on mains power supplies,
- line to line and line(s) to earth on data communication, signal and telephone lines.

Thus, a good protector must have a low let~through voltage between every pair of conductor.

#### 8.2.2.4. End of life

When the protector comes to the end of its working life it should not leave equipment unprotected. Thus in-line protectors should take the line out of commission, preventing subsequent transients from damaging equipment. Protectors for data communication signal and telephone lines and protectors for low current mains power supplies are usually in-line devices. Where protectors are installed at mains power distribution boards it is usually unacceptable for these to suddenly fail, cutting the power supply. Consequently, to prevent equipment being left unprotected, the protector should have a clear pre end-of-life warning, which allows plenty of time for it to be replaced.

#### 8.2.2.5. Installation

The performance of transient overvoltage protectors is heavily dependent upon their correct installation. Thus, it is vital that protectors are supplied with clear installation instructions.

## 8.3. CHARACTERISTICS OF SURGE PROTECTION

The main "requests" about a surge protector would be:

- Voltage of the protection must correspond to the one of the network to protect
- When there is no overvoltage, no 'leaking' current should circulate through the protection
- When an overvoltage, just above the rated value of the protection, immediate conduction towards ground is to be established limiting the voltage to the required level.
- At overvoltage clearance, protection should stop conduction, and go back to its initial status (still with no leaking current)
- Response time to be lowest (as per standards)
- Sizing adapted for releasing of "extra" voltage and current which could appear in the installation to protect

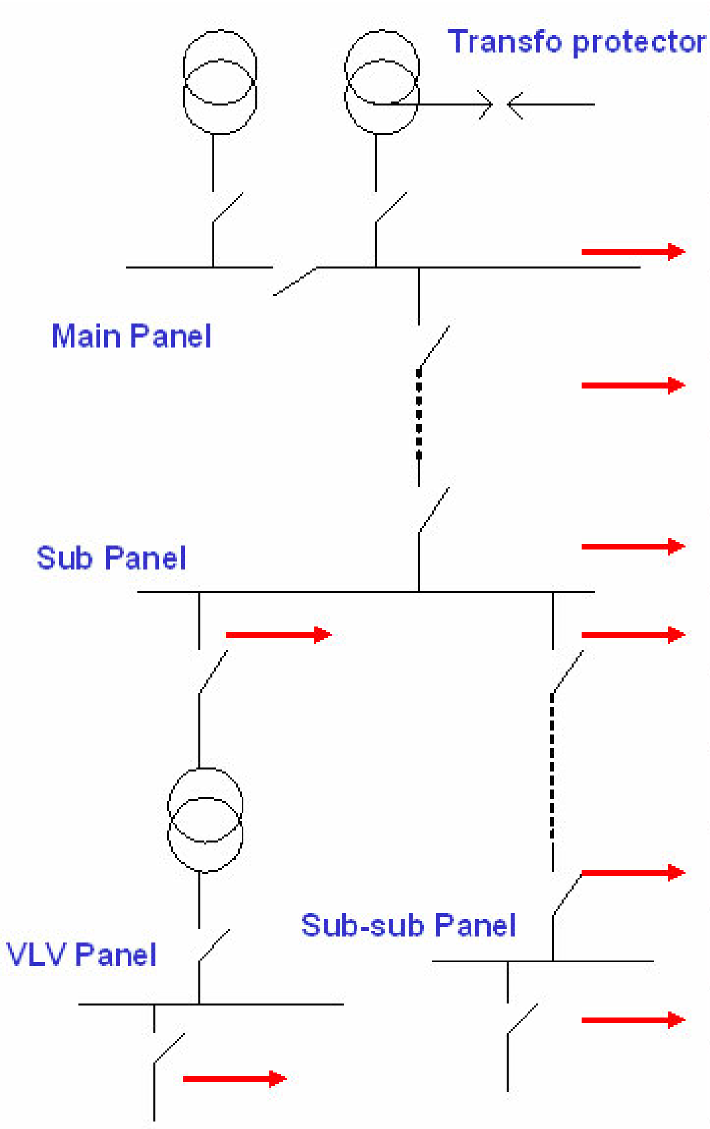
Follows specific Standards requirement such as : "support 20 times an overvoltage in the range of 8/20 µs of nominal current and one time the maximum admissible current. " (French Standard)

## 8.4. THE PRODUCTS FOR PROTECTIONS

### At different levels / voltage

Examples of vendor product are given for each type, level, and voltage of protection. - All in Low Voltage

