Protection of Electrical Networks

Chapter 2: Elements of the Protection System

1. Introduction

The protective devices continuously monitor the electrical state of network components and trigger their disconnection (for example, by opening a circuit breaker) when these components are subject to unwanted disturbances: short-circuits, insulation faults, overvoltages, etc. The choice of a protective device is not the result of isolated deliberation but one of the most crucial steps in the design of an electrical network.

Based on the analysis of the behavior of electrical equipment (motors, transformers, cables, etc.) during faults and the resulting phenomena, the most suitable protective devices are selected. This is what will be presented in this chapter.

2. Protection system :

1- Definition :

The International Electrotechnical Commission (IEC) defines protection as all the measures designed to detect faults and abnormal network situations in order to trip one or more circuit breakers and, if necessary, to generate other signalling commands.

2- Protection functions:

A protection system consists of a set of devices designed to detect network faults and abnormal situations in order to trip one or more circuit-breaking elements.

3- Rôle d’une protection

system When a fault or disturbance occurs on an electrical network, it is essential to de-energise the faulty part using a protection system. The role of the protection system is to limit the damage that may be caused by the fault.

3. Schematic Diagram of a Protection System

Regardless of the technology used, the protection system consists of three fundamental parts:

- ❖ Sensors or measurement transformers that reduce the monitored values (current, voltage, etc.) to levels usable by the protection devices;
- ❖ Protective relays ;
- ❖ Switchgear (one or more circuit breakers).

An example of a protection system for a high-voltage line is shown in the figure below.

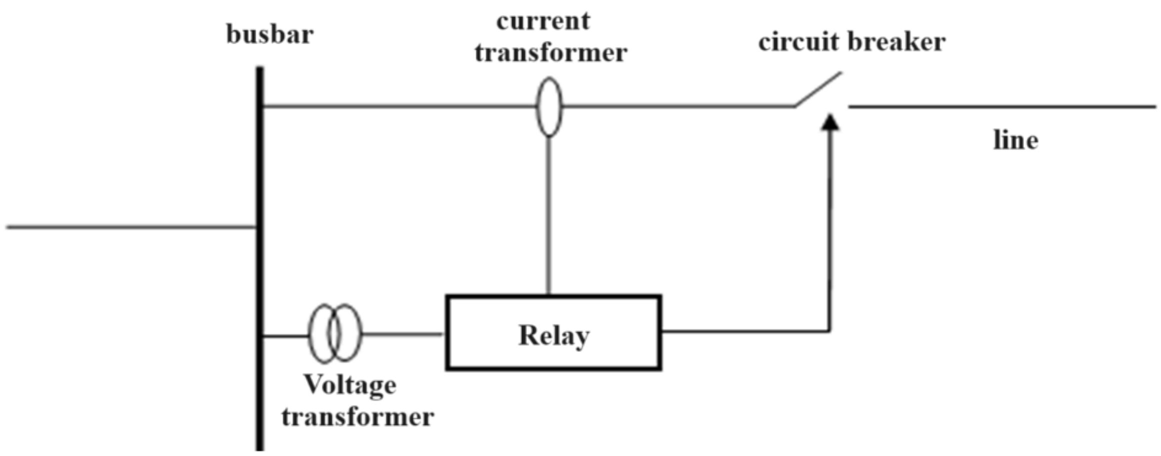


Figure 1: Elements of a protection system.

The protection relays are connected to the measurement transformers (**CTs and PTs**) to receive input signals and to the circuit breakers to deliver opening or closing commands. So in case of a fault, the task of the circuit breaker is to **eliminate the fault** while the task of the protection relay is to **detect this fault**. In high voltage, the relays are located in substations. The fault elimination time includes:

- The operation time of the protections (fault detection).
- The opening time of the circuit breakers (fault elimination).

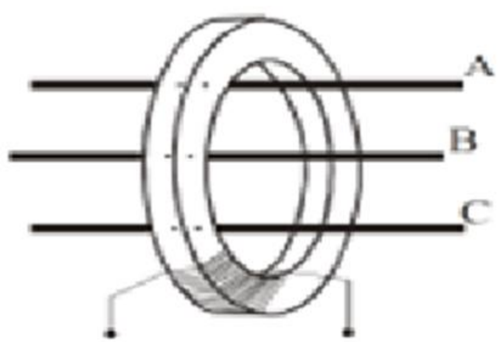
3.1. Measurement Transformers (CTs and PTs)

3.1.1. Current Transformer (CT):

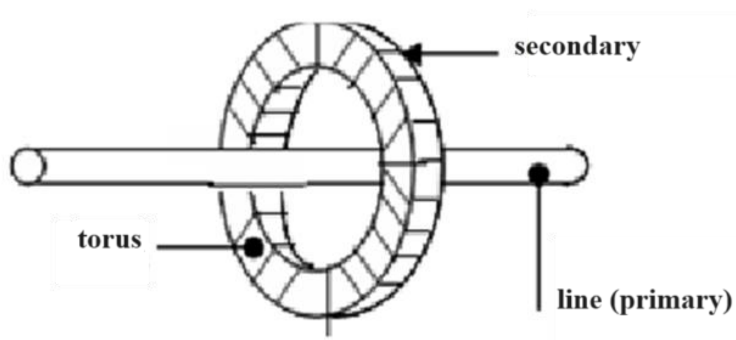
❖ Definition :

From an electrical perspective, CTs (as shown in the figure below) have several roles:

- ❖ Delivering to their secondary side an accurate representation of the current flowing through the respective line.
- ❖ Ensuring galvanic isolation between the line and the measurement and protection circuits.
- ❖ Protecting the measurement and protection circuits from any damage when a fault occurs on the line.



Measurement of homopolar current



Phase current measurement

Figure. Transformateur de courant type tore.

The current transformers used allow reducing the level of currents from thousands of Amperes to standard outputs of 5A or 1A. During a fault, the current level of the transformer increases, which makes their selection critical for the correct operation of the relay. Based on this current intensity information, the relay then formulates a tripping command according to the type of protection it provides and the pre-set values (threshold, time delay). This command is transmitted to one or several switching devices (circuit breakers, contactors, switches). Depending on the type of protection needed, the current transformers are associated and used in different configurations; they can be isolated or integrated within the circuit breaker.

