Protection of Electrical Networks

Reminder: Overview of Electrical Networks

Chapter 1. Introduction to Protection

Chapter 2. Elements of the Protection System

Chapter 3. Protection of Network Elements

Reminder: Overview of Electrical Networks

I. General Introduction

The **SONELGAZ** protection plan is designed to anticipate all necessary low-voltage equipment to **safely** and **selectively** protect lines and transformers against all types of faults. Additionally, a philosophy is developed that specifies the setting parameters and functions to adopt in order to define harmoniously the different action priorities **among protections to ensure good selectivity** and **guarantee power continuity**. The calculation of settings depends on several parameters including:

1- Network Type:

- Interconnection network.
- Transmission network.
- Distribution network.
- Distribution network.

2- Network Topology:

- Regular line in a meshed transmission or distribution network.
- Long line connecting stations with short lines. Antenna line.
- Branch line.
- High Voltage (HV)/Medium Voltage (MV) interconnection transformer.
- MV/Low Voltage (LV) transformer.

3- Type of Protection:

- Distance protection.
- Differential protection.
- Overcurrent protection.
- Thermal overload protection.
- Voltage maximum or minimum protection, etc.

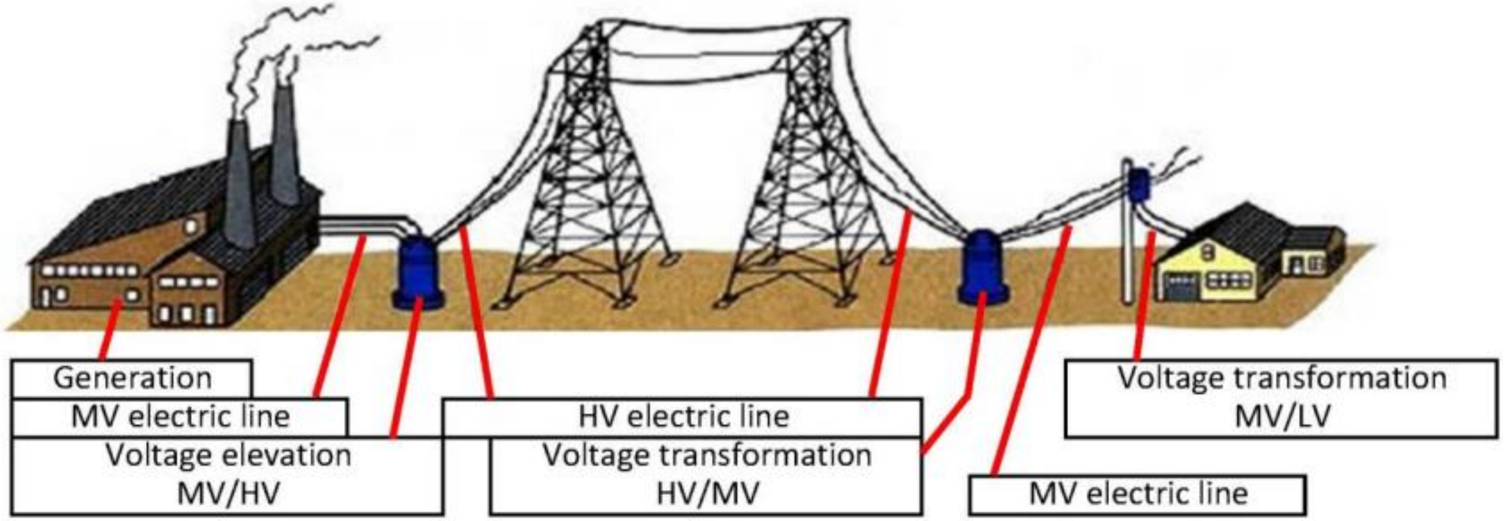
4- Protection Technology:

- Electromechanical.
- Static.
- Digital.

Classification of the different voltage ranges

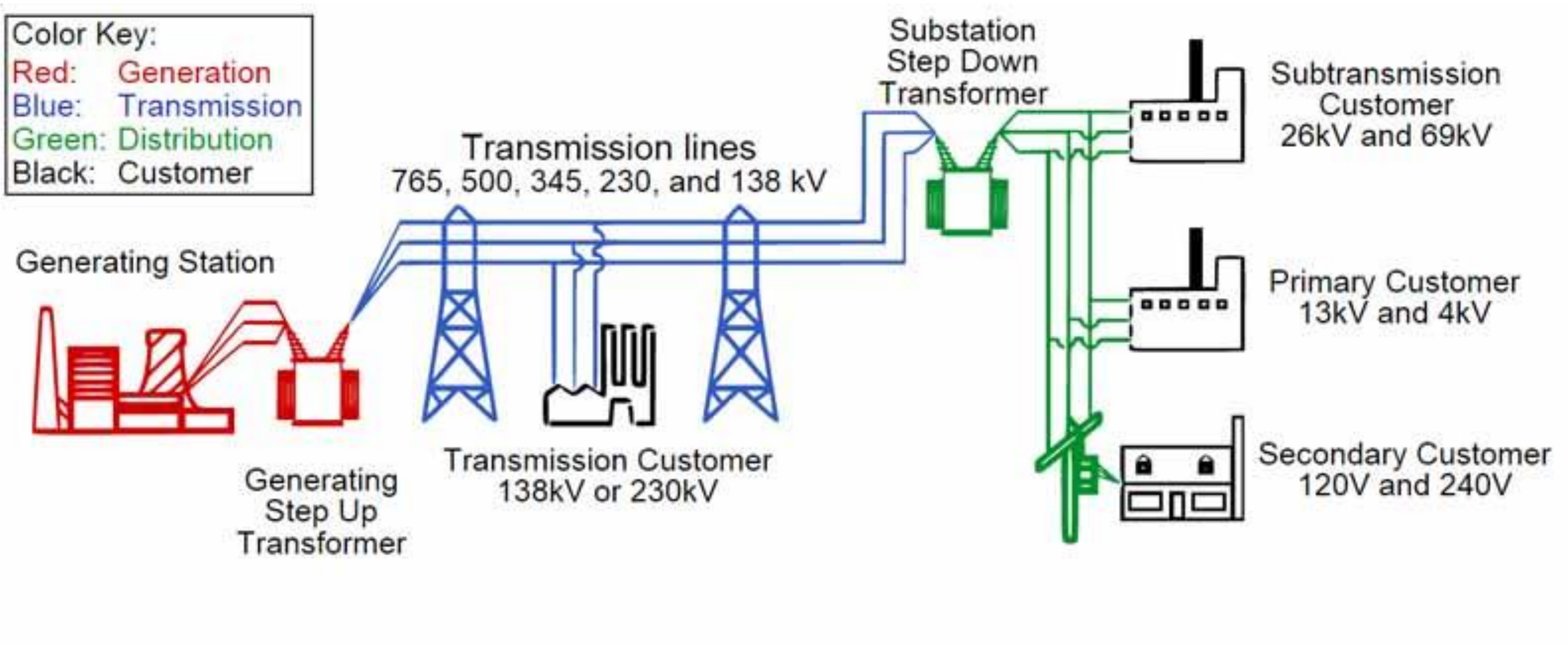
Designation	Voltage Ranges
Extra Low Voltage	<50 V(AC), <120 V(DC)
Low Voltage	<1 kV(AC), <1,5 kV(DC)
Medium Voltage	3 kV, 6 kV, 10 kV, 15 kV, 20 kV, 30 kV
High Voltage	60 kV, 110 kV
Extra High Voltage	220 kV, 380 kV, 500 kV, 700 kV, 1.150 kV

The electricity distribution

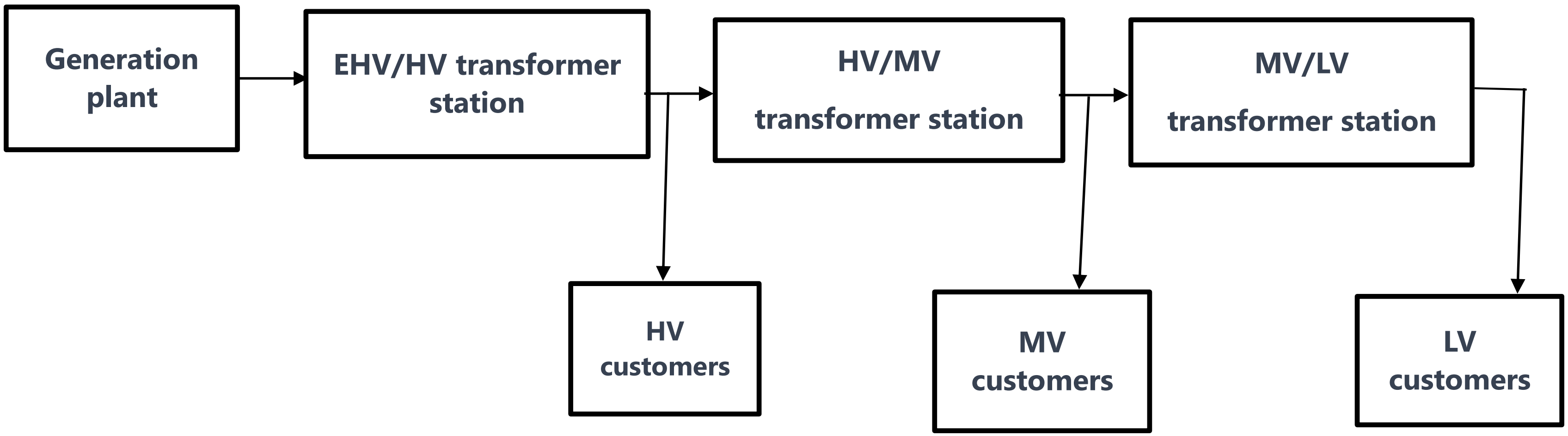


II. Presentation of an electrical network

The modern electrical networks in industrialized countries are complex and highly interconnected systems of lines operating at various voltages, due to their extensive coverage.

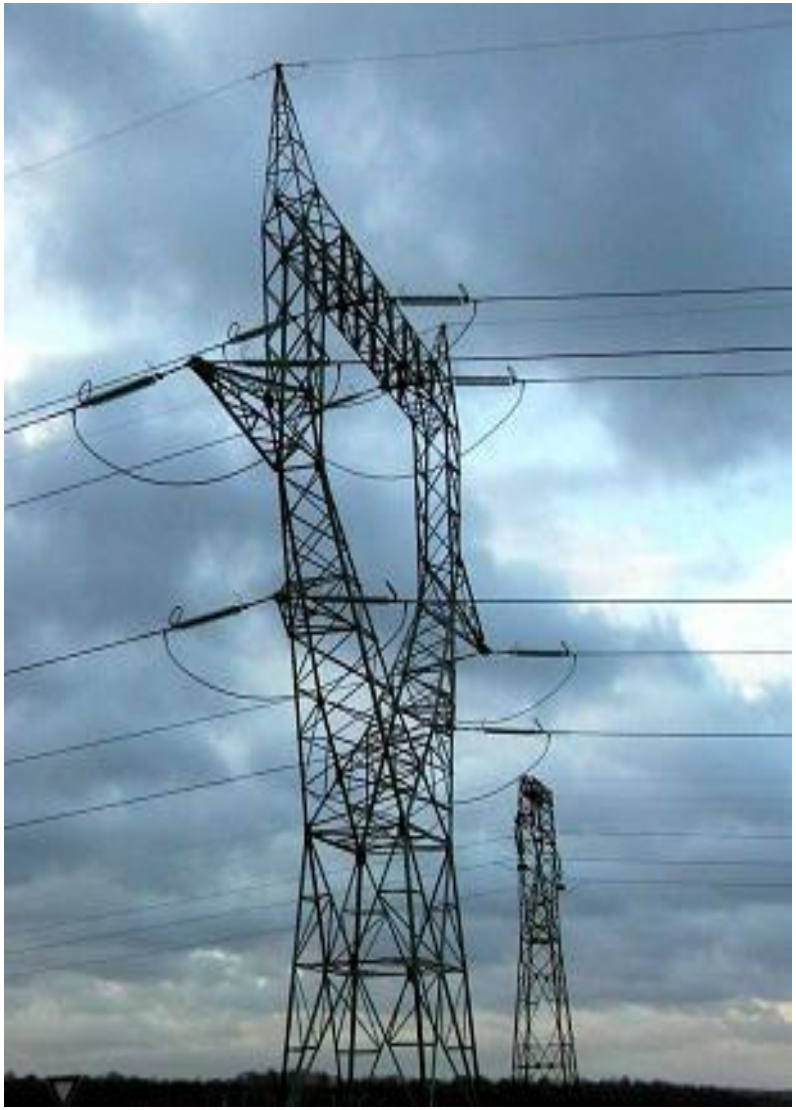


Simplified diagram of an electrical network



There are several types of line, depending on the functions they perform:

Very high voltage lines (400 kV) are used for the mass transmission of electrical energy over long distances. They form a vast network, the nodes of which either receive the electrical energy from the power stations or transfer the energy to the regional networks.



