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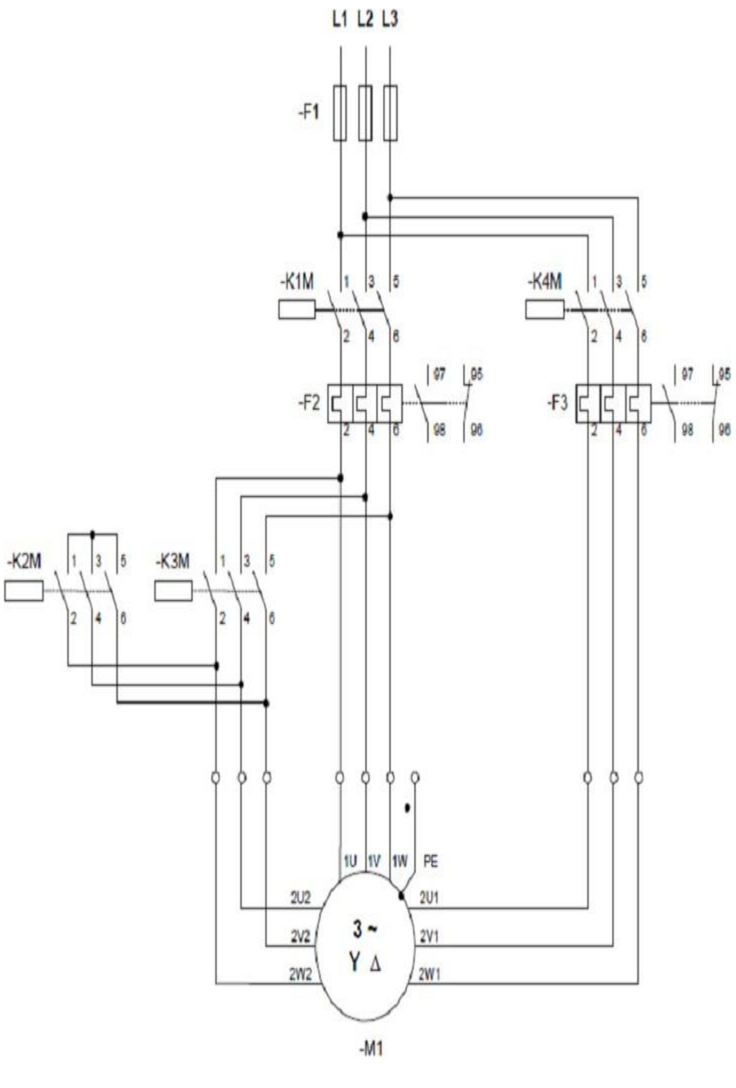
قسم الهندسة الكهربائية

Course: Electrical Diagrams and Equipment

3rd Year: Electromechanics
Electrical Engineering

3rd year Engineer:
Electrical Systems Engineering



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SUMMARY

FOREWORD

Everyone knows that our specialty ELECTRICAL ENGINEERING is a science intended to study three main domains which are the production, transport, and utilization of electromagnetic energy, thus an entire electricity chain. Understanding the different phenomena that occur and accompany its operation requires knowledge of the role and function of each element of this chain.

_This course is addressed to students pursuing studies in the third year of a bachelor's degree, options: Electromechanics and Electrical Engineering, as well as to all persons interested in electricity and particularly to electrical installers.

The main objective of this course material is to present basic notions of fundamental electricity and to facilitate the learning of the different types of equipment constituting an electrical installation, certainly after having mentioned the different phenomena related to current and voltage, as well as knowing how to develop and decode electrical diagrams based on standardized rules and symbols.

Introduction

In any domestic and industrial installation, the connection of electrical equipment is one of the basic rules to be respected to guarantee the safety of the electrical network. The absence of these rules can lead to real dangers for people's lives and put electrical installations and property at risk. Electrical devices play a very important role in electrical circuits, whether they are power or control circuits, from very high to very low power. The nature and function of the equipment are the predominant technological parameters in applications. To improve the performance of devices and consequently the electrical contacts (resistance to arc erosion, contact resistance, welding on bounce…) it is essential to understand the different phenomena that occur during their opening or closing, notably the effect of the different forces that develop between the electrodes of the electrical equipment. In order to affect the efficiency of installations or electrical devices as little as possible, a contact must consume only very little energy.

I. Generalities on Equipment

Electrical energy, made available to industrial or domestic installations via the distribution network, cannot be permanently connected to all receivers. It is therefore essential to use power control systems allowing the transfer or interruption of electrical energy from the origin of the network to the receivers.

It is the equipment (switches, circuit breakers, disconnectors, contactors, etc…) that ensures this activity called "power control".

Before reading an electrical diagram, it is necessary to know the different equipment that constitutes it, and whenever we have to deal with an electrotechnical problem, we will be led to look at the function of the appropriate equipment.

Generally, the classification of equipment is done according to several parameters:

a. *The input parameters of the installation;*

- The nature of the network: alternating, direct, single-phase, three-phase, frequency, etc…

b. *The output parameters of the installation;*

- The nature of the receiver: resistive, inductive, domestic, industrial, etc……
- The rated power (assigned current, rated voltage).
- The category of use.
- The size: unipolar, bipolar, tripolar, and tetrapolar.

c. *The function; the equipment is classified according to the function it performs..*

- Distribute.
- Isolate, connect, link, separate.
- Protect.
- Control.
- Energy management.
- Convert, etc……

d. *The voltage class: the equipment is also classified according to its voltage.*

- B.T.A: 50 V < Un < 500 V. This is the terminal low voltage (BTT) with 400V between phases.
- B.T.B: 500 V < Un < 1 kV. This is the low voltage (LV) network.
- H.T.A: 1 kV < Un < 50 kV. This level covers customer supply networks, called medium voltage (MV) network before 1989.
- H.T.B: rated voltage greater than 50 kV (HV).

e. *The nature of the control; two techniques that can be presented.*

- Manual.
- Remote.

f. *Location and destination; three categories according to the place of installation.*

- Aerial, outdoors.
- In a metal enclosure, equipped with compressed blast gases.
- Immersed in oil.

I.1. Electrical Contact Phenomena

I.1.1 Definition :

An electrical contact is established by pressing two conductive electrodes against each other. To improve the performance of electrical device contacts, it is essential to understand the different phenomena that occur during their opening or closing, notably the effect of the different forces that develop between the electrodes (electromagnetic forces, forces exerted by the arc on the contacts….). Given the importance and in order to affect the efficiency of circuits or devices as little as possible, a contact must consume only very little energy, hence the interest of the following characteristics: Contact resistance, voltage drop, and current density. Also, to combat poorly conductive layers and allow the creation of conductive paths, one can act on four main parameters: The terminal coating of the electrodes, the contact force, the curvatures of the electrode surfaces, and the friction of one electrode relative to the other.

I.1.2 Types and Characteristics

Contacts play a very important role in electrical installations. Because they can take extremely varied configurations, it is difficult, if not impossible, to establish an indisputable classification of electrical contacts. Nevertheless, there are major families that we will try to illustrate according to the role required of them. - Permanent (Fixed) Contacts: ensuring permanent electrical continuity between two pieces in relative immobility, two cases that may arise;

- 1. <u>Non-removable permanent contacts</u> (soldering, splices, lugs, and crimping, etc…).
- 2. <u>Removable permanent contacts</u> (screwed or clamped).

- <u>Semi-fixed (Temporary) Contacts</u>: ensuring electrical continuity between two pieces in relative immobility, making contact and separation being effected by a simple maneuver (power outlet, lamp holder, switch terminal, etc…).

- <u>Sliding Contacts</u>: ensuring electrical continuity between two pieces in relative translational or rotational motion (the case of electric transport means: locomotive, trolleybus, metro, etc….).

II. Phenomena Related to Current and Voltage

The expansion of electrical networks of all kinds: power transmission, distribution, in both industrial and domestic sectors, has strongly contributed to the increase in the risk of faults, such as overvoltage or overcurrent. The role of electrical protection of equipment is to avoid or limit the destructive consequences of faults (anomalies related to current and voltage) and to separate the faulty part from the rest of the installation. Among these phenomena, the following classification can be established:

II.1 <u>Overcurrent's</u>: Overcurrent detection is generally installed on all phase conductors. It does not necessarily cause omnipolar tripping, we distinguish:

Overcurrents

Normal Overcurrents (Temporary)

Abnormal Overcurrents

- Overloads
- Short-circuits

II.1.1 <u>Temporary Overcurrents</u>:

They occur during motor starting, transformer energization, or fluorescent tube ignition, etc……

These overcurrents should not cause the protection devices to trip (no power cutoff).

II.1.2 <u>Abnormal Overcurrents</u>: two cases that may arise

II.1.2.1 <u>Overloads</u>:

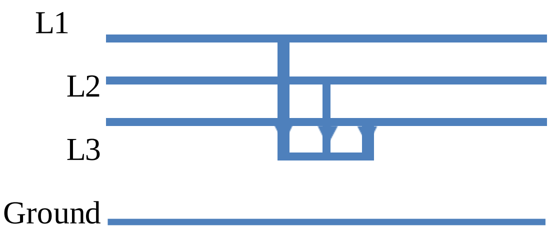
Overloads are generally due to a momentary abundance of receivers in operation, especially during peak hours. As an example, in summer, the successive demand for electricity consumed by cooling devices; fans, air conditioners, etc… causes overloads. The demand for mechanical power (case of electric motors) greater than normal can also lead to overloads. In this case, the electrical circuits are sound, the current values are generally of the order of 1.5 to 3 times the rated current, never exceeding ten (10 In). The prolongation of these overloads causes excessive thermal heating in the installation. Protection against overloads is provided by circuit breakers and thermal relays (power cutoff occurs after certain waiting delays).

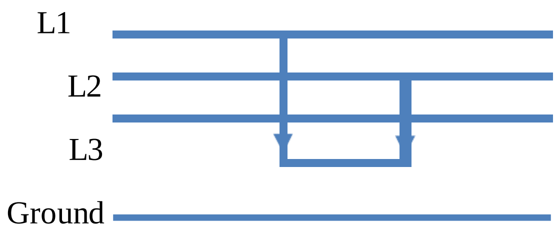
II.1.2.2 Short - circuits :

Any operation of an electrical network may be subject to the appearance of faults often manifested by high "short-circuit" currents. A short-circuit is a transient regime of an electromagnetic nature during which the system impedance decreases and then cancels out. Several types of faults exist depending on the distribution network (overhead line or underground cable), the fault location, the number of phases that are in contact, and also the duration of the fault (fugitive if less than 0.3 seconds, semi-permanent for faults less than 15 seconds, or permanent if the duration exceeds 15 seconds). Many other factors can also influence the type of fault, such as the operating mode, the neutral system, or the performance of the protections.

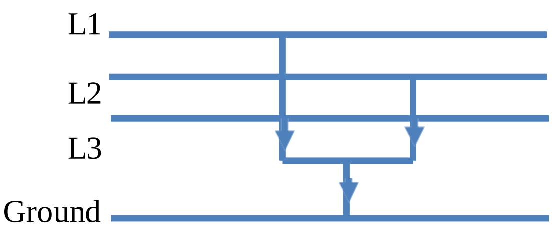
Electrical networks must not only be sized to support their nominal regimes (assigned current and rated voltage), but also in case of fault.

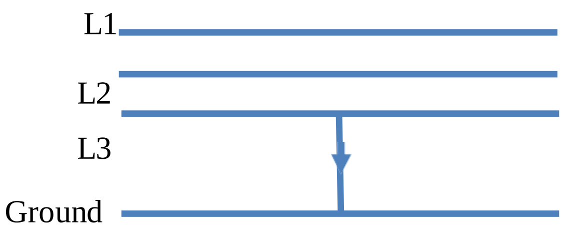
Short-circuit currents, as expected, are consecutive to a fault in a circuit (connection error, insulation deterioration, etc…). These currents are harmful to networks, either for thermal reasons (fusion of conductors, degradation of insulators), or for mechanical reasons due to deformations caused by electromagnetic forces, or for cost reasons as they cause premature aging of equipment. The following types are distinguished:





a) Symmetrical three-phase short circuit (LLL). b) Isolated phase-to-phase short circuit (LL).





c) Phase-to-phase short circuit with Earth (LLT). d) Phase-to-earth short circuit (LT).

→ The values of short-circuit currents are, in general, greater than 10 times In and can reach 100 times In or more.

Protection is generally provided by circuit breakers or fuses (power cutoff is immediate).

II.2 Overvoltage's :

Any electrical installation can be subjected to occasional overvoltages of very diverse origins such as:

- Overvoltages of atmospheric origin (case of a lightning strike): these overvoltages are due to and caused by the direct or indirect strike of lightning on all conductive elements and particularly on cabling and electrical equipment.
- Switching Overvoltages: caused by a modification of the established regime in an electrical network (during an equipment maneuver, the opening of an inductive circuit under load generates an overvoltage

proportional to the factor L dl/dt at the moment of interruption, etc...).

- Overvoltages due to a fault: caused by a permanent change of state of the network (following an insulation fault, neutral conductor break, etc….).

- Overvoltages consecutive to an HV/LV flashover: localized in transformer substations.

1. **Effect of the Arc on Contacts**: at the contact level, note that the materials must present the following characteristics:
   - Good electrical and thermal conductivity.
   - Good resistance to oxidation in the presence of SO_2 and H_2S.
   - High superficial mechanical hardness to resist friction stresses.
   - Resistance to welding and electrical erosion.

2. **Electrodynamic Forces**: when two parallel conductors are traversed by currents in the same direction, there is an attractive force; if they are traversed by currents in opposite directions, there is repulsion. Electrodynamic forces can also be created when a conductor forms a loop and is traversed by a current.
   In case of significant overcurrents (short-circuit), these attractive or repulsive forces can have destructive effects.
3. **Electrical Breakdown:** when the potential difference applied to two metal electrodes separated by an insulator is sufficiently increased, an electric arc will originate and can be observed. The voltage that generates the electric arc between the two electrodes is called the breakdown voltage (disruptive voltage).
4. **Gas Ionization**: under usual conditions, gases are insulators. But under the action of a temperature rise, they can become conductors.

5. **Dielectric Strength (Potential Gradient)**: If the voltage to which an insulator is subjected is increased beyond a certain value called the breakdown voltage, an electric arc appears in the insulator in the form of an intense current crossing the insulator following a path formed by the arc itself.

   In this case, the insulator is punctured (there is a rupture of the dielectric strength). The latter is expressed in kV/mm and it depends on:

   - The frequency, shape, and duration of application of the voltage.
   - The temperature, pressure, and humidity of the atmosphere.
   - The presence of impurities in the insulator (air bubbles,…).

6. **Electrical Insulation**:
   Insulators are materials with very high resistivity: 10^8 to 10^{16} Ω.m, they do not conduct electric current because they contain very few free electrons in the valence band. They are characterized by chemical, mechanical, thermal, and electrical properties with the objective of fulfilling the following functions:

   - To ensure electrical separation between conductors held at different potentials.
   - To support the elements of an electrical network and isolate them from each other and from earth.
   - To perform the dielectric functions of a capacitor.

III. Phenomena of Electrical Current Interruption

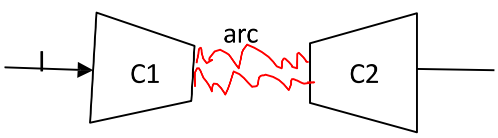
III.1. <u>Introduction</u>: To break the current in a direct or alternating electrical circuit, it is sufficient to open a device such as: a switch, contactor, circuit breaker, etc. The resistance of the device in the circuit, which was zero, reaches its maximum value (infinity) during the sudden separation of the device's two contacts, which causes an electric arc resulting from the ionization of the air or dielectric located between the two contacts.

III. 2. <u>Definition</u>: An electric arc corresponds to a luminous electrical discharge carrying a high current under a low potential difference; this phenomenon was discovered in 1813 by the English physicist and chemist DAVY. The electric arc is a conductive medium, it has a very high temperature which can reach 5000 °C to 8000 °C depending on the nature of the electrodes and the medium in which it propagates. Its appearance is facilitated if the circuit carrying a current I is inductive, because an overvoltage proportional to the factor LdI/dt is generated at the moment of interruption. In the absence of special precautions, the arc can lead to the welding of the electrodes.

III.3 Birth of an Electric Arc

III.3.1 In Air: La The contact resistance is given by the following relation: $R=\rho L/As$; ρ resistivity of the medium, L the distance between the contacts and As the contact area.

At the beginning of the movement of the movable contact C2 (opening of the loaded circuit), the distance L between the contacts increases and the surface As decreases and then cancels out; therefore R increases, which leads to local heating of the electrodes with metal fusion. The potential gradient between the contacts is very high; a jet of electrons ionizes the inter-electrode space. It is in this column of electrons and ionized gas that the arc will propagate (Fig.1).



C1 : fixed contact

C2 : mobile contact

Fig.1 Birth of an arc in air.

Thus, the appearance of the arc in air manifests as the continuity of the current in a more or less ionized and mobile gaseous column.

III.3.2 <u>In Oil</u>:

The initial process is identical: increase in L, decrease in Δs, hence increase in R and heating; this causes local melting on the electrodes and the vaporization of a small quantity of oil, which forms a gas bubble containing hydrogen, acetylene, methane, etc. It is inside this bubble of very hot gas, traversed by a jet of electrons, that the arc propagates (Fig.2).

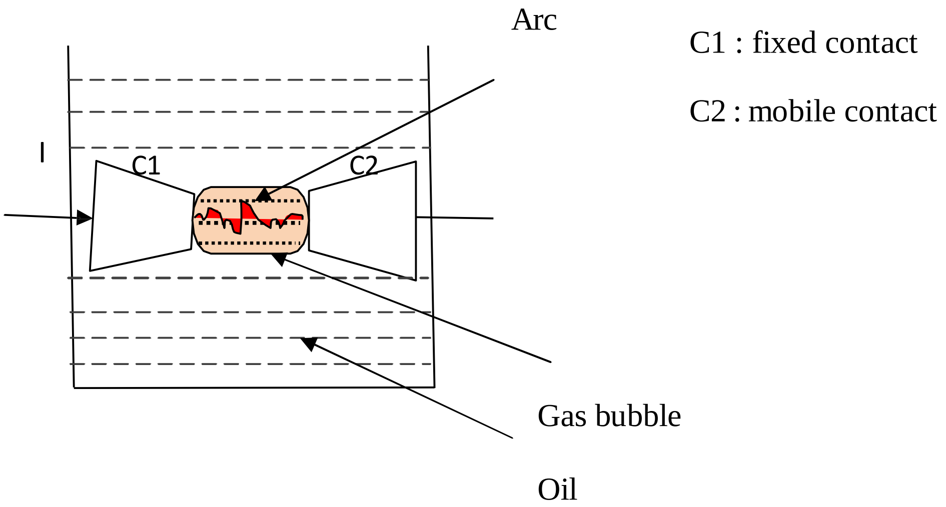


Fig.2 Birth of an arc in oil.

III.4. <u>Properties of the arc</u>:

III.4.1 <u>Arc voltage</u> :

Whatever the nature of the current (direct or alternating), at any time, the potential difference between the two moving electrodes (complete opening or even a small gap between the electrodes) promotes the establishment of the arc with an establishment voltage Uarc (fig.3).

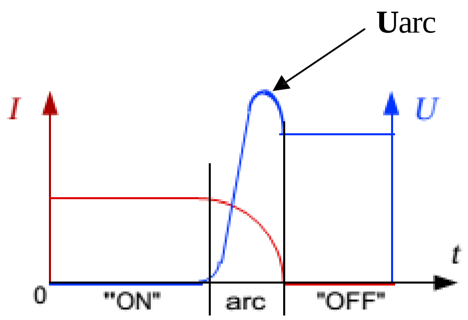


Fig.3 Arc ignition voltage Uarc

The arc ignition voltage is defined as follows:

$\mathbf{U_a = \alpha + \beta\, l = \alpha + \beta.v.t}$

$\mathbf{U_a}$: Arc voltage

$\boldsymbol{\alpha}$: Voltage drop at the negative electrode

$\boldsymbol{\beta}$: Voltage drop per unit length of arc

l : Length of the arc

v : Arc elongation speed

t : Arc time (counted from the start of contact separation)

III.4.2 Arc Energy:

The energy dissipated in the arc is:

$W = W_1 + W_2$

W_1 : Energy applied directly to the negative contact (at the root of the arc); one part will be conducted into the electrode metal as heat and dissipated further away; the other part will serve to volatilize metal particles; the degradation and fusion of the contacts is therefore inevitable.

W_2 : Energy developed in the arc column in the form of intense luminous radiation and high temperature.

III.4.3 Arc Cross-Section:

The cross-section of the arc depends only on the intensity of the current I to be interrupted, it is proportional to this intensity

III.4.4 Arc Length:

The maximum length of an arc is proportional to the voltage U applied to the electrodes; the higher the voltage, the greater the arc length. In high voltage, the arc can reach several meters in length.

III.4.5 **Arc Mobility**:

The arc being formed of a column of electrons in air or in a gas, it is very mobile, therefore very sensitive to air currents, electric and magnetic fields.

III.4.6 **Arc Volume** :

The volume of the arc is proportional to the product U.I and therefore to the power expended by the arc.

III.4.7 **Arc Interruption Media** :

Thanks to significant progress in the field of arc modeling and gas flow simulation, arc energy could be controlled and used effectively to define high-performance interruption chambers. Historically, the following interruption media can be summarized:

- Air
- Oil
- Compressed air
- SF6
- Vacuum

For years, manufacturers have sought, developed, tested, and implemented interruption devices based on these media. For successful interruption, the medium must have the following characteristics:

- Have high thermal conductivity to be able to evacuate the thermal energy generated by the electric arc.
- Have a high deionization speed to avoid reignition of the medium.
- Have low electrical resistivity when the temperature is high to minimize the energy dissipated for the arc.

- Have high electrical resistivity when the temperature is low to minimize the dielectric recovery time.
- The inter-contact space must offer sufficient dielectric strength.

The dielectric strength of the medium depends on the distance between the electrodes and the pressure of the medium. For air, the PASCHEN curve (Fig.4) shows the variation of dielectric strength as a function of the medium pressure.

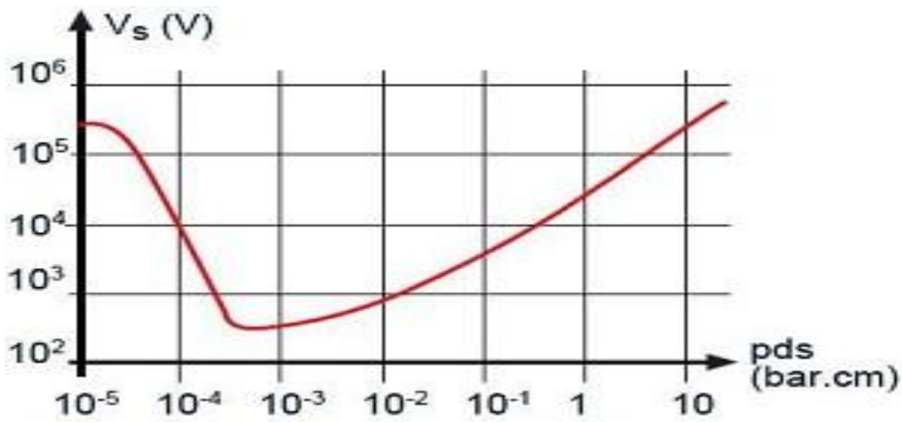


Fig.4 The PASCHEN curve

The following curves (Fig.5) and (Fig.6) show the variation of dielectric strength as a function of the inter-contact distance.

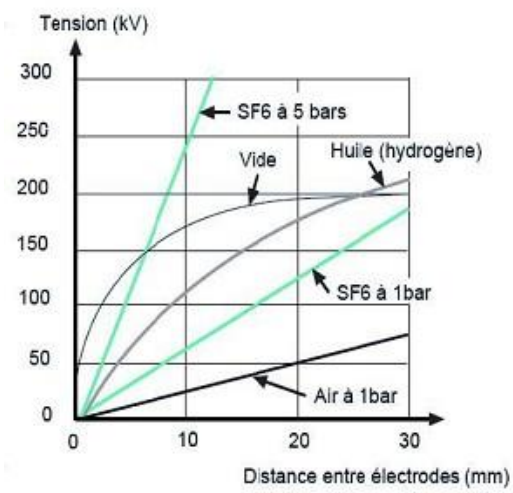


Fig.5 Dielectric strength as a function of distance between electrodes

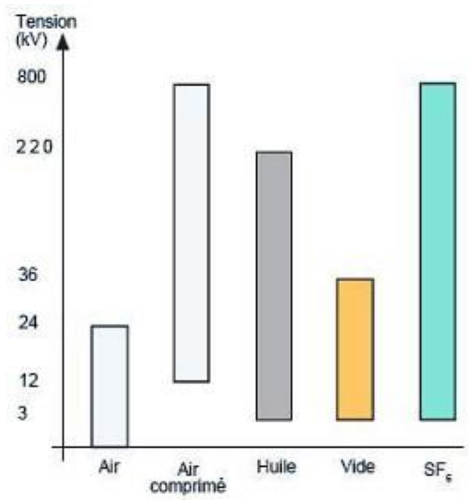


Fig.6 Application range of different interruption media

Several interruption media have been developed to date:

1. Interruption in air up to 24 KV, but today limited to low voltage users.
2. Interruption in oil up to 200 KV.
3. Interruption in SF6 up to several hundred KV.
4. Interruption in vacuum up to 36 KV.

III.4.8 Danger of the Arc :

The arc is very dangerous due to its mobility, hence the risk of phase-to-ground or phase-to-phase flashover and risk of electrocution for personnel; it is also dangerous due to its intense luminous radiation, hence the risk of blindness; finally, it is dangerous due to its harmful effects on the contacts, on nearby conductive and insulating parts due to high temperature.

Note:

- The current to be interrupted is high, especially in direct current and on highly inductive loads if it is an alternating current circuit.
- Direct current is more difficult to interrupt than alternating current which passes through zero one hundred times per second.

III.5 Principle of Arc Interruption:

By separating the contacts of a load-breaking device, an electric arc is caused; the arc does not extinguish by itself and the current interruption is only effective after its extinction. It must therefore be cut off quickly to avoid its destructive effects, but it only extinguishes if the network voltage is insufficient to maintain it between the contacts, i.e.: U network < U arc; we can therefore:

- Either increase U arc, but U arc = $\alpha + \beta.l$; we can therefore act on α, β and l.

-Or indirectly decrease U network

The process which consists of increasing the arc voltage until Uarc > Unetwork is called: "interruption by extinction" (or current zero interruption), it is used in direct current and in low and medium voltage AC (36 KV).

In medium voltage AC, especially high voltage and extra high voltage, the principle of interruption called: "interruption by blocking" at reduced arc voltage is used, which consists of suppressing ionization between contacts at the moment when the alternating current passes through zero.

III.6 Arc Extinction Condition :

In 50 Hz alternating current, the arc extinguishes by itself one hundred times per second and reignites at the same rate; it is therefore sufficient to prevent its re-ignition; two processes can be used:

- In a first process, we wait for the arc to extinguish, at that instant a dielectric barrier is interposed between the contacts (interruption by blocking) at reduced arc voltage.
- In a second process, the arc is forced to extinguish prematurely, as in direct current; this occurs when Uarc > Unetwork (interruption by extinction), high arc voltage.

III.6.1 Arc Interruption by Blocking :

It therefore consists of preventing the re-ignition of the arc, after natural extinction, by deionizing the medium between contacts, i.e., by replacing ionized gases with non-ionized gases, in order to increase the dielectric strength between contacts.

III.6.2 Arc Interruption by Extinction :

- Action on the term α (fragmentation)

It is necessary to multiply the number of cathode falls by arranging and splitting the arc into several arcs in series.

- Action on the term β (deionization)

This consists of deionizing the medium between contacts; it is about increasing the potential gradient; it is therefore necessary to replace the air or ionized (hot) gases with non-ionized (cool) air or gases.

- Action on the term l (stretching)

This consists of lengthening the arc as much as possible; it must be forced into a sinuous path to obtain great elongation with a small footprint.

III.7 Arc Recovery Voltage (U_R):

This is the voltage U_R that appears between the contacts at the precise moment of arc extinction:

- De-energizing an unloaded installation: dangerous instantaneous overvoltages can occur (line, transformer).
- Taking out of service.
- Tripping on short-circuit.

III.8 Different Arc Interruption Techniques:

III.8.1 Interruption in Air :

For voltages above 24 KV, compressed air is used to improve dielectric strength, cooling speed, and deionization time constant. The arc is cooled by high-pressure blast systems.

This interruption method is not widely used in medium voltage due to size and cost reasons. Nevertheless, interruption in air remains the most used solution in low voltage thanks to its simplicity and endurance.

Air at atmospheric pressure has low dielectric strength and a high deionization time constant. The technique used consists of keeping the electric arc short to limit the dissipated thermal energy and elongating it via plates once the current passes through zero.

III.8.2 <u>Interruption in Oil</u>:

It consists of immersing the electrodes (contacts) in oil. At the moment of contact separation, the oil decomposes and releases H_2 and C_2H_2 mainly into a gas bubble. The latter is subjected to high pressure during interruption. When the current passes through zero, the arc extinguishes due to the presence of H2.
Oil circuit breakers have given way to other types of technology such as SF6 and vacuum for the following reasons and disadvantages:

✓ The decomposition of oil at each interruption is an irreversible phenomenon.

✓ The level of security and maintenance is high to control the degradation of the dielectric properties of the oil and the erosion of the contacts.

✓ Risk of explosion and fire.

III.8.3 <u>Interruption in SF6</u>:

Given its chemical and dielectric properties, for several years, circuit breaker manufacturers have turned to SF6 as an interruption medium.
Under the effect of temperature, the SF6 molecule decomposes, but as soon as the current returns to low values, the molecule recombines. SF6 has thermal conductivity equivalent to that of air, high dielectric strength, and a low deionization time constant. The electric arc is composed of a plasma of dissociated SF6, of cylindrical shape. This plasma has a core at very high temperature, surrounded by a sheath of cooler gas. The entire current is transported by the core and the outer sheath remains insulating.

III.8.4 <u>Interruption in Vacuum</u> :

In vacuum interruption, the electric arc is composed of metal vapors and electrons resulting from the materials making up the contacts. This arc can be diffuse or concentrated. Manufacturers of vacuum bottle circuit breakers have focused their research on contact materials, their shape, and interruption mechanisms. Vacuum interruption is widely used today in MV (Medium Voltage) thanks to its high electrical endurance, very little used in LV (Low Voltage) for cost reasons, and remains a potential area for HV (High Voltage).

III.9 Advantages and Disadvantages of the Arc:

III.9.1 Advantages::

- The main advantage of the electric arc is arc welding.