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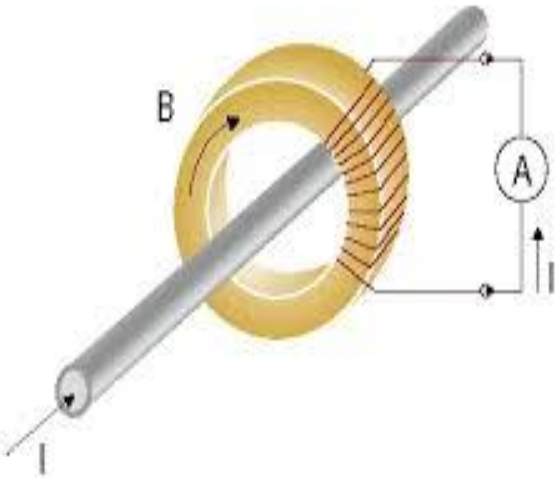
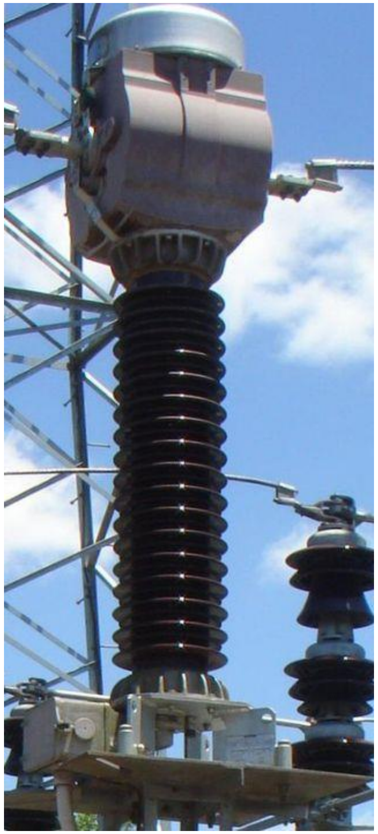




Current transformer with nominal voltage of 138 kV

Current transformer

3.1.2. Voltage Transformer:

❖ Definition :

The voltage transformer (VT) is a true transformer, with its primary receiving the network voltage, and its secondary providing an image voltage (Figure below). Since the voltage levels in the network are in the order of kilovolts, voltage transformers are used to lower the voltages to levels acceptable by the relays. They are supplied in standard form with a secondary voltage of 100V or 10V (phase-to-phase voltage).

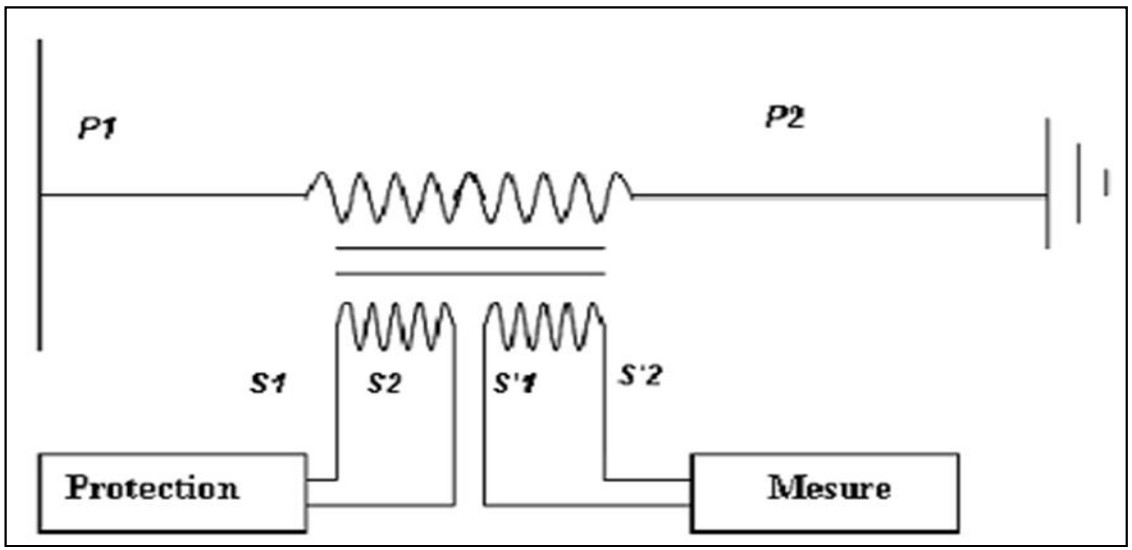


Figure: Voltage transformer with dual secondary

3-3- General information on fault detection:

The primary purpose of protection is not only to detect faults but also to automatically control the necessary switching devices to eliminate the fault. The parameters used to detect a fault are:

- Speed.
- Pressure.
- Temperature.
- Appearance of smoke.
- Voltage U.
- Frequency F.
- Current I.
- Rate of change (derivative) of U, I, or F.
- Apparent power $S = UI$.
- Active power $P = UI\cos\psi$.
- Reactive power $Q = UI\sin\psi$.
- Impedance $Z = U/I$.

3- 4- Relays

❖ Définition

Protection relays are devices that receive one or more analog signals (current, voltage, power, frequency, temperature, etc.) and convert them into a binary command (closing or opening of a control circuit) when these received signals reach values above or below certain predetermined limits.

The role of protection relays is therefore to detect any abnormal phenomenon that may occur on an electrical network, such as a short-circuit, voltage variation, etc. etc. A protection relay detects the existence of abnormal conditions by continuous monitoring, determines which circuit breakers to open and supplies the tripping circuits.

❖ Constitution :

An electrical relay consists schematically of one or more coils, through which a current flows, designed to create one or more electric fields which cause the movement of a moving armature attached to one or more contacts. Depending on the type of supply current, they can be direct or alternating current and, depending on their operation, ampermetric, voltmetric or wattmetric.

❖ Relay classification :

The relays used are provided with the action of one of the preceding quantities. They are adjustable and characterised by their operating threshold. A distinction is made between :

- Relays which can measure or operate on an on/off basis..
- Relays which can be instantaneous or timed.

❖ Relay qualities :

- **Robustness:** a relay must perform several operations without deterioration to ensure safe operation.
- **Overload capacity**: the relay must be able to withstand overcurrents or overvoltages to a certain extent without deterioration, which characterises the choice of relay in practice.
- **Power consumption:** this is the power, expressed in VA, absorbed by the relay at the rated voltage or current. It defines the impedance of the relay's excitation circuit (coil).
- **Sensitivity:** defines the minimum operating value. This notion (expressed as an absolute value or as a %) is only considered for the measuring relay.