High-voltage lines (90 kV or 63 kV) act as regional distribution lines, supplying small towns and rural areas.

Medium-voltage lines (20 kV) irrigate the countryside and villages.

Low-voltage lines (230/400 V) carry electricity to the end user.

In addition to lines, an electricity network includes **substations**. These are the **nodes of the network** where the lines that bring in the energy end up, and from where the lines that supply the regions leave.

A substation contains **circuit breakers**, whose function is to switch the lines and transformers on or off, but to interrupt the current in the event of a short-circuit; **disconnectors**, which are veritable electrical **switches** that can be used to change the network's operating diagram; and **transformers**, which transfer electrical energy between lines of different voltages.

There are several types of electrical substations:

- **Power plant exit substations:** these substations serve to connect a power generation plant to the network.
- **Interconnection substations:** the purpose is to interconnect multiple high-voltage electricity lines.
- **Voltage boosting substations:** the goal is to increase the voltage level using a transformer.
- **Distribution substations:** the objective is to lower the voltage level to distribute electrical energy to residential or industrial customers.

III. Different types of electricity network :

Electricity networks are divided into three types:

1- Transmission and interconnection networks:

The main role of transmission and interconnection networks is to :

- ❖ Collect the electricity produced by major power plants and transport it in large flows to consumption areas (transmission function),
- ❖ To enable economic and safe operation of generation facilities by ensuring compensation for various contingencies (interconnection function),
- ❖ The voltage is 150 kV, 220 kV and recently 420 kV,
- ❖ Neutral directly earthed,
- ❖ Meshed network.

2- Distribution networks :

The role of the distribution networks or High Voltage networks is to distribute, at regional level, the energy from the transmission network. Their voltage exceeds 63 kV, depending on the region.

3-Distribution networks :

Distribution networks start from voltages below 63 kV and from EHV/MV transformer substations, with the help of medium-voltage lines or cables to EHV/MV distribution substations. The MV/LV transformer substation is the final link in the distribution chain and covers all uses of electricity.

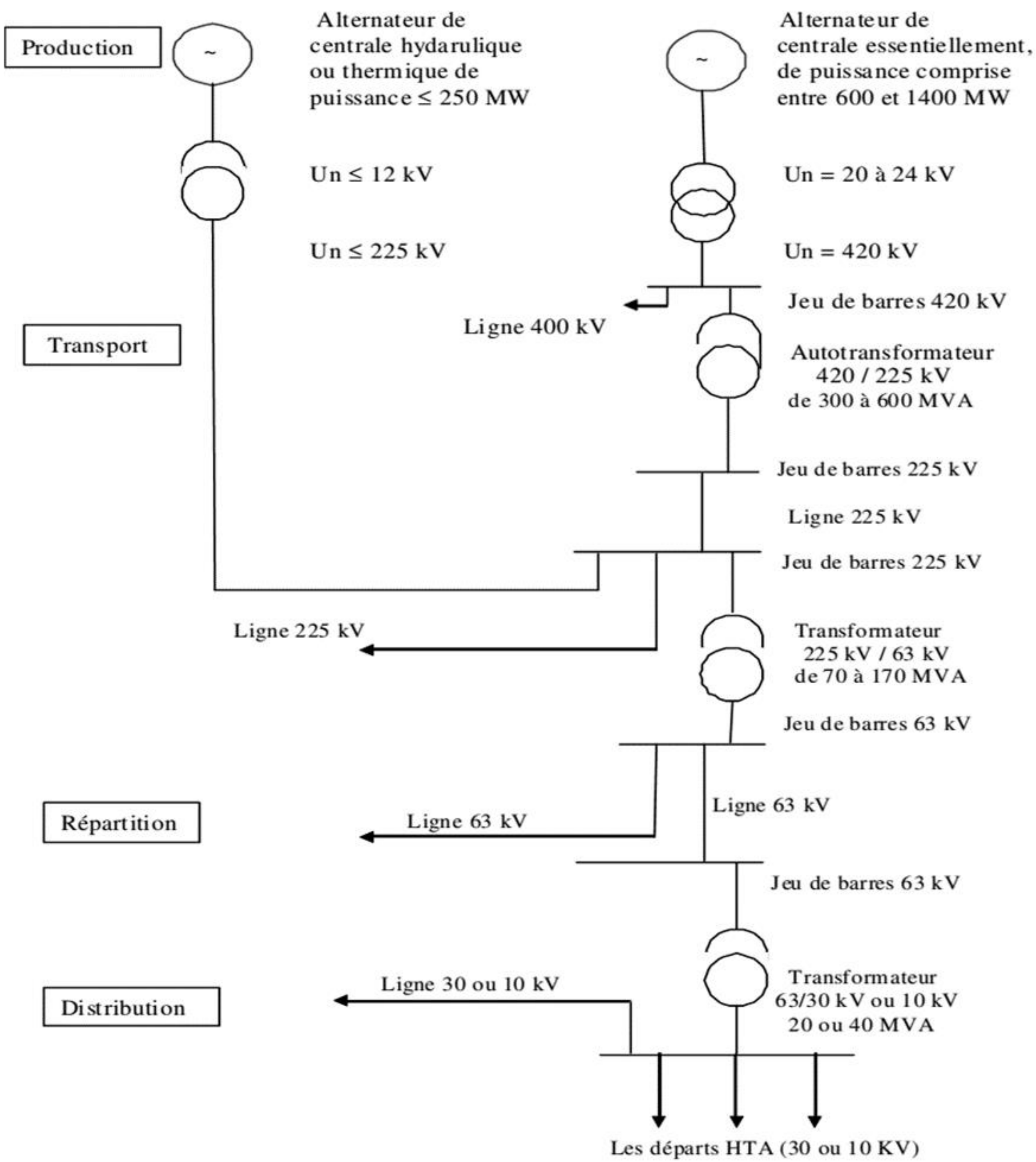
3.1) - Medium voltage distribution networks :

- HTA (High Voltage) - (30 and 10 kV most common),
- Neutral to earth via a resistor,
- Limited to 300 A for overhead networks,
- Limited to 1000 A for underground networks,
- Open loop underground networks.

3.2) - Low voltage distribution networks :

- BTA (Low Voltage) - (230 / 400 V),
- Neutral directly earthed,
- Radial type networks,
- meshed and looped.

General architecture of the electricity network in Algeria



IV. Architectures of High Voltage Distribution Substations (HVB):

They generally involve powers greater than **10 MVA**. The installation of the distribution substation is located between:

On one hand, the point of connection to the High Voltage **HVB** Distribution Network,

On the other hand, the downstream terminal of the **HVB / HV** transformer(s).

Index **O** for "open position" and **F** for "closed position".

The electrical diagrams of the most commonly encountered high voltage **HVB** delivery substations are as follows:

1. Single antenna

➢ Architecture :

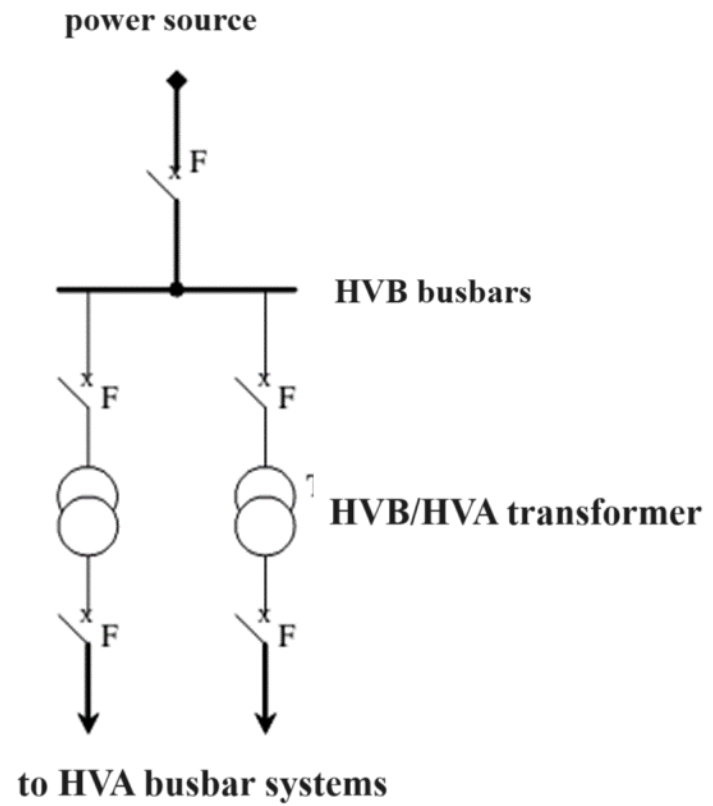


Fig. 1: Simple antenna architecture

➢ Operating mode:

- **Normal:**

HVB/HVA transformers are powered by a single set of HVB busbars.

- **Disturbed:**

In case of loss of a power source, HVTB/HVA transformers are taken out of service.

- **Advantages and Disadvantages:**

Advantage: Minimal cost.

Disadvantage: Low availability.

1. Dual antenna :

▪ Architecture :

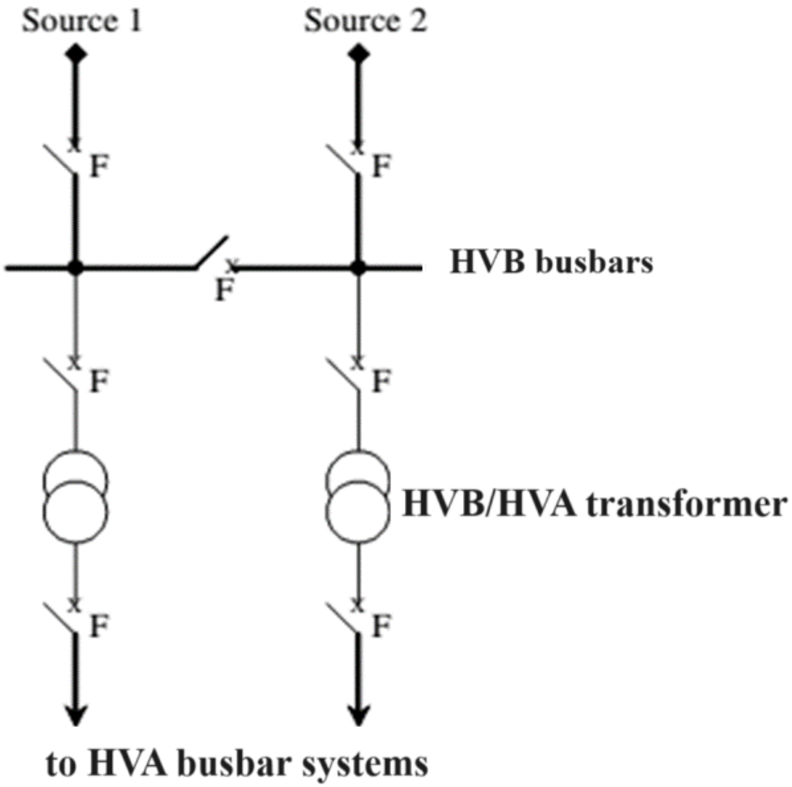


Fig.2. Dual antenna architecture

➢ Operating mode :

▪ Normal :

- The two incoming circuit-breakers for the sources are closed, as is the coupling isolator.
- The transformers are therefore supplied by the 2 sources simultaneously.