### 8.4.1. Principle of protection




| Series | Imax | Description | Page |
|---|---|---|---|
| DS150 | 140 kA | Heavy duty AC power surge protector | D6 |
| DS70R | 70 kA | Primary AC power surge protector - redundancy | D7 |
| DS100EG | 150 kA | Heavy duty N/PE spark gap | D8 |
| DS100SG | 100 kA | Heavy duty AC power surge protector with spark gap | D9 |
| DS40 | 40 kA | Primary AC power surge protector | D10 |
| DS40D | 40 kA | Primary AC power surge protector - differential mode | D11 |
| DS30G | 30 kA | N/PE gas tube | D12 |
| DS230G | 30 kA | Single-phase AC power surge protector | D13 |
| DS410D | 30 kA | Three-phase AC power surge protector | D14 |
| DS10 | 10 kA | Secondary AC power surge protector | D15 |
| DS210D | 10 kA | Single-phase secondary AC power surge protector | D16 |
| DSHF | 10 kA | Single-phase AC power surge protector with RFI filtering | D17 |
| DS210DC | 6 kA | DC surge protector | D18 |
| DSH | - | Coordination inductor | D19 |

*Figure 153: Example of surge protectors ranges for an electrical distribution*

The surge protector is the reverse of a fuse…In normal conditions, it is open circuit, in case of over voltage, it closes its circuit to ground. A lightning strike being a matter of micro/milli- second, the surge protector comes back to open circuit and the fuse or breaker installed upstream has no time to blow. However if the surge is too long the upstream protection has to blow, we are in short-circuit in that case!

It exists for each level of protection an adapted surge protection corresponding to the voltage of the installation and to the current it can drives towards earth

It corresponds (roughly) to the calculation of short-circuit current an electrical distribution must support, Cables, busbars of big sizes can carry much more current, they need consequently a “bigger” size protector able to drive out this important current. The more we go down the installation, the less the current which can be carried by cables is important, surge protectors are therefore less “powerful”.

The figure represents the ranges of modular surge protectors (from one manufacturer) which could be installed in distribution panels at different levels

***An installation must be protected at different levels***; a downstream protector must be able to rely upon a “big fellow” above in the distribution. If not supported, this downstream protector could be overcharged….

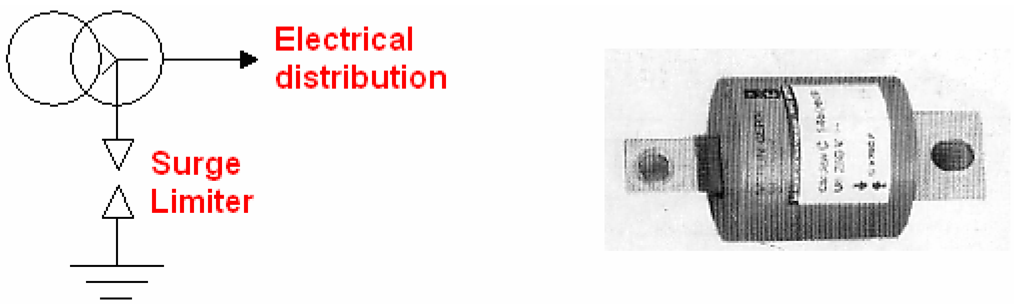
Lightning protection is nor yet an “exact science”. How to choose a surge protector is function of

- Voltage: rated voltage and voltage maximum at which the protector reacts
- maximum discharge current (Imax)
- network configuration (single / three-phase / 3 + N)
- protection diagram, type, technology (varistors, spark gaps, filter)
- functionality's (redundancy, differential mode, remote signalling)
- …/…

If you need to make choices of such material, please refer to vendor’s documentation, subject is too wide for more development here. We are just going to see the example of protections at each level and the (basic) technology.