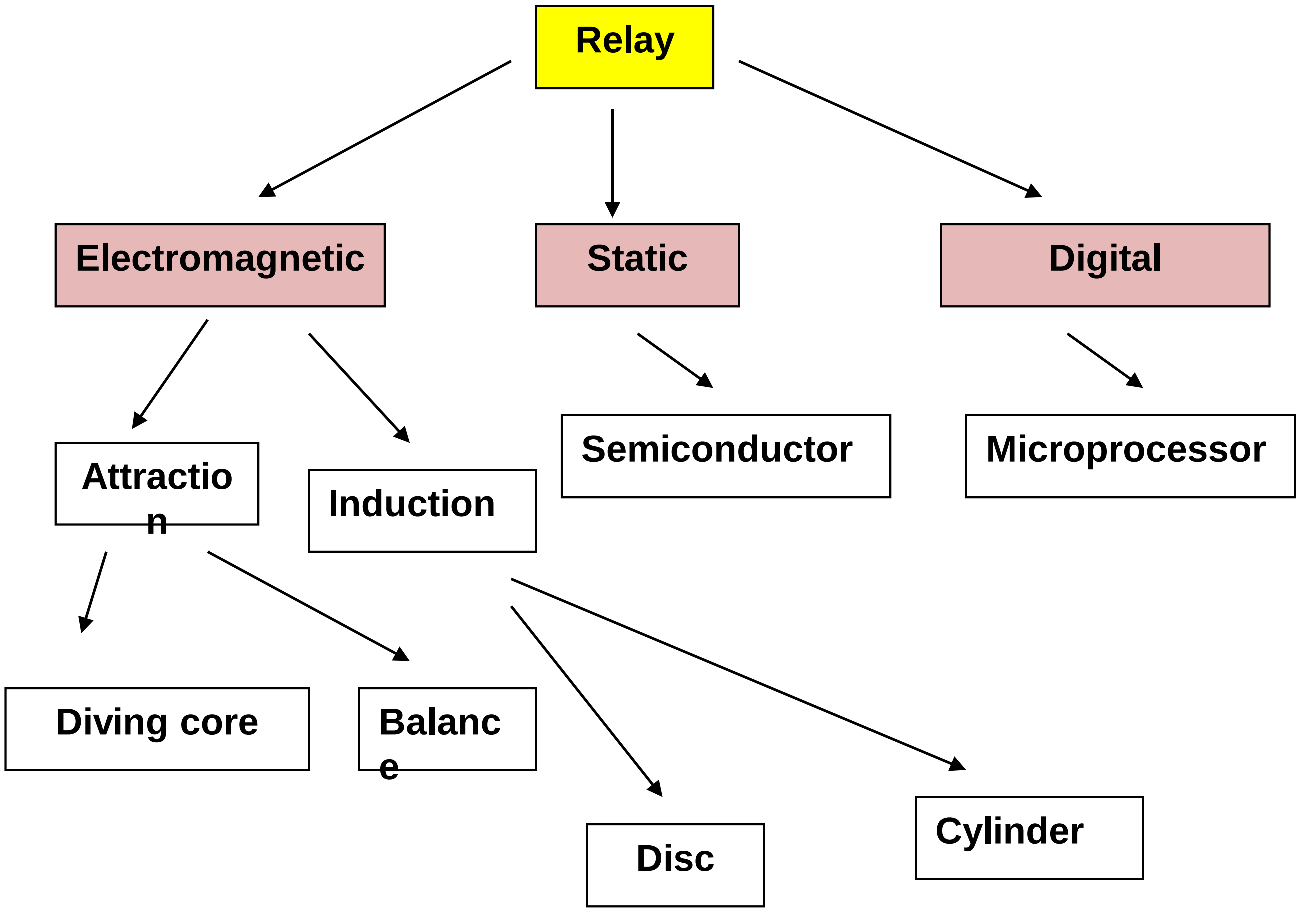
❖ Criteria for choosing a protection relay

The choice of a relay is guided by several criteria:

- **Protection Relay Function:** measurement of current, voltage, frequency, power.
- **Adjustment Range:** the interval between the smallest and largest nominal current.
- **Power Supply:** type, frequency, voltage of measurement quantities, and auxiliary inputs.
- **Environmental Conditions:** response to specific conditions such as temperature, explosive atmosphere, electromagnetic interference, switching surges, vibrations, shocks, earthquakes.

❖ Different types of relay

There are essentially three classes of relay, as shown in the diagram below:



❖ Electromagnetic relay

The **electromagnetic relay** is a component used to control a switch which is completely isolated electrically from the control (often to isolate the high power passing through the switch).

This is known as "**galvanic isolation**".The electromagnetic relay consists of a coil with a soft iron core (control part), and a switch with a "**break**" contact position and a "**make**" contact position.

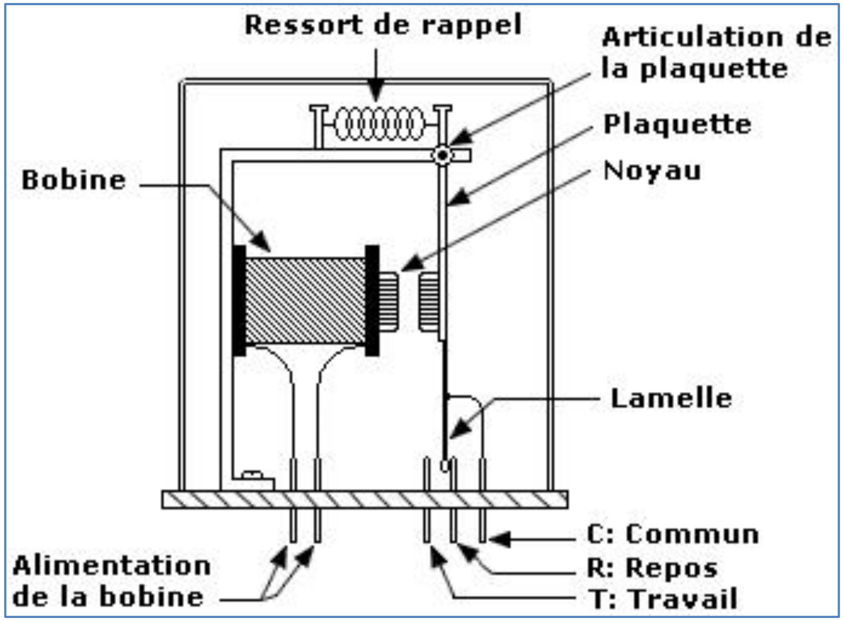
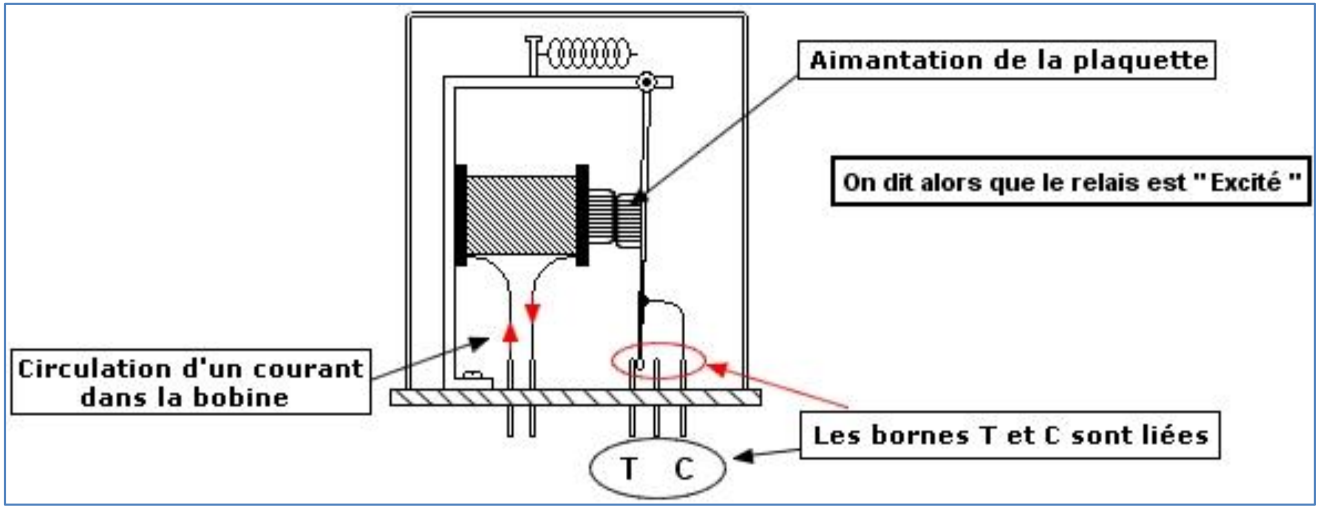