▪ Disrupted:

- In the event of the loss of one source, the other source provides the entire power supply.

➢ Advantages and disadvantages :

Advantages :

- Good availability, as each source can supply the entire network
- Busbar maintenance possible, with partial busbar operation

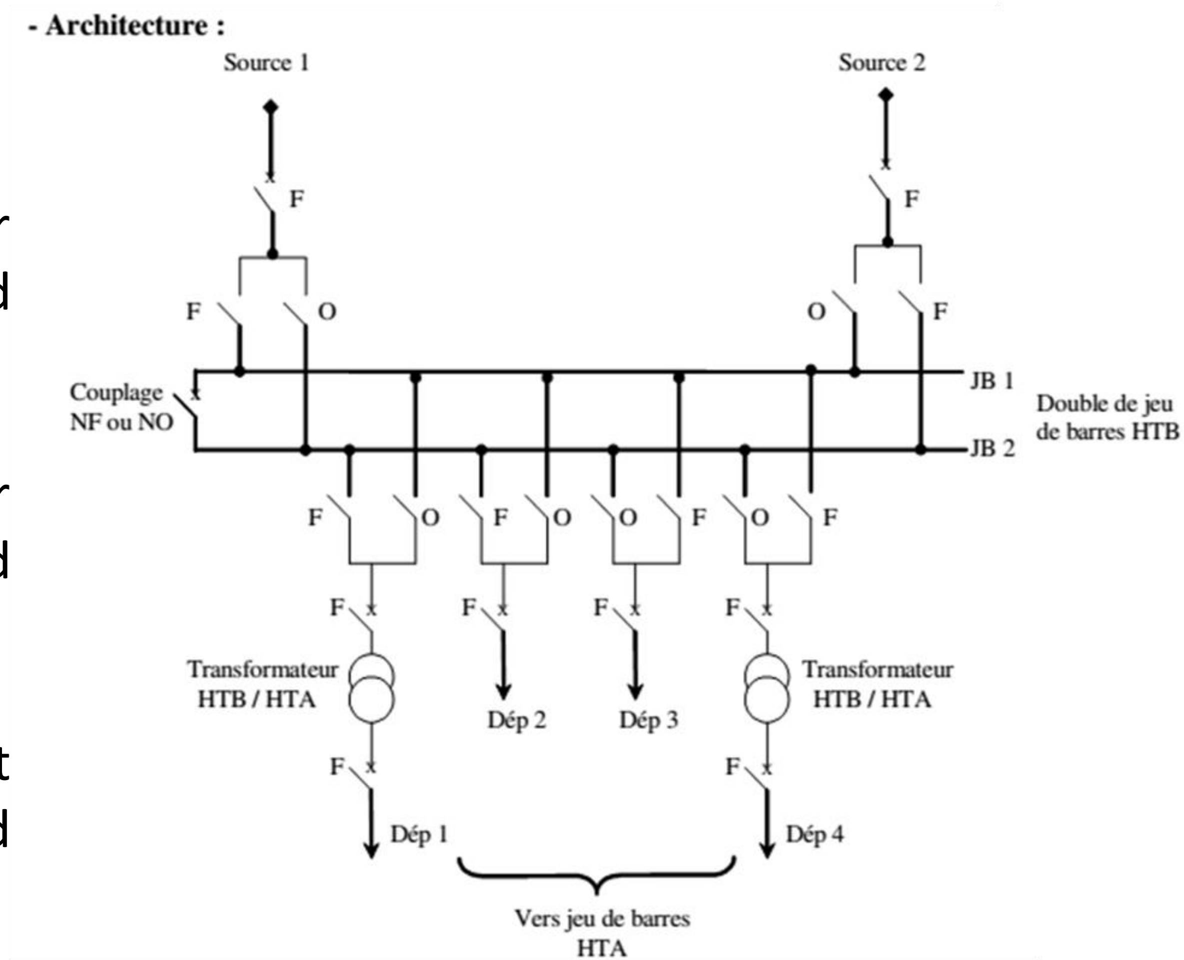
Disadvantages :

- More expensive solution than single-antenna power supply - Only allows partial operation of the busbar in the event of maintenance

3. Double antenna with double busbar :

- **Operating mode :**
- **Normal :**

- Source 1 supplies, for example, busbar **BB1** and feeders **Dep 1** and **Dep 2**.
- Source 2 supplies, for example, busbar **BB2** and feeders **Dep 3** and **Dep 4**
- The coupling circuit breaker can be kept closed or open.



double antenna architecture with double busbar

- Disrupted :

- In case of loss of one source, the other source ensures the entire supply.
- In case of fault on one set of busbars (or maintenance of it), the coupling breaker is opened, and the other set of busbars supplies all the outgoing circuits.

- Advantages and disadvantages :

Advantages:

- Good power supply availability,
- Very high flexibility in the allocation of sources and loads, and for maintenance of busbar sets,
- Possibility of busbar transfer without interruption (when busbars are coupled, it is possible to operate a disconnector if its adjacent disconnector is closed)

Disadvantage:

- Significant additional cost compared to the simple busbar solution.

4. A busbar set with a source:

- Architecture :

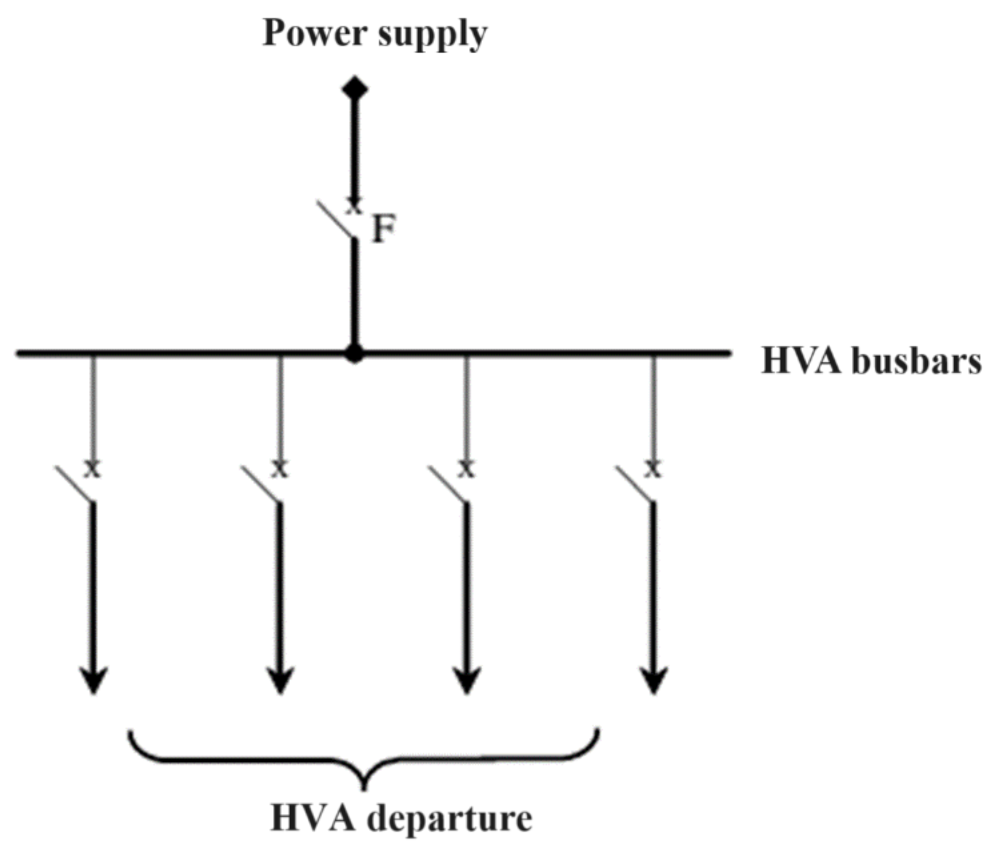


Fig. 4 .Architecture of a busbar set with a power source

- Operation:

In the event of loss of power source, the busbar set is out of service until repair operation is conducted.

5- A busbar set without coupling with two power sources:

- **Architecture:**

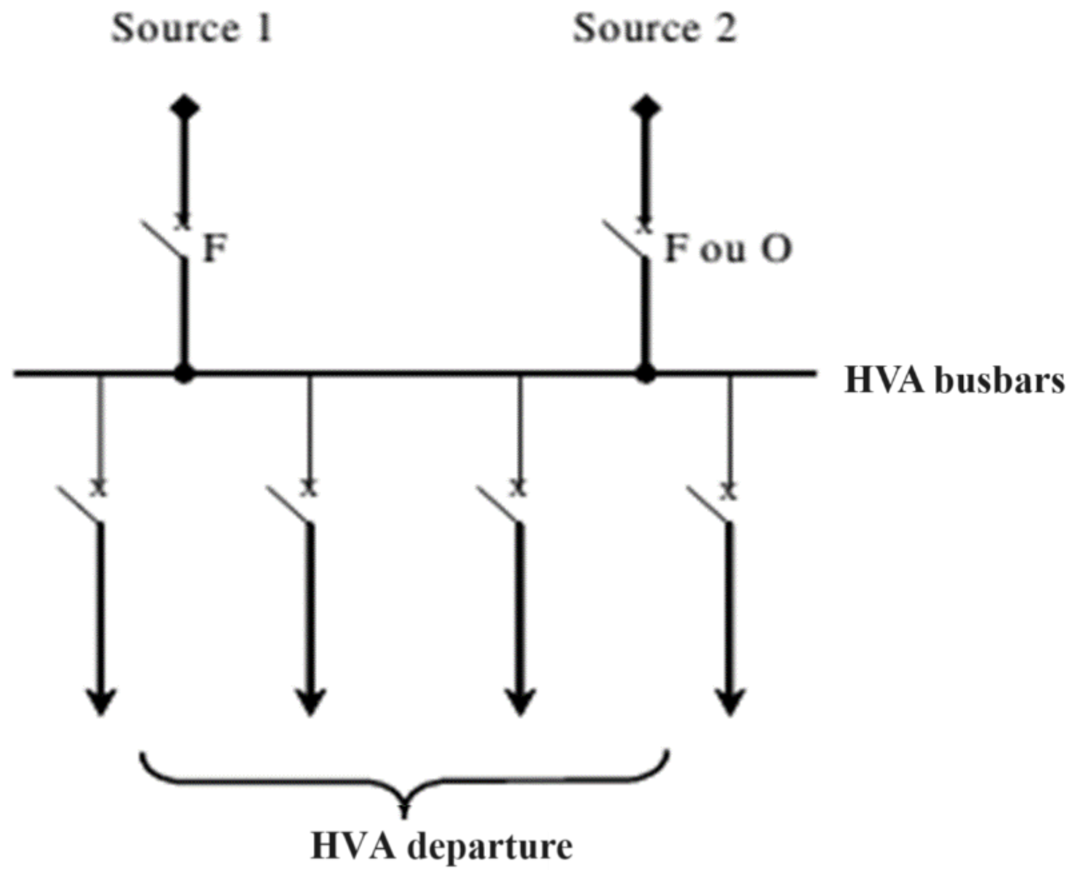


Fig. 5 - Architecture of a busbar set without coupling with two power sources.