### 8.4.2. At origin of electrical supply

The HV/LV transformer is protected on the secondary side in system IT (neutral Isolated or Impedant). One Surge Limiter is connected between the neutral and the ground. Voltage of this limiter must correspond with the one of the transformer




| Un rated network phase-to phase voltage ∿ | | Ui flash voltage | Cardew C |
|---|---|---|---|
| accessible neutra | inaccessible neutral | | "typical" |
| U ≤ 380 V | U ≤ 220 V | 400 V < Ui ≤ 750 V | « 250 V » |
| 380 V < U ≤ 660 V | 220 V < U ≤ 380 V | 700 V < Ui ≤ 1100 V | « 440 V » |
| 660 V < U ≤ 1000 V | 380 V < U ≤ 660 V | 1100 V < Ui ≤ 1600 V | « 660 V » |
| 1000 V < U ≤ 1560 V | 660 V < U ≤ 1000 V | 1600 V < Ui ≤ 2400 V | « 1000 V » |

*Figure 154: Surge protection at source of power – the “Cardew” of Merlin Gerin*

### 8.4.3. At Power distribution (Switchgear – MCC)

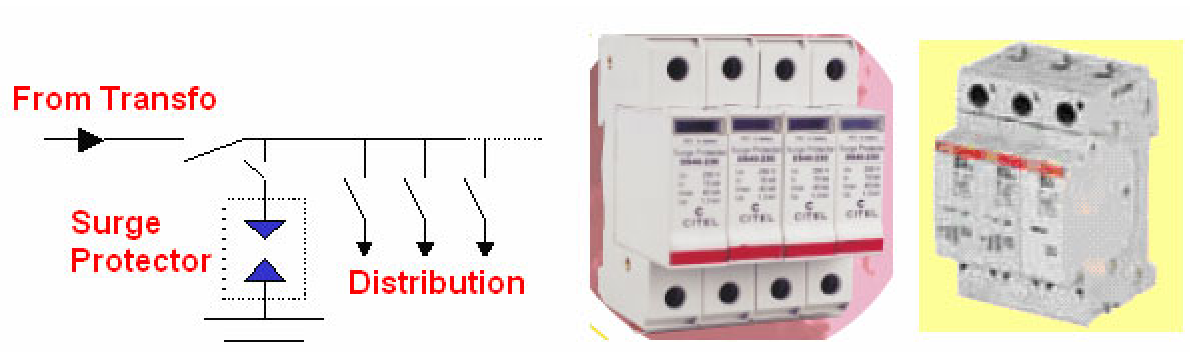



*Figure 155: Surge protection at level of busbars distribution*

They are 2 phases or 3 phases or 3 phases + neutral surge protector installed in the main cabinet. Sizing is according to the nominal power to protect with a nominal voltage of 230 or 400 V AC. They are panel mounting or ‘modular’; connection on the bus-bars is made through breaker or fuses.

Regular survey is necessary for replacing the "burned" elements

### 8.4.4. Sub-Power distribution - MCC / Distribution panel

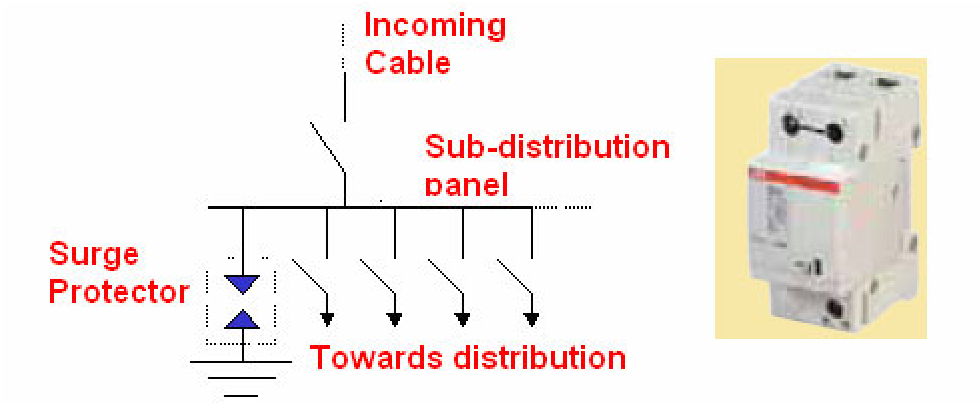



*Figure 156: Surge protection at level of busbars of sub-distribution*

Used material is in the same standard and construction than for the previous paragraph, the difference being in the amperes rating.

