# POWER SYSTEMS MODELLING AND FAULT ANALYSIS

Sreekanth Kondreddy
Ragasudha Chundampunathil

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# CHAPTER 1

# EXPLORING THE ELECTROMAGNETIC DEVICES UTILIZED IN ELECTRICAL POWER SYSTEMS

Mr. Sreekanth Kondreddy
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:ksreekanthreddy@presidencyuniversity.in

**ABSTRACT:**

Induction relays are electromagnetic devices widely utilized in electrical power systems for protection and control. They function according to the electromagnetic induction principle, which states that a changing magnetic field causes a current to be induced in a closed loop of wire. Induced current is utilized in power systems to identify abnormal circumstances like overcurrent, undercurrent, and fault conditions. We give a succinct review of induction relays in this chapter, including their function, varieties, and uses. Induction motor-based electromagnetic relays are frequently utilised for protective relaying applications requiring a.c. amounts. Due to the way they work, they are not usable with DC amounts. A pivoting aluminium disc suspended in two alternating magnetic fields with the same frequency but different positions in time and space constitutes the basic building block of an induction relay. One of the magnetic fields interacts with the currents that the other magnetic field induces in the disc to create the torque.

**KEYWORDS:**

Electromagnetic Induction, Electrical Power System, Induction Relay, Shaded Pole Structure, Wattmeter Structure.

## INTRODUCTION

Electromagnetic devices called induction relays are utilised in electrical power systems for protection and control. These relays function according to the electromagnetic induction principle, which states that a fluctuating magnetic field causes a current to be induced in a closed loop of wire. Induced current is utilised in power systems to identify abnormal circumstances like overcurrent, undercurrent, and fault conditions.

A trio of components—an electromagnet, an armature, and a series of contacts make up the induction relay's operating system. The electromagnet's coil produces a magnetic field when current flows through it. The armature moves as a result of the magnetic field's interaction with it. The contacts are mechanically attached to the armature, and its movement causes the contacts to open or close. Induction relays can respond to variations in current or voltage levels in a power system because to this process [1]–[3].

### Working principle of induction relay

An induction relay's operation is based on the idea of electromagnetic induction. It detects abnormal situations in a power system by utilizing the interplay between a magnetic field and an electrical current. Here is a step-by-step explanation of how an induction relay operates:

Electromagnet: An electromagnet, which is essentially a coil of wire twisted around a magnetic core, makes up an induction relay. A magnetic field forms around the centre of the coil when electricity runs through it.

Armature: An armature is a moveable component often constructed of ferromagnetic material that interacts with the magnetic field of an electromagnet. According to the direction and force of the current flowing through the coil, the armature is placed close to the electromagnet and is either attracted or repelled by the magnetic field.

Contacts: An array of contacts is mechanically connected to the armature. These contacts open or close in response to the magnetic field's movement of the armature.

Current Sensing: The induction relay is wired in the circuit such that it can detect the flow of current via the electrical system that is being safeguarded. The electromagnet's coil conducts current, creating a magnetic field surrounding the core.

Magnetic Field Interaction: If the current is running within normal limits, the electromagnet's magnetic field is balanced, and the armature remains in its default position, the contacts remain in their normal state.

Abnormal Conditions: The amplitude or direction of the current changes when an abnormal condition, such as an overcurrent, undercurrent, or fault condition, takes place. The magnetic field's equilibrium is upset by this shift in current, which unbalances the forces pulling on the armature.

Armature Movement: The armature moves as a result of an imbalance in the magnetic forces operating on it. Depending on the relay's design and intended use, this movement is transmitted to the contacts, causing the contacts to open or close.

Protective Action: The induction relay's contacts opening or shutting sets off the operation of safety features like disconnect switches or circuit breakers, which can isolate the malfunctioning area of the electrical system and avert damage.

Induction relays operate by creating a magnetic field as a result of current flowing through an electromagnet, to put it briefly. Contacts open or close as a result of the interaction between this magnetic field and the moveable armature moving. The induction relay can identify abnormal circumstances in the electrical system and start the required protection measures thanks to this contact movement.

**Construction of Induction relay**

An induction relay is normally built from a number of essential parts that cooperate to detect abnormal situations and start preventative measures. The following are the fundamental elements present in the majority of induction relays, while the precise design may vary based on the application and relay type:

Frame or Enclosure: To ensure the safe operation of the relay's components, the relay is contained in a protective frame or enclosure that offers mechanical support and insulation.

Coil or Electromagnet: The coil, which is the main part of the relay and is normally formed of copper wire wound around a core, is also known as an electromagnet. When a current passes through the coil, a magnetic field is created that is essential to the relay's functionality.

Core: Coil's magnetic circuit path is provided by the core, which is commonly formed of a ferromagnetic material like iron or laminated steel. The coil's magnetic flux is concentrated by the core, improving the relay's sensitivity and effectiveness.