- **Operation:**

Both sources can operate in parallel or one can serve as a backup for the other. In the event of a fault on the busbar set (or maintenance of it), the outgoing circuits are no longer supplied.

6- Two busbar sets with coupling and two power sources:

❑ Architecture :

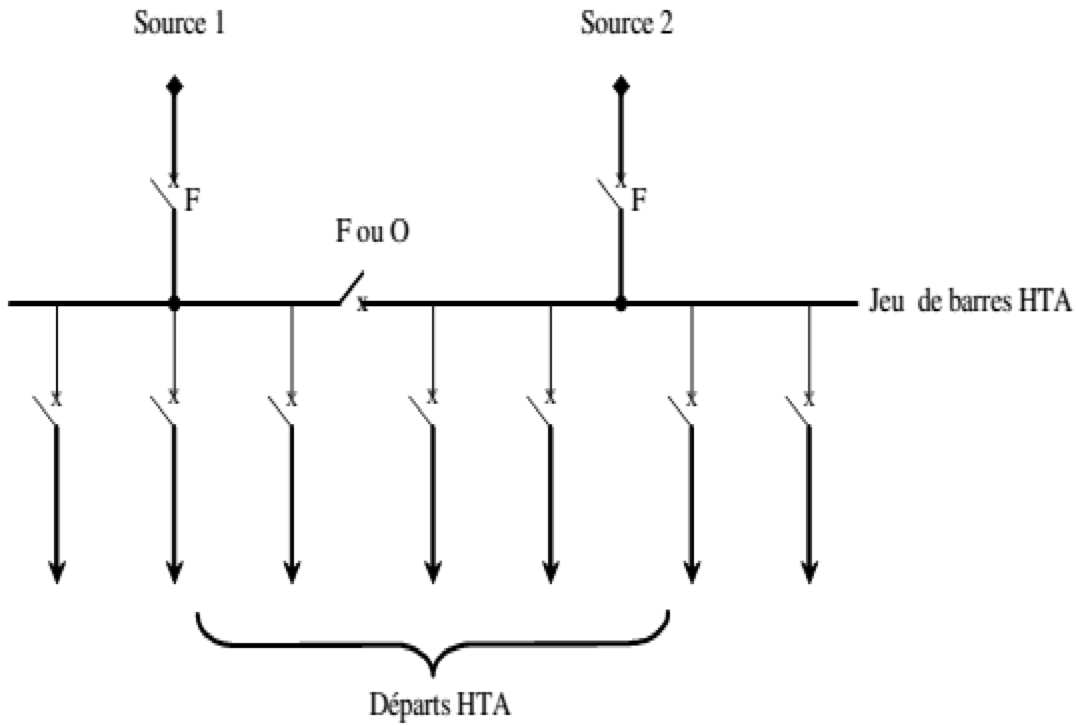


Fig. 6 : Architecture of two busbar sets with coupling and two power sources.

❑ Operation:

- The coupling breaker can be kept closed or open.
- If it is open, each source feeds a set of busbars. In the event of a loss of one source, the coupling breaker is closed and the other source feeds both sets of busbars.
- In the event of a fault on one set of busbars (or maintenance of it), only a portion of the outgoing circuits is no longer supplied.

V. HVA network architectures

- We will identify the main structures of HV (High Voltage) networks used to supply secondary switchboards and HV/LV transformers. The complexity of the structure varies according to the desired level of operational safety.
- The electrical diagrams of the most commonly encountered HV networks are as follows:

1. Single antenna radial:

❑ Architecture :

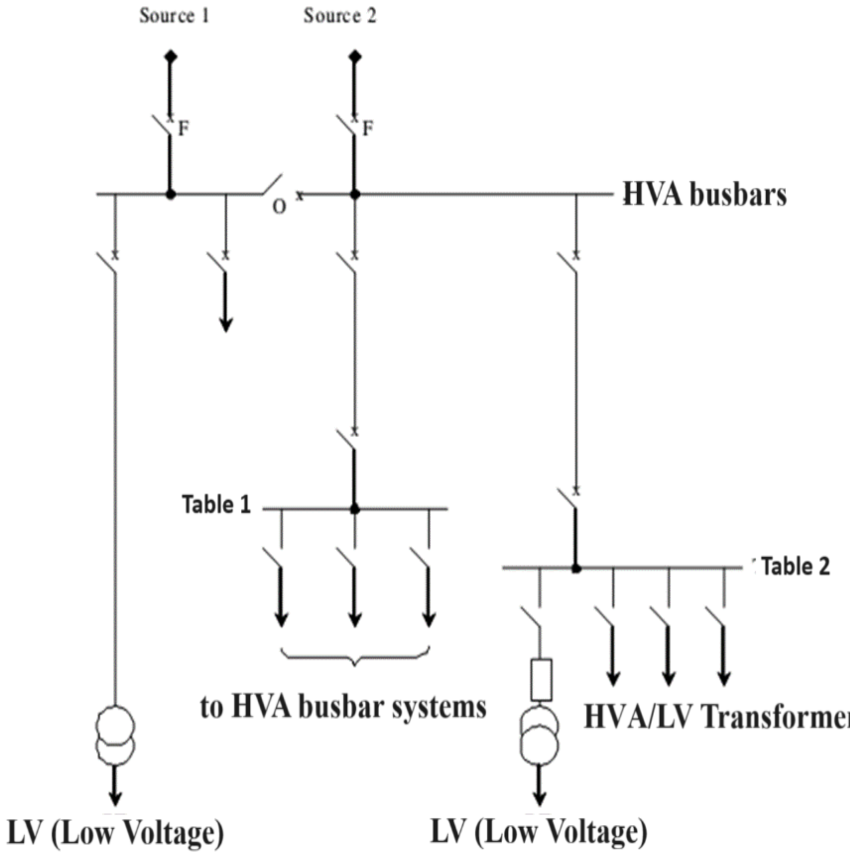


Fig.1- Radial High Voltage Network with Single Antenna.

❑ Operation:

- Tables 1 , 2 and the transformers are powered by a single source, with no backup solution.
- This structure is recommended when availability requirements are low; it is often chosen for cement plant networks.

2. Radial en double antenne sans couplage :

❑ Architecture :

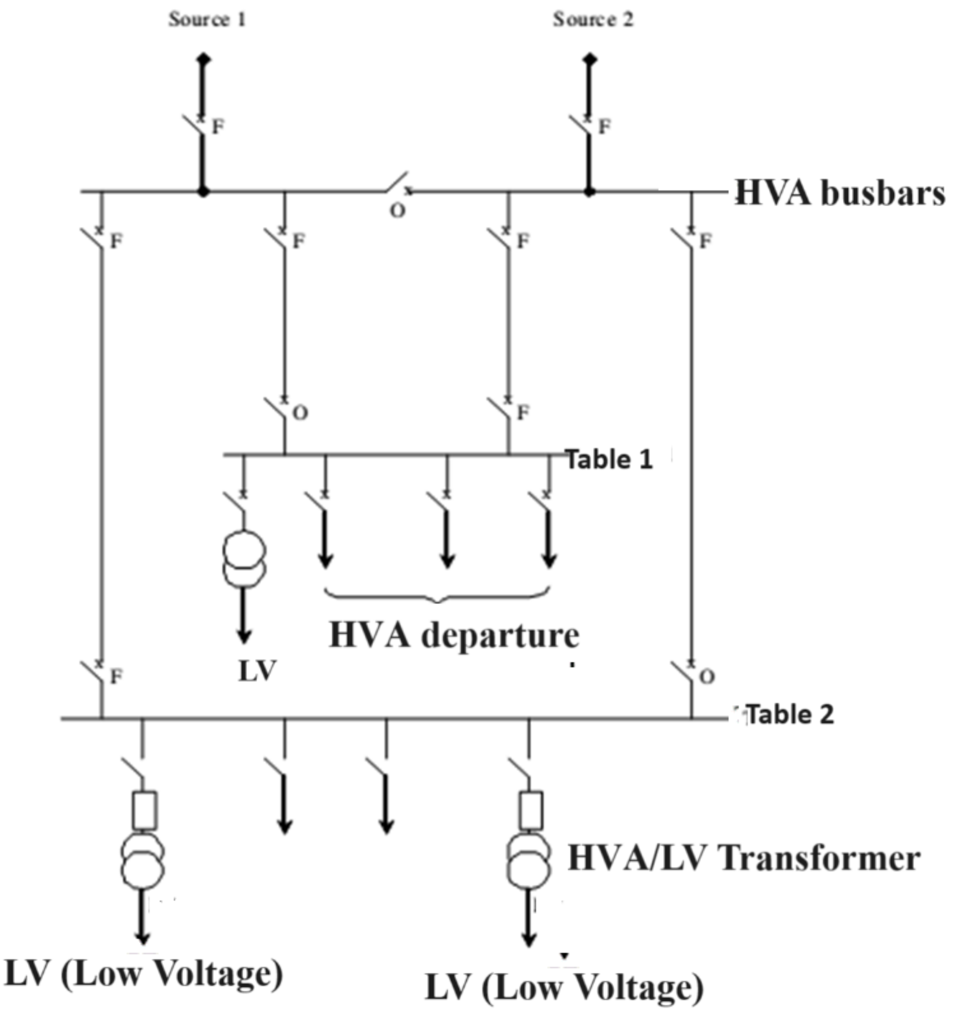


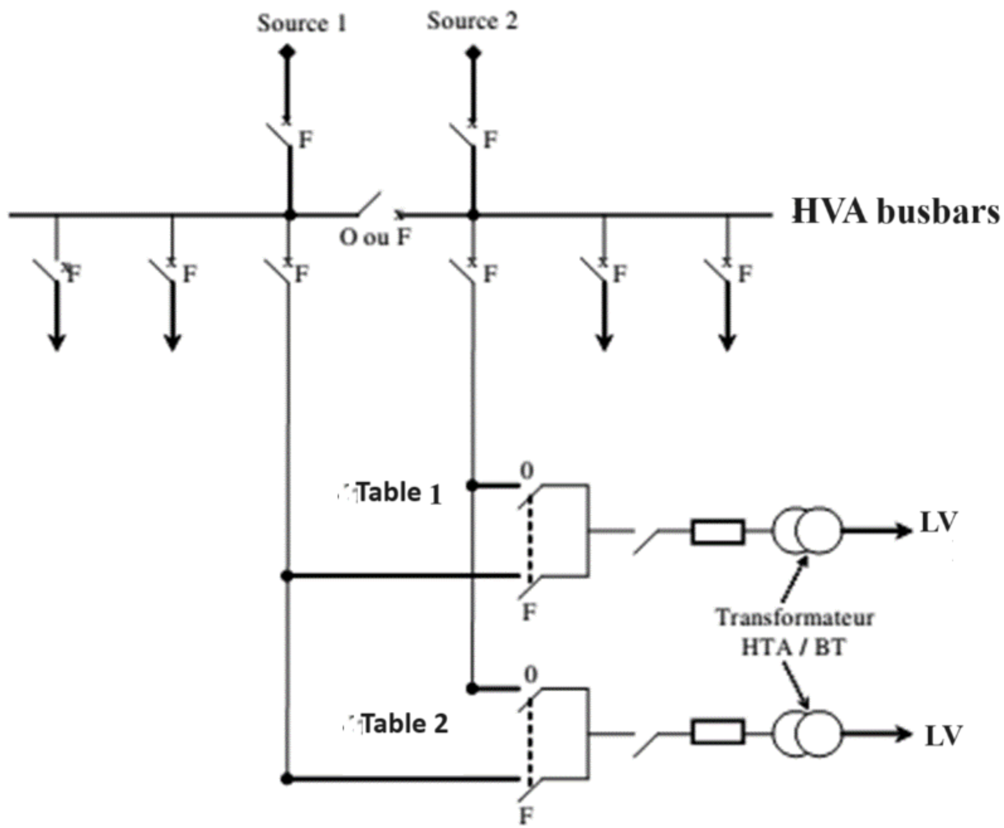
Fig.2- Radial High Voltage HVA Network with Dual Antennas without Coupling.