### 8.4.5. 'Other' Sub-Power distribution - UPS / DC Distribution panel

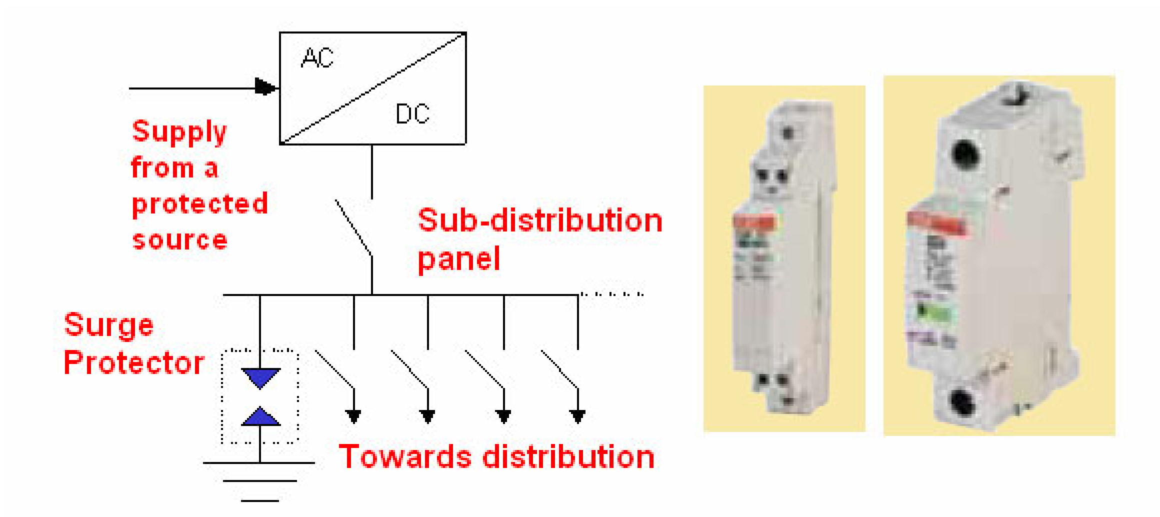



*Figure 157: Surge protection at level of busbars of sub-sub-distribution DC*

Each device to be adapted to the nominal voltage to protect.
Ex: a 24V surge protector cannot be used for 48V and in reverse a 48V must not be used to protect a 24V distribution

This type of device can be used in Instrumentation individual loop protection.

### 8.4.6. 'End of line' power distribution protections

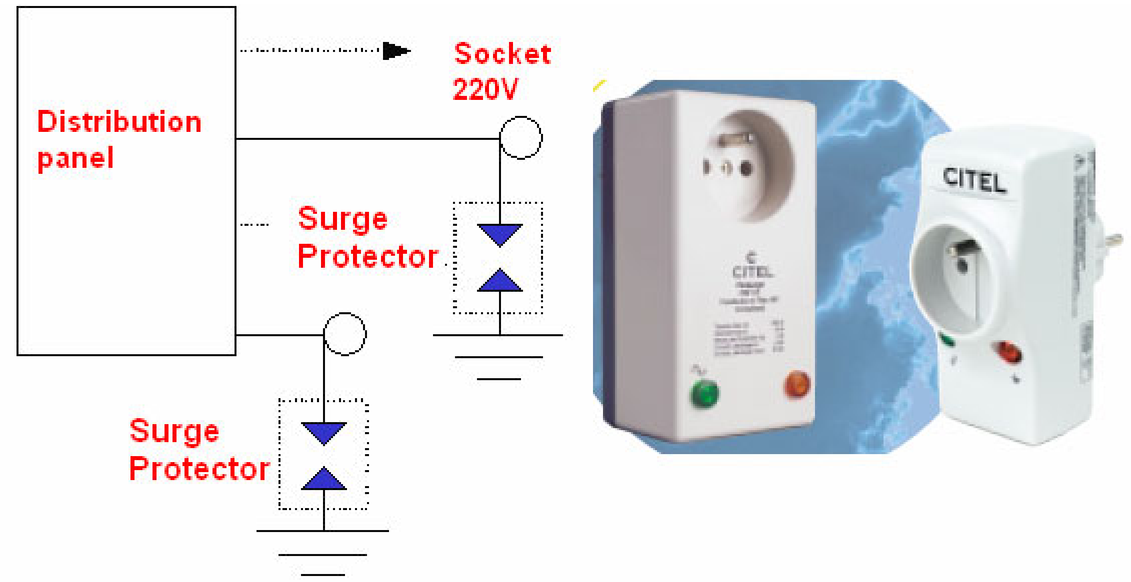



*Figure 158: Surge protection at socket level*

Each individual socket can be equipped with its own surge protector, this to ensure the direct safety of the device (sensitive) connected on power supply.