III.9.2 Disadvantages:

- Circuit breaking is not effective as long as the arc persists.
- Electrodes are destroyed by fusion.
- The arc presents a serious risk of fire or explosion.
- The high temperature of the gases imposes significant thermal stresses on both conductors and insulators, reducing their lifespan.
- Parasitic electromagnetic radiation is produced.

IV .Electrical Equipment

Introduction:

An electrical circuit is a set of conductors (wires) and electrical components. The electrical schematic aims to best represent the electrical circuit using standardized symbols. Therefore, to present an electrical circuit, the use of a schematic and standardized symbols proves very practical. Four types of schematics can be presented: developed electrical schematic, architectural schematic, single-line schematic, and multi-line schematic. Before reading a schematic, it is necessary to know the different devices that constitute it.

It should be noted that equipment is classified according to the function it performs, and any installation must include at least the following five functions:

- Separate, lock out, and isolate (connection equipment)
- Protect against short circuits (protection equipment)
- Protect against overloads (protection equipment)
- Protect people (protection equipment)
- Establish and interrupt power (control equipment)

IV .1 Connection Equipment:

Connection equipment ensures the connection between two parts of an electrical circuit or the isolation of the installation and isolates the downstream part, guaranteeing its separation from any source of electrical energy. These devices are always operated off-load (no current). We can distinguish:

- **Electrical Contacts**:

As discussed previously, electrical contacts ensure electrical continuity between two parts in relative immobility, with contact making and breaking performed by a simple maneuver. These include: permanent contacts, temporary contacts, and sliding contacts.

- **<u>Connection Terminals</u>**:

Connection terminals are installed in various equipment and electrical loads (electric motors, transformers, heaters, control devices, measuring instruments, etc.) to ensure the passage of electrical energy between two connectors, one male and the other female (cleaning action), forming an electrical contact.

- **<u>Power Outlets (Sockets)</u>**:

Power outlets supply all electrical appliances in ordinary domestic life (refrigerator, washing machine, coffee maker, vacuum cleaner, television, etc.) as well as industrial ones (three-phase asynchronous motors, etc.) by connecting them to the electrical network. Power outlets can be flush-mounted or surface-mounted. The female socket is recessed into the wall. For safety reasons, the contacts are at the bottom of circular holes. The male plug (plug) inserts into the female socket; the pins are brass and correspond to phase and neutral, with possibly an earth (ground) pin. There are different types of electrical outlets:

✓ Two-pole outlet, when it has two contact parts insulated from each other.

✓ Three-pole outlet, when it has three contact parts insulated from each other.

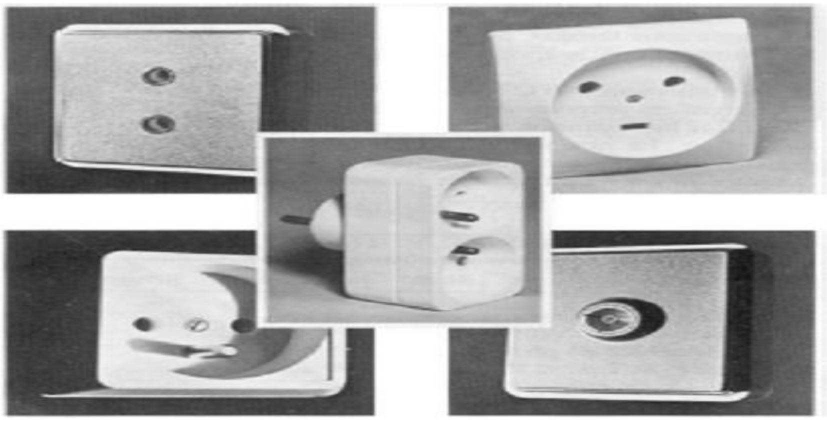
✓ Four-pole outlet, when it has four contact parts insulated from each other.

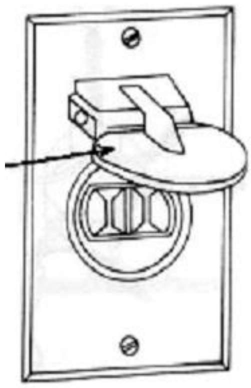
Power outlets cannot be placed anywhere and at any height. A minimum distance from the floor must be respected. Hence the following classification:

✓ Ordinary outlets (bedrooms, corridors, hall ...) they are simple.

✓ Outlets protected against splashes and vertical water falls (kitchen, bathroom,...) they are usually covered with a spring-loaded cover, the seal between the wall and this cover-plate must also be tight and well enclosed.

The figures below show the different types of power outlets.





Spring-loaded cover

Simple outdoor outlet

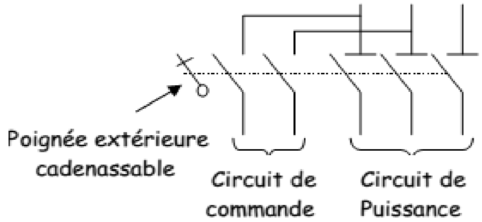
Fig.7 Types of power outlets

➢ **<u>The Disconnector (Isolator)</u>**:

- **<u>Definition</u>:** A disconnector is a device used to de-energize an installation by separating the installation part from any source of electrical energy. It has no breaking capacity; therefore, it cannot be operated on-load (always operated off-load). Its purpose is to isolate (its function) a part of the circuit to allow inspection, maintenance, troubleshooting, or modification on the downstream electrical circuits, safely.

- **Symbol :**

The symbol for a disconnector is:

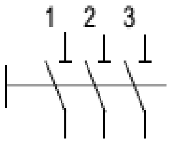


Poignée extérieure codenassable` (Exterior lockable handle)

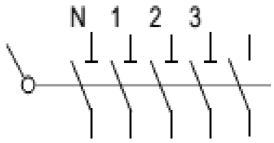
`Circuit de commande` (Control circuit)

`Circuit de Puissance` (Power circuit)

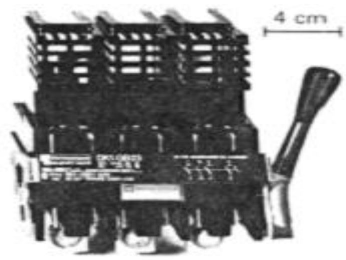
- **Appellation :** Q, Q_1, Q_2 etc.

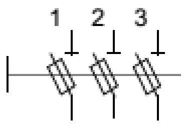


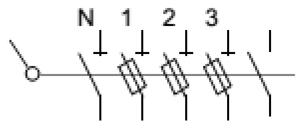
sectionneur à commande manuelle (symbole général), 3 phases



sectionneur à levier, 3 phase + neutre, avec contact auxiliaire







sectionneurs porte-fusible

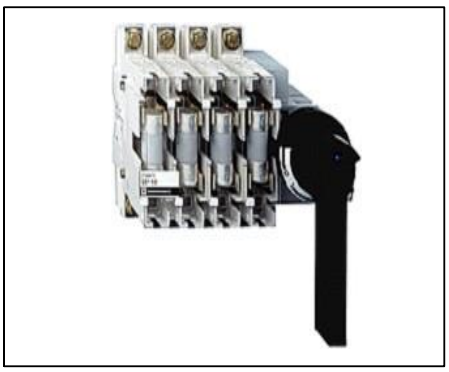


Fig.8 Different types of disconnectors

- **Role of Disconnectors:**

✓ Its main purpose is to separate and isolate a circuit from any current source.

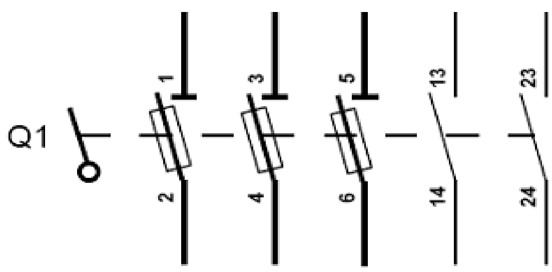
✓ Never operate a disconnector on-load; this device's capacity to close or open a circuit is zero, so no current should flow through it when operated. The downstream circuits must be open.

✓ The disconnector will therefore not be the device that must withstand an electric arc because it is not the first element to open in the motor supply line.

✓ We can find this device in different voltage classes: LV (Low Voltage), HV (High Voltage), etc.

✓ The disconnector can be found in different application areas: domestic, industrial, etc

- **Role of Different Components:**
  ✓ The main contacts (power poles: 1-2, 3-4, 5-6 and 7-8) ensure the isolation of the installation (power circuit) and isolate the downstream part. They are wired in the power part of the installation and are identified on the device symbol by numbers 1 to 8.



Power Poles Pre-break Contacts

- ✓ The auxiliary contacts (pre-break) are used to cut the control circuit; they are identified (13-14, 23-24).

Fig.9 Three-pole fuse-disconnector switch

- **Main Characteristics:**

✓ Number of power poles (three-pole, four-pole…).

✓ Rated current supported by the power poles.

✓ Maximum insulation voltage between power poles.

✓ Number of auxiliary contacts.

✓ With or without handle.

✓ Type of control.

✓ Breaking capacity (B.C.) is zero.

IV .2 . Control and Interruption Equipment:

➢ **Switches** :

Switches provide manual control of the opening and closing of an electrical circuit under load. Generally, switches are used for lighting circuits in residential or office premises.

- **Symbol :**

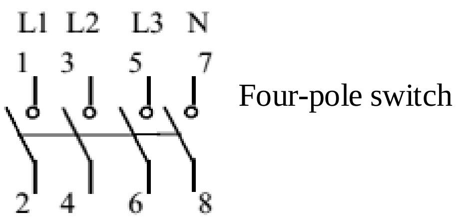


Fig.10 four-pole switch

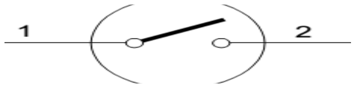
- **Appellation :** K, K1, K2...

- **Different types:** two categories are distinguished:

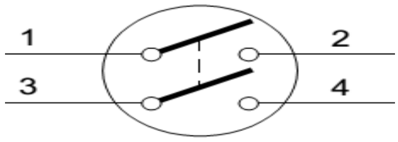
✓ Simple switches
✓ Combined switches

Examples of simple switches include the following models:

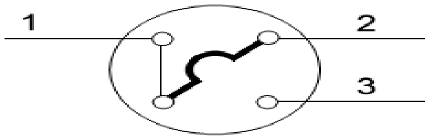
Single-pole switch



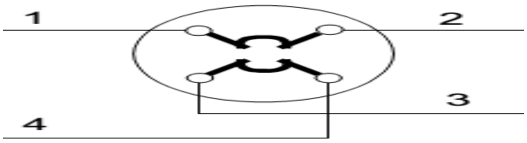
Double-pole switch



Two-way switch



Intermediate switch



The single-pole switch:
Allows controlling one or more lighting lamps from a single location.

The double-pole switch:

Allows controlling two different lighting circuits from a single location.

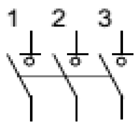
The principle of the two-way switch [Va-et-vient] is: to be able to control the switching on and off of one or more lamps from two different locations.

The intermediate switch [Permutateur]:

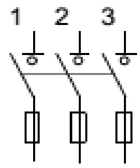
Allows controlling a lighting circuit from any number of locations, like the remote breaker (télérupteur is a remote-controlled circuit breaker). The latter is a device allowing the switching on and off of a light point from several locations, using push buttons. It is suitable when you want to install more than three control points for lighting.

Timer switch: This device allows the automatic switching on and off of one or more lamps, for a limited time set in advance (used particularly in corridors and stairwells).

Examples of combined switches include the following models:



Switch-disconnectors



Fused switch-disconnectors

The switch-disconnector: its function is manual opening and closing of the circuit under load and isolation.

The fused switch-disconnector: performs three functions simultaneously: interruption, isolation, and protection.

- **Main Characteristics:**

✓ Size : single-pole, double-pole, three-pole, etc.

✓ All switches must break the phase and not the neutral.

✓ Have their fixed pole connected to the phase.

✓ Breaking capacity (B.C.) is on the order of 2 to 3 In.

✓ The mode of opening and closing is manual.

➢ **Commutators (Multi-position Switches)**:

A commutator is a switch with several positions (multi-position), we distinguish:

✓ Two or three-way commutator with off position.

✓ Double lighting commutator.

✓ Two-way commutator.

✓ Triple lighting commutator.

✓ Reversing switch.

➢ **<u>Push Buttons</u>** :

These are manual control auxiliaries, always found in control circuits, aimed at managing power from a control panel. Examples include:

✓ Maintained push buttons.

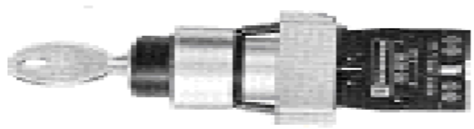
✓ Momentary push buttons.

✓ Rotary buttons.

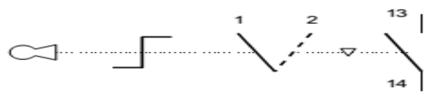
- **<u>Symbols</u> :**

Push button opening with automatic return

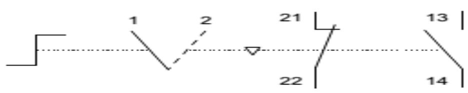
Push button closure with automatic return



Bouton tournant à serrure (clé n°455) 2 positions fixes.



Boutons tournants 2 positions fixes



- **<u>Appellation</u> :** S, S1, S2...

➢ **<u>Contactors</u>**:

a. **<u>Power Contactor</u>**:

- **<u>Definition</u>:** It is a control device (controlled junction) operated by an electromagnet; it works on an all-or-nothing (ON/OFF) principle. It is capable of establishing or interrupting the flow of electrical energy, thus it has a non-zero breaking capacity. It is also called a pre-actuator since it is located before the actuator in the energy chain. It can be controlled remotely by means of manually operated push buttons or automatically controlled by a physical quantity: pressure, temperature, speed, etc.
- **<u>Operating Principle</u>:**

When the electromagnet coil is energized, the contactor closes, establishing connection via the power poles. The moving part of the electromagnet drives the moving parts of the poles and auxiliary contacts, where these latter move either:

❖ By rotation, turning on an axis.

❖ By translation, sliding parallel to the fixed parts.

❖ By a combined movement of both.

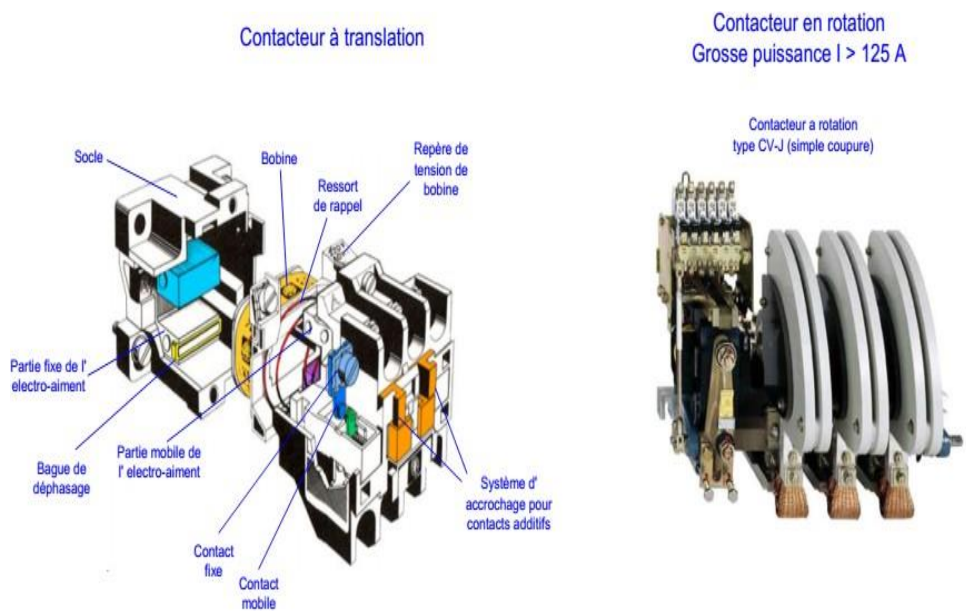


Fig.11 Contactors with translation and rotation closure.

The contactor is the first element that opens in the supply line of the receiver, load, motor, etc. As soon as the coil is de-energized (cutting the control part de-energizes the contactor coil), the magnetic circuit demagnetizes and the contactor opens under the effect of:

- ✅ The pole pressure springs.

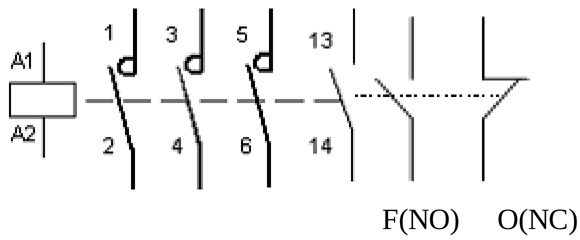
- ✅ The return spring of the moving armature.

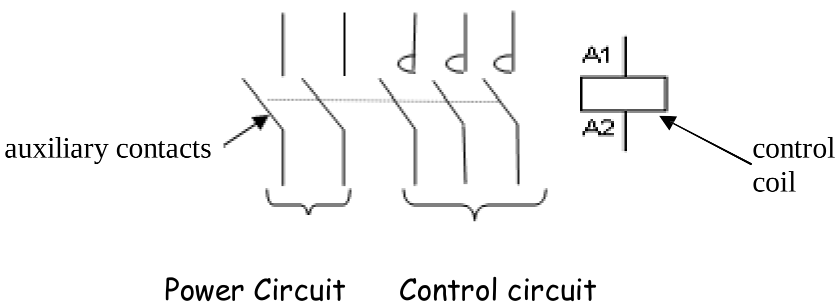
The contactor has three setting positions: stop, automatic run, and forced run (during peak hours). It can be put into operation manually or automatically.

- **<u>Role</u> :**

  Start and stop an actuator (motor, oven, transformer, etc.) under load. Its power poles are designed to withstand electric arcs; the ability to extinguish this arc (to suppress it) will therefore be ensured by its breaking capacity.

- **<u>Symbol</u> :**





- **<u>Appellation</u> :** KM, KM1, KM2...
- **<u>Main Characteristics</u>:** The characteristics of a power contactor are:

 Number of power poles ; single-pole, double-pole, three-pole, and four-pole.

 Number and type (NC, NO) of instantaneous or timed auxiliary contacts.

 Control coil voltage (24V, 110V, 220V, and 380V).

 Maximum current supported by the power poles.

 Maximum insulation voltage between power poles.

 Electrical endurance.

 Breaking capacity is on the order of 10 In.

- **<u>Construction of a Contactor</u>:**

✓ **<u>The Electromagnet</u>:**

It mainly comprises a magnetic circuit and a coil. Its shape varies depending on the type of contactor and may differ according to the nature of the supply current, AC or DC. To avoid any risk of remanence, a slight air gap is provided in the magnetic circuit in the closed position. In a magnetic circuit, the pickup stroke is the distance separating the fixed part from the moving part when the contactor is at rest; the compression stroke is the distance separating these two parts when the poles come into contact.

✓ **<u>Magnetic Circuit (AC current case)</u>:**

This circuit is characterized by: silicon steel laminations, laminated circuit to reduce eddy currents. This type can also be used without drawback in DC current.

✓ **<u>Magnetic Circuit (DC current case)</u>:**

In DC current, there are no eddy currents. Therefore, a specific electromagnet with a solid steel magnetic circuit is used.

✓ **<u>The Coil</u>:**

The role of the coil is to produce the magnetic flux necessary to attract the moving armature of the electromagnet. It is designed to withstand the mechanical shocks caused by the closing and opening of the contactors as well as the electromagnetic shocks due to the passage of current in its turns. The coils used today are particularly resistant to shocks, overvoltages, etc.

- ✓ **The Power Poles :**

These are the poles that allow establishing and interrupting the current in the power part of the installation. They are identified in the device symbol by numbers 1 to 8.

- ✓ **The Auxiliary Contacts:**

  The main functions of the auxiliary contacts are:

  - To perform latching (memory function).

  - Electrical interlocking.

  - Control sequencing.

  - Control logic.

  Auxiliary contacts are identified in the device symbol by two-digit numbers 13-14, 21-22, etc. They are located in the control circuit; either incorporated in the contactor itself or in an additional additive auxiliary block. These blocks generally clip onto the front of the contactor; there are also fewer blocks that clip laterally. Two categories are distinguished :

- **Standard (Instantaneous) Auxiliary Contacts**:

Two types of contacts exist; the normally open (NO) ⇨ contact **F**.
The normally closed (NC) ⇨ contact **O**.

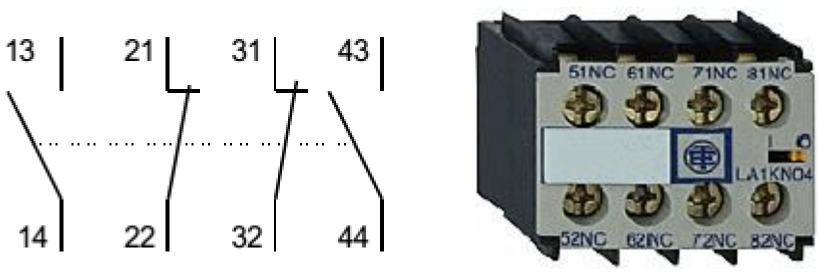


Fig.12 Instantaneous auxiliary contacts

- **Timed Contacts:**

Unlike instantaneous contacts which change position immediately upon energization or de-energization of the control coil, timed auxiliary contacts open or close after a certain time depending on the desired time delay duration. Generally, this type of contact is incorporated in an additional additive block, aiming to have the possibility to delay an action either upon operation or release, to allow equipment to function properly. For example, the star-delta starting of a three-phase squirrel-cage asynchronous motor requires timed auxiliary contacts to ensure the transition from star connection to delta connection after certain adjustable delays.

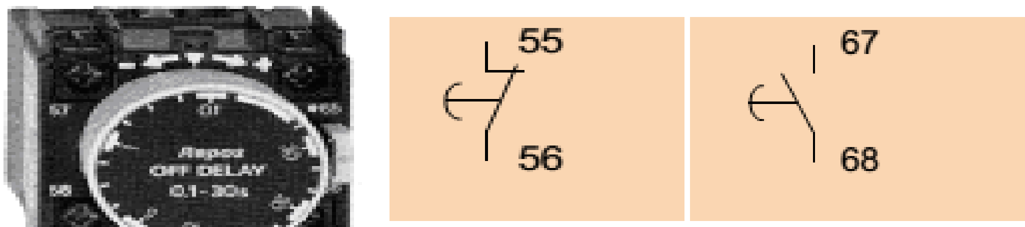
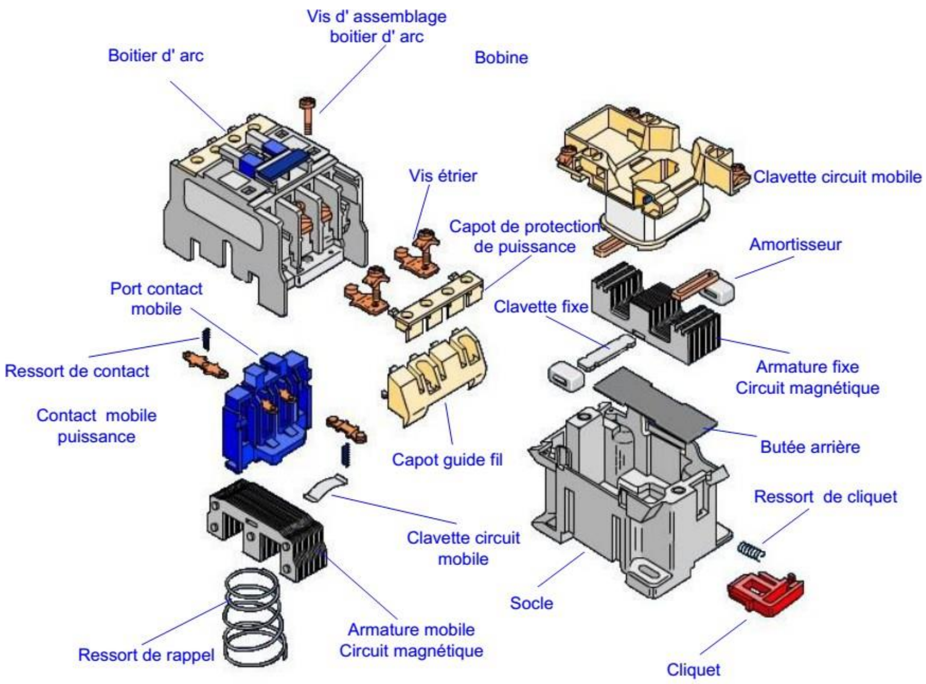


Fig.13 Timed auxiliary contacts

✓ **Exploded View of a Contactor:**



Arc chute- Coil Arc box- Strap screw- Power protection cover-
Fixed clip- Wire guide cover- Moving circuit clip- Base -Moving armature- Magnetic circuit- Pawl-
Moving circuit clip- Damper- Fixed armature - Magnetic circuit- Rear plate- Pawl spring

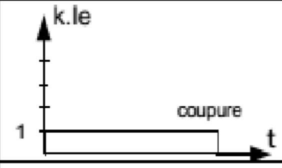
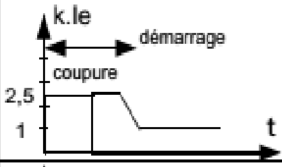
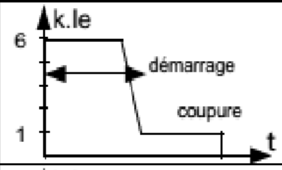
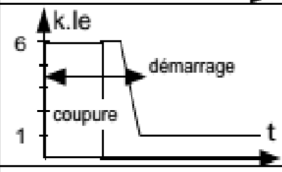
✓ <u>Selection of a Power Contactor</u>:

Several parameters come into play when choosing a contractor, primarily based on input variables: network voltage, nature of current, and frequency. Then, output variables: nature of the receiver, power, operating duration, etc.

Manufacturers, following standardized tests, have established tables that directly give the results. Once the power of the receiver to be controlled is determined, the utilization category defined, the supply voltage chosen, reading a table directly gives the suitable device to purchase.

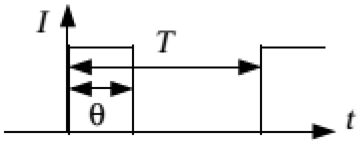
▪ Utilization Category of a Contactor:

The utilization category depends on the nature of the load and the desired application. The table below explains the different utilization categories of a contactor.

Catégorie		Description	Fermeture / Ouverture	Exemples
Alt.	AC1	tout récepteur tel que : cos phi ≥ 0,95		Chauffage, éclairage, distribution
	AC2	Commutation en régime sévère des moteurs asynchrones à bagues		Coupure en cours de démarrage, inversion rapide de marche, marche par à-coups, freinage en contre-courant
	AC3	Commutation des moteurs asynchrones à cage dont la coupure s'effectue moteur lancé		Tous moteurs à cage courants: pompe, compresseur, malaxeur, climatiseur, bande transporteuse, élévateur
	AC4	Commutation en régime sévère des moteurs asynchrones à cage		Coupure en cours de démarrage, inversion rapide de marche, marche par à-coups, freinage en contre-courant
Cont.	DC1	tout récepteur tel que : tau = L/R ≥ 1 ms	comme AC1	Charges résistives ou peu inductives
	DC3	Commutation en régime sévère des moteurs shunt tau = L/R ≤ 2 ms	comme AC2	Démarrage, inversion rapide, marche par à-coups, freinage en contre-courant
	DC5	Commutation en régime sévère des moteurs série tau = L/R ≤ 7,5 ms	comme AC2	Démarrage, inversion rapide, marche par à-coups, freinage en contre-courant

- **Duty Cycle of a Contactor:**

It is the ratio m between the duration Θ of current flow during an operating cycle and the duration T of that cycle.



$$m_{\%} = \frac{\theta}{T}$$

- **Electrical Reliability of a Contactor:**

It is the average number of operating cycles under load that the poles are likely to perform without maintenance (replacement).

Example of a table provided by manufacturers to determine the selection of a contactor.

puissances normalisées des moteurs triphasés 50/60 Hz en catégorie AC-3 (θ ≤ 60 °C)							courant assigné d'emploi en AC-3	contacts auxiliaires instantanés	référence de base à compléter par le repère de la tension (1) fixation (2)					
220 V 230V kW	380 V 400 V kW	415 V kW	440 V kW	500 V kW	660V 690 V kW	1000 V kW	440 V jusqu'à A		vis	ressort	tensions usuelles ~		⎓	BC (3)
2,2	4	4	4	5,5	5,5		9		LC1 D09•• (4)	LC1 D09•• (4)	B7	P7	BD	BL
3	5,5	5,5	5,5	7,5	7,5		12		LC1 D12•• (4)	LC1 D123•• (4)	B7	P7	BD	BL
4	7,5	9	9	10	10		18		LC1 D18•• (4)	LC1 D183•• (4)	B7	P7	BD	BL
5,5	11	11	11	15	15		25		LC1 D25•• (4)	LC1 D253•• (4)	B7	P7	BD	BL
7,5	15	15	15	18,5	18,5		32		LC1 D32•• (4)	LC1 D323•• (4)	B7	P7	BD	BL
9	18,5	18,5	18,5	18,5	18,5		38		LC1 D38•• (4)	LC1 D383•• (4)	B7	P7	BD	BL
11	18,5	22	22	22	30	22	40		LC1 D40•• (4)		B7	P7	BD	
15	22	25	30	30	33	30	50		LC1 D50•• (4)		B7	P7	BD	
18,5	30	37	37	37	37	37	65		LC1 D65••		B7	P7	BD	
22	37	45	45	55	45	45	80		LC1 D80••		B7	P7	BD	
25	45	45	45	55	45	45	95		LC1 D95••		B7	P7	BD	
30	55	59	59	75	80	75	115		LC1 D115••		B7	P7	BD	
40	75	80	80	90	100	90	150		LC1 D150••		B7	P7	BD	

(1)Tensions du circuit de commande préférentielles.
Courant alternatif

volts	24	48	115	230	400	440	500
LC1 D09...D150 (bobines D115 et D150 antiparasitées d'origine)							
50/60 Hz	B7	E7	FE7	P7	V7	R7	
LC1 D40...D115							
50 Hz	B5	E5	FE5	P5	V5	R5	S5
60 Hz	B6	E6				R6	

b. <u>Control Contactor (Separate Automation Relay)</u>:

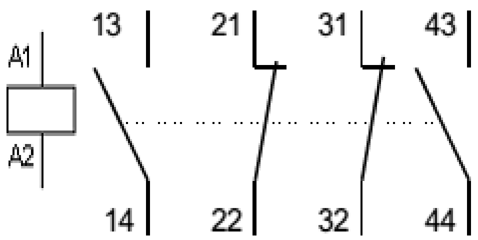
- **<u>Definition</u>:**

Also called an auxiliary contactor with low breaking capacity, whose contacts only act in control or signaling circuits (found only in the control part of the installation).