Fig. Relais électromagnétique

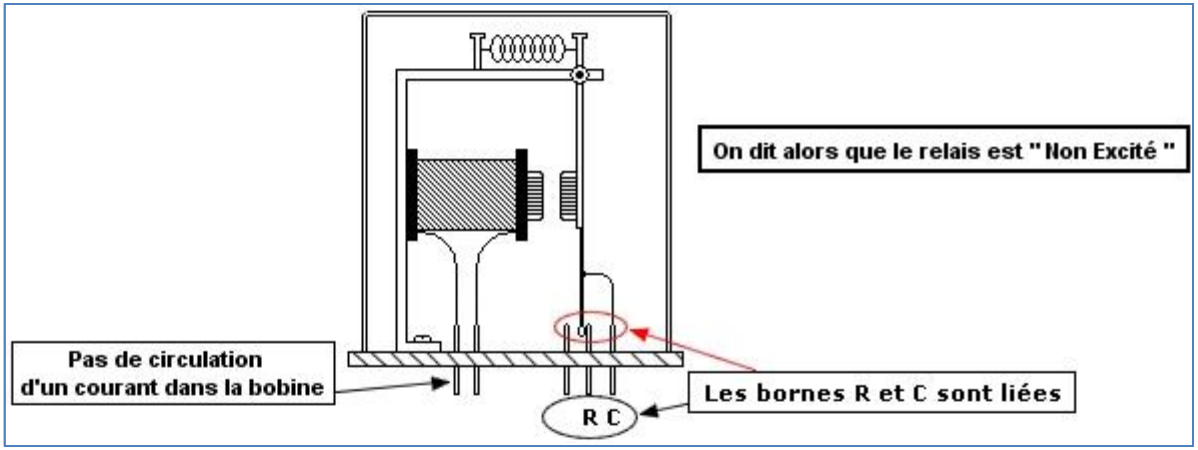
Operating case n°1 :

When the electric current flows through the coil, the hinged plate is magnetised (position of the plate on the "**work**" contact).



Operating case n°1 :

When no current flows through the coil, the hinged plate returns thanks to the hinged spring (position of the plate on the "**rest**" contact).



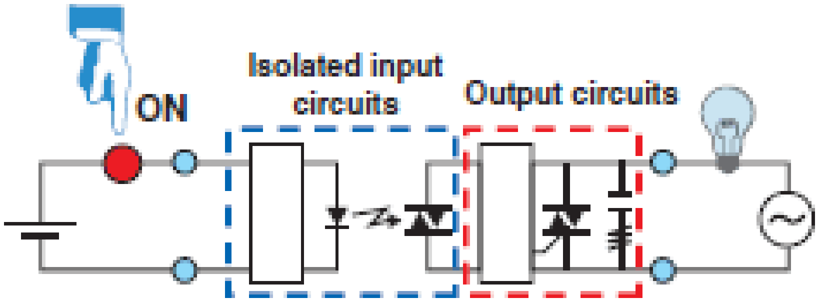
❖ Solid-state relay

Definition : A Solid State Relay (SSR) is a relay that does not have a moving contact. In terms of operation, SSRs are not very different from mechanical relays that have moving contacts. SSRs, however, employ semiconductor switching elements, such as thyristors, triacs, diodes, and transistors.

Advantages include: Longevity/reliability, low response time, no moving mechanical parts, no mechanical wear, resistance to shocks, and no acoustic noise.

Major disadvantages: Solid-state relays generate more heat than mechanical relays (due to non-zero internal resistances of electronic systems), and they are unusable in applications where contact closure must occur in the absence of voltage.

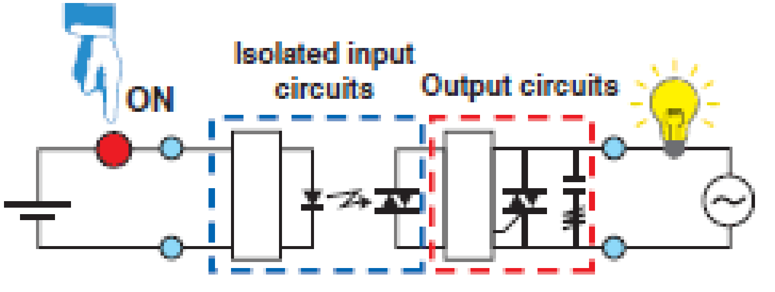
❑ Structure and Operating Principle



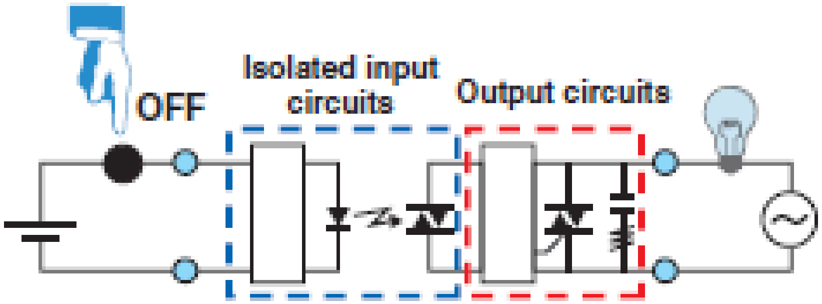
1.The input device (switch) is turned ON.

2.Current flows to the input circuits, the **photocoupler** operates, and an electric signal is transferred to the **trigger circuit** in the output circuits.

3.The switching element in the output circuit turns ON.



4.When the switching element turns ON, load current flows and the lamp turns ON.



5. The input device (switch) is turned OFF.

6. When the photocoupler turns OFF, the trigger circuit in the output circuits turns OFF, which turns OFF the switching element.

7. When the switching element turns OFF, the lamp turns OFF.

❖ Digital Relay:

Digital technology emerged in the early 1980s. With the development of microprocessors and memories, digital chips were integrated into protective equipment. A distance relay is intended to monitor the status of certain elements of an electrical network, particularly high-voltage lines or cables, but also power transformers and generators.