Same type of protection exists on the multi socket connector

*Figure 159: Multi-socket equipped with surge protector*

## 8.4.7. Telephone and Data line surge protection

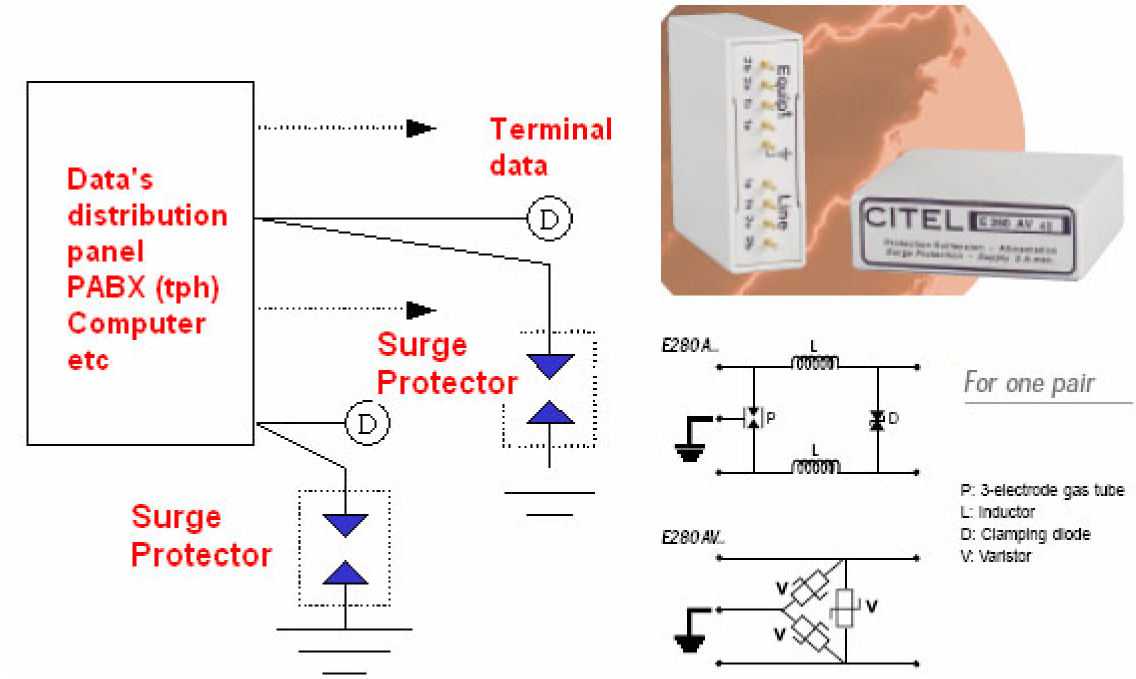



*Figure 160: Surge protection for data's lines*

Each line/ cable going outside has "normally" its own independent protection…..

Each type of circuit has its protection also, hereafter example of data for a 2 pairs plug-in surge protector for power supply in telephone / data distribution

| CITEL P/N | E280A6 | E280A12 | E280A24 | E280A48 | E280AV12 | E280AV24 | E280AV35 | E280AV48 | E280AV120 | E280AV220 |
|---|---|---|---|---|---|---|---|---|---|---|
| Max DC voltage | 6 V | 12 V | 24 V | 48 V | 18 V | 26 V | 35 V | 54 V | 125 V | 300 V |
| Max AC voltage | 5 V | 10 V | 18 V | 40 V | 14 V | 20 V | 30 V | 40 V | 95 V | 250 V |
| Max line current | 500 mA | 500 mA | 500 mA | 500 mA | 10 A | 10 A | 10 A | 10 A | 10 A | 10 A |
| Residual voltage ([1]) | 20 V | 30 V | 50 V | 60 V | 40 V | 60 V | 90 V | 130 V | 250 V | 600 V |
| Nominal discharge current ([2]) | 5 kA | 5 kA | 5 kA | 5 kA | 1,5 kA | 1,5 kA | 1,5 kA | 1,5 kA | 4,5 kA | 4,5 kA |

*([1]) 8/20 $\mu$s waveform - ([2]) 10 8/20 $\mu$s waveform*

*Figure 161: Example of possible protections for data lines*

As numbers of protections installed are up to the designer, customer, system of protection for telephone / data distribution can provide "racks" including as many pair as required (4, 8,10,16, 25, 32, 64,128).

Wiring of these protecting devices becoming parts of the general data's distribution.