- **<u>Role</u>:**

This type of contactor ensures the control function through its auxiliary contacts under the guidance of the coil.

- **<u>Symbol</u> :**



- **<u>Appellation</u> :** KA, KA1, KA2...

- **<u>Main Characteristics</u>:** The characteristics of a control contactor are:
  - ✓ Number and type (NC, NO) of instantaneous or timed auxiliary contacts.
  - ✓ Control coil voltage (24V, 110V, 220V, and 380V).
  - ✓ Breaking capacity on the order of 2 to 3 In.

These auxiliary contacts, like those of the power contactor, are intended to ensure latching (hold), interlocking, and sequencing of contactors in equipment.

V.Protection Equipment :

- **General :**

Tout Any receiver can be the site of a number of mechanical or electrical incidents. To prevent these from causing its deterioration as well as that of the automatic contactor equipment controlling it and disturbing the supply network, it is essential to protect it. This is the role of protective devices. Among the most common incidents that can occur on a receiver (specifically a motor), we cite:

✓*Incidents of mechanical origin:*

Jamming, momentary or prolonged overloads which systematically lead to an increase in the current drawn by the motor, and thereby dangerous heating of the windings. When the overload persists, the motor is damaged, and if the line cross-section is suited to the absorbed current and the motor duty, the wires also heat up, the insulation melts, and there is a risk of fire.

✓*Incidents of electrical origin:*

Overvoltage, voltage drop, phase imbalance, loss of phase which also cause an increase in the current flowing through the windings and the supply circuit.

Protection equipment must perform the following functions:

- Protection against short circuits.
- Protection against heavy overloads.
- Protection against weak and prolonged overloads.
- Protection against insulation faults.
- Protection against single-phasing (operation with missing phase).
- Protection against excessively long or frequent starts.

Among the protection equipment, we cite:

Fuses, Protection relays, Circuit breakers, Motor protection circuit breakers (Discontacteurs), Current limiters, Voltage limiters, surge arresters (parafoudre), etc.

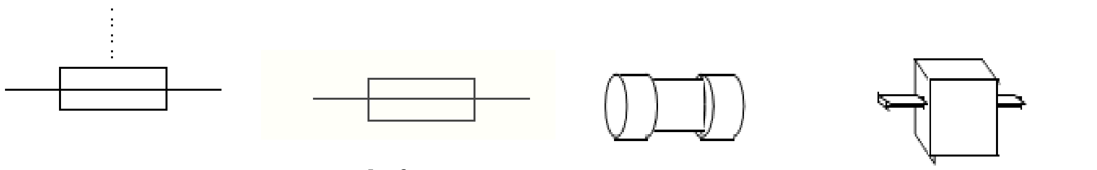
- **<u>Fuses</u>** :
- **<u>Definition</u>:**

Fuses are the weak points in electrical circuits. If there are overcurrents, that is where the circuit should break.

- **Role:**

Fuses are safety devices that protect against short circuits and very rapid and very strong overcurrents. They come in the form of a cylinder, made of glass or ceramic, whose core is traversed by a filament. The latter melts (hence the name "fuse", meaning "that can melt") when subjected to very high heat generated by an overcurrent. This aims to break the circuit and protect the equipment against potential damage or fire risks.

- **<u>Symbol</u> :**



Fuse with striker | Simple fuse | Cylindrical cartridge | Knife-blade cartridge

- **<u>Appellation</u> :** F, F1, F2, etc.
- **<u>Constitution :</u>**

Insulating tubular ceramic envelope
Silvered copper end cap
Fuse wire made of metal alloy of precise cross-section
Filling of silica powder to quickly quench the electric arc and ensure isolation after breaking

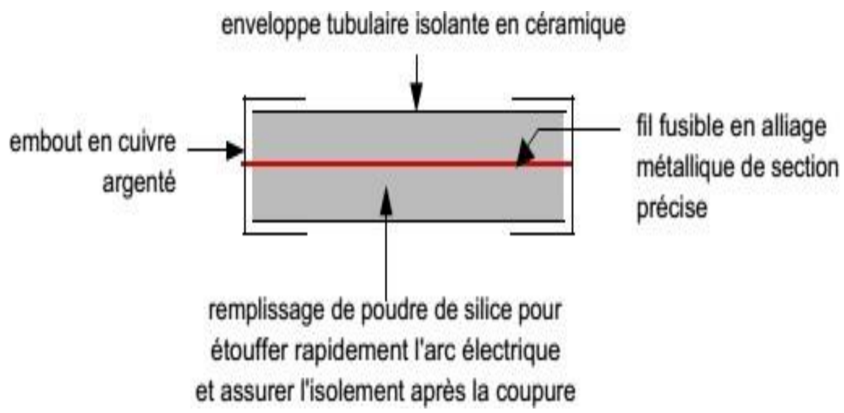


Fig.13 Constitution of a simple cylindrical fuse.

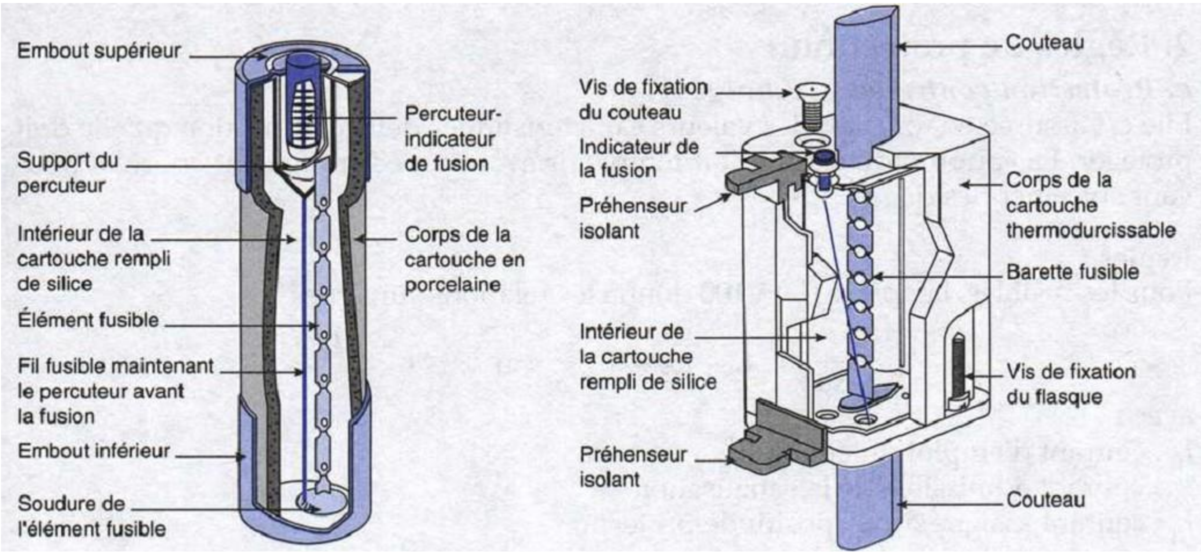


Fig.14 constitution of a fuse with striker and a knife-blade fuse.

[Image of a fuse with striker construction:]
- **Top end cap**
- Striker support
- Cartridge interior filled with silica
- Fusible element
- Fuse wire holding the striker before fusion
- Inner end cap
- Fusible element solder

[Image of a knife-blade fuse construction:]
- **Striker-fusion indicator**
- Cartridge body made of porcelain
- Knife blade fixing screw
- Fusion indicator
- Insulating grip
- Cartridge interior filled with silica
- Insulating grip

- **Knife blade**
- Thermosetting cartridge body
- Fusible link
- Flange fixing screw
- Knife blade

Fuses are found in electrical installations and can be of different types: fuse with fusion indicator, fuse with striker, and knife-blade fuse. The striker, if extended, indicates the fuse has blown and presses on a microswitch which can cut everything. A fuse is used only once and must be changed if it is damaged.

- **Operating Principle:**

The fuse consists of a fuse element in a sealed envelope. This element melts if the current passing through it exceeds the rated value. The envelope, in turn, contains sand (silica) to allow a clean break, thus preventing the maintenance of current flow through an electric arc.

Currently, fuses are in cartridges; several types are distinguished:

- **Types :**

Fuse cartridges provide protection phase by phase with high breaking capacity in a small volume. They meet the requirements of current standards and are classified as follows:

- ✓ **<u>Cartridge "distribution" type gl (gG new standards)</u>:**

These cartridges are used in domestic installations or in distribution circuits. They provide both protection against short circuits and overloads for circuits that do not have significant current peaks (example: Lighting, heating, resistive circuit). Generally, the fuse rating should be the value immediately higher than the full load current of the circuit to be protected. The conductor cross-section must also be taken into account. General use, marked in Black.

- ✓ **<u>Industrial cartridge "motor" type aM</u>:**

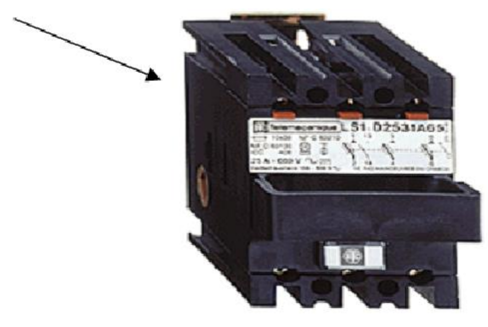
They are intended to provide only protection against short circuits on devices with high current peaks such as asynchronous motors (they withstand transient overcurrents during motor starting). In fact, they are not suitable for protection against weak and prolonged overloads (unlike type gG cartridges). This is why it is necessary to add a thermal overload relay in the motor supply circuit. Generally, their rating must be immediately higher than the full load current of the motor to be protected. Industrial use (motor, transformer, etc.), marked in green.

- ✓ **<u>Ultra-rapid cartridge UR</u>:**

They are intended mainly for electronic components (semiconductors). Use: diodes, thyristors.

All these fuse cartridges are mounted in supports called: Fuse holders or in disconnectors.

Fuse holders **Disconnectors**.



- **Characteristics of Fuses:**

They are characterized by:

- ✓ **Rated current (In):**

This is the current that can flow indefinitely through a fuse without causing excessive heating or melting. It is the fuse rating, expressed in amperes (A).

- ✓ **Network voltage (Un):**

This is the voltage of the network in which the fuse can be used, generally it is of the order of: 250, 400, 500, or 600. It is expressed in Volts (V).

- ✓ **Non-fusing current (Inf):**

This is the current that can be supported by the Fuse for a specified time without melting.

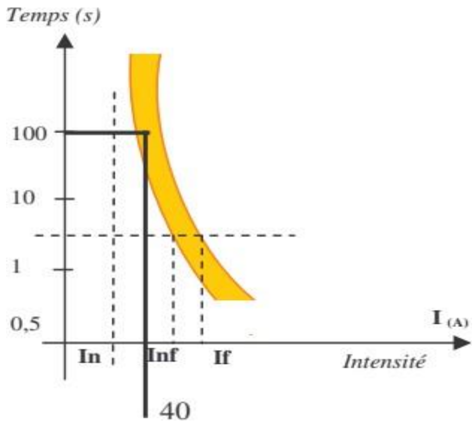


Fig.15 Time-current curves for melting and non-melting a fuse cartridge.

- ✓ **Fusing current (If):**

This is the current that causes the Fuse to melt before the end of the specified time.

- ✓ **Breaking capacity (B.C.)**:

This is the highest short-circuit current that a fuse can break while avoiding the formation of an electric arc that could dangerously delay the interruption of the current. It is expressed in kilo amperes KA (generally B.C. ≥ 50 In).

- ✓ **Limiting capacity (L.C.)**:

This is the property of a fuse cartridge to limit the intensity of the fault (short - circuit) and therefore the electrodynamic and thermal effects of the current.

✓ **<u>Breaking duration (B.D.):</u>**

This is the time that elapses between the moment when a current sufficient to cause fusion starts to flow and the end of fusion.

✓ **<u>Designation of a Fuse Cartridge</u>**:

A fuse cartridge is designated by the following elements:

- Its type (gl, gf, gG, UR, or aM).
- Its rating (A).
- Its rated voltage (V).
- Its breaking capacity (KA).
- Its size (cartridge dimension = diameter (mm) × length (mm)).

Figure.16 shows the description of a fuse cartridge well.

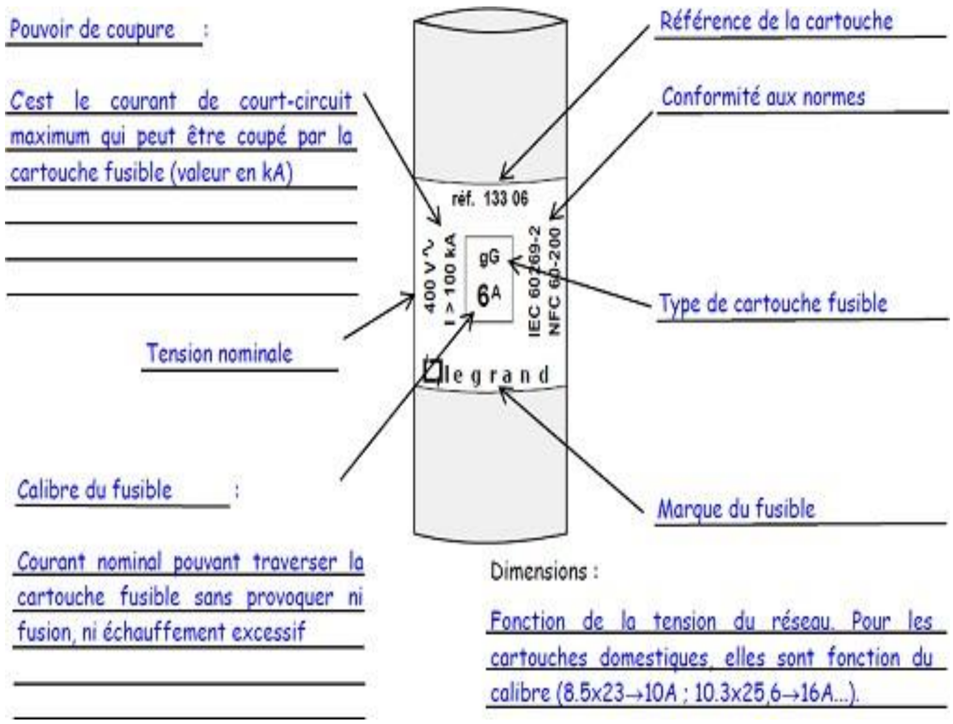


Fig.16 Designation of a fuse cartridge.

<u>Breaking Capacity:</u>

- This is the maximum short-circuit current that can be interrupted by the fuse cartridge (value in kA)

Cartridge Reference- Compliance with standards - Type of fuse cartridge- Fuse brand- Rated Voltage

- Fuse rating

- Rated current that can flow through the fuse cartridge without causing melting or excessive heating

Dimensions:
- Function of the network voltage. For domestic cartridges, they are a function of the rating (8.5x23→10A; 10.3x25.6→16A...)

- ✓ ***Thermal stress (I^2t):***:

Elle It represents the limit of energy supported by the fuse cartridge without deterioration. It is expressed in A^2s and is noted I^2t.

- **<u>Fusion curves</u>**: They allow determining the operating time of the fuse based on the current flowing through it before it melts.

  - **Cartridge type gG**

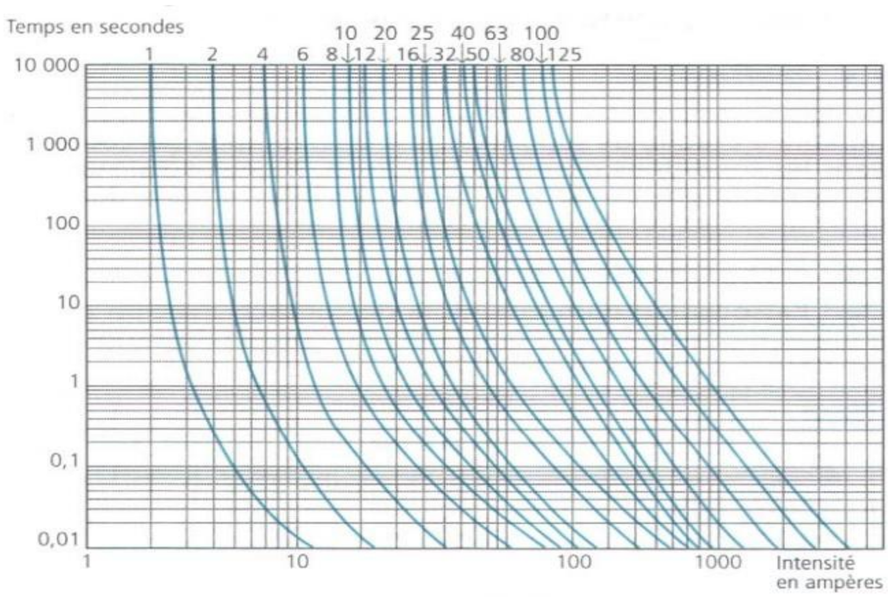


Fig.17 Fusion curves of a type gG fuse cartridge.

  - **Cartridge type aM**

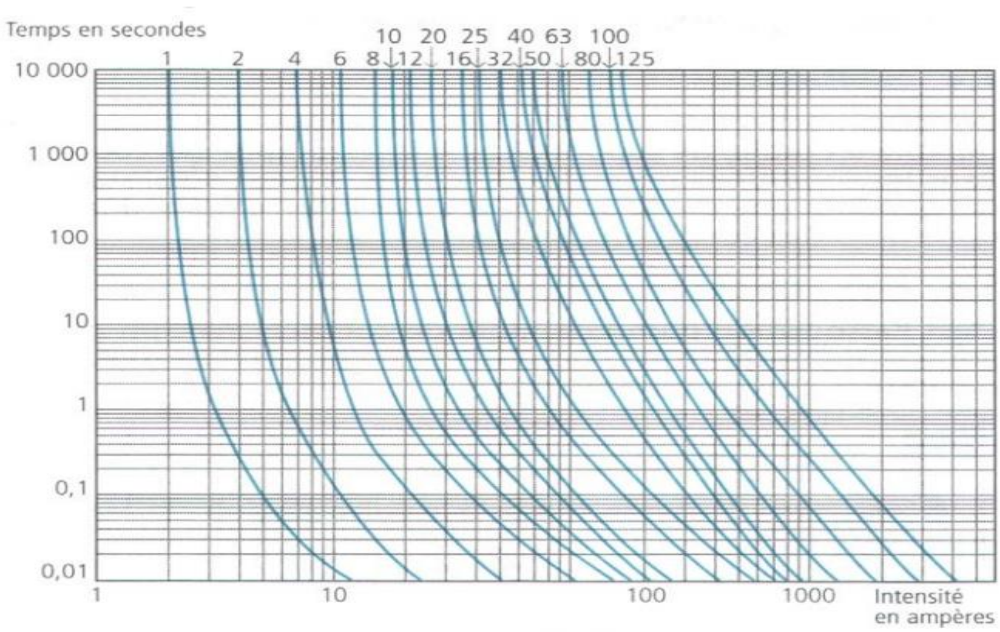


Fig.18 Fusion curves of a type aM fuse cartridge.

- **<u>Advantages and Disadvantages of Fuses</u>:**

- **Advantages:**

- Simple and easy to install.
- Low cost.
- Reduced size.
- High breaking capacity, gG and aM are called: H.R.C. (High Rupturing Capacity), as they can break overcurrents up to 100 KA RMS.
- No maintenance.
- Guaranteed.

Disadvantages:

- A fuse is used only once and must be changed. The major drawback comes from the fact that it must be replaced after use. This is why circuit breakers are increasingly used; they have the advantage of being resettable at will.
- To change a fuse cartridge, one must be authorized (B0V habilitation level implied).
- To change the fuse holder, one would need to be (B1V habilitation level implied).
- Overvoltage during fusion.
- A fuse is a resistive element, it consumes a certain amount of energy when an electric current flows through it.

- **Protection Relays**:

Relays are devices that monitor the value of an electrical parameter. They cause the opening or closing of the power circuit through their control auxiliary contacts when the current exceeds the pre-set (threshold) value. We distinguish:

a. Thermal Overload Relay:

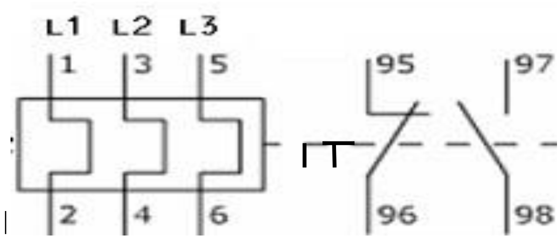
- **Definition:**

It is a protection device capable of protecting against weak and prolonged overloads. A thermal relay has no breaking function; it is intended to command the opening of a breaking device, a device which must have the required breaking capacity for the fault current to be interrupted, generally a contactor. For this purpose, thermal relays have a fault contact (NC) which is to be placed in series with the supply of the contactor coil.

- **Role:**

The thermal relay measures the current flowing in each of its power circuits and compares it with the intensity pre-set on the front. If the current is higher in one or more of its circuits, it activates the two control contacts. Moreover, if there is a current difference between the circuits (example: loss of a phase) it also trips (differential relay).

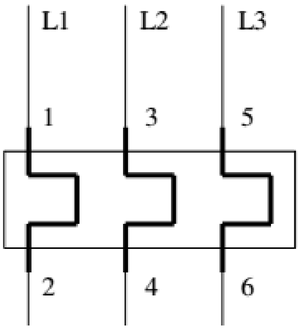
- **Symbol :**



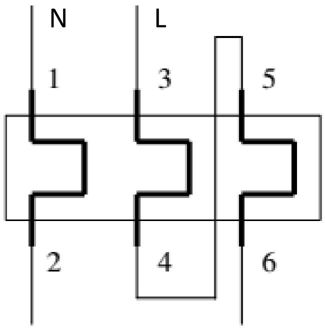
Power poles Auxiliary contacts

Thermal overload relays are usable in alternating current and direct current:

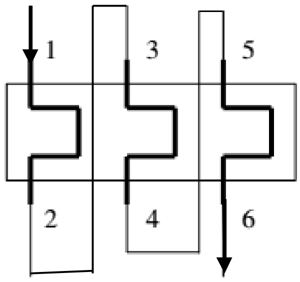
- **In three-phase network**



- **In single-phase network**

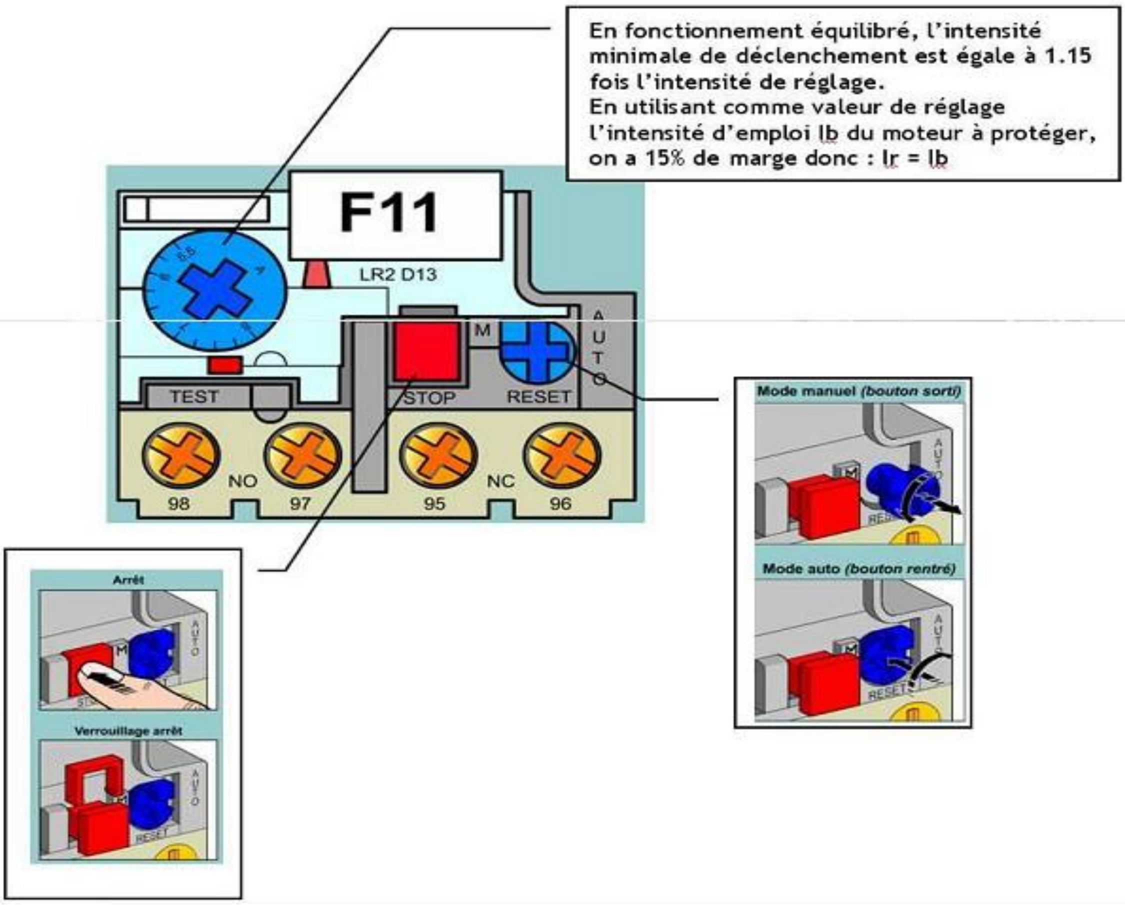


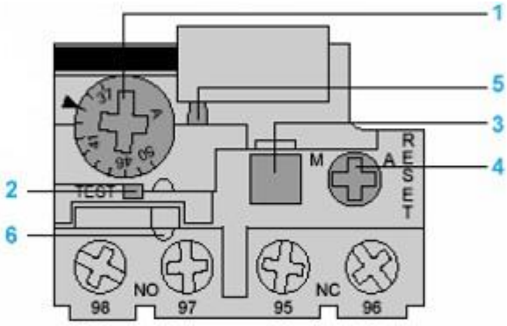
- **In direct current**



- **Appellation :** F, F1, F2 etc.
- **Constitution :**

Constitution of the front:

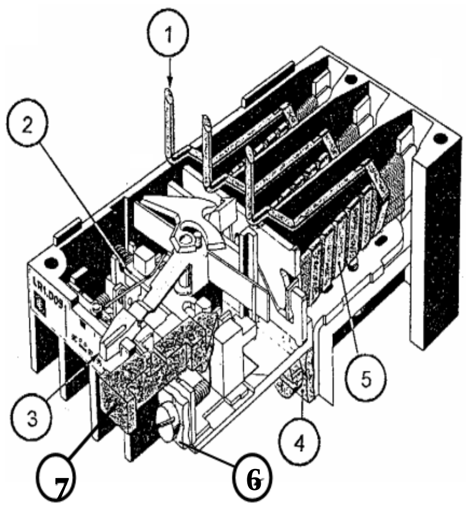


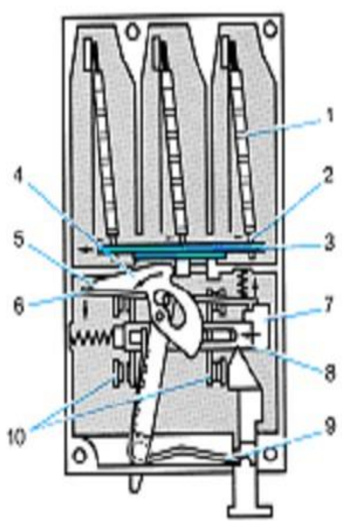


1	Bouton de réglage I_r
2	Bouton Test : L'action sur le bouton Test permet: - le contrôle du câblage du circuit de commande - lasimulation du déclenchement du relais (action sur les 2 contacts "O" et "F").
3	Bouton Stop. Il agit sur le contact "O" et est sans effet sur le contact "F
4	Bouton de réarmement et sélecteur de choix entre réarmement manuel et auto.
5	Visualisation du déclenchement
6	Verrouillage par plombage du capot

Constitution inside:

①	Arrivé du courant
②	Système de déclenchement
③	Réglage du calibre de déclenchement
④	Départ courant
⑤	Elément bimétallique
⑥	Contact auxiliaire
⑦	Bouton de réarmement





Lorsqu'un courant important parcourt les enroulements chauffants (1), les bilames (2) se déforment et les réglettes du différentiel (3) sont entraînées dans le sens de la flèche.

La came (4) est entraînée également et tourne autour de son axe. Le bord d'attaque de cette came (5) provoque la rotation du bilame de compensation (6), la butée de maintien (7) libérée laisse échapper la pièce mobile (8) qui est sollicitée par un ressort en épingle (9).

Les contacts (10) changent de position.

Sur cette figure, le relais est en position « armé », en attente de déclenchement.

1	Setting button \(I_r \)
2	Test Button: Pressing the Test button allows: - checking the wiring of the control circuit - simulating the tripping of the relay (action on both "NC" and "NO" contacts).
3	Stop Button. It acts on the "NC" contact and has no effect on the "NO" contact.
4	Reset button and selector for choice between manual and auto reset.
5	Trip indication
6	Locking by sealing the cover

Internal Construction:

①	Current input
②	Tripping system
③	Setting of the tripping rating
④	Current output
⑤	Bimetallic element
⑥	Auxiliary contact
⑦	Reset button

When a significant current flows through the heating windings (1), the bimetallic strips (2) deform and the differential adjusting rods (3) are moved in the direction of the arrow.

The cam (4) is also moved and rotates around its axis. The leading edge of this cam (5) causes the rotation of the compensation bimetal (6), the retaining stop (7) released lets the moving part (8) escape, which is actuated by a hairspring (9).

The contacts (10) change position.
In this figure, the relay is in the "armed" position, waiting to trip.

- **Operating Principle:**

The operating principle of the thermal relay is based on the deformation of its metal bimetallic strips heated by the current flowing through them. When current passes, the calibrated bimetallic strips deform and actuate the differential device whose lateral or vertical movement, depending on the relay model, causes the rotation of a cam or a shaft integral with the tripping device. When the amplitude of the deformation is sufficient, the part on which the moving parts of the contacts are fixed escapes from a retaining stop, which causes the sudden opening of the relay's auxiliary contact inserted in the contactor coil circuit.
Reset can only be carried out when the bimetallic strips are sufficiently cooled. The distance that the part must travel to escape the retaining stop depends on the set current displayed on the relay and the ambient temperature of the room in which it is placed; hence the need for correction by the compensation bimetal.

Thermal relays are generally; differential or compensated.

- **Principle of the Differential Relay:**

The differential device causes the relay to trip when the currents flowing through the three bimetallic strips are not identical (example: loss of a phase). Tripping is faster the greater the difference.