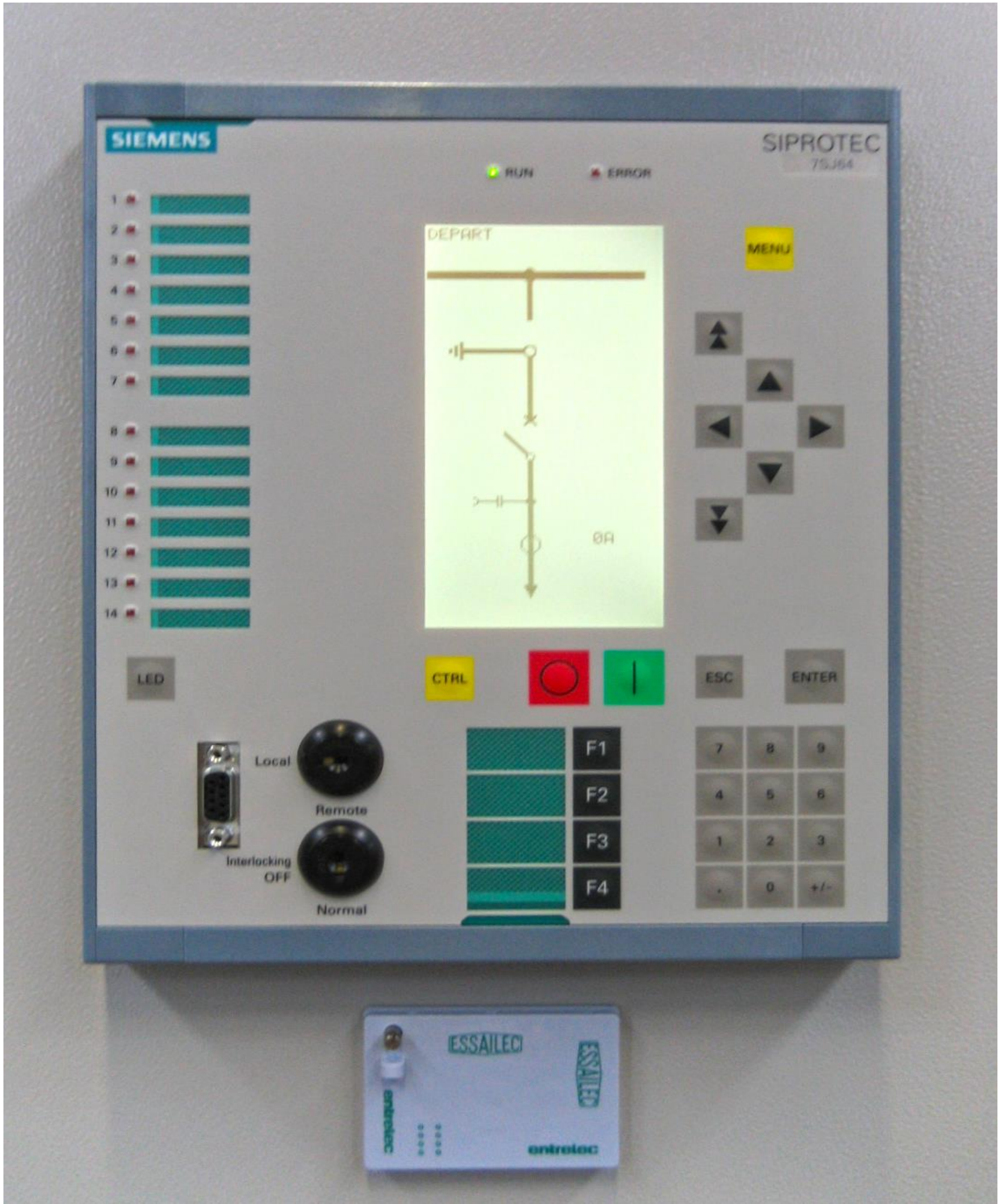
Digital protections are based on the principle of transforming electrical variables from the network, provided by measurement transformers, into low-voltage digital signals. The use of digital signal processing techniques allows the signal to be decomposed into vectors, enabling data processing via protection algorithms according to the desired protection.


500
SET
Clean Solar Energy
Ship within 24 hours


CIRCUTOR
RGU-10
INS 300mA
0mA
RESET
TEST
PROG


ORION ITALIA
RD-1


ORION ITALIA
28
RD-7



Digital protection relay used in distribution. It is, in a way, the brain of electrical protection.

3-5-Techniques used in protection

Four types of relays are used in protection arrangements:

- Differential relays.
- Overcurrent relays.
- Directional relays.
- Minimum impedance relays.

Each of the four arrangements is used individually or in various combinations for protection.

➢ Differential Protection

Differential protection is one of the most reliable and popular techniques in power system protection.

Differential protection compares the currents entering with the currents leaving the protected zone. If the sum of the entering currents and the leaving currents in the protected zone **equals zero**, it is concluded that there is **no fault**. However, if this sum is **not zero**, the differential protection concludes that **a fault exists in the zone** and takes measures to isolate the faulty zone from the rest of the system.

Differential protections are therefore logically "specialized." They can be:

- Line and cable differentials,
- Busbar differentials,
- Transformer differentials,
- Motor differentials,
- Alternator differentials.

•is the excitation current of current transformer A in the secondary.

The figure below depicts a phase of a three-phase differential protection system. Multiple circuits may exist, but the example is sufficient to explain the basic principle of differential protection. From the figure below, it can be observed that the protection zone is encompassed by two or three current transformers. The conductors bringing the current from the current transformers to the differential relay are sometimes referred to as pilot wires in certain situations.