*Figure 162: Surge protectors as plug-in modules in a computer or telephone rack distribution*


With a “small” installation, you can combine power + telephone + computer surge protections on the same support

*Figure 163: Combined power + telephone + computer surge protections*

### 8.4.8. High-frequency Coaxial line surge protection

As per one vendor catalogue, two technologies are proposed for HF coaxial lines: "Gas Discharge Tube" and "Quarter-Wave"

#### 8.4.8.1. "Gas Discharge Tube" protection P8AX series

*A gas discharge tube is an insulator placed in parallel on the line; when its sparkover voltage is reached because of an overvoltage, the line is briefly practically shorted (arc voltage).*
*The sparkover voltage depends on the rise front of the overvoltage. The higher the dV / dt of the overvoltage, the higher the sparkover voltage of the surge protector.*

*When the overvoltage disappears, the gas discharge tube returns to its original condition of insulator and is ready to function again. The discharge tube is removable, making maintenance rapid in the end-of-life case.*

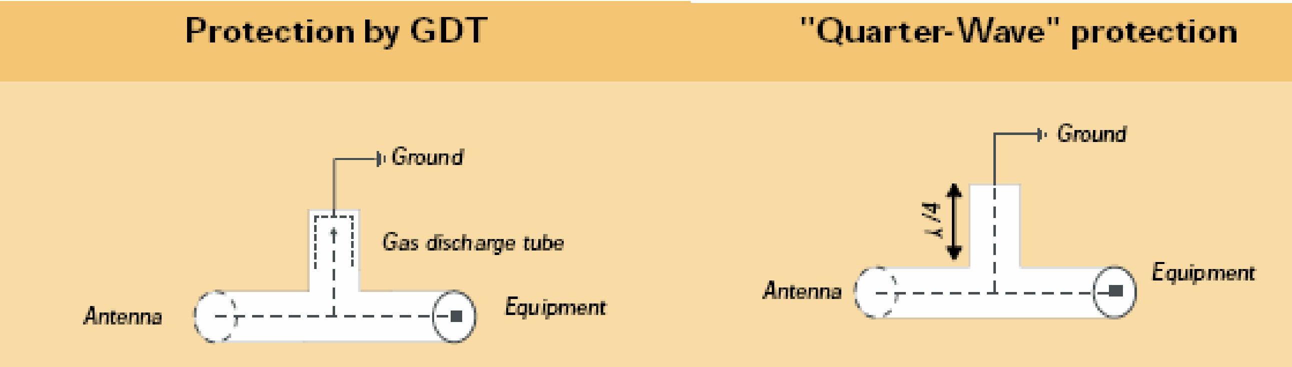



*Figure 164: Surge protections for coaxial*

### 8.4.8.2. "Quarter-Wave" protection PRC series

*(Other names: 'Shorting stub" or Protection by resonant line').*

The other way to protect antenna lines is judicious replacement of the gas discharge tube by a short-circuit chosen according to the operating frequency band.

This short-circuit is tuned to one quarter of the wavelength, giving its name to "quarter-wave protection.

This tuned short-circuit between the conducting core and the external ground acts as a band-pass filter.

The filter may be selective (narrow band) or wide-band, according to the calculation of the various mechanical elements.

Since lightning has a low-frequency spectrum (from a few hundred kHz to a few MHz), it will be filtered out from the operating frequencies.

## 8.5. TECHNOLOGY OF SURGE PROTECTORS

Essentially, 3 components are used in surge protectors:

- Zener Diode
- Discharge tubes
- Varistance

Varistance is at present the more economical product, they are efficient and at the lowest cost of production.

Other characteristics and options

- Disconnection at end of life
- Status indicator
- Remote indication facility

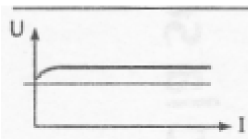
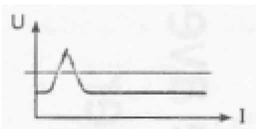
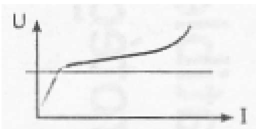
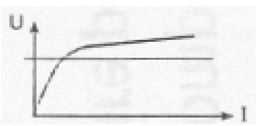
| Characteristics | Component | Leaking current If | Leaking current Is | Residual voltage | Conducted energy | Conduction delay |
|---|---|---|---|---|---|---|
|  | Ideal surge protector | 0 | 0 | Low | High | Low |
|  | Discharge | 0 | High | Low but U high | High | High |
|  | Varistance | Low | 0 | low | High | Average |
|  | Zener | Low | 0 | Low | Low | Low |
| ***If= initial leaking current     Is = Leaking after "actuation"*** | | | | | | |

*Table 13: Technology comparison for surge protectors*

### *8.5.1. Zener Diodes*

Characteristics are closed to 'ideal' curve.