- **Principle of the Compensated Relay:**

A compensation bimetal, independent of the main bimetallic strips and subjected only to the ambient air temperature, deforms according to its variations. The displacement that the set of thermal elements must perform to cause the relay to trip is the same for temperature variations between (-40° C and + 60° C).

- **<u>Tripping Curves</u>:**

This curve is provided by the manufacturer. It gives the tripping time of the relay as a function of the set current and the fault current.

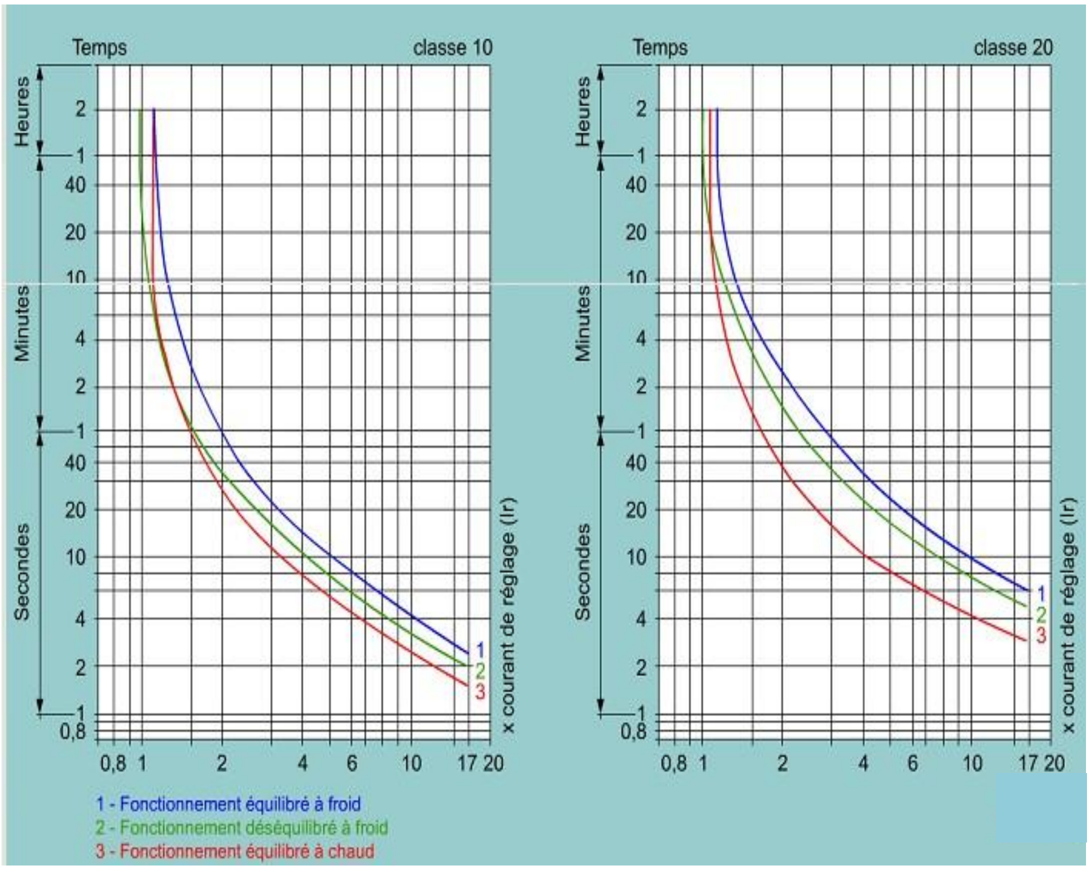


Fig. 19 Tripping Curves

- **<u>Tripping Classes</u>:**

To meet the needs of protection against overloads, the standard defines three tripping classes for thermal protection relays:

- Class 10: starting time less than 10 s.
- Class 20: starting time less than 20 s.
- Class 30: starting time less than 30 s.

	1.05 Ir	1.2 Ir	1.5 Ir	7.2 Ir
Classe	Temps de déclenchement à partir de l'état froid			
10A	>2 h	< 2h	< 2 min	$2s \leq t \leq 10s$
10	>2 h	< 2h	< 4 min	$2s \leq t \leq 10s$
20	>2 h	< 2h	< 8 min	$2s \leq t \leq 20s$
30	>2 h	< 2h	< 12 min	$2s \leq t \leq 30s$

- Table showing tripping times for different classes

- **Main Characteristics:**

- The relay rating is to be chosen according to the motor's rated current and the calculated starting time.
- Maximum current supported by the power poles.
- Setting current (Ir = In) actual tripping occurs from 1.15 to 1.2 In.
- Number of auxiliary contacts and type (NC, NO).
- Manual or automatic reset.
- Differential or temperature compensated.

The manufacturers at TELEMECANIQUE have developed a table determining the selection of thermal relays according to the motor power.

Zone de réglage du relais	Fusibles à associer			Pour montage sous contacteur	Référence	Masse
	aM	gI-gL	BS88	LC1, LP1		
A	A	A	A			kg
0,10 - 0,16	0,25	2	-	D09-D32	LR2 D13 01	0,165
0,16 - 0,25	0,5	2	-	D09-D32	LR2 D13 02	0,165
0,25 - 0,40	1	2	-	D09-D32	LR2 D13 03	0,165
0,40 - 0,63	1	2	-	D09-D32	LR2 D13 04	0,165
0,63 - 1	2	4	-	D09-D32	LR2 D13 05	0,165
1 - 1,6	2	4	6	D09-D32	LR2 D13 06	0,165
1,25 - 2	4	6	6	D09-D32	LR2 D13 X6	0,165
1,6 - 2,5	4	6	10	D09-D32	LR2 D13 07	0,165
2,5 - 4	6	10	16	D09-D32	LR2 D13 08	0,165
4 - 6	8	16	16	D09-D32	LR2 D13 10	0,165
5,5 - 8	12	20	20	D09-D32	LR2 D13 12	0,165
7 - 10	12	20	20	D09-D32	LR2 D13 14	0,165
9 - 13	16	25	25	D12-D32	LR2 D13 16	0,165
12 - 18	20	35	32	D18-D32	LR2 D13 21	0,165
17 - 25	25	50	50	D25-D32	LR2 D13 22	0,165
23 - 32	40	63	63	D25-D32	LR2 D23 53	0,320
28 - 36	40	80	80	D32	LR2 D23 55	0,320
17 - 25	25	50	50	D40-D95	LR2 D33 22	0,510
23 - 32	40	63	63	D40-D95	LR2 D33 53	0,510
30 - 40	40	100	80	D40-D95	LR2 D33 55	0,510
37 - 50	63	100	100	D50-D95	LR2 D33 57	0,510
48 - 65	63	100	100	D50-D95	LR2 D33 59	0,510
55 - 70	80	125	125	D65-D95	LR2 D33 61	0,510
63 - 80	80	125	125	D80-D95	LR2 D33 63	0,510
80 - 93	100	160	160	D95	LR2 D33 65	0,510

Table showing selection of thermal relay based on motor power (kW)

b. Magnetic Protection Relay:

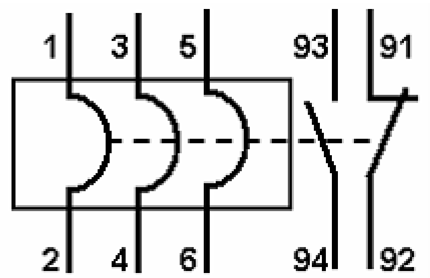
- **Definition:**

It is a protection device that protects against short-circuits. It is a relay with instantaneous operation, whose tripping threshold is adjustable. It is intended to control the opening of a breaking device, a device which must have the required breaking capacity for the fault current to be interrupted, generally a contactor. For this purpose, magnetic relays have a fault contact (NC) which is to be placed in series with the supply of the contactor coil.

- **Role:**

The magnetic relay measures the current flowing in each of its power circuits and compares it with the intensity pre-set on the front. If the current is higher in one or more of its circuits, it actuates the two control contacts. Moreover, if there is a current difference between the circuits (example: loss of a phase) it also trips (differential relay).

- **Symbol :**



Power poles Auxiliary contacts

- **Appellation :** F, F1, F2 etc.

- **Operating Principle:**

The operating principle of the magnetic relay is based on the attraction of a magnetic core by the magnetic field created by the current flowing through the coils. When the current exceeds the pre-set value, the core is attracted, causing the opening of the NC contact and the closing of the NO contact.

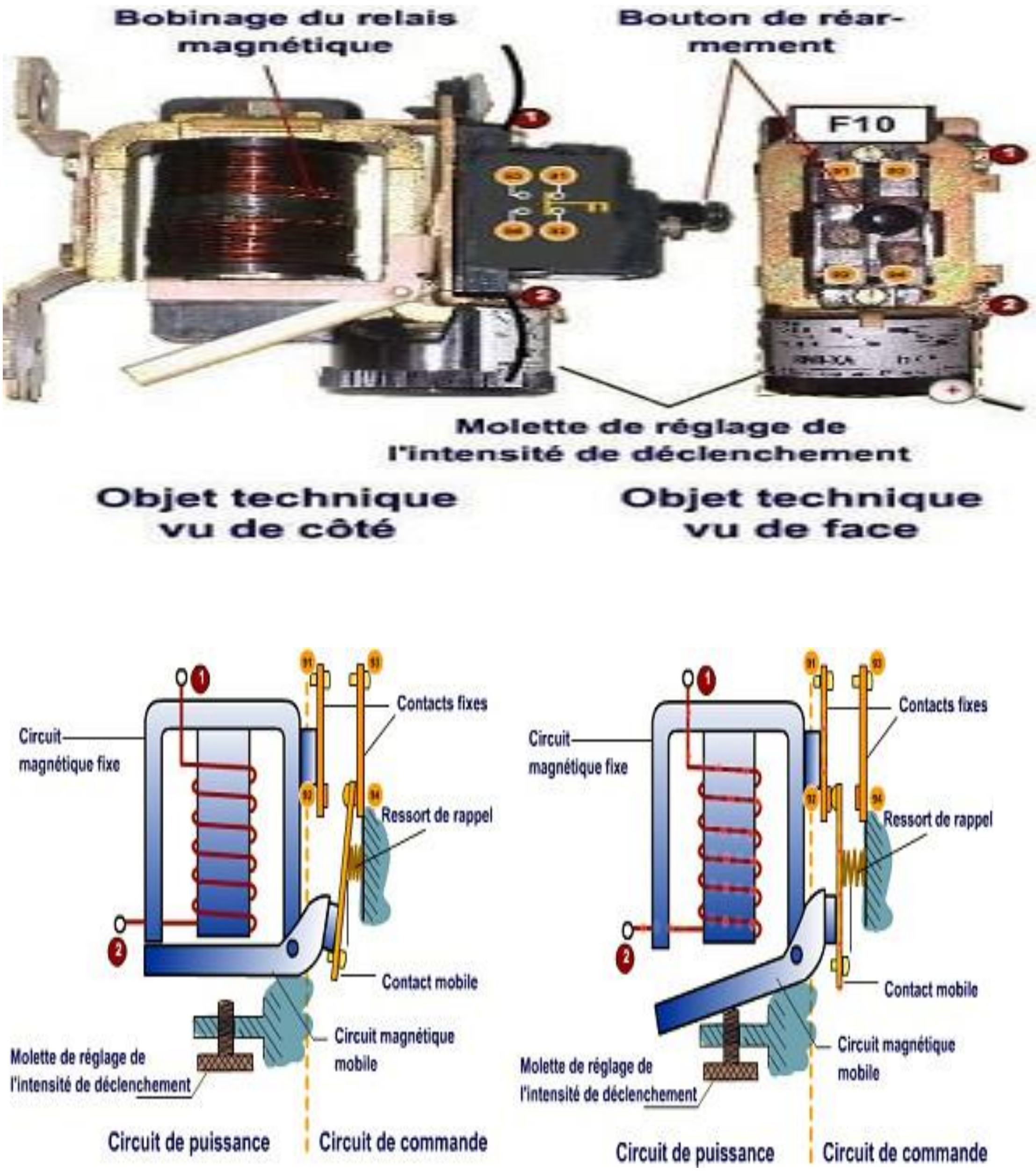


Fig.20 Relais magnétique ayant fonctionné à la suite d'une surintensité

La rigidité de ressort permet de fixer pour quelle valeur du courant se fera la coupure.

Pour réarmer le relais magnétique, il faut intervenir manuellement.

c- Undervoltage Protection Relay:

- Definition:

  It is a protection device that protects against voltage drops. It is a relay with instantaneous operation, whose tripping threshold is adjustable. It is intended to control the opening of a breaking device, a device which must have the required breaking capacity for the fault current to be interrupted, generally a contactor. For this purpose, undervoltage relays have a fault contact (NC) which is to be placed in series with the supply of the contactor coil.

- **Role**:

The undervoltage relay measures the voltage of the network and compares it with the voltage pre-set on the front. If the voltage is lower in one or more of its circuits, it actuates the two control contacts. Moreover, if there is a voltage difference between the circuits (example: loss of a phase) it also trips (differential relay).

- **Operating Principle**:

The operating principle of the undervoltage relay is based on the attraction of a magnetic core by the magnetic field created by the voltage applied to the coil. When the voltage drops below the pre-set value, the core is released, causing the opening of the NC contact and the closing of the NO contact.

- **Main Characteristics:**

- The relay rating is to be chosen according to the motor's rated voltage and the calculated starting time.

- Maximum voltage supported by the power poles.

- Setting voltage (Ur = Un) actual tripping occurs from 0.85 to 0.9 Un.

- Number of auxiliary contacts and type (NC, NO).

- Manual or automatic reset.

- Differential or temperature compensated.

d- Phase Failure and Unbalance Protection Relay:

- **Definition:**

It is a protection device that protects against phase failure and unbalance. It is a relay with instantaneous operation, whose tripping threshold is adjustable. It is intended to control the opening of a breaking device, a device which must have the required breaking capacity for the fault current to be interrupted, generally a contactor. For this purpose, phase failure and unbalance relays have a fault contact (NC) which is to be placed in series with the supply of the contactor coil.

- **Role:**

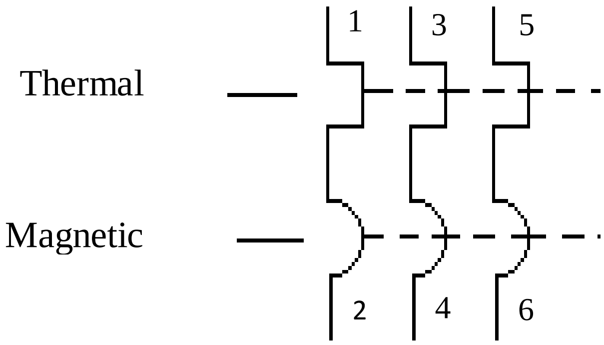
The phase failure and unbalance relay measures the current flowing in each of its power circuits and compares it with the intensity pre-set on the front. If the current is not identical in the three circuits, it actuates the two control contacts. Moreover, if there is a current difference between the circuits (example: loss of a phase) it also trips (differential relay).

c. Magnetothermal Relays:

- **Definition:**

The magnetothermal relay is designed to protect motors against overloads. Its triggering is delayed for low overloads and instantaneous for high overcurrents. It is therefore the combination of a thermal relay and a magnetic relay, the first against low and prolonged overloads, the second ensuring protection against sudden overcurrents, probably short circuits. It is available in different sizes; single-pole, double-pole and three-pole.

- **Symbol :**



- **Operating principle:**

Depending on the nature of the incident, two tripping methods are considered: delayed thermal tripping and instantaneous magnetic tripping.

❖ Delayed thermal tripping:

If the current exceeds the setting value, the bimetallic strip heats up, deforms, and after a certain time releases the stop. The stop-blade assembly tilts, and the lever arm acting on the transmission shaft causes the contact to open. Reset can only be performed when the bimetallic strip has cooled sufficiently.

❖ Instantaneous magnetic tripping:

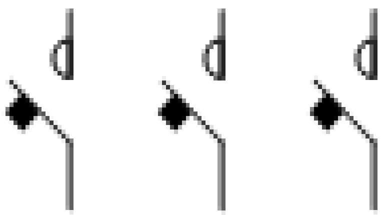
If the current quickly reaches a high value before the bimetallic strip has had time to deform sufficiently to release the stop, the moving magnetic armature is attracted and opens the control contact, which causes the contactor to trip and, consequently, the power circuit.

- **<u>Discontactors</u>**:

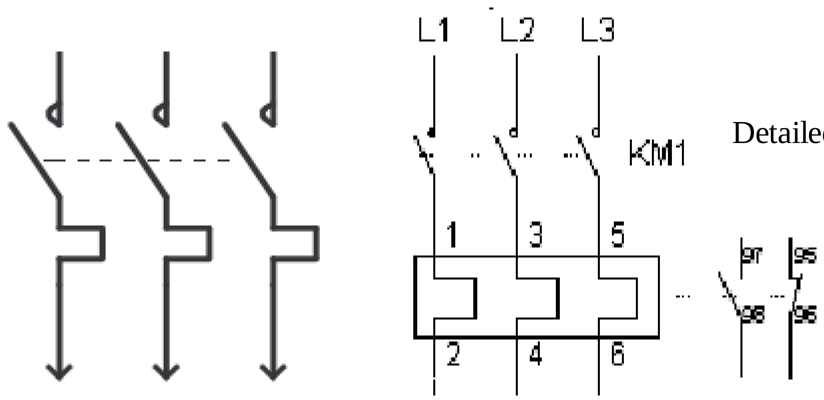
  - **<u>Definition</u>:**

This is the combination of a contactor and a thermal relay. In the power circuit, each heating coil must be connected to each phase or polarity of the load to be protected.
In the control circuit, the relay's trip contact must be connected in series with the contactor coil circuit that controls the load's power supply.

  - **<u>Symbol</u> :**



Simplified symbol



Detailed symbol

  - **<u>Role</u>:**

This combination has a breaking capacity equal to that of the contactor (10 In). Protection against overloads and against single-phase operation is provided by the thermal relay compensated according to the ambient temperature and equipped as previously with a phase imbalance protection device.

- **<u>Circuit Breakers</u>**:

- **<u>Definition</u> :**

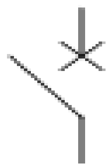
A circuit breaker is a protection device capable of making, carrying and breaking currents under normal circuit conditions and also making, carrying for a specified time and breaking currents under specified abnormal circuit conditions such as those of short-circuit. It is a device that combines the functions of a switch and a fuse. It is resettable and can be used multiple times.

- **<u>Role</u> :**

The power poles of a circuit breaker can act as a switch; they are capable of withstanding overcurrents and overvoltages. The circuit breaker is also equipped with a trip system that causes it to open automatically. The trip system allows the circuit breaker poles to open in the event of a fault. It can be thermal, magnetic, or magnetothermal; electronic trip systems also exist. There is a mechanical connection between each trip system and the system that causes the main poles to open. The magnetic trip unit has a significant breaking capacity, capable of interrupting short-circuit currents. Circuit breakers have two main functions:

- To cut and disconnect: the role of the main poles.
- To protect against short circuits and overloads: the role of the magnetic trip unit and the thermal trip unit.

- **<u>General symbol</u>:**



- **<u>Appellation</u> :** Q, Q1, Q2 etc.

  - **<u>Constitution :</u>**

Operating handle, Moving contact, Fixed contact, Bimetallic strip (thermal protection), Magnetic coil (magnetic protection), Arc chute, Terminal.

- **Operating Principle:**

The operating principle of the circuit breaker is based on the deformation of its metal bimetallic strip heated by the current flowing through it and the attraction of a magnetic core by the magnetic field created by the current flowing through the coil. When current passes, the calibrated bimetallic strip deforms and actuates the tripping device. When the amplitude of the deformation is sufficient, the part on which the moving parts of the contacts are fixed escapes from a retaining stop, which causes the sudden opening of the circuit breaker's contacts. Similarly, when the current exceeds the pre-set value, the core is attracted, causing the opening of the contacts.

Circuit breakers are classified according to the number of poles, the breaking capacity, the rated current, etc. We distinguish:

✓ Miniature Circuit Breakers (MCB)

✓ Molded Case Circuit Breakers (MCCB)

✓ Air Circuit Breakers (ACB)

✓ Oil Circuit Breakers (OCB)

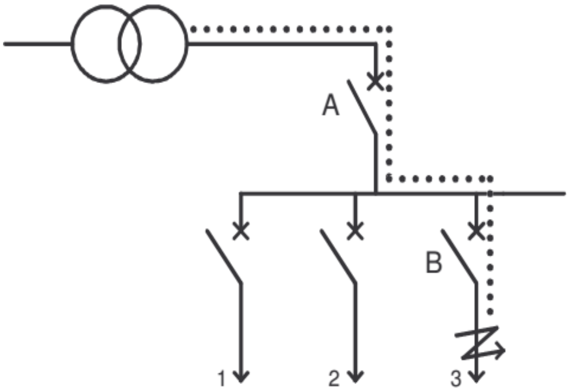
✓ SF6 Circuit Breakers

- **Basic characteristics:**

Circuit breakers are characterized by

- ✓ Nominal current (In): This is the maximum current the device can withstand under specific heating and operating conditions (steady state). Its value is indicated in the device's designation (rating).
- ✓ Nominal voltage (Un): This is the maximum operating voltage.
- ✓ Operating current (Im): This is the current that triggers tripping in the event of high overcurrents. It can be fixed or adjustable and can vary between 1.5 In and 20 In.
- ✓ Setting current (Ir): This is the maximum current the circuit breaker can withstand without tripping. It can be adjustable from 0.7 In to 10 In for thermal trip units, from 5 In to 10 In for magnetic trip units, and from 0.4 In to 10 In for electronic trip units.
    - ✓ Breaking capacity (pdc): This is the highest (presumed) short-circuit current intensity that a circuit breaker can interrupt at a given voltage. It is expressed as e (KA), generally greater than 30 In.
    - ✓ Limiting capacity (pdl): This is the capacity of a circuit breaker to only allow a current lower than the presumed short-circuit current to pass.
    - ✓ The number of power poles: single-pole (1p), double-pole (2p), three-pole (3p), and four-pole (4p).
    - ✓ Protection type: There are two categories: general circuit breaker and branch circuit breaker (modular).
    - ✓ Circuit breaker selectivity: This is the coordination of circuit breakers such that a fault occurring at any point in the installation is eliminated by the circuit breaker located immediately upstream of the fault, and by it alone. The choice allows total selectivity from the point of view of overloads and low short circuits. On the other hand, selectivity is only partial for high short circuits.

Consider the diagram opposite:



In the event of a fault on feeder 3:

There is discrimination if only circuit breaker B opens (fault clearance).
• In the event that the fault on feeder 3: causes circuit breakers B and A to open.
There is no longer discrimination.

Two classic parameters involved in the selection of discrimination are:

o Tripping current values: Current discrimination.
o Tripping time: Time discrimination.

There is also logic discrimination.

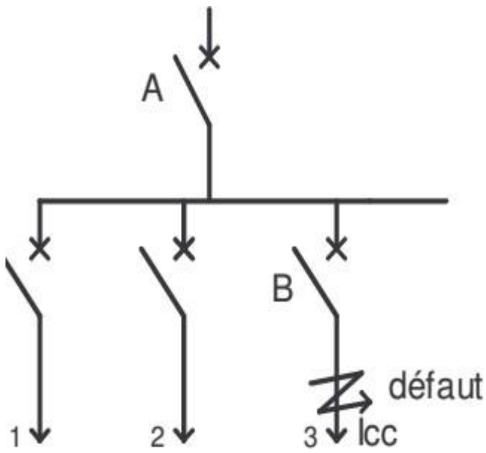
❖ **Amperometric selectivity:**

This selectivity is linked to the settings of the Im tripping thresholds of the magnetic trip units on the upstream and downstream circuit breakers.

The circuit breakers' ability to reduce the disturbed surface area to the smallest possible size, therefore

If the short circuit is located on feeder 3, IscB: maximum possible short-circuit current downstream of circuit breaker B.

Two possibilities may arise: Depending on the value of IscB relative to the circuit breaker setting threshold Im.



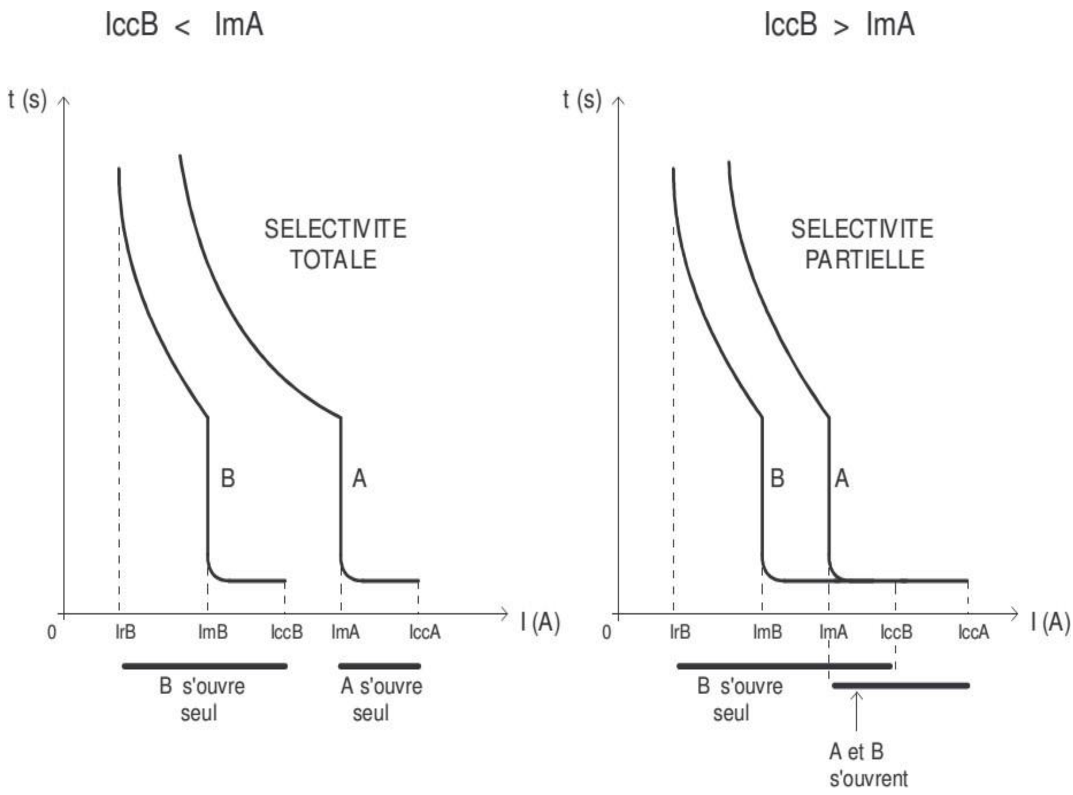


Fig.21 Current selectivity between two circuit breakers

Selectivity is often difficult to achieve, because the difference between IccB and IccA is generally insufficient. In this case, selectivity is partial and limited to the ImA setting intensity of the magnetic trip unit of the upstream circuit breaker.

- **Chronometric selectivity:**

This selectivity consists of delaying the tripping of the upstream circuit breaker relative to that of the downstream circuit breaker. The upstream circuit breaker is called a "selective" circuit breaker. It is equipped with a tripping delay, adjustable to several levels.

We say there is total time selectivity if the total tripping time of downstream circuit breaker B is less than the non-tripping time of upstream circuit breaker A.

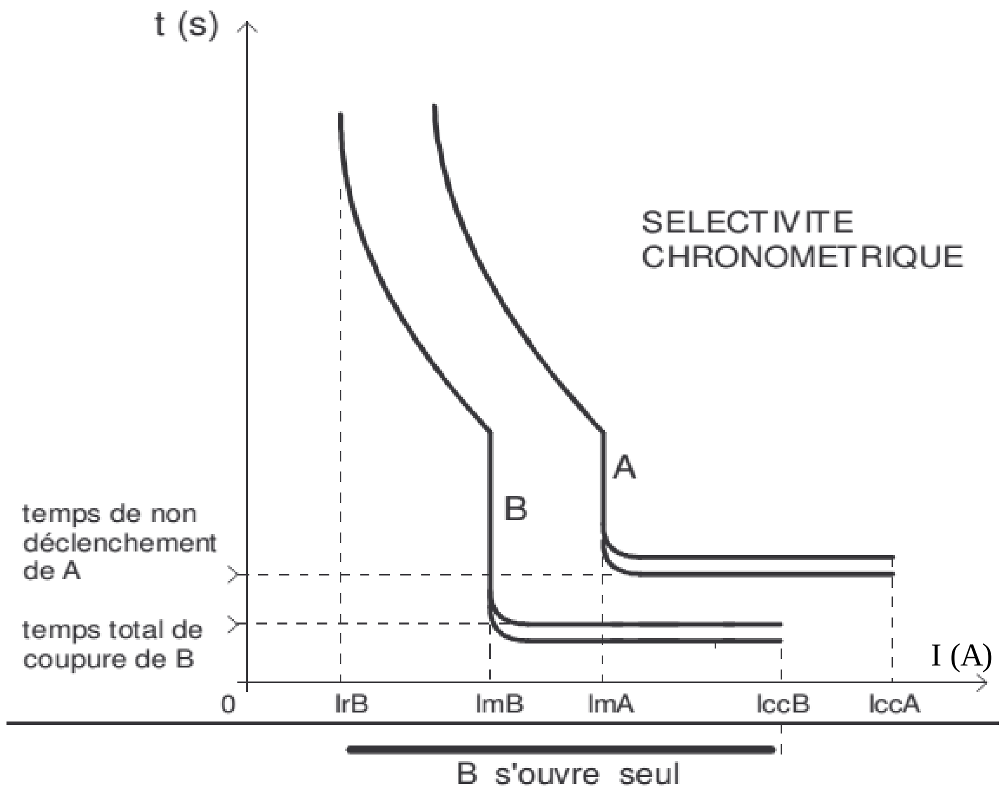


Fig.22 Time selectivity between two circuit breakers.

❖ <u>**Logical selectivity:**</u>

Each circuit breaker is associated with a logic relay that receives "fault" information from sensors. When the relay is triggered by a fault, it sends:

- ✓ A wait command to the upstream relay's own time delay (increase command to the upstream relay's own time delay).
- ✓ A trip command to the circuit breaker with which it is associated (unless it has itself received a wait command from the downstream stage).

This selectivity can be used across all networks, from the main Low Voltage Outgoing (LVO) circuits to the General Low Voltage (GLV) circuit breaker.