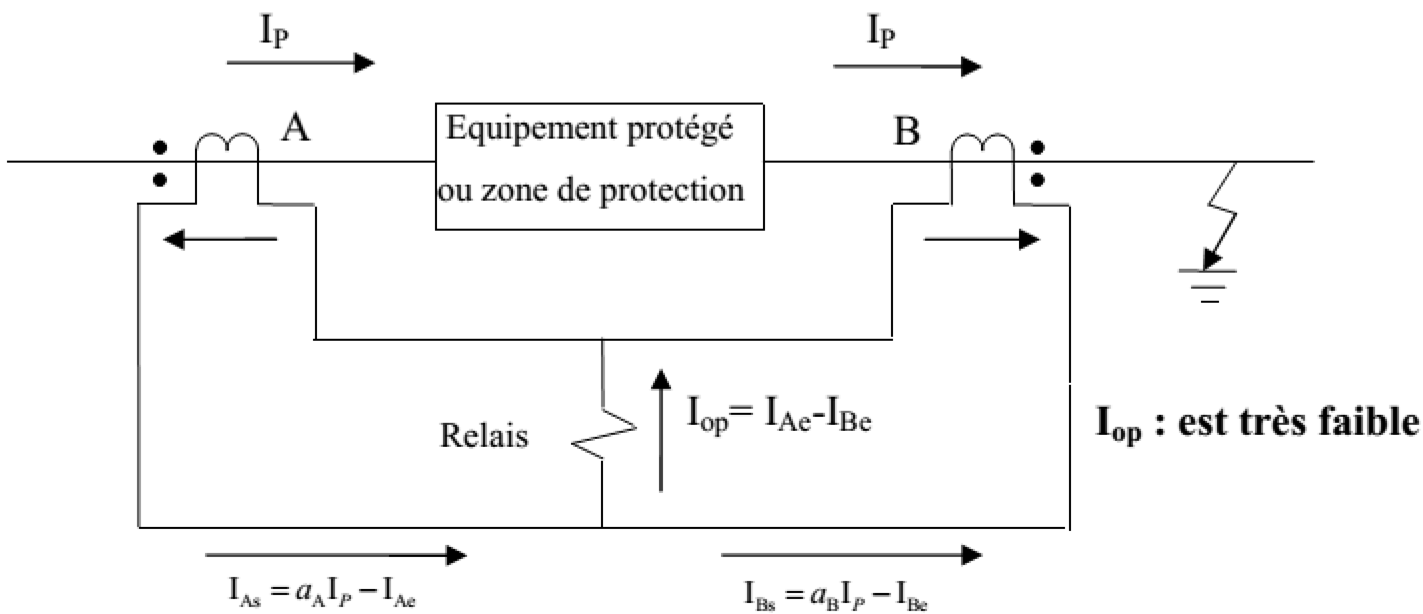


Figure: Differential Protection During an External Fault

Where: :

a_A : is the transformation ratio of current transformer A..

I_{Ae} : est le courant d'excitation du transformateur de courant A dans le secondaire.

Under normal conditions, the current Ip at the input of the protected unit would be equal to the outgoing current at all times.

In the event of a fault within the protected zone, the input current is no longer equal to the output current. The operating current of the differential relay is now the sum of the input currents feeding into the fault as per the indications.

$$I_{op} = a(I_{F1}+I_{F2})-I_{Ae}-I_{Be}$$

This current triggers the relay to isolate the faulty zone.

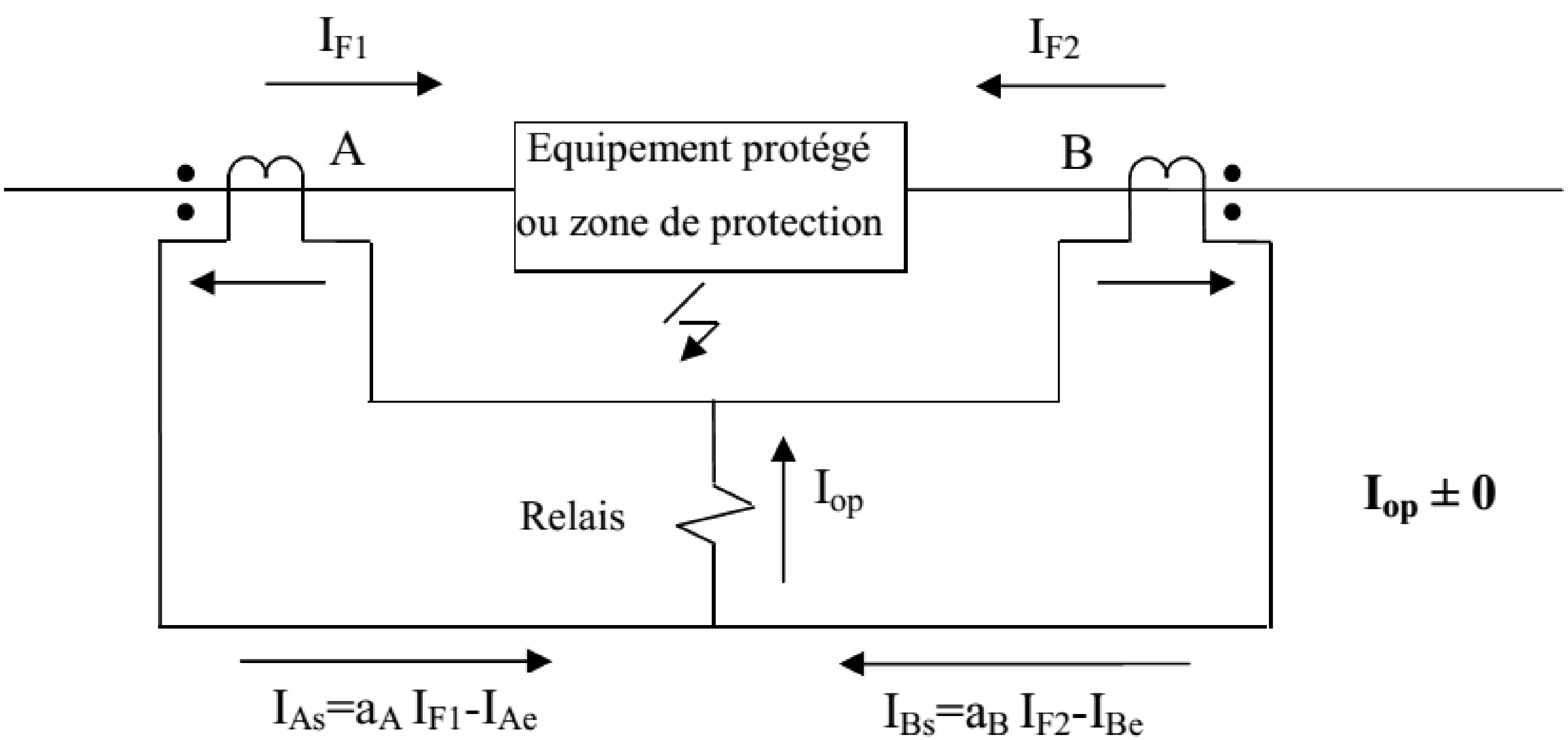


Figure: Differential Protection During an Internal Fault

➢ Overcurrent Protection

Overcurrent relays offer a simpler form of protection for transmission lines.

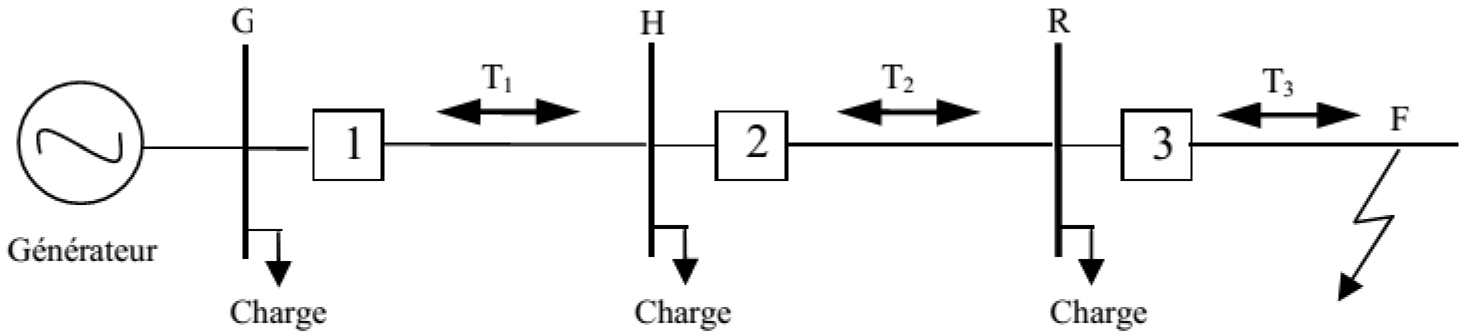
These relays measure the current flowing through the line to be protected and compare this current to a set value called the **pickup current**. If the measured current **exceeds** the pickup value, the relay commands the local circuit breaker to **open** the circuit and **isolate** the faulty section.