Response time is fast (in picoseconds: $10^{-12}$) for an accurate Voltage setting

Leaking current can be neglected

The main inconvenient is the low energy dissipation. This type of concept cannot be used at head of an installation only as last protector for individual devices protection.

### 8.5.2. Gas discharge

**A) power protection**

They can be only electrodes in ambient air or electrodes within a hermetic casting filled with gas. When overvoltage, air or gas is ionised and provoke a strike between electrodes

The air electrodes are subject to external interference's (rain, birds, etc) causing unwelcome functioning.
The gas system is subject to quality of gas itself, especially if it has already 'worked'.
After a strike, a residual leaking current (Is) can last some tens of seconds and induce increase of potential.

These systems have low reliability.

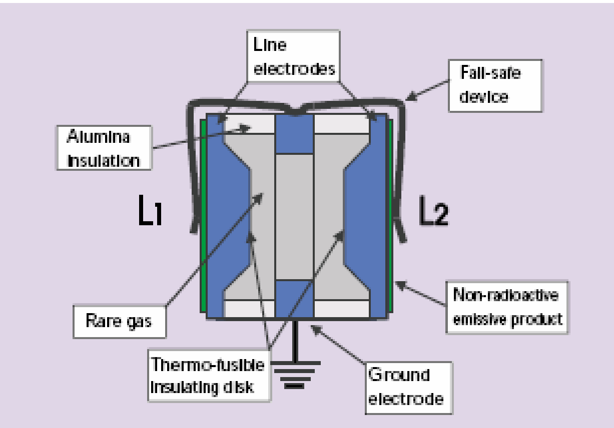
They were used on HV overhead lines and progressively replaced by direct protection devices.

Advantages are: big energy dissipation and a leaking current (after the initial residual current 'evacuated') which can be neglected.

**B) Data lines protections**

Product description as per vendor catalogue

*These components are made of two or three electrodes in an enclosure filled with a (non-radioactive) rare gas at a controlled pressure.*




*The enclosure is a ceramic tube with its ends closed off by metal caps that also serve as electrodes.*

*Their main use is to protect telecommunications lines.*

*All our gas discharge tubes are certified radioactive-free.*

Figure 165: 3 electrode gas discharge tube

***Operation:***

*The gas discharge tube may be regarded as a sort of very fast switch having conductance properties that change very rapidly, when breakdown occurs, from open-circuit to quasi-*

*short circuit (arc voltage about 20V). There are accordingly four operating domains in the behaviour of a gas discharge tube:*

**  Non-operating domain, characterised by practically infinite insulation resistance,'*

**  Glow domain. At breakdown, the conductance increases suddenly; if the current drained off by the gas tube is less than about 0.5A (this is a rough value that differs according to the type of component), the glow voltage across the terminals will be in the 80 - 100Vrange;*

**  Arc regime: as the current increases, the gas discharge tube shifts from the glow voltage to the are voltage (20V). It is in this domain that the gas discharge tube is most effective, because the current discharged can reach several thousand amperes without the arc voltage across its terminals increasing.*

** Extinction: At a bias voltage roughly equal to the glow voltage, the gas tube recovers its initial insulating properties.*

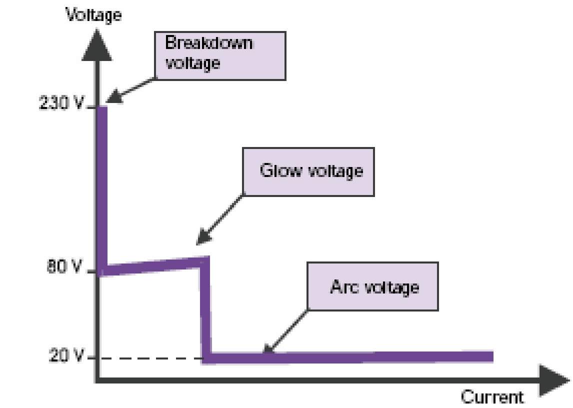



*Figure 166: Operating regimes of a gas discharge tube*

***The main electrical characteristics defining a gas discharge tube are:***

- *DC sparkover voltage (Volts)*
- *Impulse sparkover voltage (Volts)*
- *Discharge current capacity (kA)*
- *Insulation resistance (G-ohms)*
- *Capacitance (pF).*