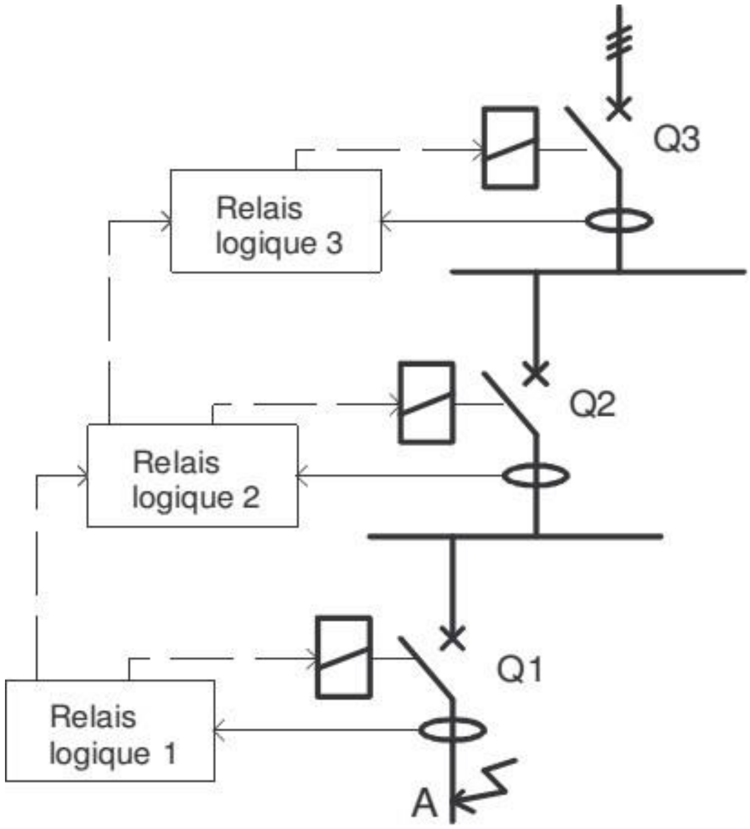


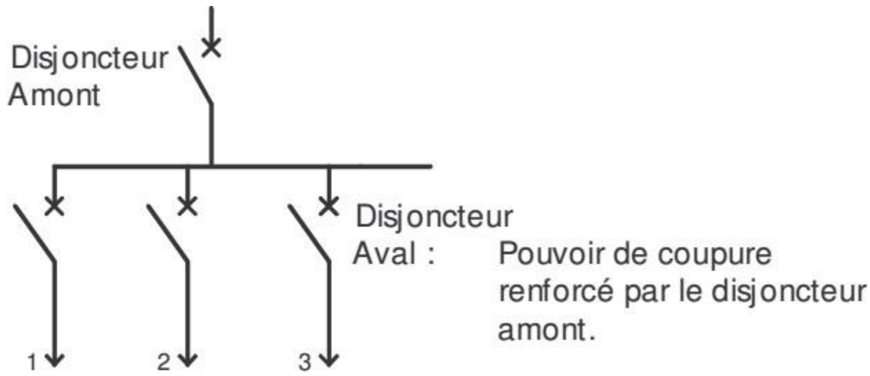
Fig.23 Logical selectivity between two circuit breakers.

When a fault occurs at point A, this fault will be detected by the three circuit breakers on the downlink:

- ✓ Relay 1 puts relay 2 on standby and trips circuit breaker Q1.
- ✓ Relay 2 puts relay 3 on standby.

✓ **The Circuit Breakers Filiation**:

The filiation is an association technique that utilizes the current-limiting capability of circuit breakers. This allows for the installation of downstream circuit breakers with a lower breaking capacity, thereby reducing the overall installation cost. Circuit breaker discrimination makes it possible to install a less robust circuit breaker downstream, as the upstream circuit breaker acts as a barrier against high short-circuit currents. It can also enhance the breaking capacity of a downstream circuit breaker. However, establishing a discrimination relationship between an upstream and a downstream circuit breaker means that full selectivity between them can no longer be achieved.



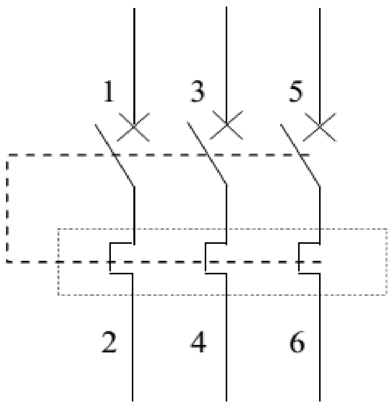
- **<u>Different types of circuit breakers:</u>**

  We distinguish:

- ✓ Thermal circuit breakers
- ✓ Magnetic circuit breakers
- ✓ Thermal-magnetic circuit breakers
- ✓ Residual current circuit breakers

a. <u>Thermal circuit breaker</u>:

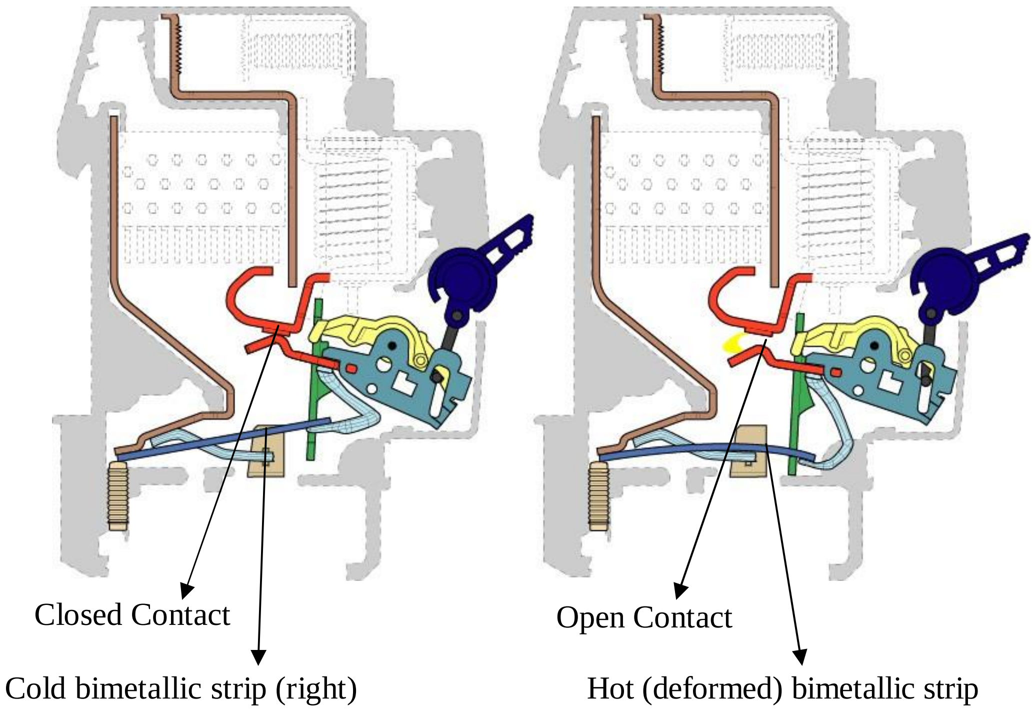
- **<u>Symbol</u> :**



- **<u>Function</u> :** protection against overloads due to a network anomaly (overvoltage) or a mechanical cause (excessive resistive torque when starting an asynchronous motor, for example).

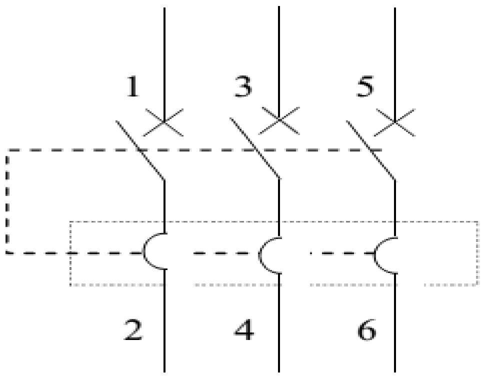
- **Operating Principle:**

Thermal trip devices detect low overloads using a bimetallic element called a bimetallic strip that deforms (twists) due to heating caused by overloads. When triggered, the circuit breaker opens, eliminating the fault.



b. Magnetic circuit breaker:

- **Symbol :**



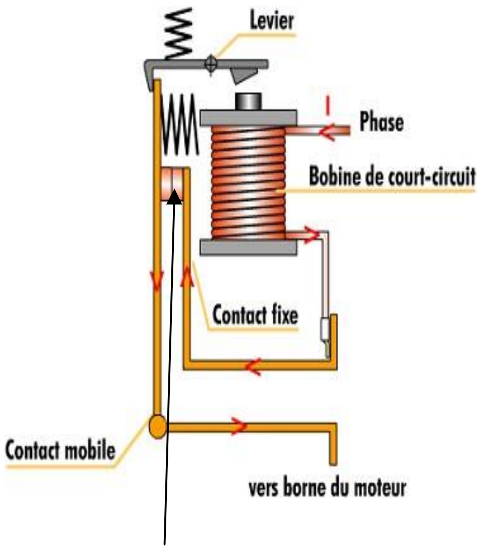
Function: Short-circuit protection:

- ✓ Impedance short circuit $10 \leq Isc \leq 50$ In, often caused by deterioration of conductor insulation (motor winding).
- ✓ Isc short circuit ≥ 50 In, caused, for example, by a connection error during a maintenance operation.

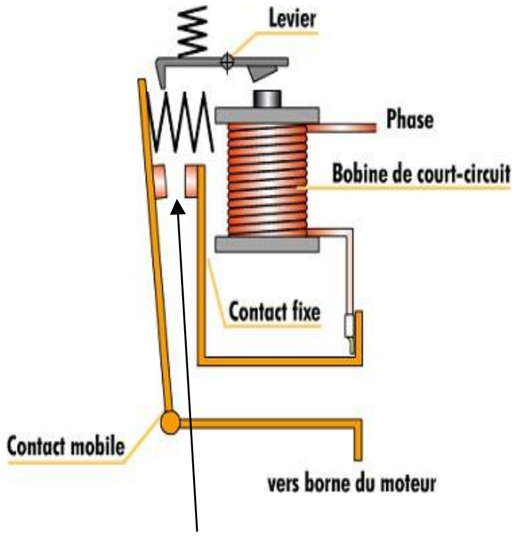
- **Operating Principle:**

Magnetic trip devices detect and protect against high overloads and short-circuit currents. Their triggering, caused by the movement of the magnetic armature attached to the moving contact, opens the circuit breaker, thus eliminating the fault. During normal operation, the current flowing through the coil of the magnetic circuit is not sufficient for the magnetic field it creates to attract the armature. The electrical circuit is therefore closed.

During a short circuit, this current will increase very suddenly, and consequently create a strong field sufficient to attract the magnetic armature, causing the electrical circuit to open.



Closed Contact

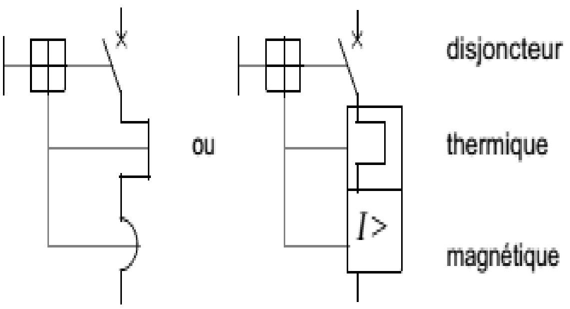


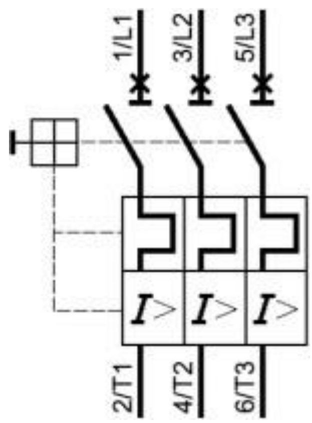
Open Contact

c. Magnetothermal circuit breaker:

It is the combination of a thermal circuit breaker and a magnetic circuit breaker

- **Symbol :**



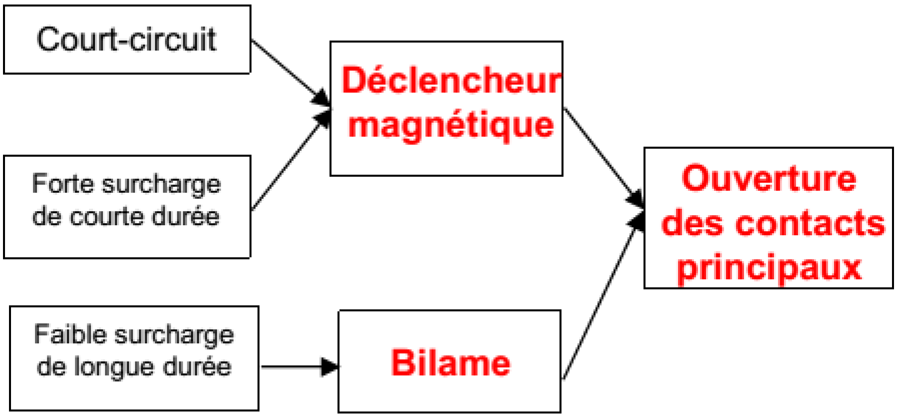


- **Function:**

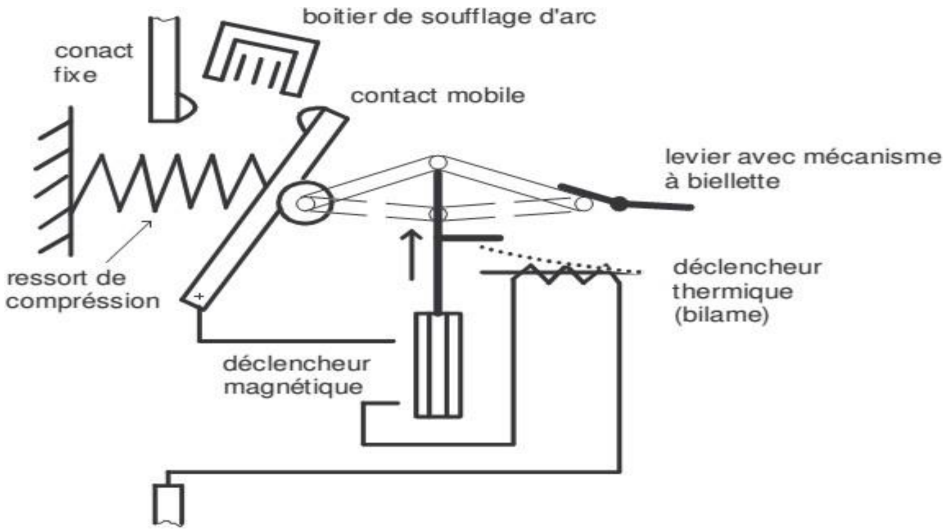
The thermal-magnetic circuit breaker protects property against short circuits, short-term heavy overloads and long-term light overloads.

- **Operating Principle:**

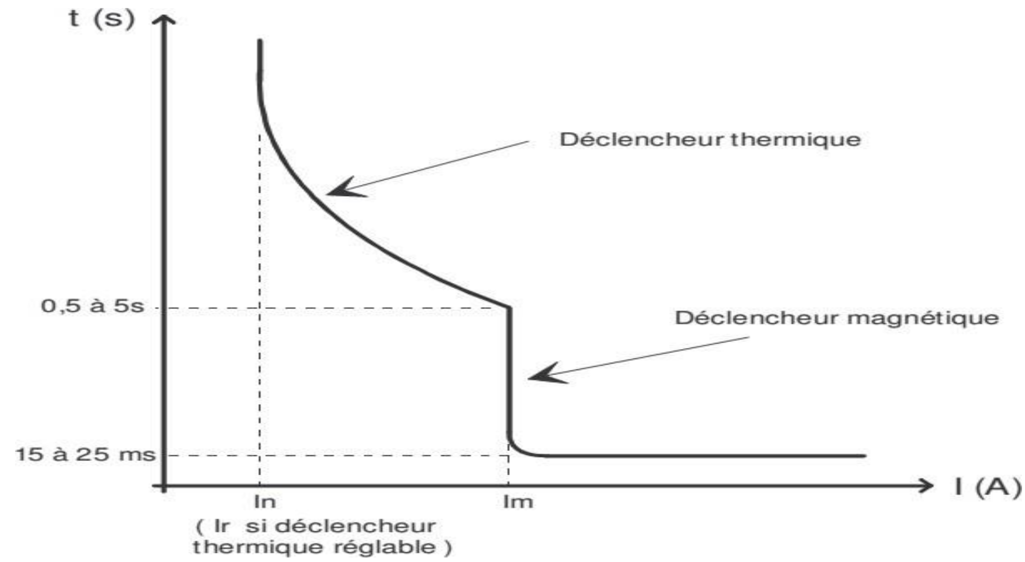
Thermal-magnetic circuit breakers have a magnetic trip unit per phase and a bimetallic strip per phase. In the event of a high overcurrent or short circuit (current much higher than the setting current Ir), the magnetic trip unit acts on a mechanical system which opens the main poles; in the event of a low overload (current slightly higher than Ir) of long duration, the bimetallic strip acts on the same mechanical system.



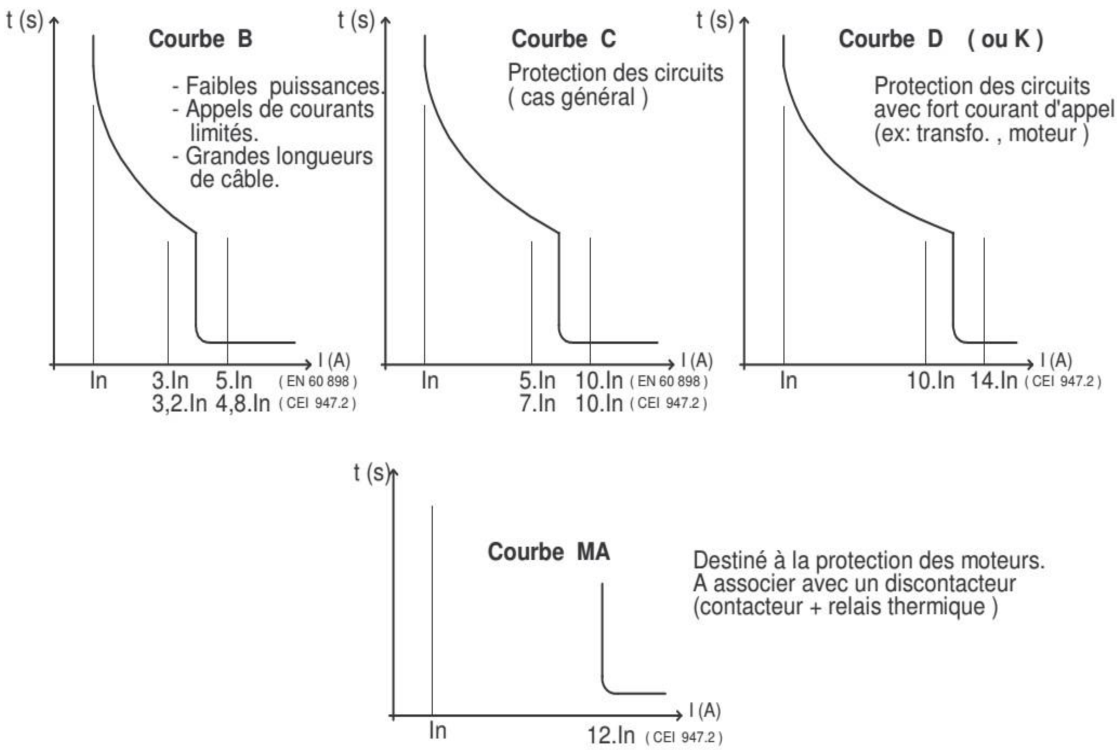
- **General structure of a magnetothermal circuit breaker:**



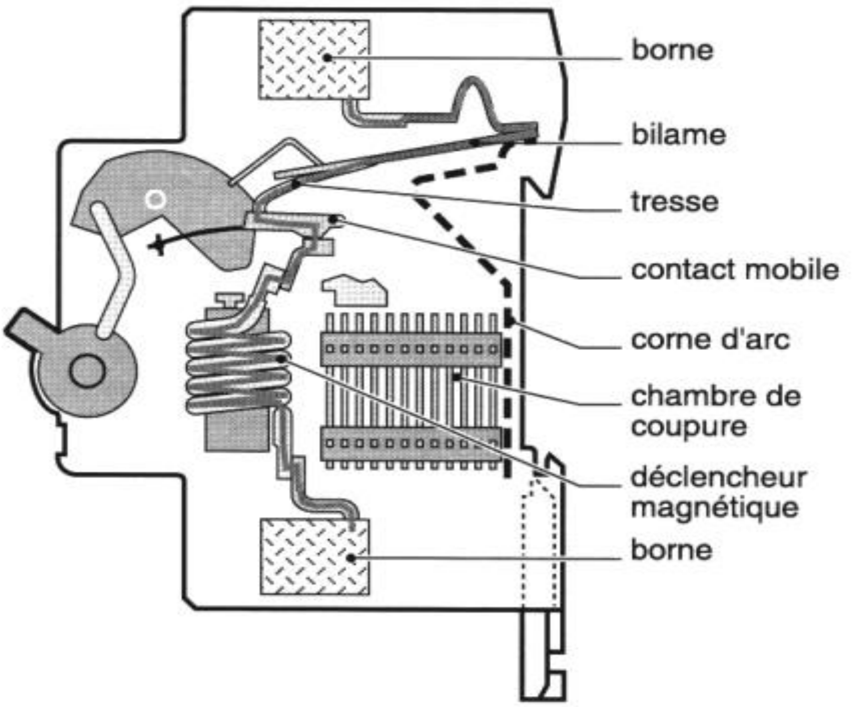
- **Operating curve**: this is the superposition of the tripping curves of thermal trip devices (bimetallic strip) and the tripping curves of electromagnetic trip devices (electromagnet). It represents the tripping time of the magnetothermal circuit breaker as a function of the multiples of the setting intensity Ir.

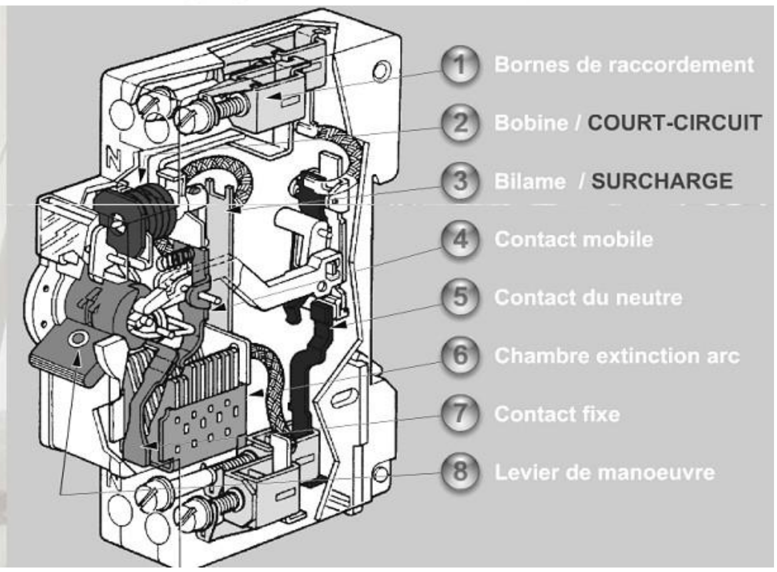


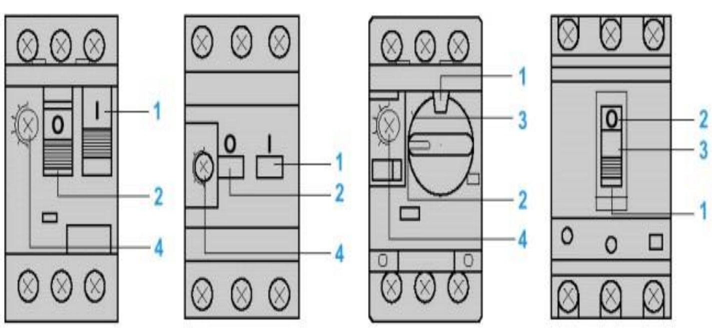
The standardized trigger curves types: B, C, D and MA according to the manufacturing standards (IEC 947-2 and EN 60 898), are given as follows:



- **Constitution:**







1 : Enclenchement manuel par poussoir, bouton rotatif ou levier basculant

2 : Déclenchement manuel

3 : Position de déclenchement automatique « Trip » du bouton rotatif ou du levier

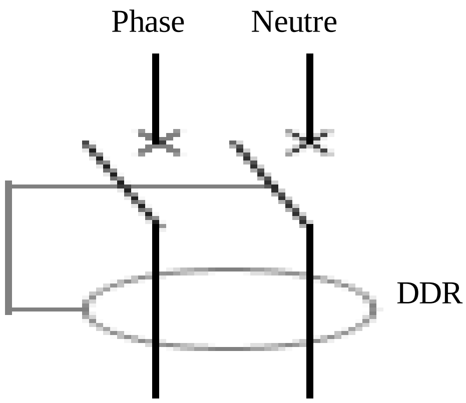
4 : Réglage du déclencheur thermique (bilame) par bouton gradué

d. <u>Differential circuit breaker:</u>

This is a combination of a residual current device (RCD) and a thermal-magnetic circuit breaker. The residual current device (RCD) is primarily characterized by its sensitivity (IΔn), which depends on the location of use (industrial, domestic, etc.). The following classes are distinguished:

- ✓ High-sensitivity RCDs: IΔn ≤ 30 mA.
- ✓ Medium-sensitivity RCDs: IΔn varies from 100 mA, 300 mA, 500 mA to 1 A.
- ✓ Low-sensitivity RCDs: IΔn varies from 3 mA, 5 mA, 10 mA to 20 mA.

- **<u>Symbol</u> :**



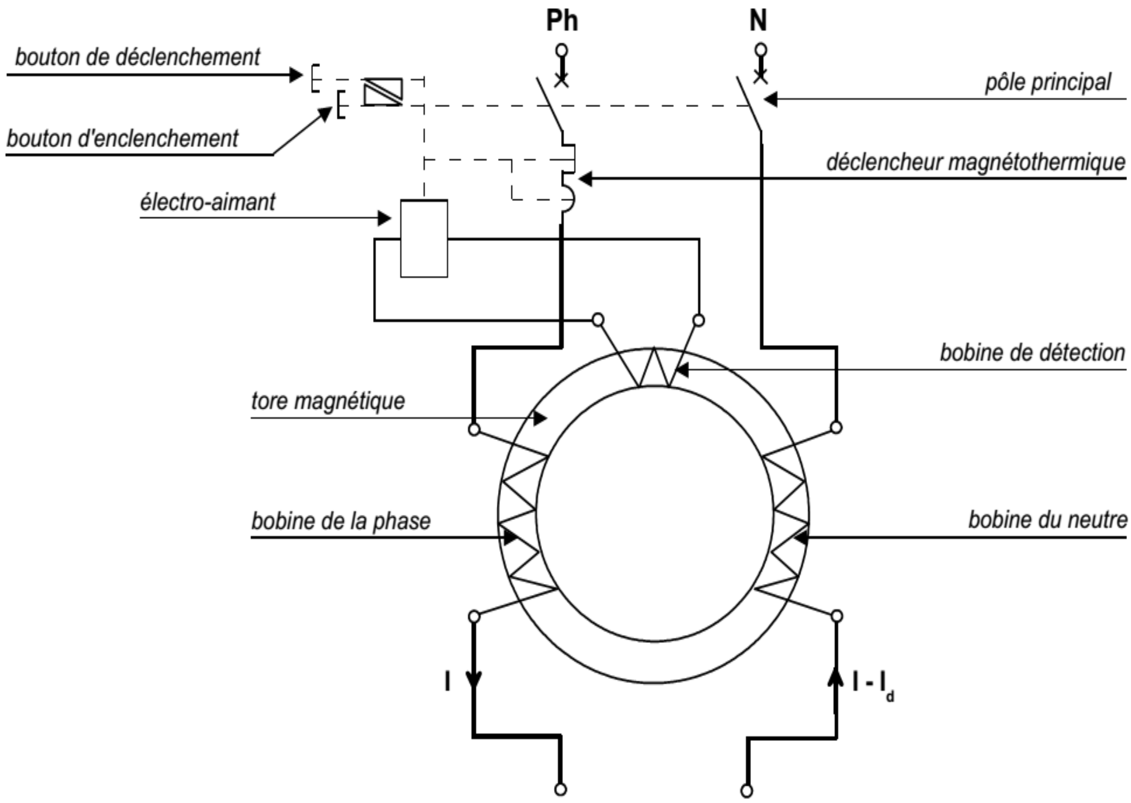
- **<u>Function</u> :**

Protection of people in TT system against indirect contact (risk of electrocution), it also fulfills all the functions of the magnetothermal circuit breaker.

- **<u>Operating Principle</u>:**

The residual current device consists of three coils placed on a magnetic circuit called a toroid:

- ✓ The phase coil corresponding to the incoming current Ie.
- ✓ The neutral coil corresponding to the outgoing current Is.
- ✓ The detection or trigger coil corresponding to the leakage current If.



During normal operation, the current flowing in the phase is equal to the current flowing in the neutral. Since the phase and neutral coils are connected in opposite directions, the flux generated by the two coils is zero in the toroid, and the trip coil detects no flux. Therefore, during normal operation, we must have:

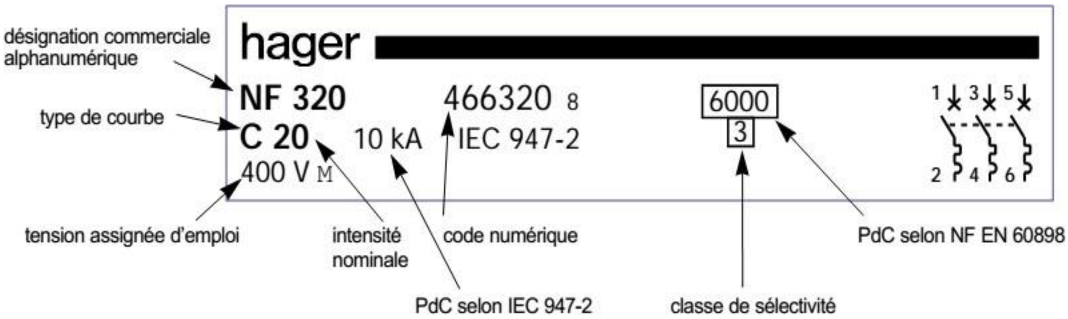
o Single-phase: Iph1 + In = 0

o Three-phase without neutral: Iph1 + Iph2 + Iph3 = 0

o Three-phase with neutral: Iph1 + Iph2 + Iph3 + In = 0

During an earth leakage fault (case of a person in indirect contact with a live metal frame), part of the phase current is diverted by the earth. The entire phase current no longer flows in the neutral coil, so the two currents (Iph + In $\neq$ 0) are no longer equal. An imbalance is then created at the level of the toroid, which allows the electromagnet to be powered by the flux detected by the trigger coil. The latter then gives the order to open the trigger circuit and consequently the opening of the power poles.