❑ Operation:

- The tables 1 and 2 are powered by 2 uncoupled sources, one serving as a backup for the other.
- The availability is good.
- The lack of coupling between the sources for tables 1 and 2 results in less flexible operation.

3. Double derivation :

❑ Architecture :



❑ Operation:

- Tables 1 and 2 can be serviced and powered by either of the sources independently.
- This structure is well-suited for extensive networks with limited future expansions and requiring very high availability

VI- Architectures of HVA/LV substations with a capacity exceeding 630 kVA

1- Generalities:

These types of HV/LV substations are characterized by::

- Input voltages: 10 or 30 kV,
- Output voltages (utilization): 230/400 V,
- Power cable section: 120 mm2,
- Power: S > 630 kVA,
- Supply mode:

➢ *Underground: Main artery disconnection,*

➢ *Overhead: Derivation..*

- General protection cell by HV circuit breaker,
- Energy metering cell (voltage and current),
- Protection of transformers by HV fuse,
- Low voltage general switchboard (LVGS).

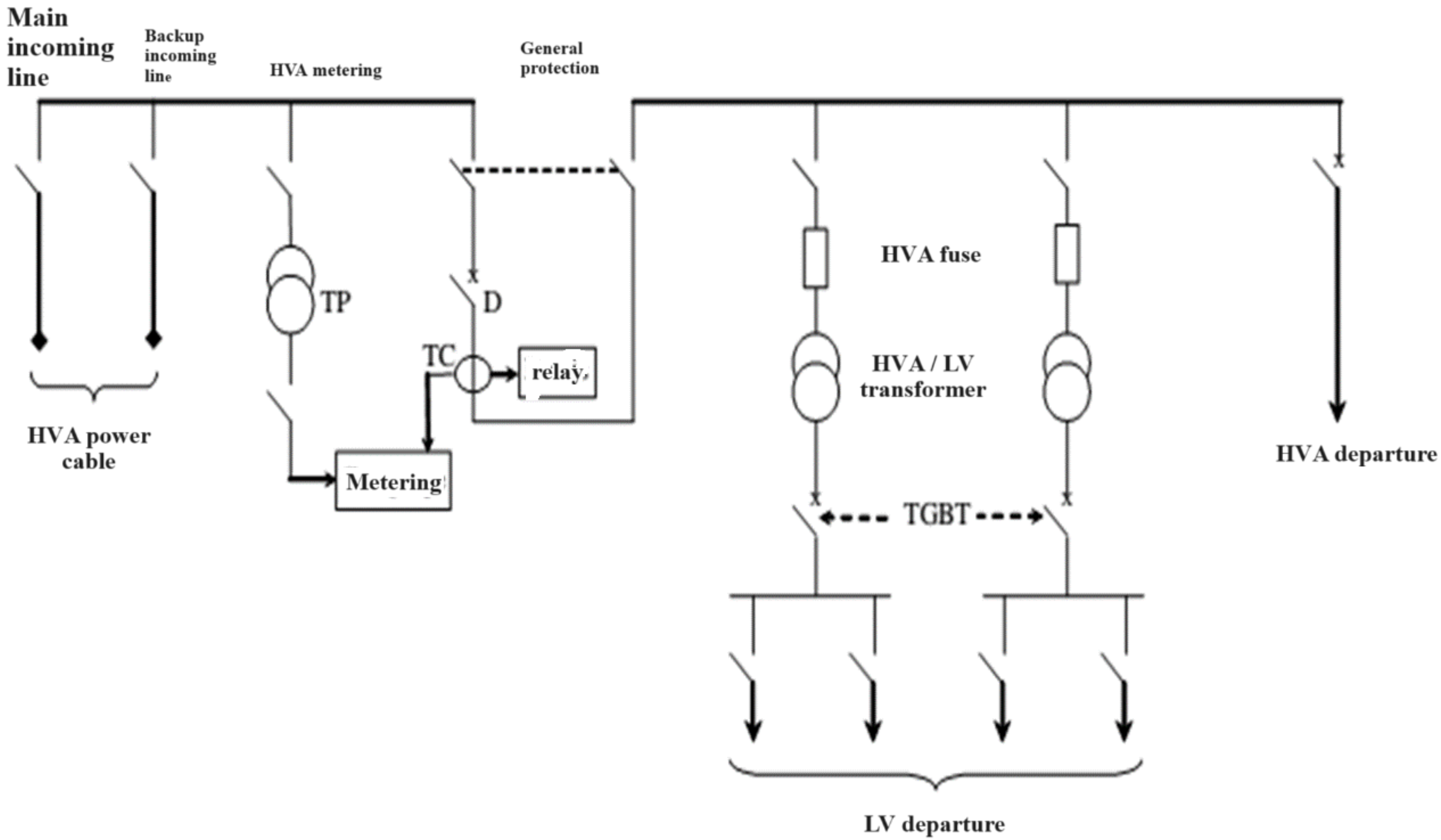


Fig . General architecture of a MV/LV substation.

2- Supply in the event of an arterial break:

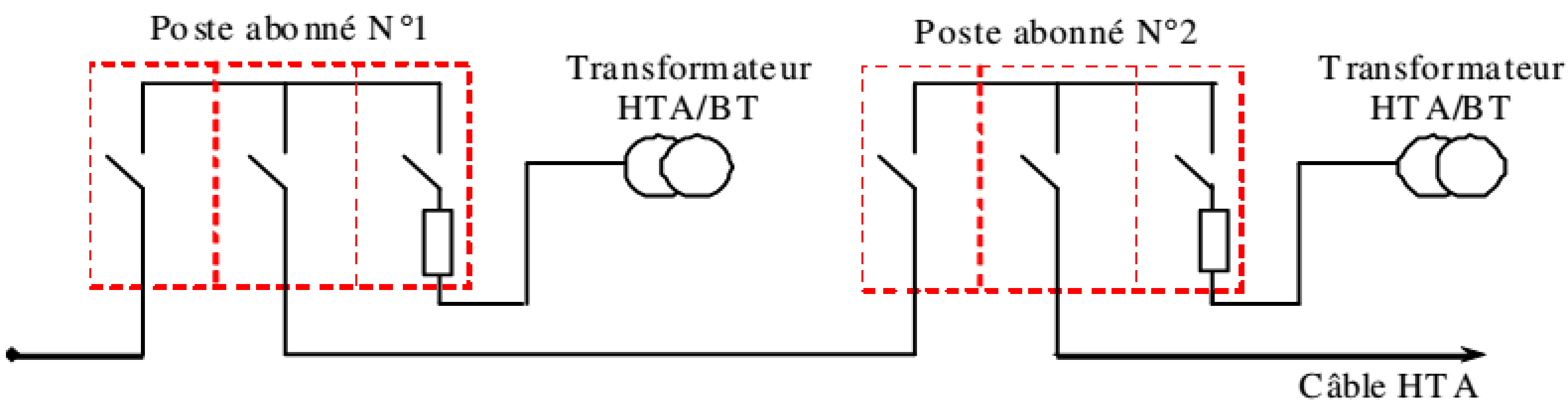
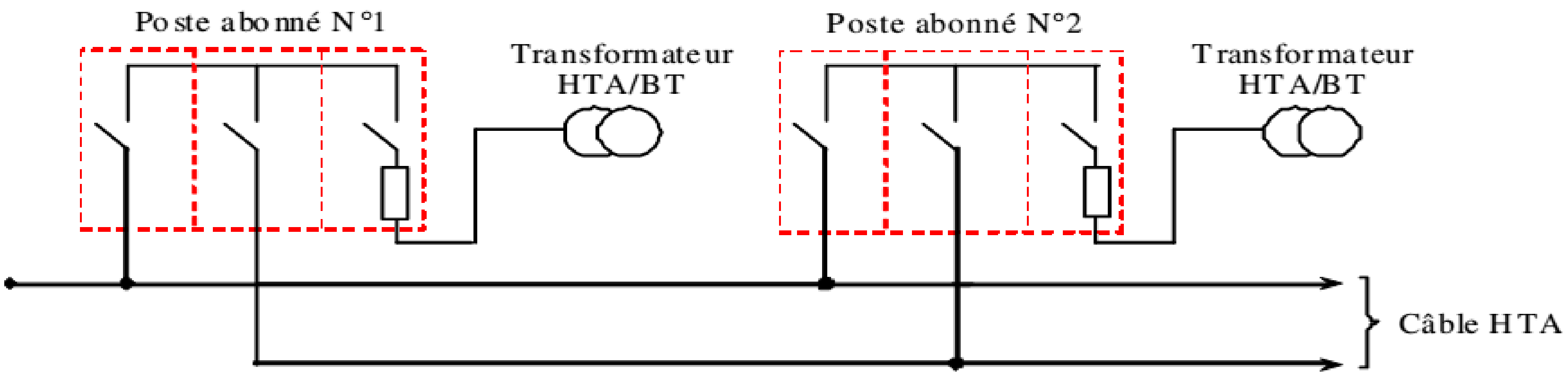


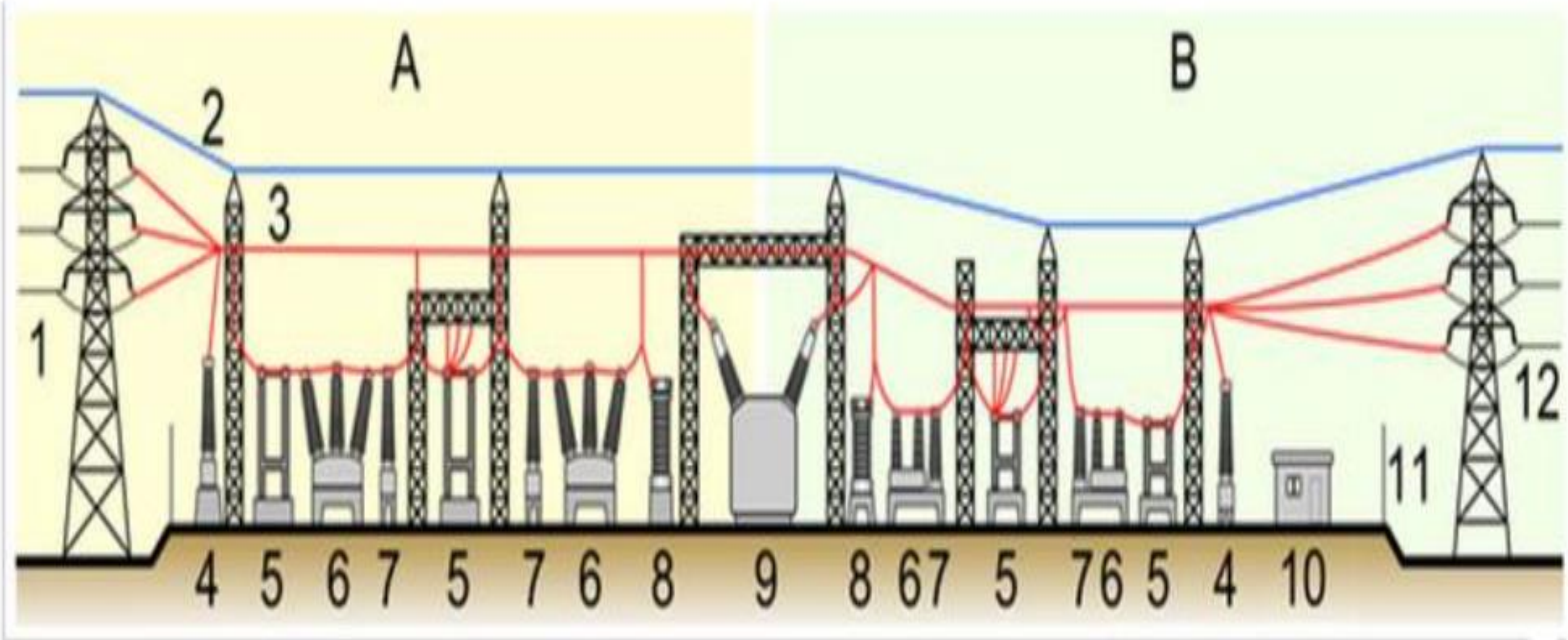
Fig- Poste abonné alimenté en coupure d'artère.