Overcurrent protection in transmission lines can be divided into two categories:

non-directional overcurrent protection and **directional** overcurrent protection.

Non-directional Overcurrent Relay Protection

Non-directional overcurrent relays are typically used to protect radial transmission lines. Three commonly used versions of the relay are: constant time, inverse time, and instantaneous.



For a fault at point 'F', none of the relays can determine whether the fault is within its protection zone or on another line beyond it. Selectivity is achieved by a time delay between the relays (constant time overcurrent relays), **allowing the relay and the nearest circuit breaker to the fault the first opportunity to clear the fault**

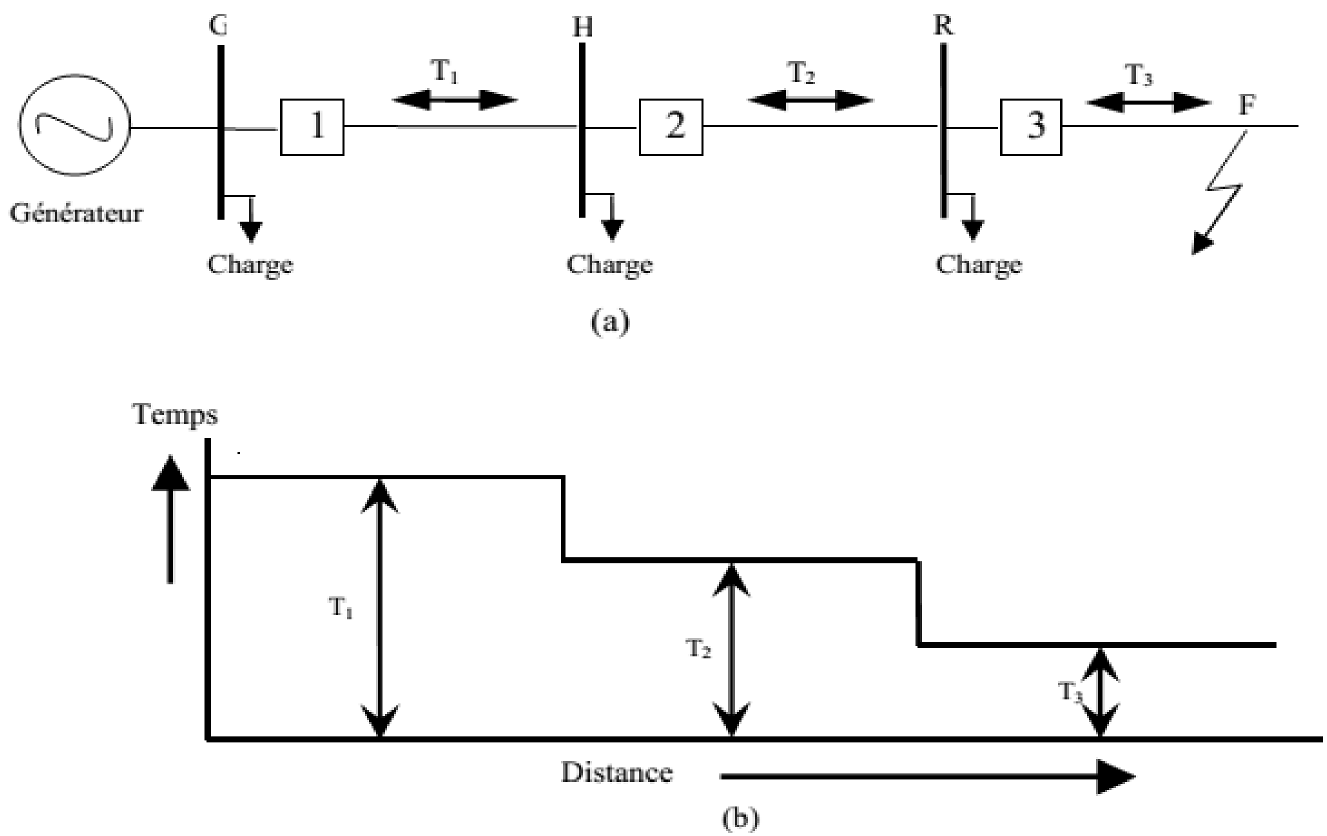
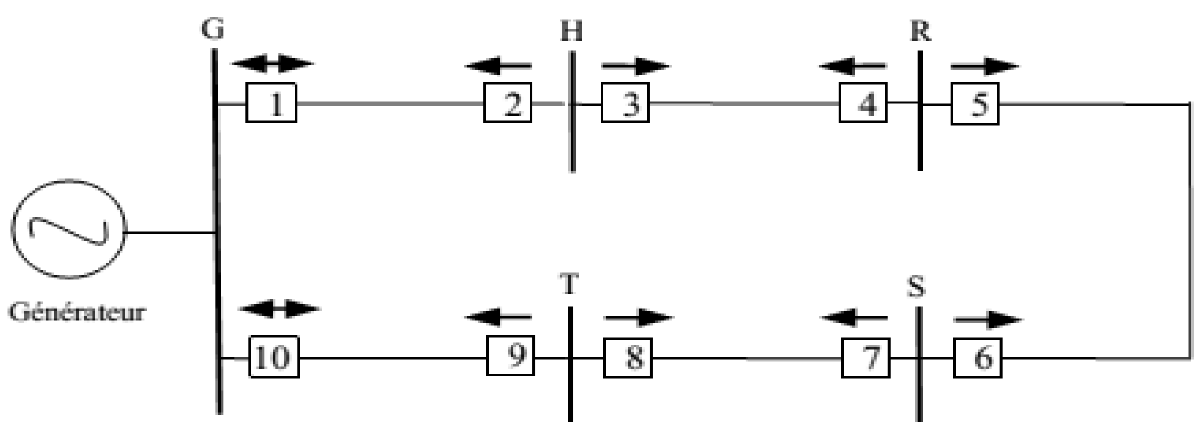


Figure: Time Grading in Radial Systems

Directional Overcurrent Relays

In a looped or radial network with multiple sources and identical fault currents, the flow of fault current relative to the relay location can be either on the line or at the busbar next to the relay. In these circumstances, achieving selectivity using overcurrent relays alone is impossible. Selectivity can be achieved using directional overcurrent relays.