- **Example of technical data of a circuit breaker:**



- **Classification and choice of circuit breakers:**

There are three types of circuit breakers:

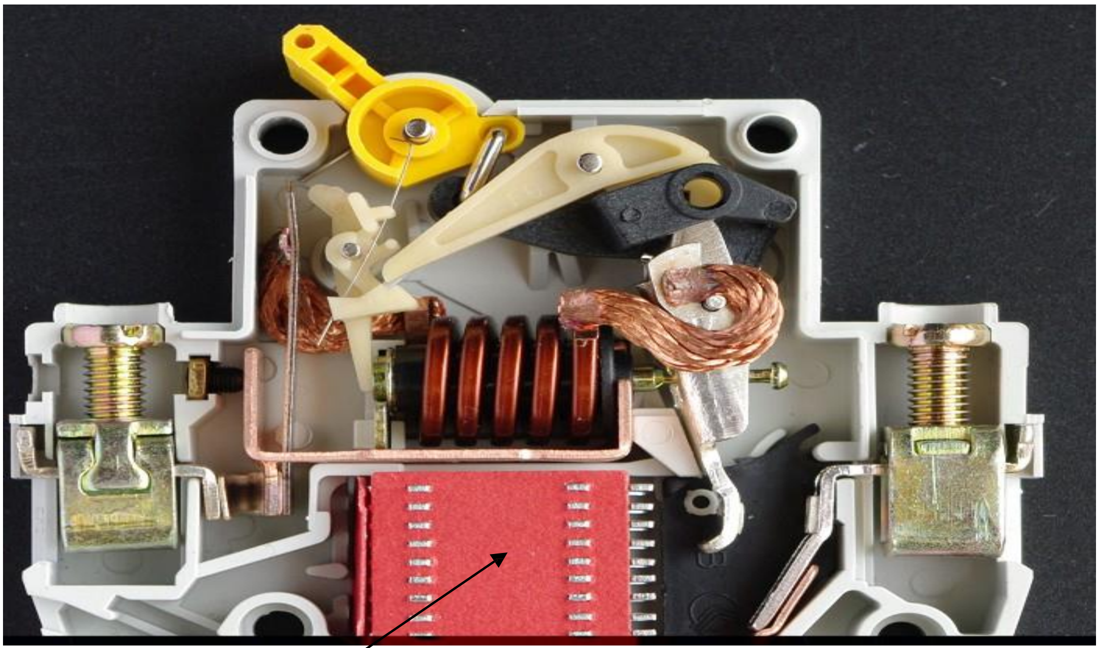
- Branch circuit breakers; ratings (10-15-20-25-32A).
- Low-voltage distribution circuit breakers:
  - Molded case circuit breakers; ratings (from 20A to 1250A).
  - Metal-frame circuit breakers; ratings (from 800A to 6300A).
- Medium (MV) and high-voltage (HV) circuit breakers.

The choice of a circuit breaker is based on:

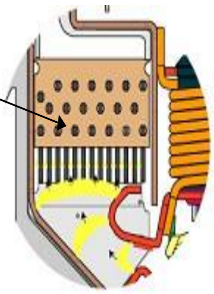
- The installation standard (domestic, industrial, etc.).
- Production standards.
- Network characteristics (voltage, frequency).
- The environment (type of premises, temperature, cross-section, and type of downstream cables).
- Operating requirements (selectivity, control auxiliaries, etc.).

- **Arc extinguishing technique in the arc chamber:**

The role of the arc chute is to attract and extinguish the arc during a short circuit that occurs between the contacts during breaking. As soon as the contacts separate, the arc is moved towards the arc chute under the effect of the so-called Laplace force, induced by the geometry of the fixed and moving contacts.



Cutting chamber



During its journey between the contacts and the chamber, the arc is channeled between two flanges that:

- ✓ Increase its travel speed.
- ✓ Guide its trajectory.
- ✓ Lengthen it.

Due to their construction and the increase in temperature, the side flanges release a gas that contributes to the deionization of the air. Then, penetrating the copper-plated steel tabs, the arc is divided into several elementary arcs. Deionization of the air inside the chamber is also achieved by cooling and exhausting the ionized air from the product. To achieve this, manufacturers use the mass of the tabs and vent it to the outside, at the top of the product. Several (medium) techniques used to extinguish the arc in circuit breakers include: SF6 gas, compressed air, oil, etc.

IV. Development of electrical diagrams:

- **Definition :**

The electrical diagram aims to best represent the electrical circuit using standardized symbols. Standardization exists at the international level, with the goal of achieving a common language for electricians that makes it easier to write, read, and understand electrical diagrams. Symbol standardization also allows any technician to read an electrical diagram more quickly. The main purpose of an electrical diagram is:

o To explain how the equipment works.

o To provide the basics for establishing and implementing installations.

o To facilitate commissioning.

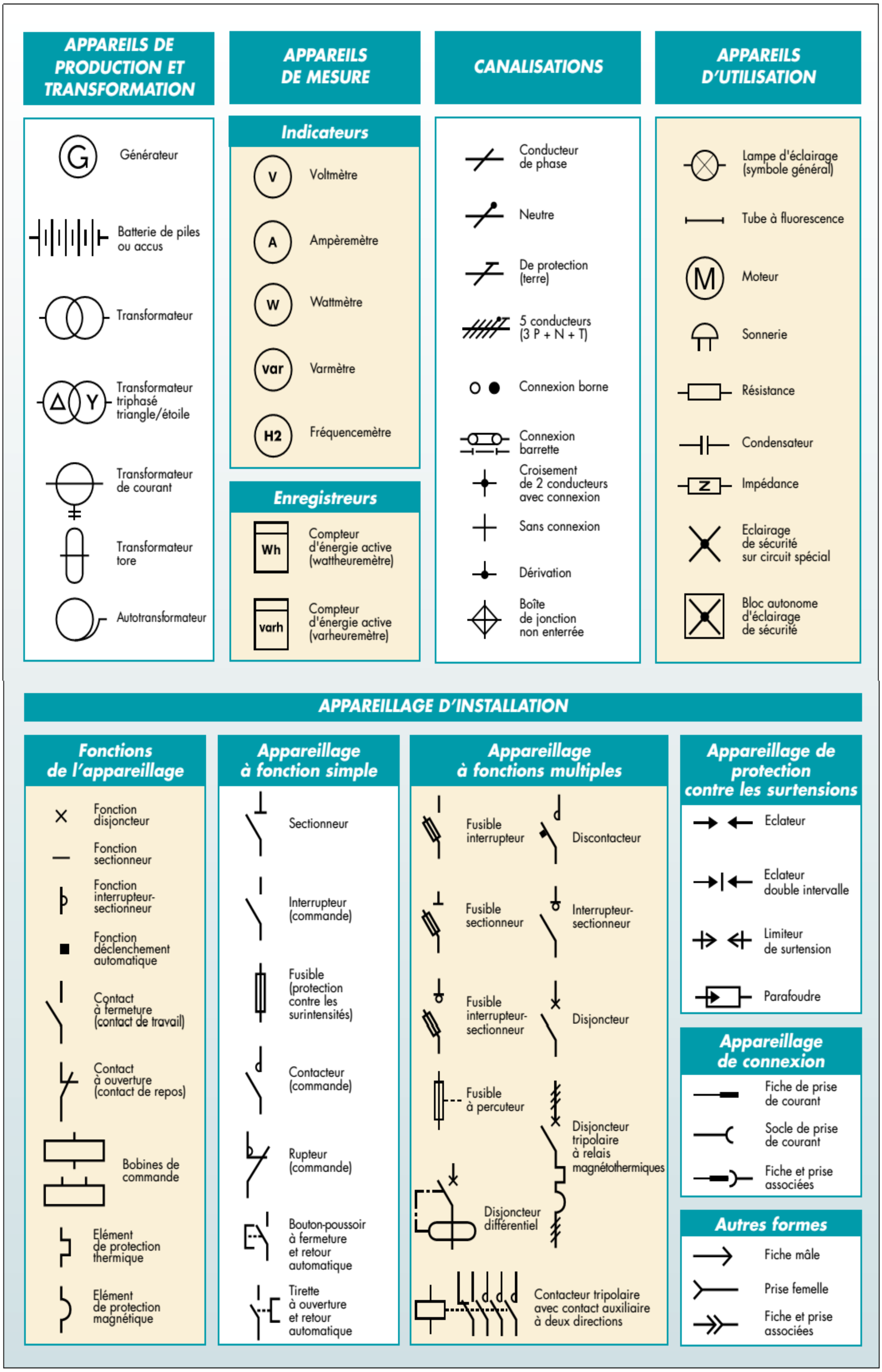
o To facilitate faster maintenance and repairs.

- **Symbols and standardizations:**

To represent an electrical circuit, the use of a diagram and standardized symbols is very practical. The table below is intended to facilitate the creation of electrical installation diagrams. These symbols are those that have been adopted internationally. They are intended to define the layout of electrical equipment not only in the architectural plan of houses, dwellings, and other domestic buildings, but also in the construction of industrial facilities. It is clear that the electrical installation must be the subject of a diagram or table indicating, in particular:

 The nature and composition of the circuits (points of use served, number and cross-section of conductors, nature of conduits, etc.).

 The characteristics of the devices providing protection, separation, control, etc. functions.



APPAREILS DE PRODUCTION ET TRANSFORMATION
G
Générateur
Batterie de piles ou accus
Transformateur
Δ Y
Transformateur triphasé triangle/étoile
Transformateur de courant
Transformateur tore
Autotransformateur
APPAREILS DE MESURE
Indicateurs
V
Voltmètre
A
Ampèremètre
W
Wattmètre
var
Varmètre
H2
Fréquencemètre
Enregistreurs
Wh
Compteur d'énergie active (wattheuremètre)
varh
Compteur d'énergie active (varheuremètre)
CANALISATIONS
Conducteur de phase
Neutre
De protection (terre)
5 conducteurs (3 P + N + T)
Connexion borne
Connexion barrette
Croisement de 2 conducteurs avec connexion
Sans connexion
Dérivation
Boîte de jonction non enterrée
APPAREILS D'UTILISATION
Lampe d'éclairage (symbole général)
Tube à fluorescence
M
Moteur
Sonnerie
Résistance
Condensateur
Z
Impédance
Eclairage de sécurité sur circuit spécial
Bloc autonome d'éclairage de sécurité
APPAREILLAGE D'INSTALLATION
Fonctions de l'appareillage
Fonction disjoncteur
Fonction sectionneur
Fonction interrupteur-sectionneur
Fonction déclenchement automatique
Contact à fermeture (contact de travail)
Contact à ouverture (contact de repos)
Bobines de commande
Elément de protection thermique
Elément de protection magnétique
Appareillage à fonction simple
Sectionneur
Interrupteur (commande)
Fusible (protection contre les surintensités)
Contacteur (commande)
Rupteur (commande)
Bouton-poussoir à fermeture et retour automatique
Tirette à ouverture et retour automatique
Appareillage à fonctions multiples
Fusible interrupteur
Discontacteur
Fusible sectionneur
Interrupteur-sectionneur
Fusible interrupteur-sectionneur
Disjoncteur
Fusible à percuteur
Disjoncteur tripolaire à relais magnétothermiques
Disjoncteur différentiel
Contacteur tripolaire avec contact auxiliaire à deux directions
Appareillage de protection contre les surtensions
Eclateur
Eclateur double intervalle
Limiteur de surtension
Parafoudre
Appareillage de connexion
Fiche de prise de courant
Socle de prise de courant
Fiche et prise associées
Autres formes
Fiche mâle
Prise femelle
Fiche et prise associées

- **<u>Classification of electrical diagrams:</u>**

Electrical diagrams can be classified in several ways (domestic, industrial, simple, complex, etc.), but the most common classification is based on two terms:

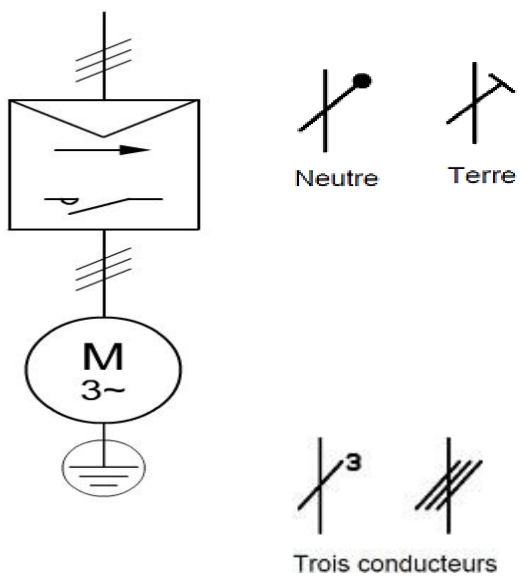
- ➢ According to the intended purpose: examples:
    - ✓ Schematic diagram.
    - ✓ Functional diagram.
    - ✓ Implementation diagram.

- ➢ According to the representation method: we are interested in three factors:
    - ✓ Number of conductors.
    - ✓ Location of symbols.
    - ✓ Topographic representation.

1- **Classification according to the number of conductors:**

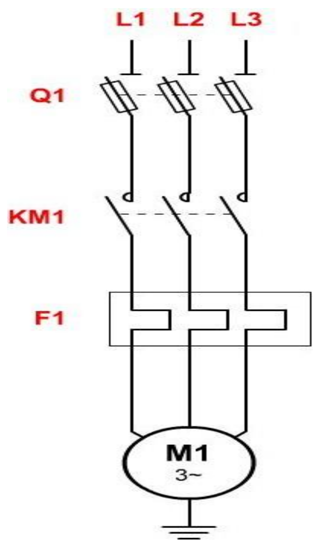
a) <u>Single-line representation :</u>

Consists of representing two or more conductors with a single line. Example: direct starting of a three-phase squirrel-cage asynchronous motor, one direction of operation only.



b) Multi-wire representation:

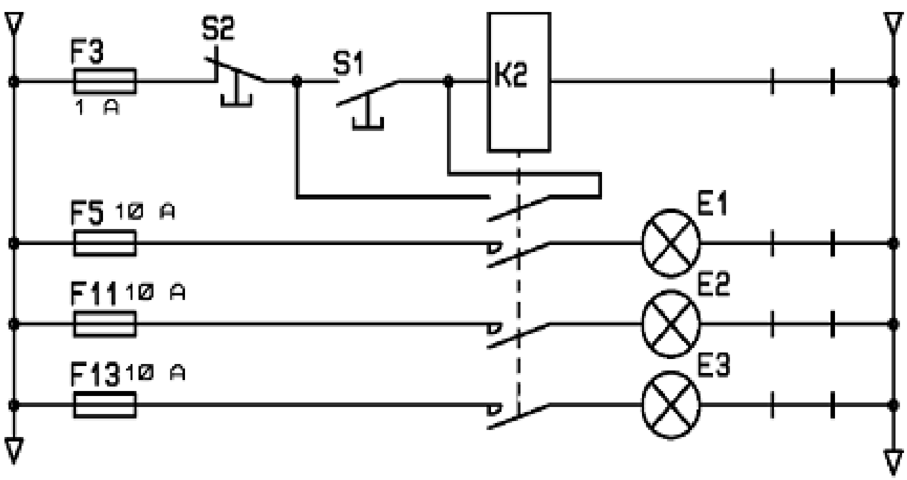
Each conductor is represented by an individual line. For example, consider the direct starting of a three-phase asynchronous squirrel-cage motor with a single direction of travel.



2 - Classification according to the location of the symbols:

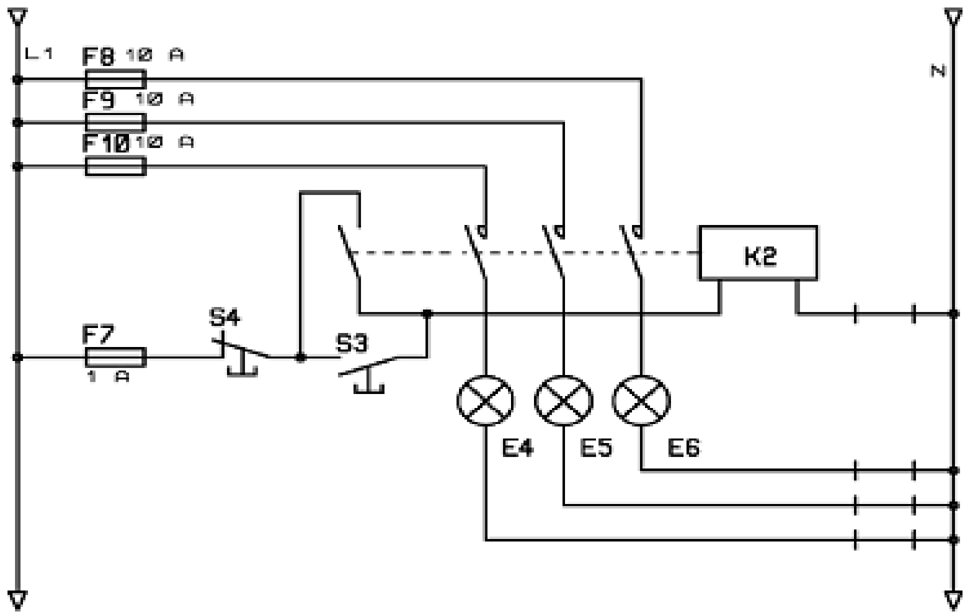
a) Assembled representation:

The symbols of the elements of a device are shown juxtaposed on the diagram.



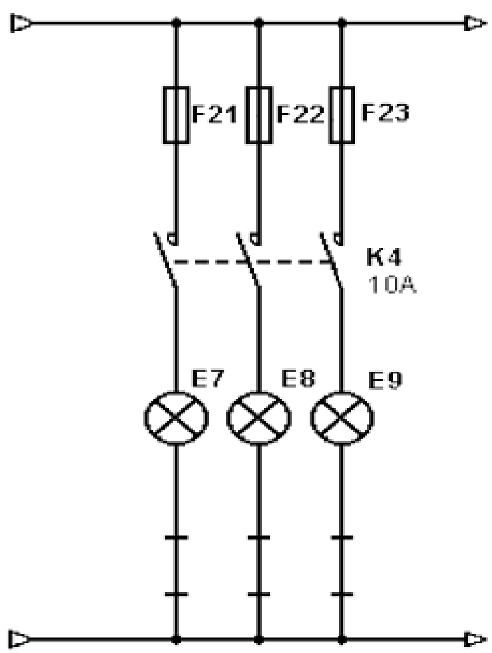
b) <u>Ranked representation:</u>

The symbols of the elements of a device are arranged in such a way that they can simply represent the mechanical connections.

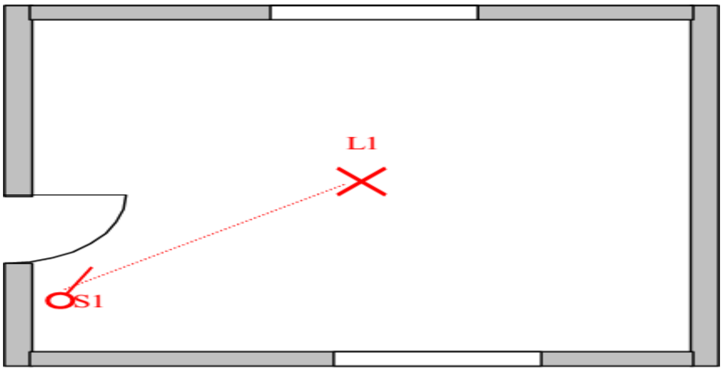


c) <u>Developed representation</u>:

The element symbols are separated and arranged to easily follow the outline



3 **- Classification according to topographic representation:** The location of the symbols recalls the topographical arrangement of the corresponding materials: construction diagrams, architectural (implantation) diagrams and network diagrams.

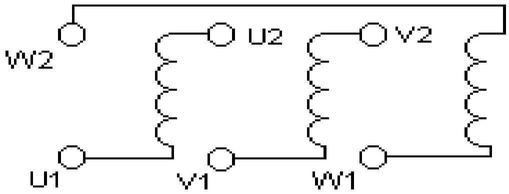


- **Designations:** The designation of the equipment allows the alphabetical characters of the type of operating means to be expressed..

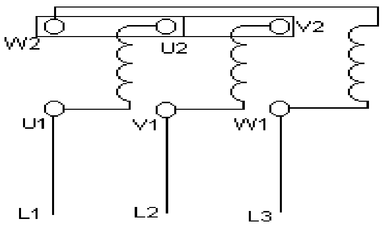
Carac-tères	Moyen d'exploitation	Exemples
A	Modules	Amplificateurs, combinaisons d'appareils
B	Convertisseurs de grandeurs non électr. en grandeurs électr. et inversement	Convertisseur de mesure, synchro-transmetteur, capteur angulaire
C	Condensateurs	Condensateurs de compensation, déparasitage, démarrage
D	Dispositifs de temporisation et de mémorisation, éléments binaires	Lignes de retard, éléments bistables et monostables, mémoire à tores, registres
E	Divers	Eclairage, chauffage ainsi que dispositifs qui ne font pas partie du tableau
F	Dispositifs de protection	Sécurités, déclencheurs, verrouillages
G	Générateurs, alimentations électriques	Batterie, blocs secteurs, oscillateurs
H	Dispositifs de signalisation	Signalisations lumineuses, signalisations acoustiques
K	Relais, contacteurs	Relais temporisés, contacteurs principaux et auxiliaires
L	Inductances	Ballasts inductifs, bobines d'allumage
M	Moteurs	Moteurs à courant alternatif, triphasé, continu
P	Appareils de mesure, dispositifs de test	Dispositifs de mesure afficheurs, compteurs
Q	Appareils de commutation à courant fort	Sectionneurs, sectionneurs de puissance, interr. principaux
R	Résistances	Résistances fixes et réglables, shunts, thermistances, etc.
S	Interrupteurs auxiliaires, sélecteurs	Touche pression, interr. de commande, commutateur rotatif
T	Transformateurs	Convertisseurs de courant et de tension, transformateurs de commande, secteur et de protection
U	Modulateurs, convertisseurs de grandeurs électriques	Convertisseurs de fréquence, transducteurs, démodulateurs, dispositifs de codage
V	Tubes, semi-conducteurs	Tubes cathodiques, diodes, tube à décharge gazeuse
W	Eléments de transmission	Guide d'ondes, jeux de barres, câbles
X	Bornes, dispositifs à enfichage	Bornes à visser et à souder, fiches, prises
Y	Dispositifs mécaniques à enclenchement électrique	Freins, embrayages, soupapes pneumatiques
Z	Terminaisons, filtres, limiteurs	Imitation de câbles, régulateur dynamique

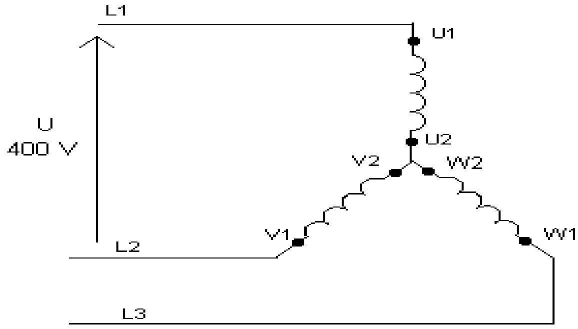
- **Principle of identification and marking for connection terminals:**

By marking the ends of the elements with reference letters, for example; U, V and W we add a numerical prefix after the letter to distinguish between the input and the output of the element (U1 for the input, U2 for the output) also if we have a group of similar elements having the same reference letters, we distinguish them by a numerical prefix placed in front of the letter (1U1, 1U2).

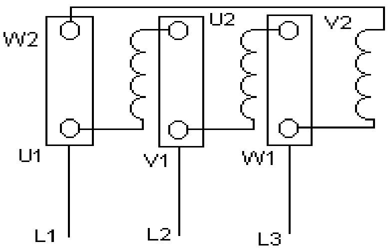


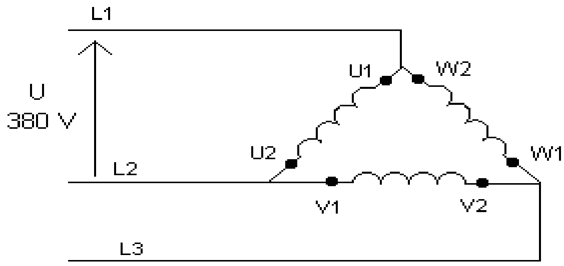
Star coupling:



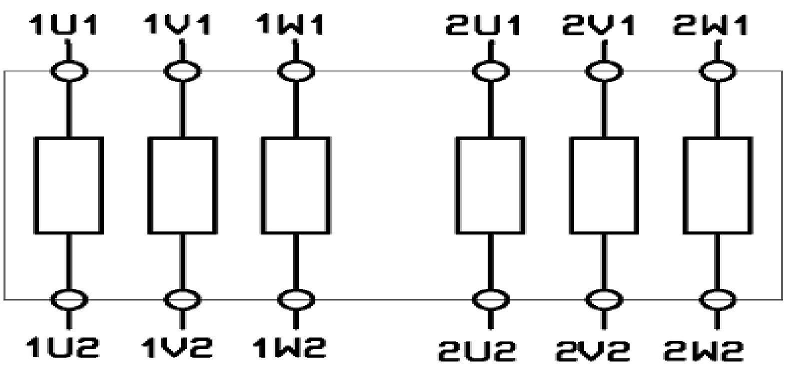


Triangular coupling:





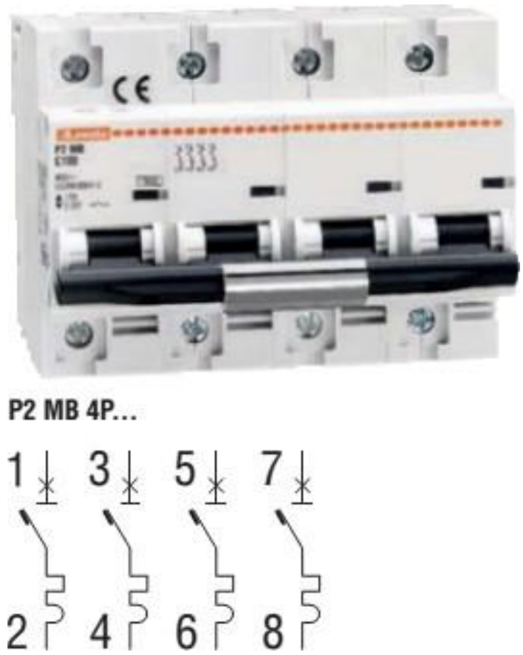
Reference letters for several similar groups:



- **Marking principle for main poles and auxiliary contacts:**

➢ Power poles:

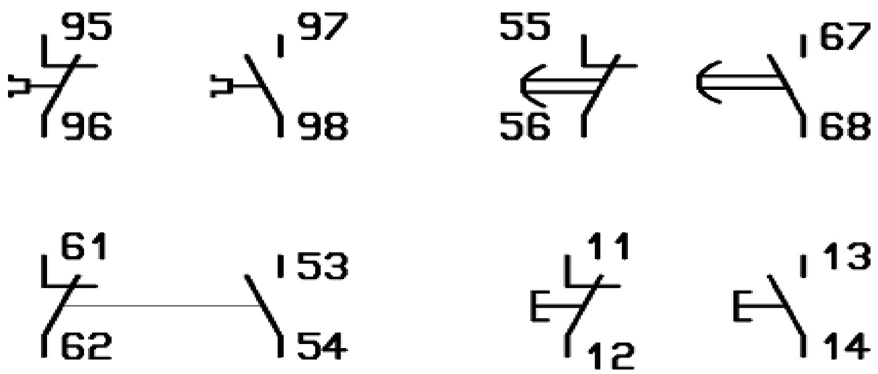
As we mentioned previously, the power poles are identified by a single number from 1 to 6 for a three-pole device and from 1 to 8 for a four-pole device, whatever its function.



➢ Auxiliary contacts:

They are identified by a two-digit number. The unit's digit indicates the function of the contact, while the tens digit indicates the serial number of each contact in the device, except for 9, which is reserved for the protection relay. These are:

- ✓ Normally closed contacts (1-2).
- ✓ Normally closed contacts (3-4).
- ✓ Specially operated contacts (5-6, 7-8).

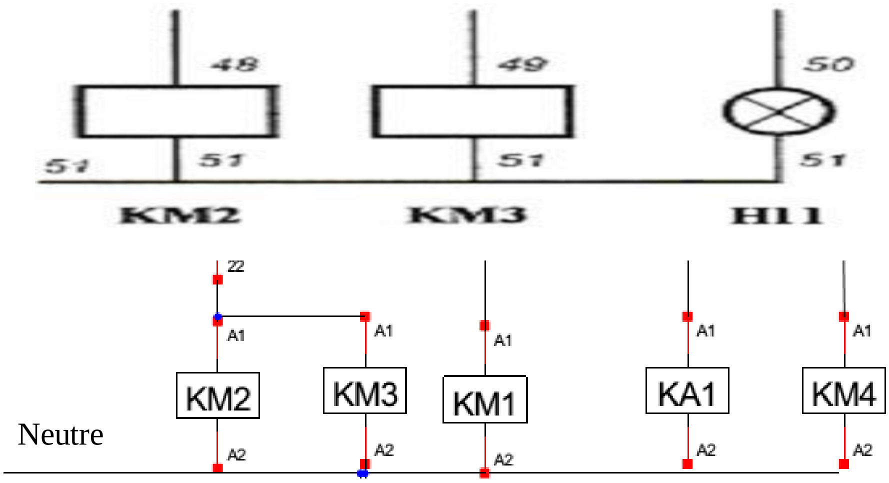


- **Driver identification:**

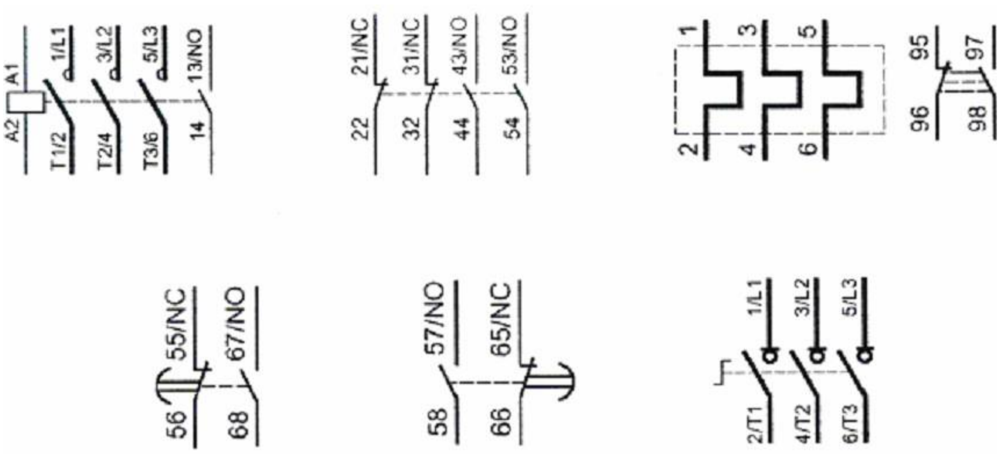
Each conductor must have a mark corresponding to that of the electrical diagram. We distinguish:

- Equipotential identification:

This is the simplest to implement. All conductors always subject to the same potential have the same number. The number changes when there is a possibility of opening the circuit.