3- Double branched power supply:

Domaines d'utilisation :

- Distributions souterraines en zone urbaine,
- Réseaux HT. d'activités tertiaires.





A : coté primaire B : coté secondaire 1. ligne électrique 2.cable de garde 3.ligne électrique 4.transformateur de tension 5.sectionneur 6.disjoncteur 7. Transformateur (de puissance) 10.Batiment secondaire 11.colecteur 12.Ligne électrique secondaire

Figure - Les différents éléments dans un poste

Chapter 1: Introduction to protection

I.1. Disruptions

They are a nuisance for users and suppliers of electrical energy without there being a real power outage. In general, regardless of the disruption, the effects can be classified in two different ways:

Instantaneous effects: Unforeseen maneuvers of contactors or protective devices, malfunction or stoppage of a machine. The impact of the disruption is then directly noticeable in terms of financial and technical aspects.

Delayed effects: Energy losses, accelerated aging of equipment due to heating and additional electrodynamic stresses caused by the disruptions. The financial impact is difficult to quantify.

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I.1.1 Short-circuit current

The short-circuit current of an instantaneous nature is an overcurrent produced by an impedance fault whose value becomes negligible between two points of the same circuit.

Detection devices reserved for this disruption are::

- Electromagnetic relays
- Fuses

Causes capable of producing a short-circuit current are:

- Breakage of conductors
- Lightning strike
- Unforeseen contact
- Insulation breakdown
- Operator error

The consequences resulting from a short-circuit current are:

- Overcurrent
- Voltage drop
- Imbalance
- Heating
- Frequency drop
- Loss of synchronism
- Overload current

I.1.2 Overload current

is a progressively increasing overcurrent that occurs in a healthy circuit following an increase in load.

Detection devices reserved for this disruption are:

- Thermal relays
- Fuses

Causes capable of producing an overload current are:

- Device used beyond its rated power (intentional or accidental)
- Malfunction

The consequences caused by an overload current are:

- Overcurrent
- Heating
- Imbalance
- Frequency drop

I.1.3 Transient disturbances

Transient disturbances could be divided into two categories:

a- Impulsive

b- Oscillatory

a- Impulsive

Impulsive disturbances are sudden events with maximum peaks that raise the level of current or voltage in the positive or negative direction. These types of events can be categorized according to their speed (Fast, medium, and slow). Impulsive disturbances can be very fast events (5 nanoseconds).

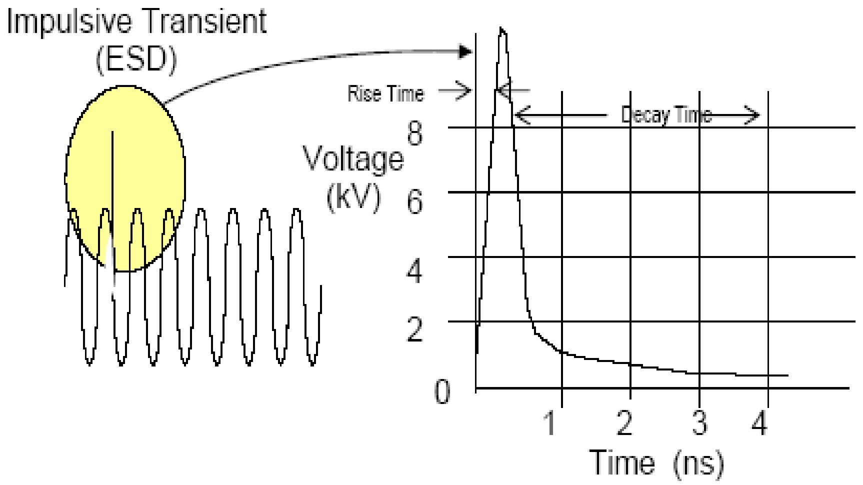


Fig. I.3.1 Impulsive positive disturbance caused by an electrostatic discharge

b- Oscillatory

An oscillatory disturbance is a sudden change in the steady-state condition of voltage or current, or both signals simultaneously, at the positive and negative limits oscillating at the natural system frequency. In simple terms, the oscillatory disturbance causes a strong power signal that disappears very quickly. Oscillatory disturbance occurs during the connection or disconnection of inductive or capacitive loads because they resist change.

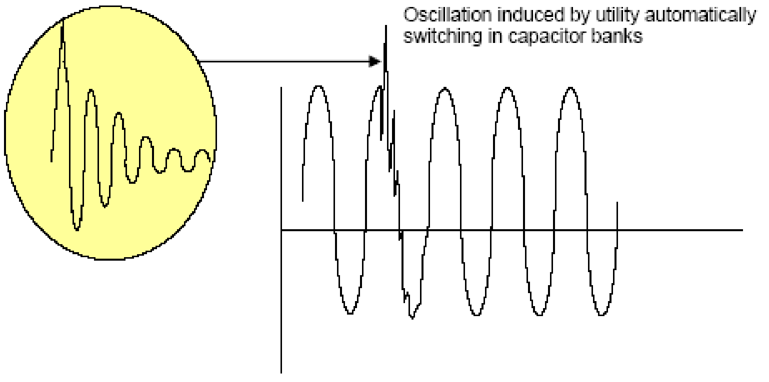


Fig. I.3.2 Oscillatory disturbance

I.1.4 Imbalance

A three-phase system is imbalanced when the three voltages are not equal in amplitude and/or are not phase-shifted from each other by 120°. The degree of imbalance is defined using Fortescue's method by the ratio of the inverse component U_{1i} (or homopolar U_{1o}) of the fundamental to that of the direct component of the fundamental U_{1d}.

$$\Delta U_i = \frac{|U_{1i}|}{|U_{1d}|} \quad \text{et} \quad \Delta U_o = \frac{|U_{1o}|}{|U_{1d}|}$$

The inverse (or homopolar) voltage is caused by voltage drops along the network impedances due to the inverse (or homopolar) currents produced by unbalanced loads leading to non-identical currents on the three phases (low-voltage LV loads connected between phase and neutral, single-phase or two-phase medium-voltage MV loads such as welding machines and induction furnaces). Single-phase or two-phase faults cause imbalances up to the operation of protections.

Detection devices reserved for this disruption are:

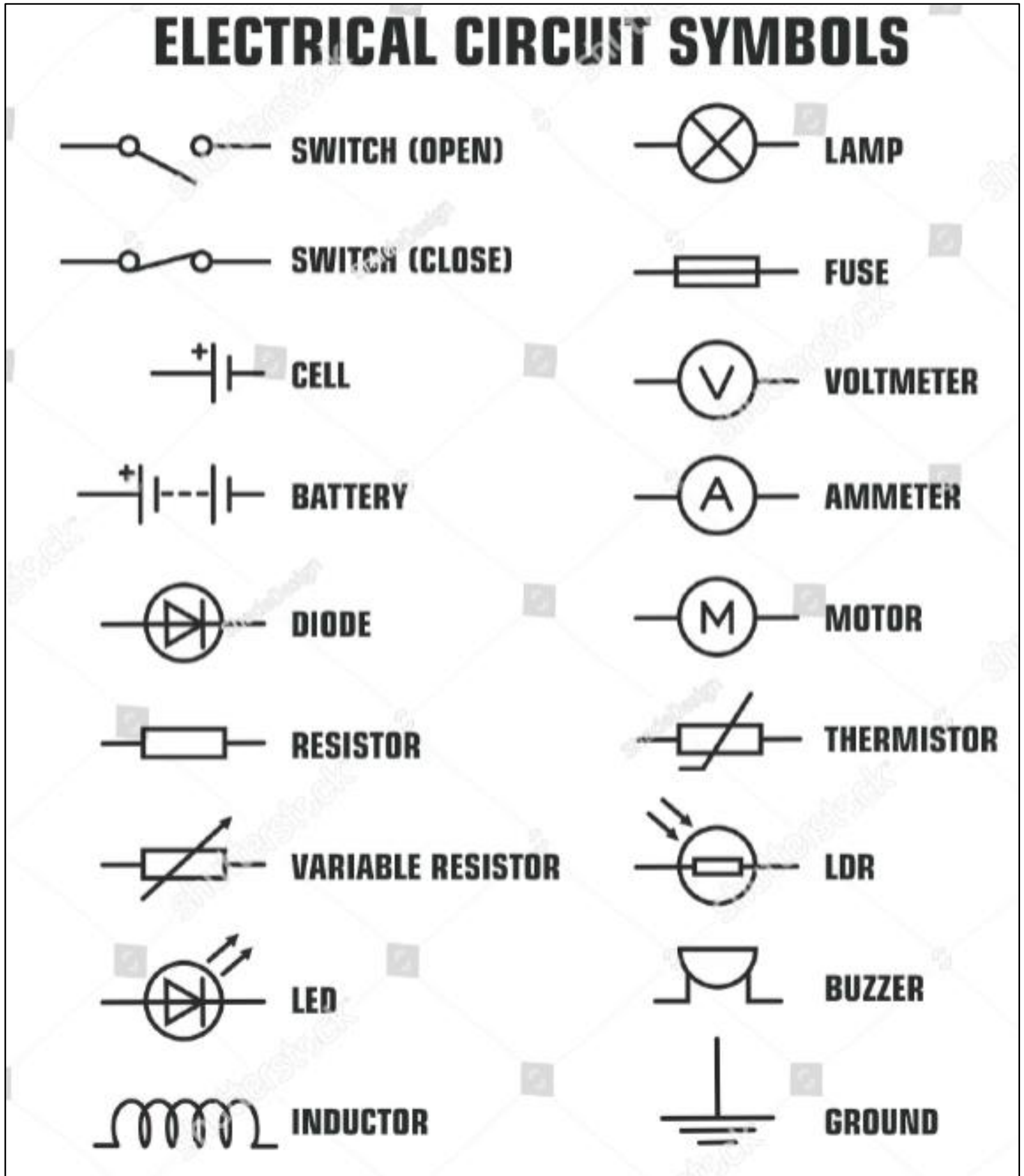
- *Electromagnetic relays*

Causes capable of producing voltage imbalance are :

- *Short-circuit current*
- *Phase breakage*
- *Malfunction of the circuit breaker*

The consequences caused by voltage imbalance are::

- *Heating*
- *Decrease in luminous flux*
- *Motor vibration*


ELECTRICAL CIRCUIT SYMBOLS
SWITCH (OPEN)
LAMP
SWITCH (CLOSE)
FUSE
CELL
VOLTMETER
BATTERY
AMMETER
DIODE
MOTOR
RESISTOR
THERMISTOR
VARIABLE RESISTOR
LDR
LED
BUZZER
INDUCTOR
GROUND

I.2 Properties of Protection

I.2.1 Definition

Protection is a set of components intended to protect either equipment or personnel.

I.2.2 Function

Generally, to protect an installation, it is necessary to:

- Monitor operation
- Detect a malfunctioning state

I.2.3 Properties

For a protection system to effectively fulfill its mission, it must possess the following qualities:

- **Reliability:**

- Activation following a real fault (reliable decision);
- which is the probability of not having incorrect operation (avoiding unintended activations).