This figure depicts a looped network protected with directional overcurrent relays. The asymmetric arrows point in the direction of fault current flow for which the relays should operate. ***Only at locations 1 and 10 can the fault current flow towards the line in the desired direction for tripping or in the opposite direction***. The relays at these locations could, therefore, be non-directional as indicated b

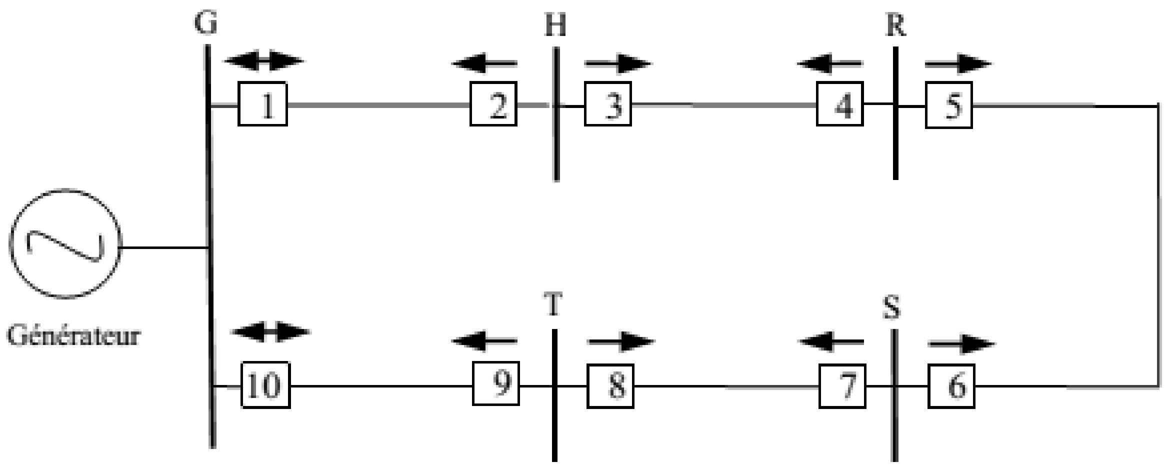


Figure: Directional Overcurrent Protection of a Loop Network.

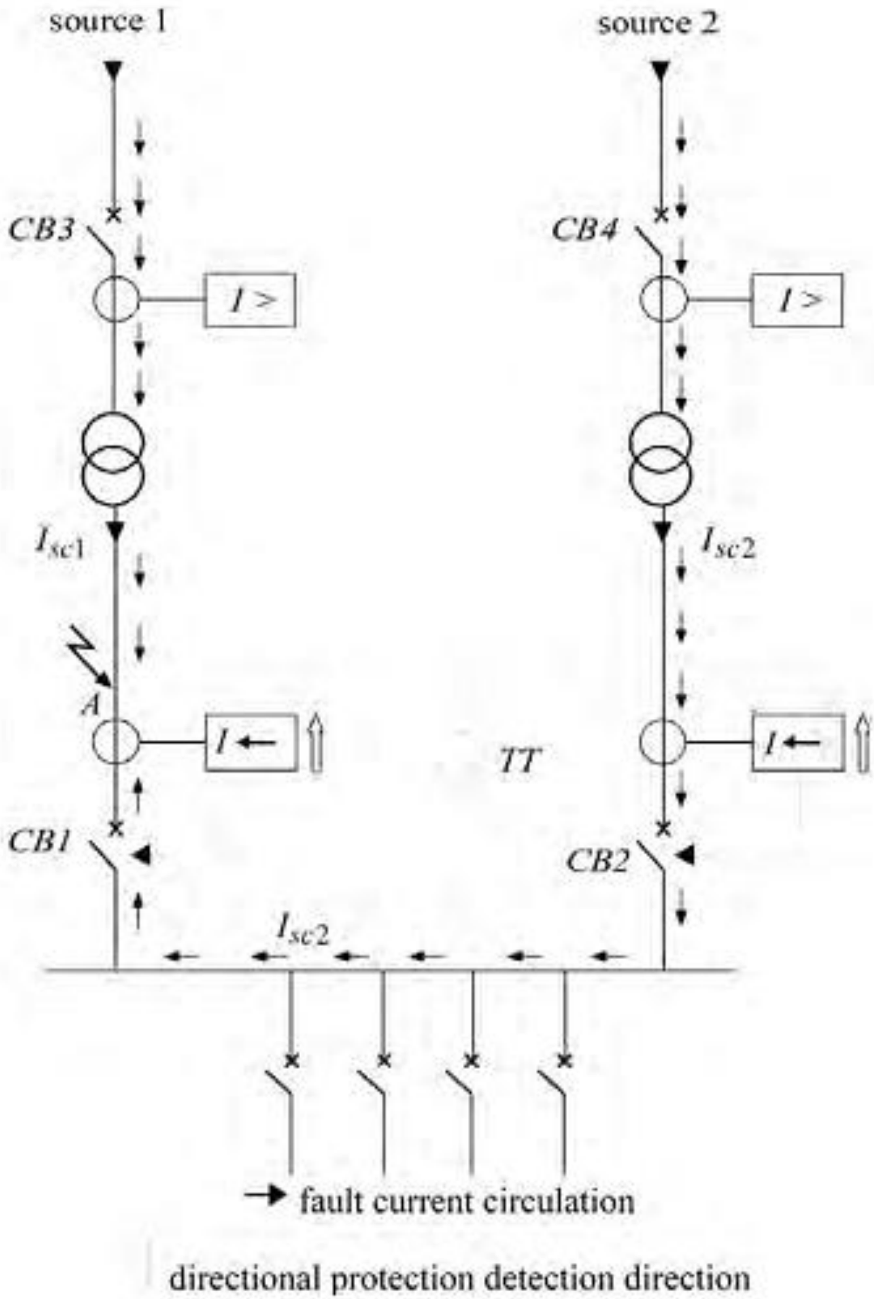
➢ Directional Protection

This type of protection operates based on current, voltage, and the direction of energy flow. It acts when both the current or power exceeds a certain threshold and when energy propagates in an abnormal direction (see Figure).

Several types of directional protection exist:

Phase current protection,

- ❑ Residual current protection,
- ❑ Active power protection,
- ❑ Reactive power protection,
- ❑ Homopolar power protection (mainly used in public distribution networks with compensated neutral).



Directional Protection for Phase-to-Phase Faults in a Network with Two Parallel Feeds

➢ Minimum Impedance Protection

This type of protection operates based on measured quantities such **as current, voltage, and the direction of energy flow**. Using this information, the protection device **calculates the impedance of the monitored equipment**. Its thresholds are adjustable (**minimum impedance Z in ohms or admittance, 1/Z in siemens**). The principle of significant impedance drop of an element during a short circuit is exploited by this type of protection.

Special Case: Distance Protection

This is a particular impedance protection applied to high-voltage lines in energy transmission networks and sometimes certain distribution networks.