- Hardware-dependent tracking: The method consists of assigning the conductors the reference numbers given to the equipment by the manufacturers. Addressing is necessary to avoid confusing conductors connected to similar equipment. Examples:



- **Device tracking: Examples;**

Marker letter	Materials
F	Protective device
M	motor
Q	Disconnecting device, circuit breaker.
S	Manual control, BP, limit switch...
KA	Auxiliary contactor
KM	Power contactor

- **Examples of reading control and power diagrams:**

The representation and development of electrical diagrams is always done with the power off under initial conditions. Different structures will constitute a file:

o Power circuit.

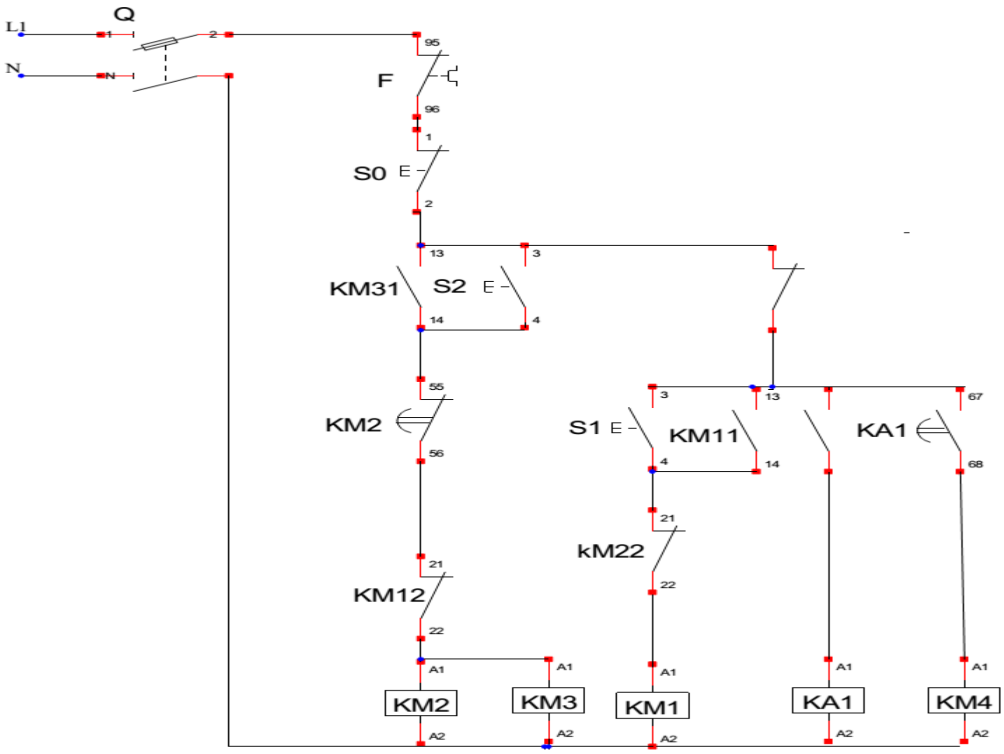
o Control circuit.

o Terminal block circuit.

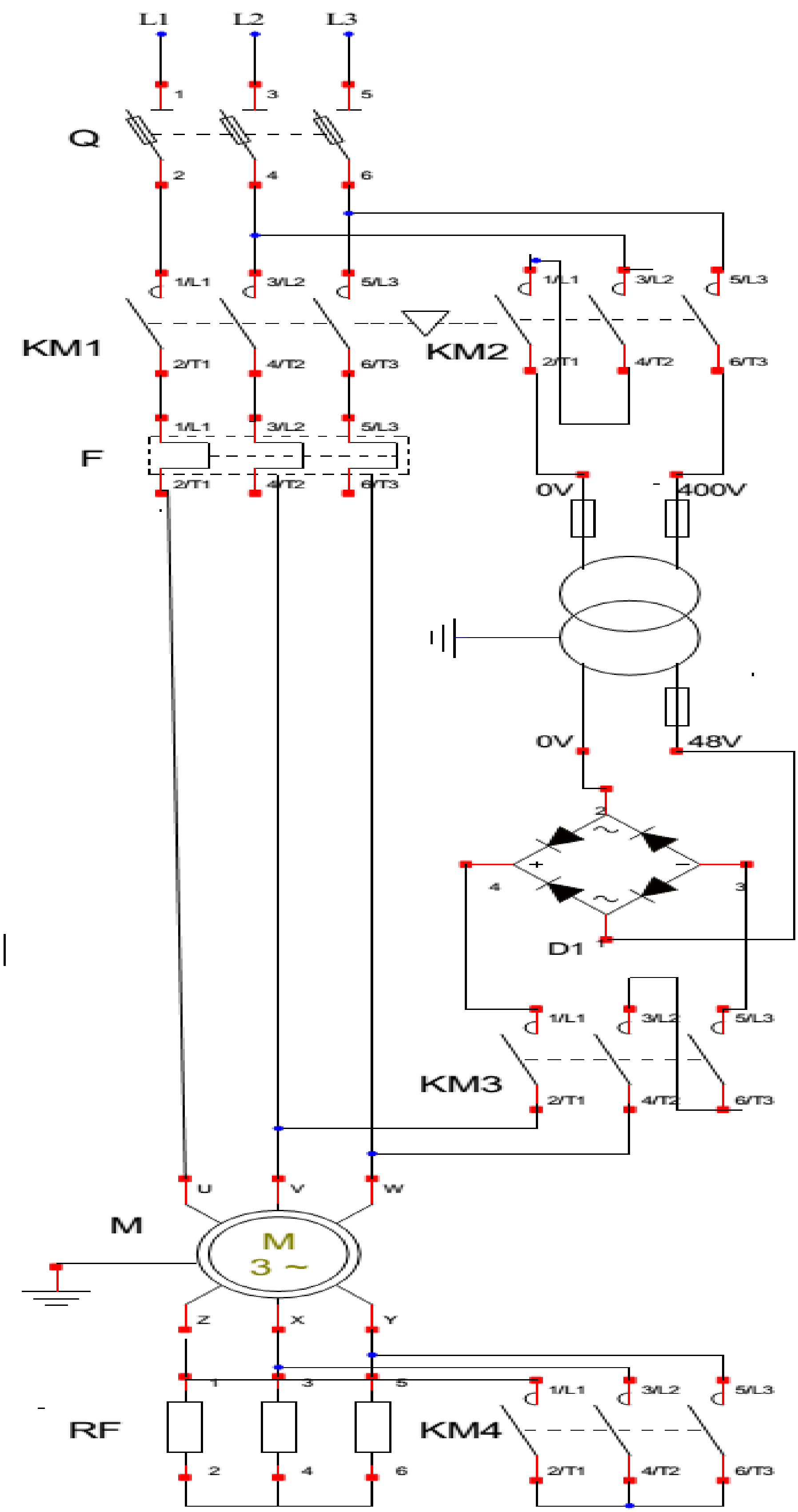
o Cable log.

o Parts list, etc.

➢ **Control circuit :**



- **Power circuit :**



Q: Disconnect switch. F: Thermal relay.

S0: Non-braked stop pushbutton. S1: Start pushbutton.

S2: Braked stop pushbutton.

KM2, KM3: Braking contactors.

KM1: Line contactor.

KM4: Resistor group short-circuit contactor.

KA1: Auxiliary contactor.

KM1 2, KM2 2: Interlock auxiliary contacts.

KM1 1, KM3 1: Self-power (maintained) auxiliary contacts.

KA1 1: Delayed closing contact.

RF: Resistor groups.

- **<u>Practical determination of the minimum cross-section of conductors:</u>**

The conductor cross-section is determined based on the maximum permissible current Iz of the pipeline, which is itself determined from the conductors and their operating conditions. The permissible current values are determined according to the fundamental principles of facility operation and personal safety. The permissible current table below allows the conductor cross-section to be directly determined based on:

o The conductor type: copper or aluminum.

o The type of insulation, which defines the maximum permissible operating temperature, denoted PR for insulation materials capable of withstanding 90°C (EPR, PRC, etc.) and PVC for insulation materials capable of withstanding 70°C.

o The theoretical permissible current.

o The number of loaded conductors.

o The reference method (installation method) (B, C, D, E, F), which are grouped under four headings:

- Open-air installation.
- Installation under conduit or trunking in the open air.
- Installation embedded in building elements.
- Buried installation.

If the installation method varies along the route of a cable or conductor, the permissible current must be determined for the most unfavorable section. However, for open-air installation, a conduit run of less than 1 m, or a buried run of less than 0.20 m, will not be considered.

Courants admissibles dans les canalisations (en A)

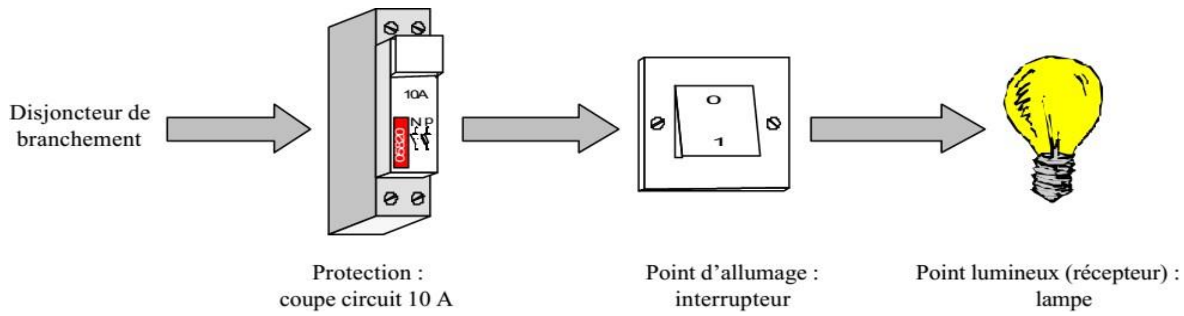
Méthodes de référence		Isolant et nombre de conducteurs chargés												
B		PVC 3	PVC 2		PR 3		PR 2							
C			PVC 3		PVC 2	PR 3		PR 2						
D											PVC 3	PVC 2	PR 3	PR 2
E				PVC 3		PVC 2	PR 3		PR 2					
F					PVC 3		PVC 2	PR 3		PR 2				
Conducteurs cuivre Section (mm²)	1,5	15,5	17,5	18,5	19,5	22	23	24	26		26	32	31	37
	2,5	21	24	25	27	30	31	33	36		34	42	41	48
	4	28	32	34	36	40	42	45	49		44	54	53	63
	6	36	41	43	48	51	54	58	63		56	67	66	80
	10	50	57	60	63	70	75	80	86		74	90	87	104
	16	68	76	80	85	94	100	107	115		96	116	113	136
	25	89	96	101	112	119	127	138	149	161	123	148	144	173
	35	110	119	126	138	147	158	169	185	200	147	178	174	208
	50	134	144	153	168	179	192	207	225	242	174	211	206	247
	70	171	184	196	213	229	246	268	289	310	216	261	254	304
	95	207	223	238	258	278	298	328	352	377	256	308	301	360
	120	239	259	276	299	322	346	382	410	437	290	351	343	410
	150		299	319	344	371	395	441	473	504	328	397	387	463
	185		341	364	392	424	450	506	542	575	367	445	434	518
	240		403	430	461	500	538	599	641	679	424	514	501	598
	300		464	497	530	576	621	693	741	783	480	581	565	677
	400					656	754	825		940				
	500					749	868	946		1083				
	630					855	1005	1088		1254				
Conducteurs aluminium Section (mm²)	2,5	16,5	18,5	19,5	21	23	24	26	28					
	4	22	25	26	28	31	32	35	38					
	6	28	32	33	36	39	42	45	49					
	10	39	44	46	49	54	58	62	67		57	68	67	80
	16	53	59	61	66	73	77	84	91		74	88	87	104
	25	70	73	78	83	90	97	101	108	121	94	114	111	133
	35	86	90	96	103	112	120	126	135	150	114	137	134	160
	50	104	110	117	125	136	146	154	164	184	134	161	160	188
	70	133	140	150	160	174	187	198	211	237	167	200	197	233
	95	161	170	183	195	211	227	241	257	289	197	237	234	275
	120	186	197	212	226	245	263	280	300	337	224	270	266	314
	150		227	245	261	283	304	324	346	389	254	304	300	359
	185		259	280	298	323	347	371	397	447	285	343	337	398
	240		305	330	352	382	409	439	470	530	328	396	388	458
	300		351	381	406	440	471	508	543	613	371	447	440	520
	400					526	600	663		740				
	500					610	694	770		856				
	630					711	808	899		996				

Practical work :

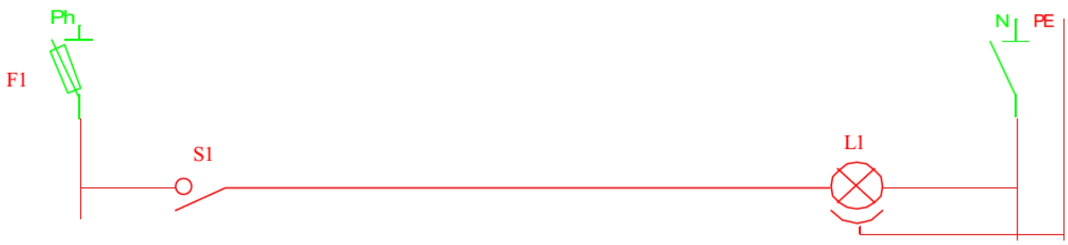
1- Domestic electrical installations (lighting circuits):

a- Single ignition assembly:

This assembly allows you to control (turn on or off) a lighting lamp from a single location.

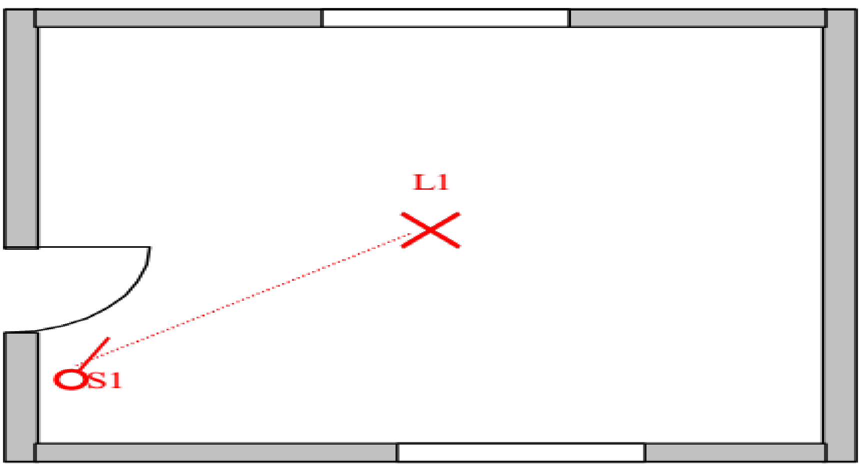


❖ Developed diagram of the assembly:



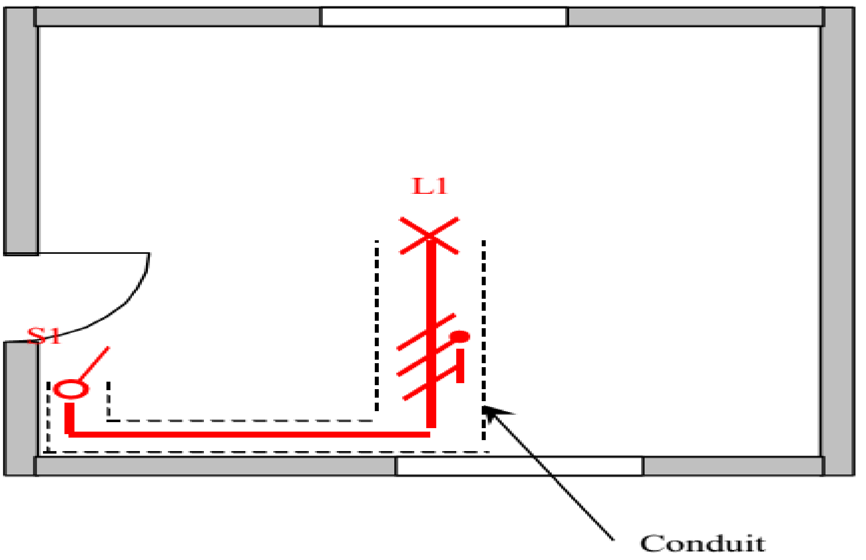
❖ Architectural diagram (layout) of the assembly:

The purpose of this diagram is to show the location of the elements of the developed diagram within the part concerned.



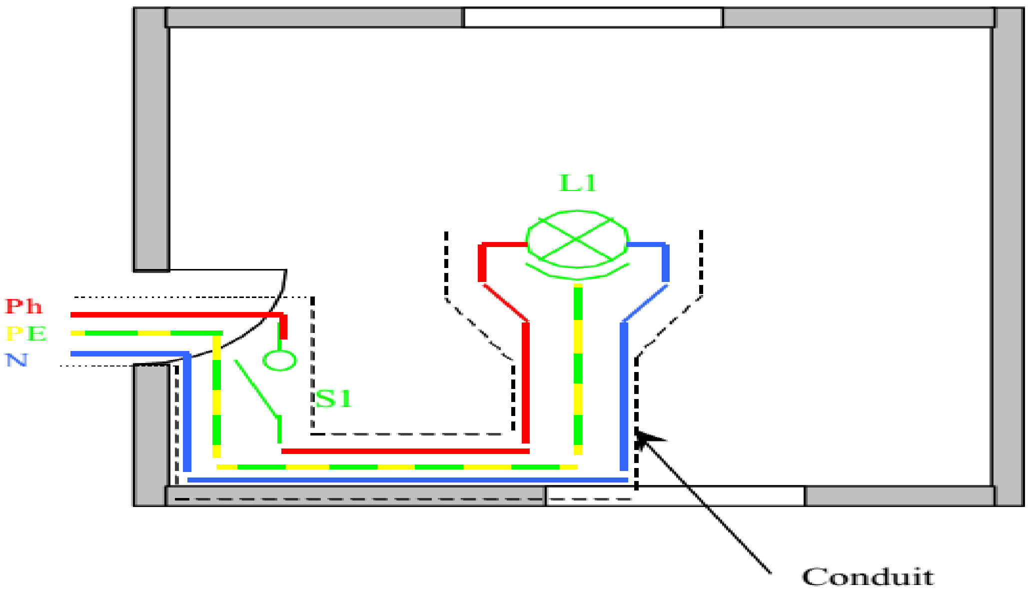
❖ Single-line diagram of the assembly:

This diagram shows the location of the conduits in which the conductors will be located. It will also indicate the number of conductors present inside and their type (phase, neutral, protective conductor, etc.).



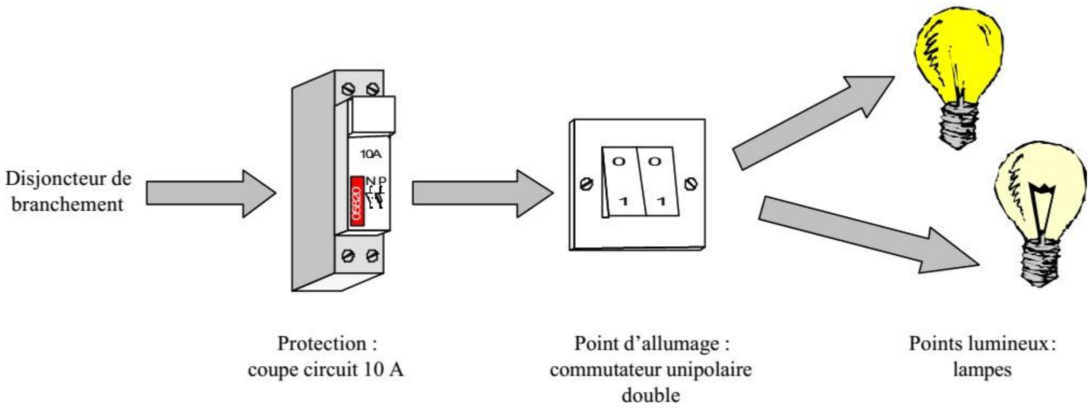
❖ Multi-wire diagram of the assembly:

This diagram explains how all the conductors (phase, neutral, protective conductor, etc.) are connected to electrical devices. This is the connection diagram for the installation.

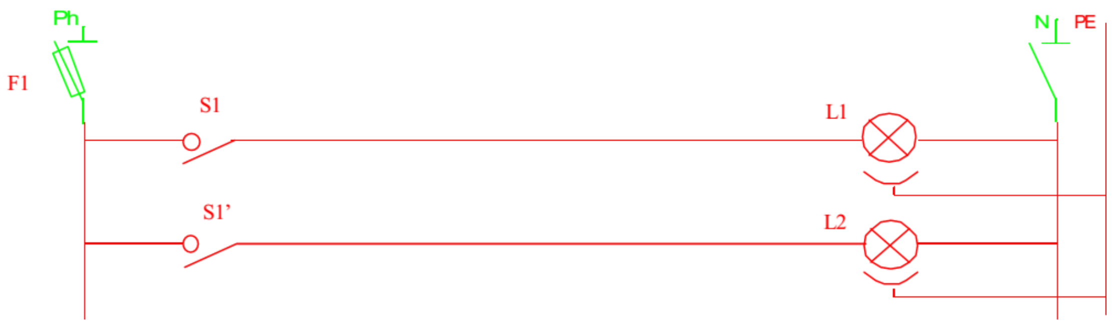


b- Dual ignition assembly:

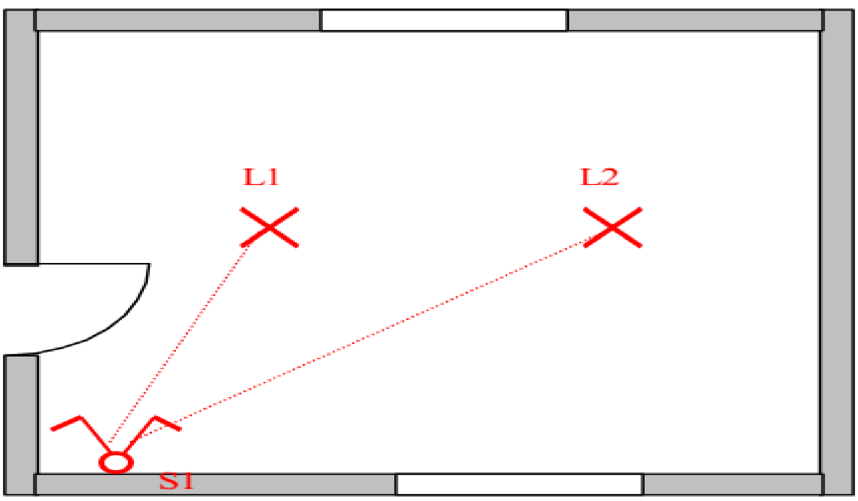
Ce This assembly allows you to control two different lighting circuits from a single location.



❖ Developed diagram of the assembly:



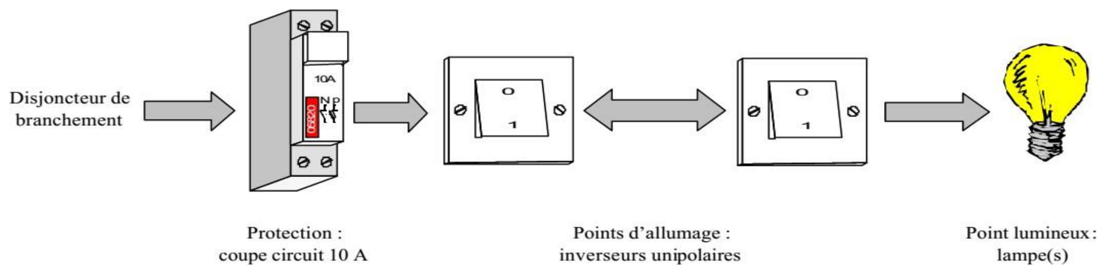
❖ Architectural diagram (layout) of the assembly:



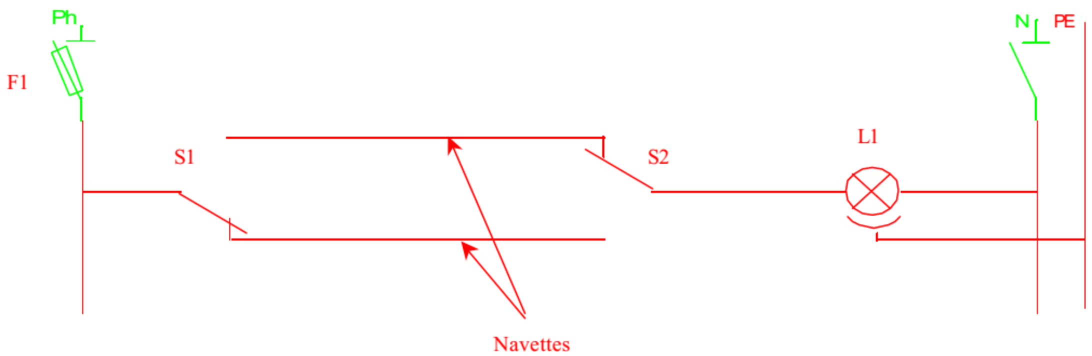
This assembly is used to control dining room chandeliers, shop window lighting, etc.

c- Two-way assembly:

This assembly allows you to control a lighting circuit from two different locations

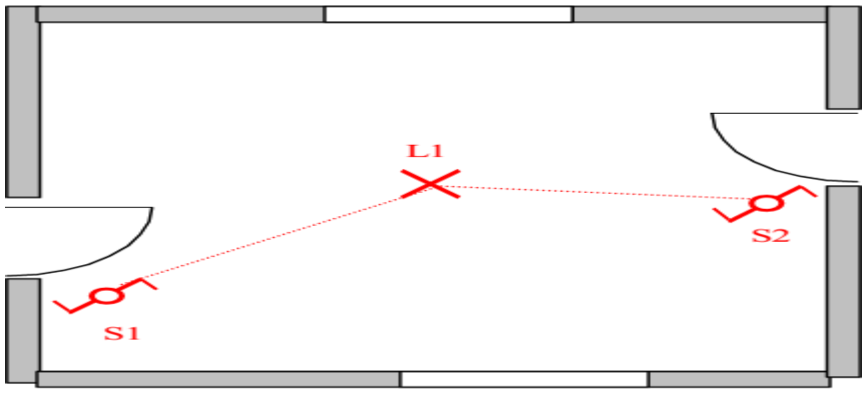


❖ Developed diagram of the assembly:



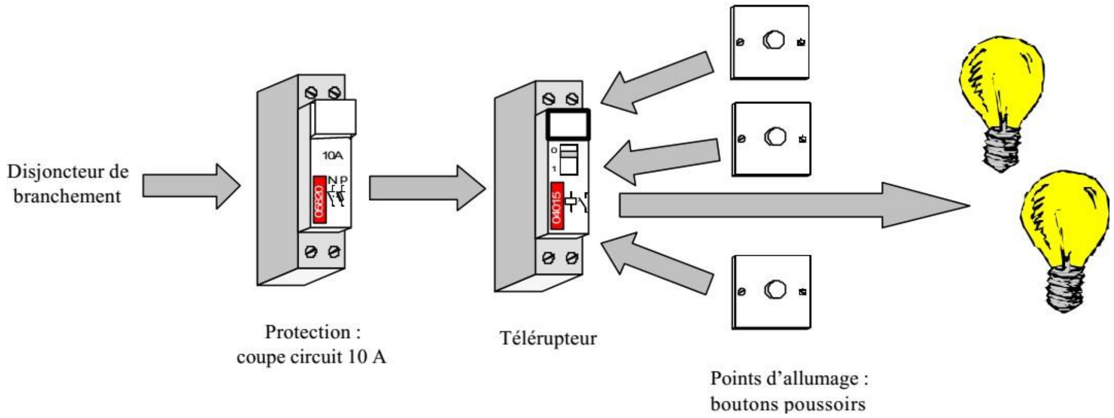
As soon as one of the switches (S1 or S2) is operated, the circuit is closed and the lamp is lit. If one of the switches is operated a second time, the circuit opens and the lamp goes out. The two conductors connecting switches S1 and S2 are called shuttles. This arrangement is used in large rooms, rooms with two entrances, hallways, garages, stairwells, etc.

❖ Architectural diagram (layout) of the assembly:

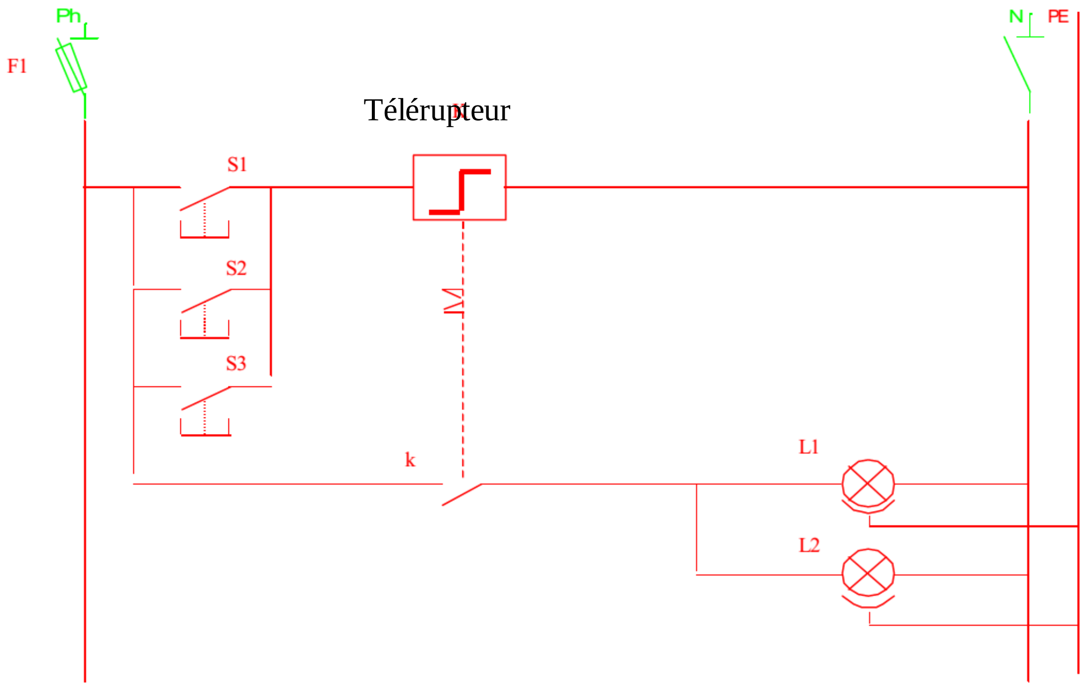


d- Assembly with remote switch::

A remote control switch is installed when there are at least three control points for switching one or more lamps on or off. This arrangement is used mainly in halls and corridors.