- **Speed of action:**

- To limit the harmful effects of the fault;
- Short circuits are incidents that must be eliminated as quickly as possible; this is the role of protections, where speed of operation and performance are prioritized.

- **Sensitivity:**

The protection must operate over a wide range of short-circuit currents between:

The maximum current which is determined by the design of the installations and is therefore perfectly known,

A minimum current whose value is very difficult to assess and corresponds to a short circuit occurring under often exceptional conditions.

The notion of **sensitivity of a protection** is frequently used in reference to the lowest short-circuit current for which the protection is capable of operating.

- **Selectivity:** Triggering only of the devices surrounding the fault, in order to keep the healthy parts under voltage.

- **Availability:** It is the ability to operate when a fault occurs, which requires various procedures or devices to ensure that the protection is operational.

I.3 Basic Principle of Protection

A protection system consists of:

❖ ***Detection and decision-making component***

1. Measurement device or measurement chain
2. Comparison device
3. Decision-making device

❖ ***Organe d’intervention***

1. Signaling and tripping device

I.3.1 Amperometric and Voltmetric Protections

I.3.1.1 Amperometric Protections

This protection prevents dangerous overcurrents by:

- Value
- Time

➢ The thermal relay protects the system against overload currents.

➢ The electromagnetic relay intervenes to protect the system against short-circuit currents.

➢ The fuse switch is a connecting device capable of protecting the system against overcurrents:

- **gI, gII cartridges** are for general use (Protect the system against all types of overcurrents)
- **aM cartridges** ensure the protection of the system against strong overcurrents.

Fig.I.1.1.3 Fused circuit breaker

a. Maximum current protection with constant time delay

Operates instantaneously or with a time delay when the current in the circuit to be protected reaches or exceeds a set value.

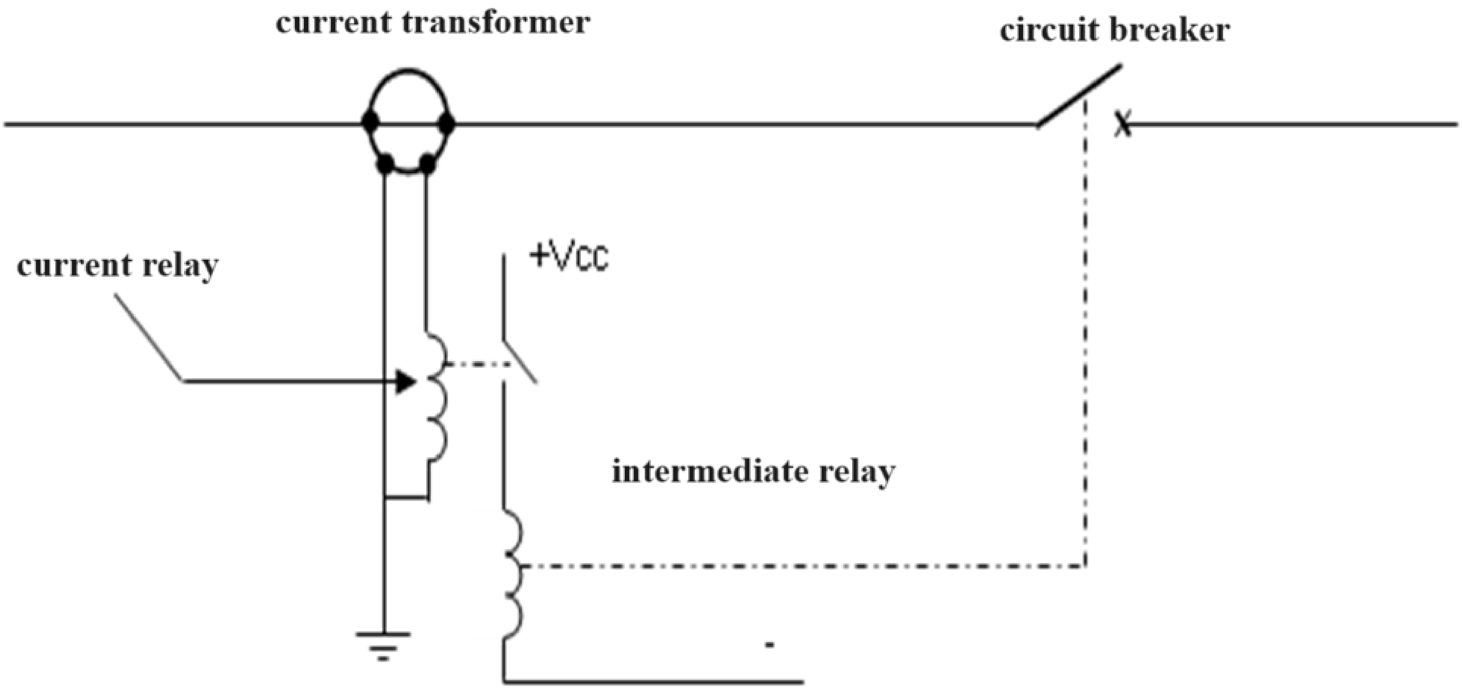


Fig. Constant-time overcurrent protection (Single-phase diagram)

I.3.1.2 Voltmetric protection

It operates instantaneously or with a time delay when the voltage in the circuit to be protected reaches or exceeds a set value. Voltage transformers ensure galvanic isolation and adaptation to measurement circuits.

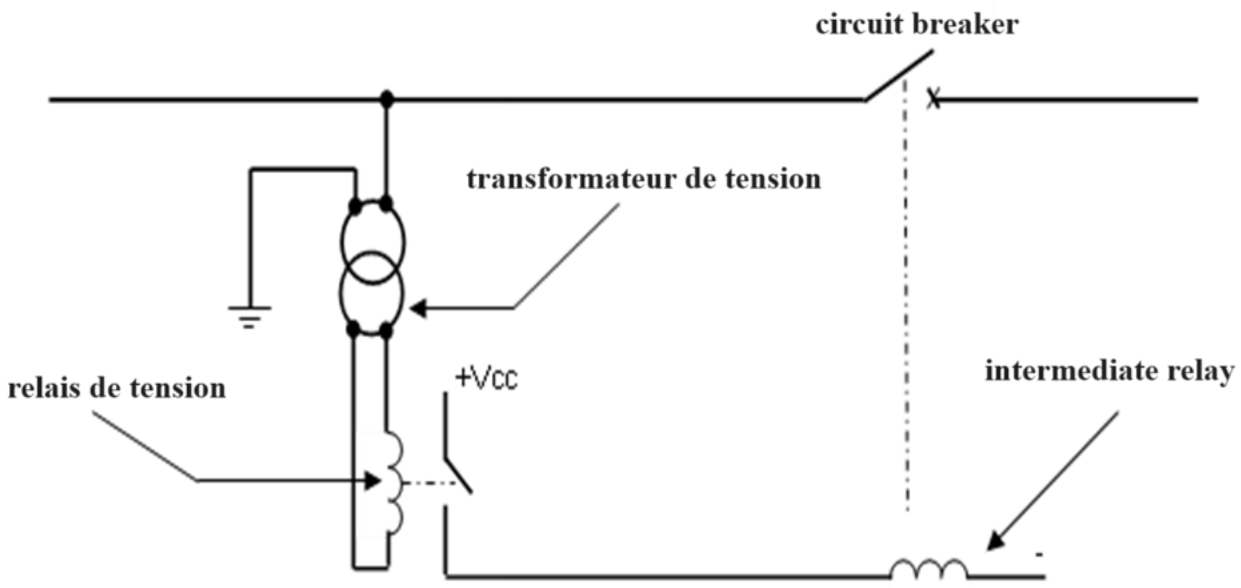


Fig.I.3.1.2.1 Voltmetric protection (one-phase diagram)

I.3.2 Selectivity Mode

- **The principles of selectivity**

Selectivity is a method that consists of **coordinating** protections so that when a fault occurs on a circuit, only the protection placed at the head of that circuit triggers, avoiding the shutdown of the rest of the electrical installation.

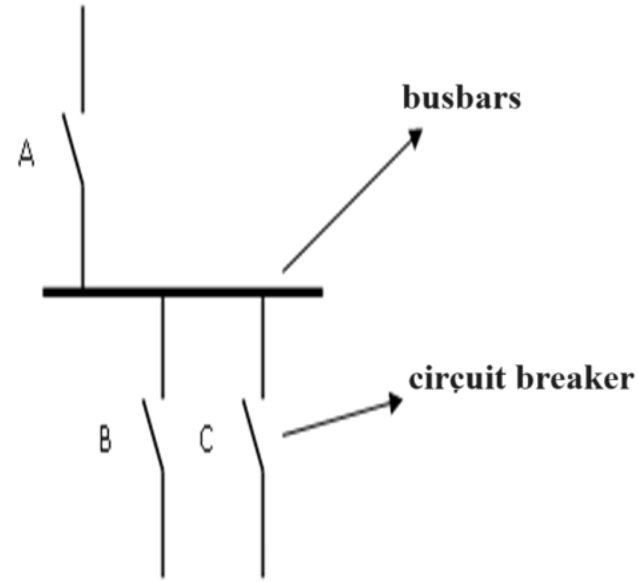
The benefits of selectivity are twofold. It aims to improve:

- **Continuity of service:** Above all, selectivity makes it possible to promote continuity of service in the other circuits of the electrical installation.
- **Increased safety:** Good selectivity between the protections of an electrical installation requires rigorous calculation, at each point of the installation, of the maximum value of the presumed short-circuit current. This makes it possible to organise the coordination of protective devices to improve the safety of the installation.

Note :

Selectivity between two circuit breakers A and B **is total** if **B** operates alone for any value of the short-circuit current at the point where it is placed (I_{ccB}).

Selectivity **is partial** if **B** operates alone up to a presumed short-circuit current **Icc** lower than **I_{ccB}**. Beyond this value, circuit breakers A and **B** operate simultaneously.



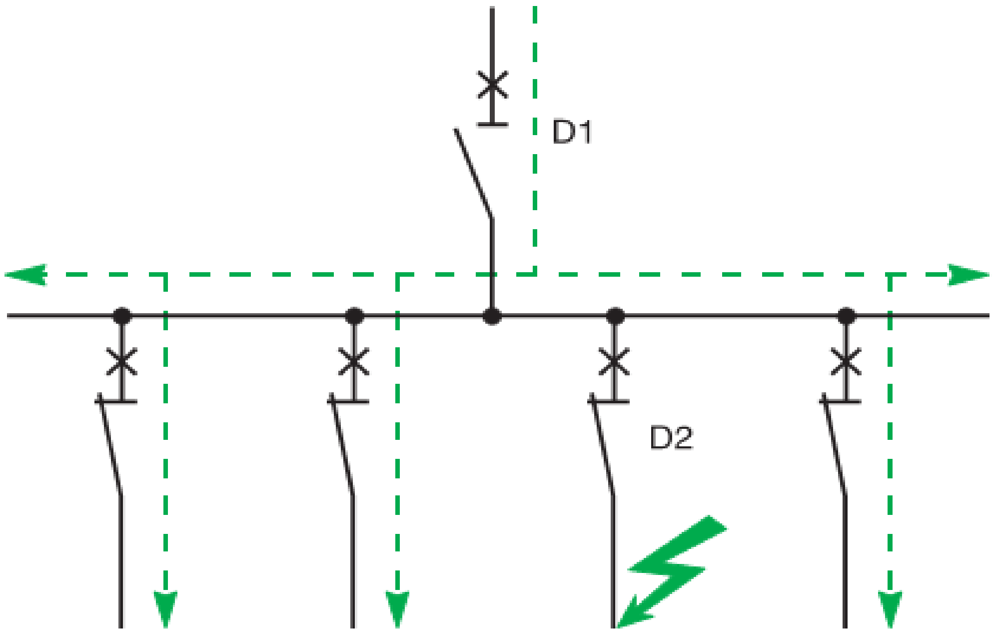
There are several techniques for selectivity:

- Amperometric selectivity by current,
- Chronometric selectivity by time,
- Selectivity by information exchange, known as logical selectivity.
- The SELLIM system (SELectivité LIMitation)

Total selectivity: for all fault values from overload to short circuit, the distribution is completely selective if **D2** opens and **D1** remains closed.