***DC sparkover voltage***

*This is the main characteristic defining the gas discharge tube. It is the voltage at which breakdown will occur between the electrodes when a slowly increasing voltage (dV I dt = 100 V / s) is applied to the component; it depends on the electrode spacing, the pressure, and the properties of the gas mixture and of the emissive substance.*

***Range of DC sparkover voltages available:***

- *minimum 75V*
- *average 230V*
- *high voltage 50OV*
- *very high voltage 1000 to 300OV*

*The tolerance on the breakdown voltage is generally ± 20%.*

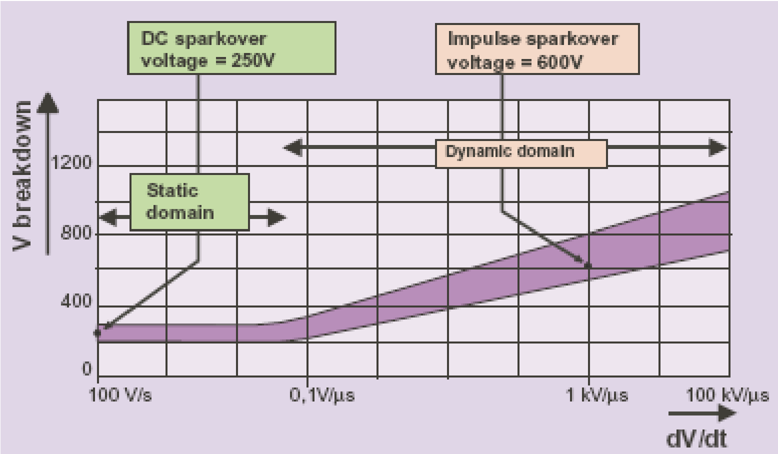



*Figure 167: DC and impulse sparkover voltage*

### 8.5.3. Varistance

This is a V.D.R (Voltage Dependant Resistor); Resistance value fluctuating according to the voltage across. With nominal voltage, resistance is 'very' high. As soon as voltage increases, resistance value goes down quickly. Resistance value stays nevertheless at a 'reasonable' level to avoid short-circuit.

Called also M.O.V. '(Metal Oxyde Varistor), GEMOV for "*General Electric*" and SIOV for '*Siemens'.*

Principal advantage is low construction cost for and a dissipation of energy

***Disadvantages:***

- After several low energy overvoltages, heating occurs and life-time shortens
- A too high overvoltage destroys the component up to short-circuit
- Explosion can even occurs with high-high voltage

***Those disadvantages have been compensated by***:

- Automatic disconnection stop the overheating and "switch off" the faulty component
- Casting in adapted resin contains the forces (for explosion)

Its characteristics are close to 'ideal curve'.

Response time is low (in nanoseconds)

Energy dissipated is high

Leaking current, low at first, will increase after each peak of voltage, after several strikes, the component has to switch off by itself. Indicator of “end-of-life” should equip those devices for proper replacement in due time.

# 9. GLOSSARY

***Glossary of terms and letters used mainly with breakers***

**EDW:** Electro Dynamic Withstand
**SCPD:** Short Circuit Protection Device
**IEC:** International Electrotechnical Commission
**BS:** British Standard
**CT:** Current transformers
**CU:** control Unit
**MSB:** Main Switchboard
**BBT:** Main Switchboard
**MV:** Medium Voltage (1kV to 36kV)
**Isc:** Short circuit current
**Isc(D1):** Short-circuit current at the point D1 is installed
**Usc:** Short-circuit voltage
**MCCB:** Moulded case circuit-breaker
**BC:** Breaking Capacity
**Icu(*):** Ultimate Breaking Capacity (Making capacity)
**IcuD1(*)** Ultimate Breaking Capacity of D1
**Ue:** Rated operational voltage
**Ui:** Rated insulation voltage
**Uimp:** Rated impulse withstand voltage
**In:** Rated operational current
**Ith:** Conventional free air thermal current
**Ithe:** Conventional enclosed thermal current
**Iu:** Rated uninterrupted current
**Icm:** Rated short-circuit making capacity
**Icu:** Rated ultimate short-circuit breaking capacity
**Ics:** Rated service breaking capacity
**Icw:** Rated short time withstand current
**Ir:** Adjustable overload setting current
**1.05 x Ir:** Conventional non-tripping current
**1.30 x Ir:** Conventional tripping current
**Ii:** Instantaneous tripping setting current
**Isd:** Short time tripping setting current

# 10. FIGURES

# 11. TABLES