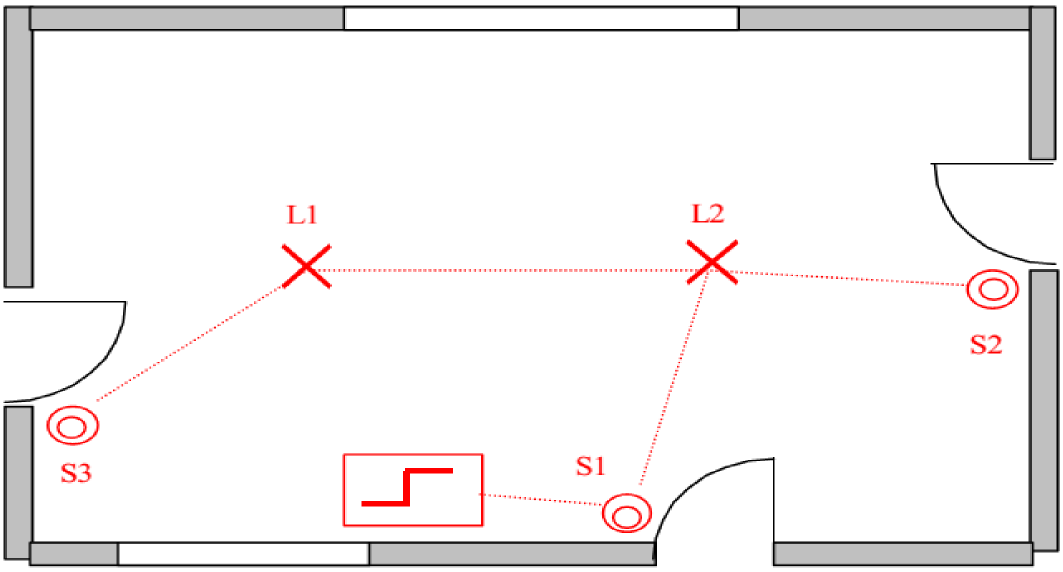


❖ Developed diagram of the assembly:



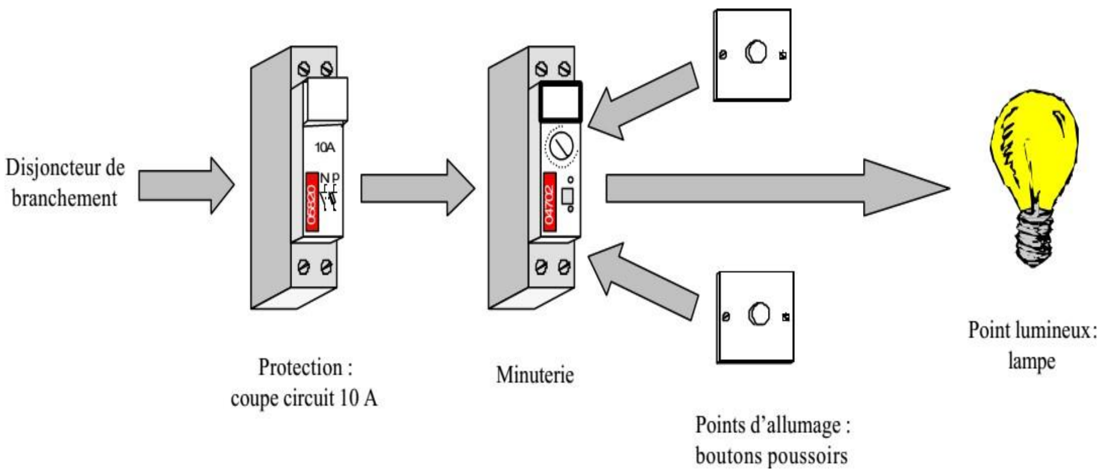
Pressing one of the push buttons on the ignition points turns on the power and lights the lamps. Pressing one of the push buttons again turns the lamps off.

❖ Architectural diagram (layout) of the assembly:



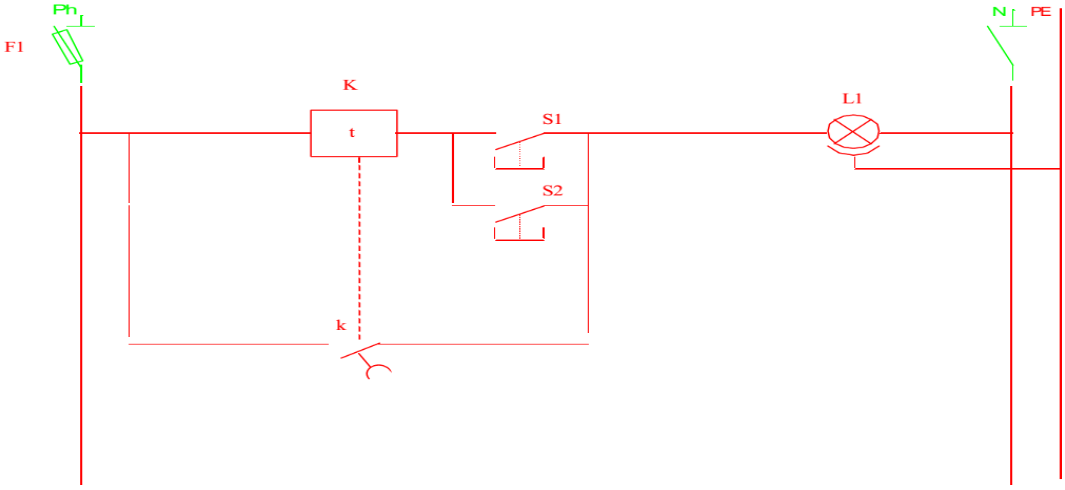
e- Assembly with timer:

A timer is installed when one or more lamps are required to turn off automatically.

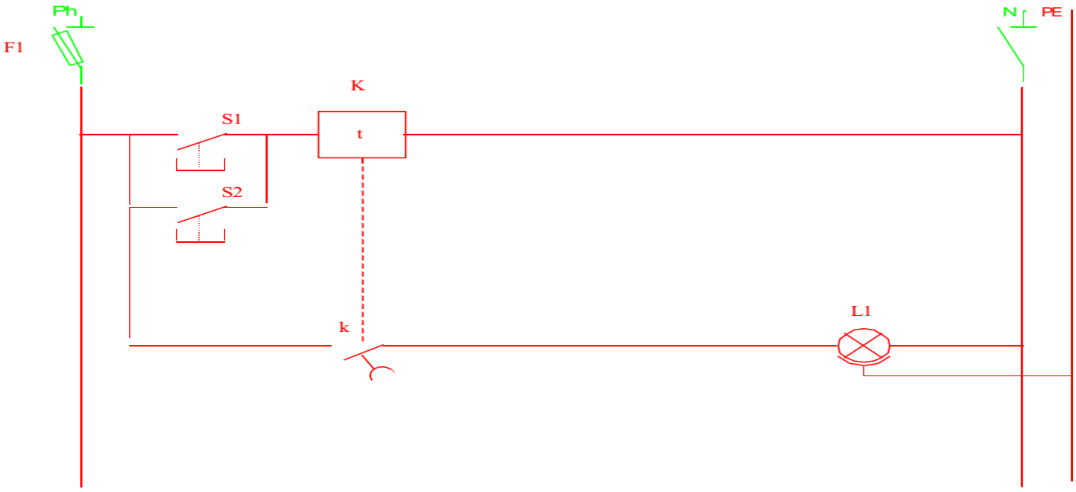


Pressing one of the push buttons switches on and turns on one or more lamps for a specific (adjustable) time. The lamps turn off automatically. There are two different schemes:

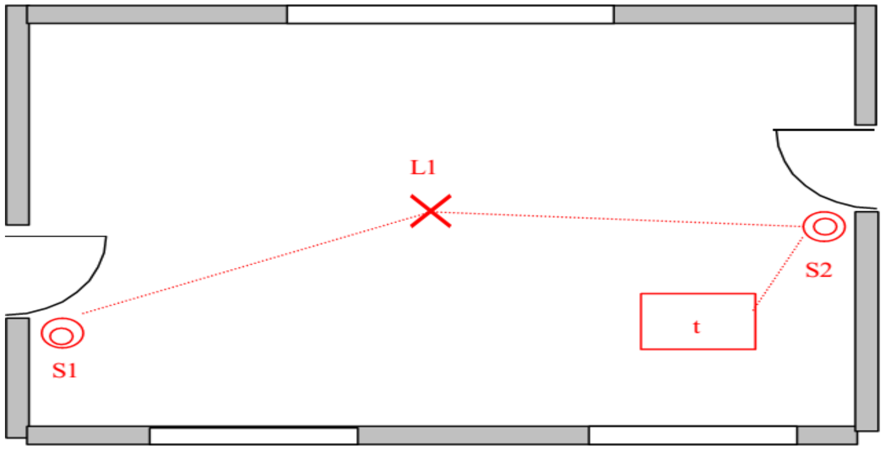
❖ Diagram developed without effect:



❖ Developed diagram with effect:



❖ Architectural diagram (layout) of the assembly:



Objective:

This part of the practical work aims to provide the student with a summary of all the domestic installations completed. The student must successfully complete the lighting of all the given installations by the end of this part.

- ✓ Assessment criteria:
  - o Correct wiring.
  - o Student work method.
  - o Completion and presentation of the various installations.
  - o Answers to questions asked at the end of the session.
- ✓ Required materials:
  - o 220 V power source.
  - o Protective equipment (circuit breaker).
  - o Push buttons.
  - o Single-throw and double-throw switches.
  - o Power outlets, lamps.
  - o Remote control switch, timer.
  - o 1.5 mm² rigid wires: red, blue, and green-yellow.
  - o 2.5 mm² rigid wires: red, blue, and green-yellow. o Wire cutters, wire strippers.
  - o Screwdriver, American screwdriver, French screwdriver.

2- <u>Electromechanical control of alternating current electrical machines</u>:

- ✓ **Objectives:**

In this part of the practical work, the student must be able to:

- ➢ Study the operation and characteristics of different types of starters and brakes for three-phase asynchronous motors.
- ➢ Demonstrate the starting and braking phenomena of three-phase asynchronous motors.
- ➢ Visualize the different wiring components.
- ➢ Distinguish practically between the power circuit and the control circuit.

- ✓ **Assessment criteria:**

- ➢ Correct wiring.

- ➢ Student work method.
- ➢ Creation and presentation of various installation setups.
- ➢ Answers to questions always asked at the end of the session.

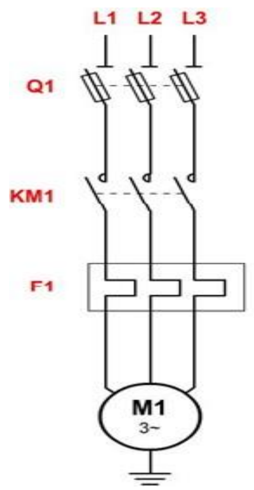
✓ **Necessary materials:**

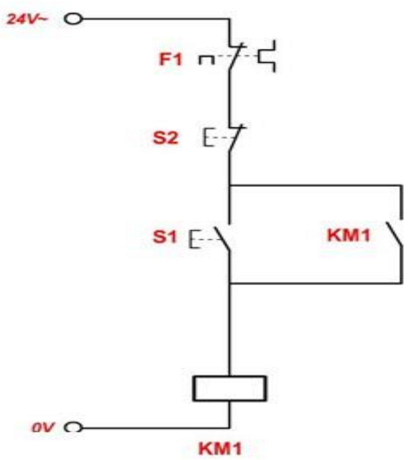
- ➢ 220 V/380 V, 230 V/400 V power supply.
- ➢ Protective devices (circuit breaker, fuse disconnector, and thermal relay).
- ➢ Pushbuttons (S). Resistor groups (R).
- ➢ Power (KM) and control (KA) contactors.
- ➢ Add-on blocks for standard auxiliary contacts.
- ➢ Add-on blocks for time-delayed auxiliary contacts.
- ➢ Power outlets, single-phase rectifier.
- ➢ 400 V/48 V step-down transformer.
- ➢ Electric motors (cage, slip-ring).
- ➢ 1.5 mm² solid wires: red, blue, and green-yellow.
- ➢ 2.5 mm² solid wires: red, blue, and green-yellow.
- ➢ Cutting pliers, wire stripping pliers.
- ➢ Test screwdriver, American screwdriver, French screwdriver.

a- <u>Direct starting of a motor with one or two directions of rotation:</u>

<u>- Direct starting in one direction of rotation</u>: this is the simplest scheme to implement; the stator windings of the cage motor are directly coupled to the network. The starting current peak varies from (5 to 8 In).

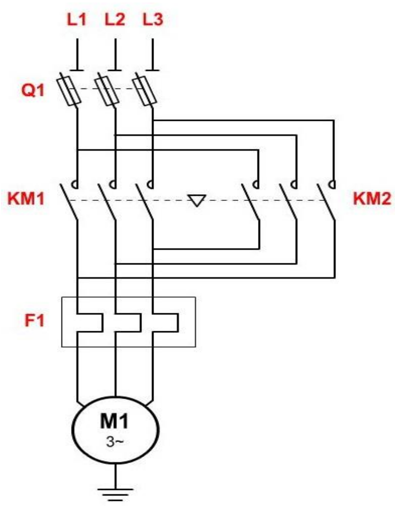
Power circuit **Control circuit**

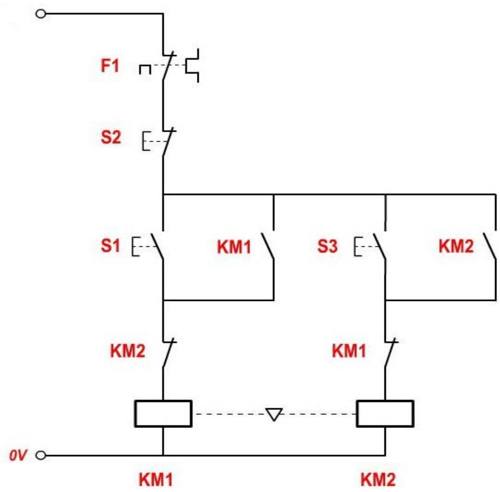




- <u>Direct start with two directions of rotation</u>: to change the direction of rotation of a three-phase asynchronous motor, two of the three phases of the supply circuit must be reversed.

Power circuit **Control circuit**



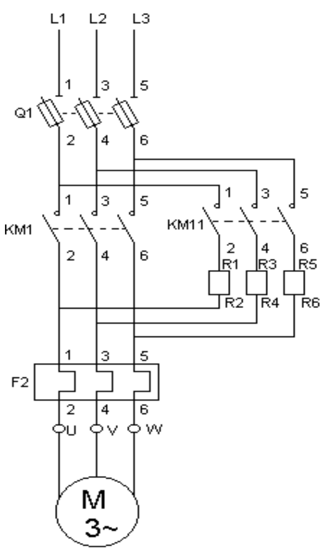


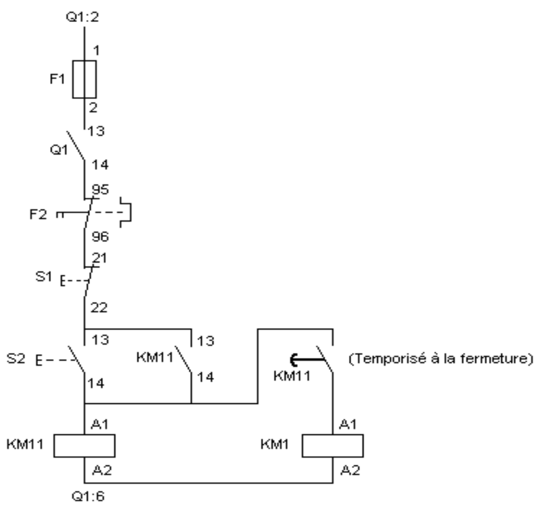
b- <u>Stator starting (squirrel cage motor)</u>: The start-up is performed in two stages and lasts between 7 and 12 seconds, with a starting current of around 4.2 in.

- In the first stage, a resistor (KM 11) is connected in series with each stator phase.

- In the second stage, the resistors (KM 1) are short-circuited.

Power circuit **Control circuit**





c- <u>Star-delta start:</u>

Starting occurs in two stages and lasts 3 to 7 seconds.

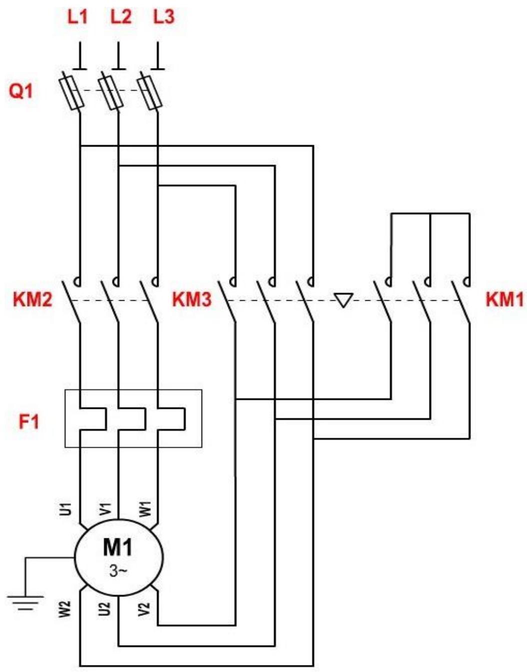
- In the first stage: star connection of the motor;

The windings are subjected to a voltage (U/root 3), the starting current Id is reduced compared to direct-on-line starting (Id = 1.3 to 2.6 In), and the starting torque is lower than with direct-on-line starting (Cd = 0.2 to 0.5 Cn).

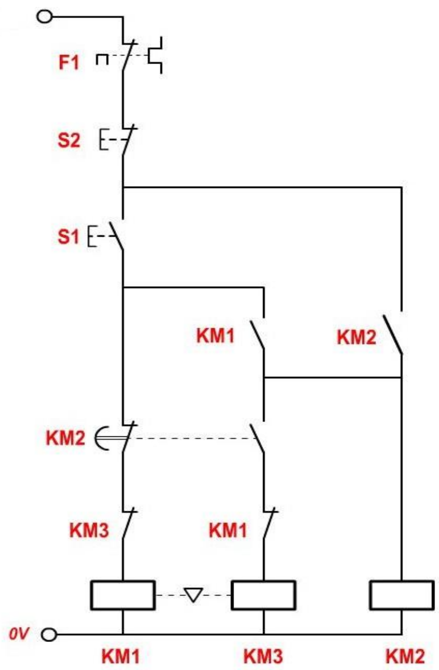
- In the second stage: delta connection of the motor;

When the motor is started, the motor switches to delta connection and reaches its rated speed at full voltage.

Power circuit



Control circuit

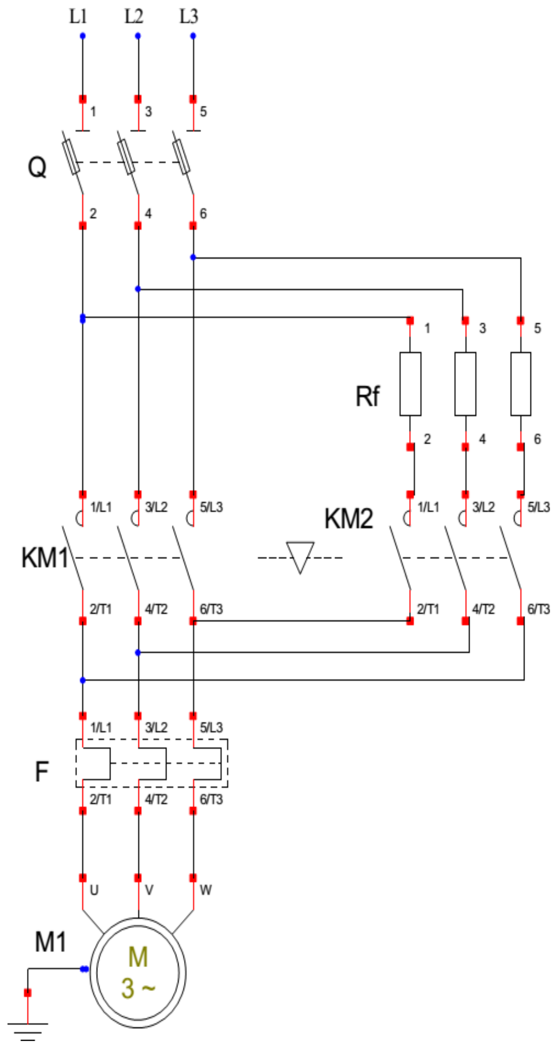


d- Countercurrent braking:

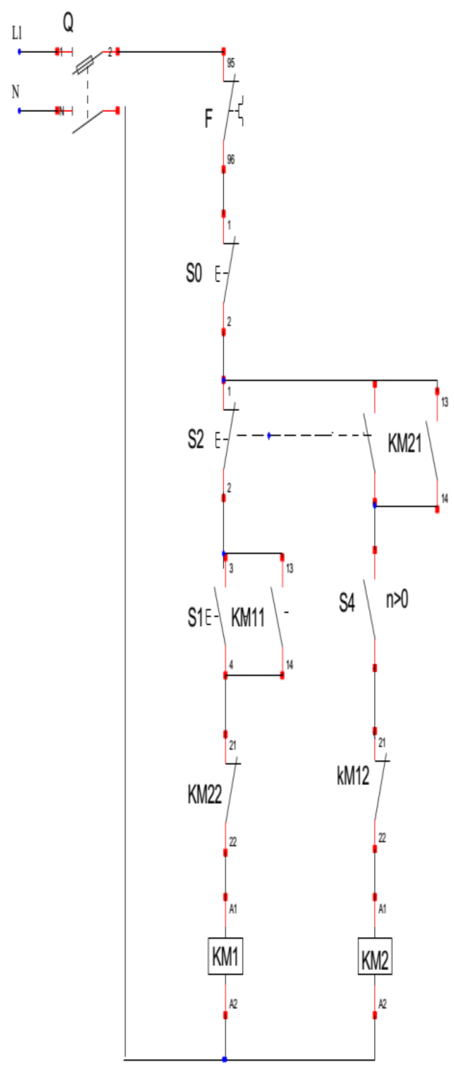
Reverse current braking involves reversing two power supply phases, with the motor running, so that it reverses its direction of rotation. The rotation frequency will then decrease rapidly, and when it reaches zero, the power supply is cut off. Changing the direction of rotation with the motor running means that the motor must overcome a greater resistive torque. It will therefore consume much more current. To limit this current, resistors must be placed in series with the stator. The brake power supply must also be cut off at the precise moment the motor stops; otherwise, it will reverse its current.

This braking method is very effective.

Power circuit

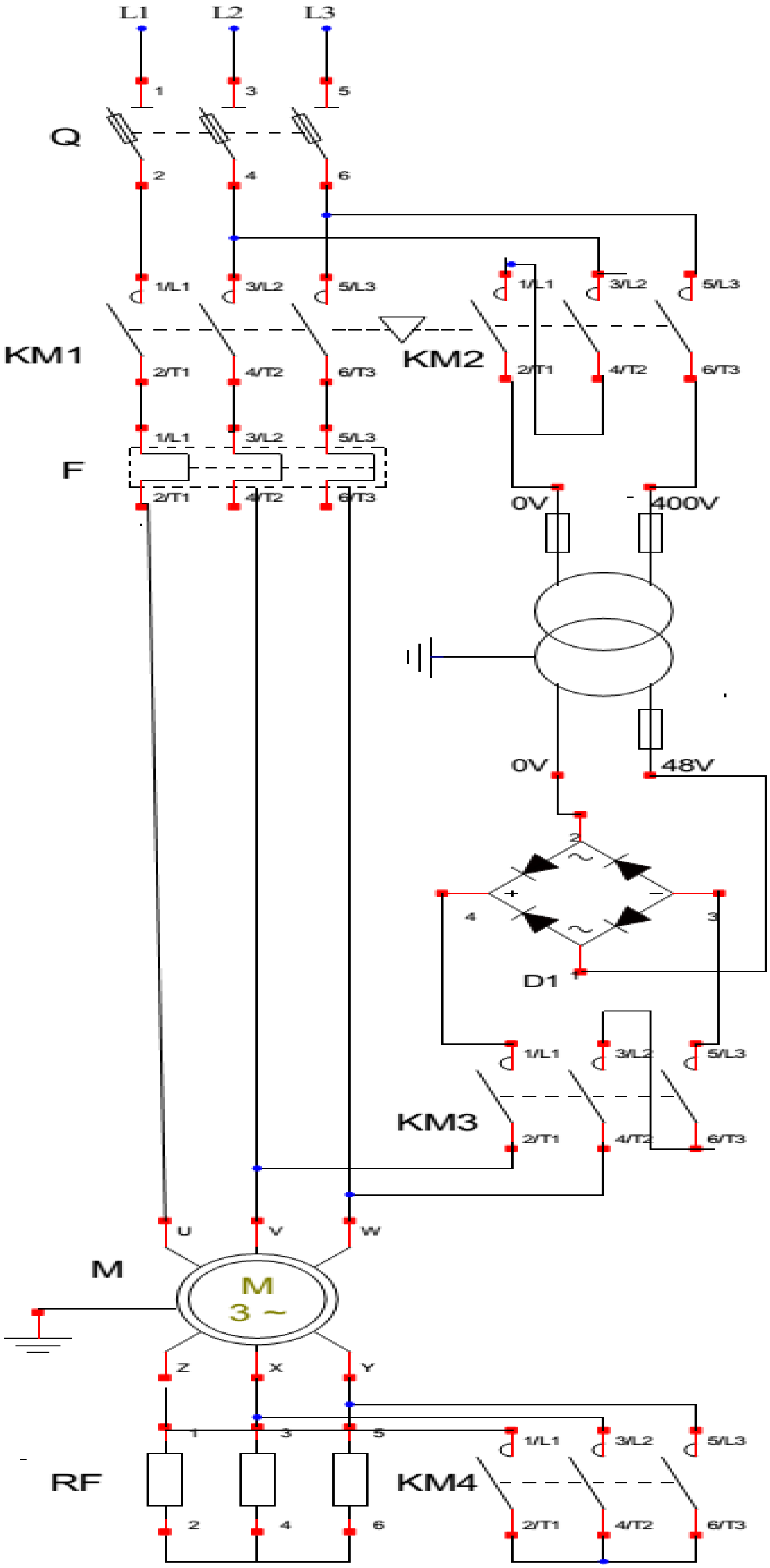


Control circuit

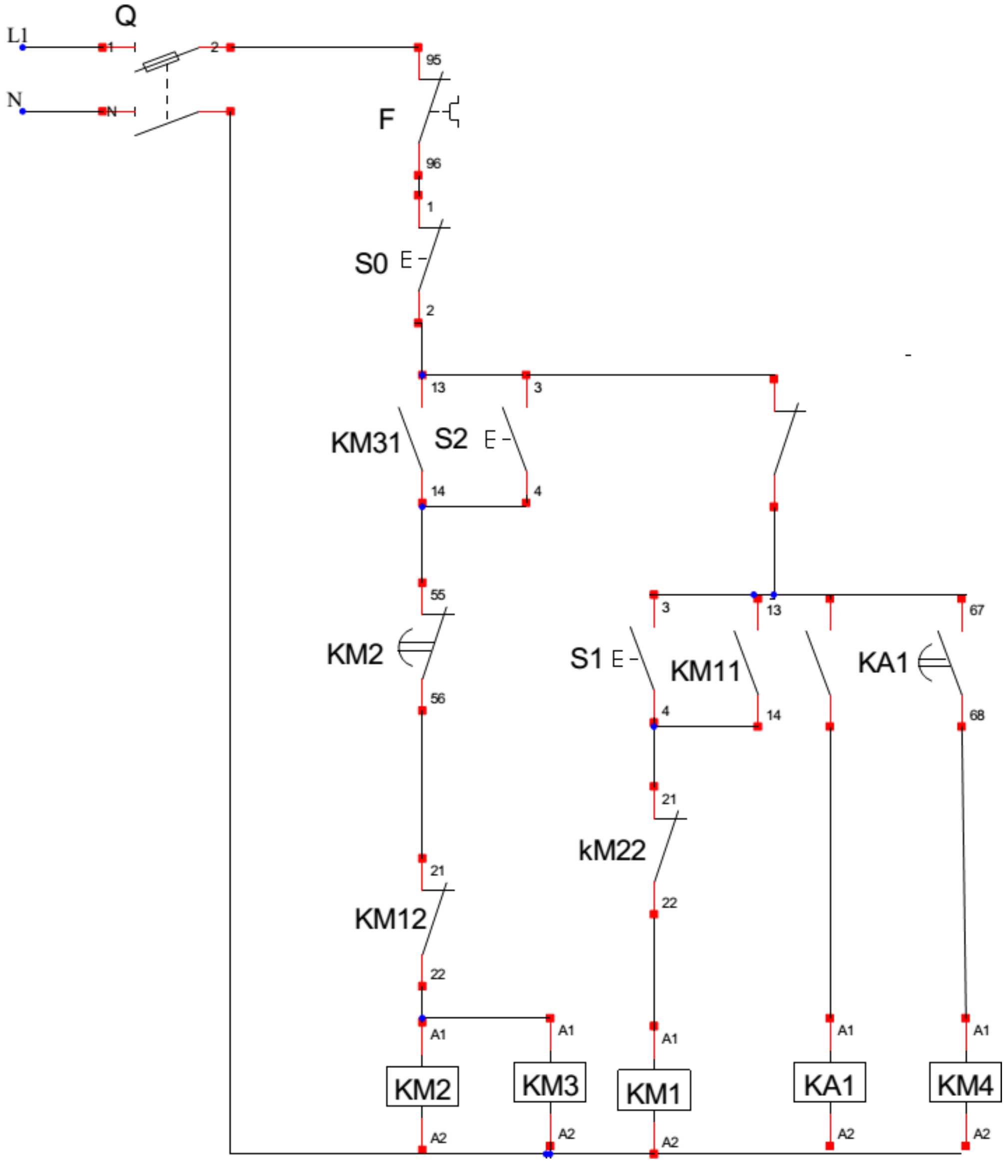


e- Braking by injection of direct current:

Power circuit



Control circuit



This braking method is used on cage and slip-ring motors. By disconnecting the three-phase power supply to the stator, a direct current voltage is applied to the stator, creating a fixed field. This fixed field is designed to block the rotation of the motor rotor.

With this braking method, there is no risk of starting in the opposite direction.

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