Partial selectivity: selectivity is partial if the above condition is not met up to the full short-circuit current, up to a lower value. This value is called the selectivity limit.

Without selectivity: In the event of a fault, circuit-breaker **D1** may open.



I.3.2.1 Amperometric selectivity

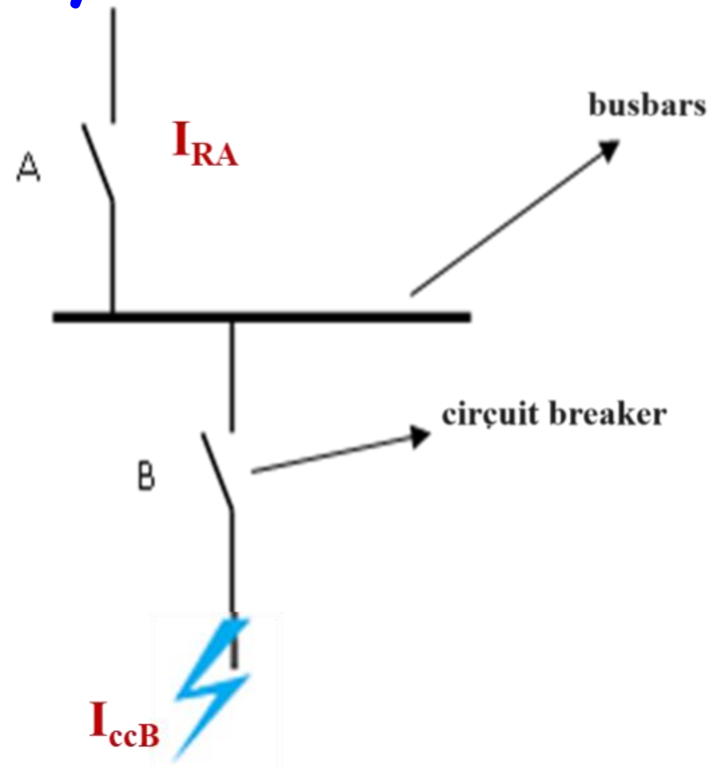


Fig- Amperometric selectivity

The short-circuit current **downstream** of circuit-breaker **B** is I_{ccB}, and the tripping value of circuit-breaker **A** is I_{RA} in this case:

- If current $I_{RA} > I_{ccB}$, selectivity is said to be total.
- If current $I_{RA} < I_{ccB}$, selectivity is partial.

I.3.2.2 Chronometric selectivity

This technique consists in delaying the circuit-breaker opening time to a greater or lesser extent, by adjusting the operating time of the devices. It requires, on the one hand, the introduction of delay devices in the circuit-breaker tripping system and, on the other, circuit-breakers capable of withstanding the thermal and electrodynamic effects of the current during the delay time.

So, in the diagram (Figure opposite), the short-circuit shown is seen by all the protection devices (at **A, B, C** and **D**). The time-delayed protection **D** closes its contacts faster than the one installed in **C,** itself faster than the one installed in **B**.

Once circuit-breaker **D** has opened and the short-circuit current has disappeared, protections **A, B** and **C**, which are no longer in use, return to their standby position.

The difference in operating times **ΔT** between two successive protections is the **selectivity interval**.

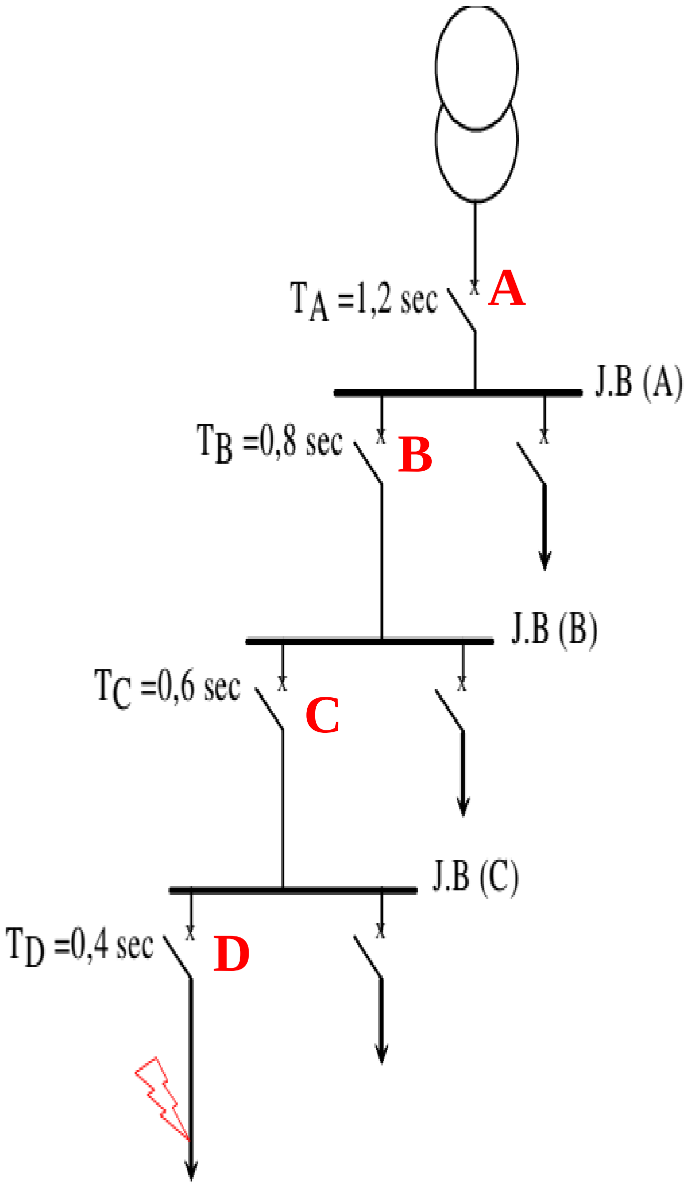
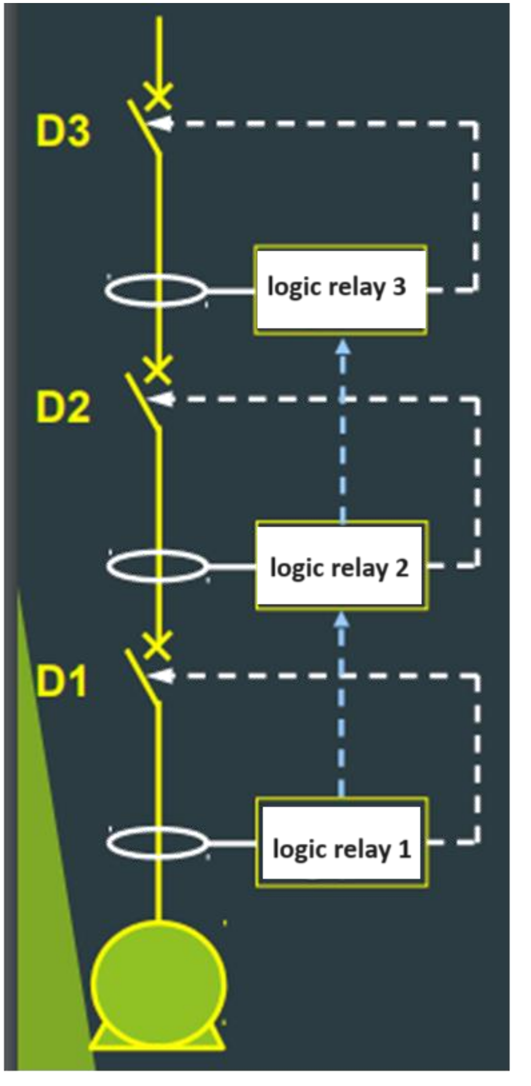


Fig. Chronometric selectivity

I.3.2.3 Logic selectivity

Logic selectivity requires the transfer of information between the circuit-breaker trip units of the various distribution stages.



Principle: Each circuit-breaker is associated with a logic relay which receives "fault" information from sensors. A relay activated by a fault sends :

- A wait command to the upstream stage;
- A trip command to the circuit-breaker with which it is associated (unless it has itself received a wait command from the downstream circuit-breaker).

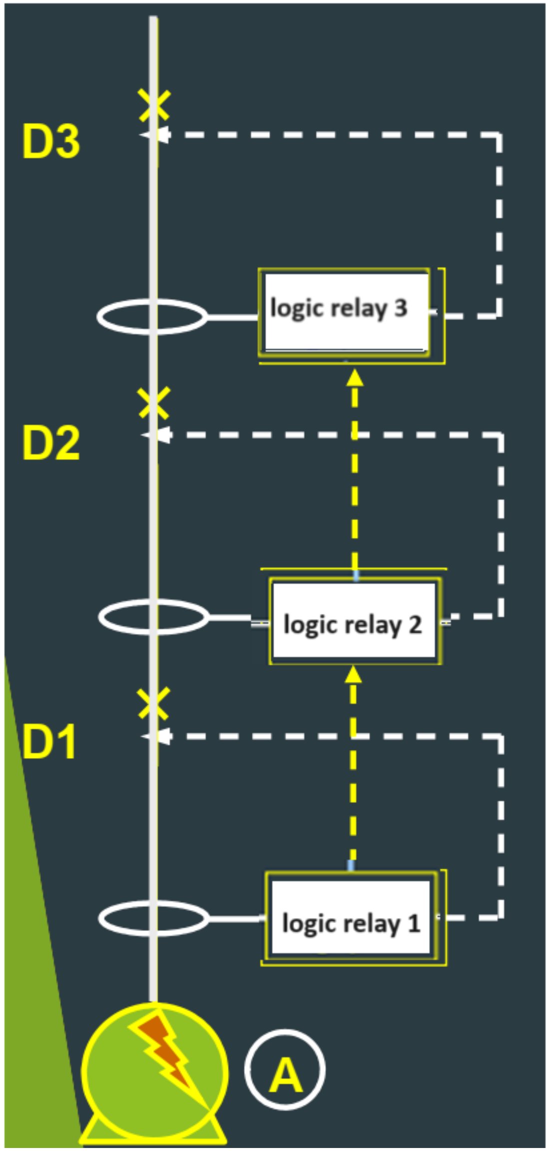
I.3.2.3 Logic selectivity

Example

A fault at point **A** will be detected simultaneously by all three relays:

- Relay **1** holds relay **2** and trips circuit-breaker **1**

- Relay **2** holds relay 3



Logic selectivity is an additive to chronometric selectivity. It reduces fault clearing times, which in turn reduces the stress on the installation. Logic selectivity applies to LV high-current selective circuit-breakers, but is also used on industrial HV networks. It requires tripping devices to be compatible with each other.

I.3.2.4 "SELLIM" type selectivity

This technique (patented by MERLIN GERIN) provides total selectivity by using an upstream Compact L-type limiting circuit-breaker fitted with an ***SB-type selective release*** without any time-delay setting, and a downstream standard circuit-breaker.

- In the case of a short circuit **downstream of B**, *the current wave is greatly reduced by the limiting power of A,* and passes through A without tripping, giving circuit-breaker B time to open.

- In the case of a short circuit **downstream of A**, *the first current wave is also greatly limited*, with A tripping only when the second current wave appears.

The "SELLIM" system thus provides total selectivity with any downstream circuit-breaker, and all the advantages of wiring for the downstream network..