Armature: The magnetic field produced by the coil attracts or repels the armature, a moving component. It typically contains a ferromagnetic substance and is placed close to the core. The relay contacts open or close in response to movement of the armature.

Contacts: The contacts are mechanically attached to the armature and are electrically conducting components. They are in charge of managing the relay circuit's current flow. The contacts open or shut as the armature moves as a result of the magnetic field, starting the intended action.

Springs: Springs are employed to supply the required mechanical force to maintain the contacts' default position. When the armature movement stops, they aid in ensuring that the contacts revert to their normal state.

Adjustment Mechanism: Some relays might have an adjustment mechanism that allows the user to select the operating conditions, such as the current or voltage levels at which the relay should activate. This method enables fine-tuning of the sensitivity and response properties of the relay.

Terminal Blocks: For the external circuitry, terminal blocks offer connection places. They enable the relay to be connected to the power system and other control devices quickly and securely.

Indicator or Flag: Activation status of a relay, for example, or whether it is in its default mode, may be visibly indicated by an indication or flag on some relays. This function aids in monitoring and troubleshooting the relay's performance.

Protective Enclosure: The induction relay may be housed in a separate protective enclosure in some applications, especially in harsh settings or high-voltage systems, to provide additional insulation and protection against environmental influences.

Overall, careful assembly of these parts is required to create an induction relay, taking into account aspects like electrical insulation, mechanical stability, and reliability. Depending on the intended use of the relay and the requirements of the manufacturer, the specific design and configuration may change [4]–[6].

## DISCUSSION

### Historical background of Induction relay

Induction relays have a long history that begins with the early 19th-century development of electrical power systems. Here is a quick rundown of the significant turning points in the history of induction relays and its leading innovators:

Electromagnetic Induction: Michael Faraday's early 19th-century discovery of electromagnetic induction served as the impetus for the creation of induction relays. The experiments of Michael Faraday showed that an altering magnetic field might cause an electric current to flow through a nearby conductor.

Charles Francis Dalziel: A British electrical engineer in the late 19th century, Charles Francis Dalziel made substantial contributions to the advancement of induction relays. He developed the idea of electromagnetic relays and patents a number of his creations. His innovation served as the foundation for the effective use of induction relays in power systems.

Development of Protective Relays: The requirement for dependable protective devices became clear as electrical power networks increased and changed. To detect and react to abnormal circumstances in power systems, engineers and innovators including William Stanley Jr., Charles F. Scott, and Frank J. Sprague helped design protective relays, including induction relays.

Principles of Electromagnetic Induction: In the late 19th and early 20th centuries, induction relays were developed employing electromagnetic induction principles, including the idea of using coils and magnetic fields to sense current and control mechanical relays. The efficiency and dependability of induction relays were enhanced by the use of laminated iron cores, better coil winding methods, and better insulating materials.

Westinghouse Electric Corporation: Under the direction of George Westinghouse, the Westinghouse Electric Corporation made substantial contributions to the invention and spread of induction relays. The Westinghouse Corporation actively contributed to the development of protective relaying technologies, particularly induction relays, and was at the forefront of the AC power system revolution.

Technology advancements: With the introduction of solid-state electronics in the middle of the 20th century, protective relays, notably induction relays, underwent substantial modifications in both design and use. Electromechanical relays were gradually superseded by digital and microprocessor-based relays, which provided more sophisticated features, programmability, and improved communication capabilities.

Even today, electrical power systems still use induction relays for a variety of purposes. Improvements in materials, manufacturing processes, and electronics have resulted in better performance, dependability, and functionality while maintaining the same core operating principle. Overall, the development and improvement of these crucial protective devices were influenced by various engineers and innovators who worked to advance the history of electrical power systems and induction relays.

**Shaded-pole structure type induction relay**

Induction relay of the shaded-pole variety Figure 1 depicts the general configuration of the shaded-pole construction. It comprises of a pivoting aluminium disc that is free to spin in an electromagnet's air gap. A copper band known as the shade ring surrounds one-half of each magnet pole. Due to the response of the current created in the ring, the alternating flux in the shaded region of the poles will lag the flux in the unshaded portion by an angle. The disc will revolve because of the phase difference between these two a.c. fluxes.

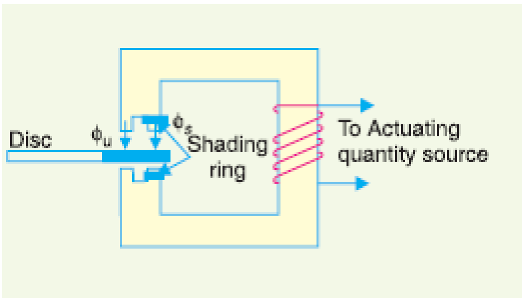


**Figure 1: Shaded-pole structure type induction relay**

**Watthour-meter structure type induction relay:** The name of this structure watthour-meter structure comes from the fact that watthour metres employ it. Fig. 2 depicts the overall configuration of this sort of relay. It is made up of a pivoting aluminium disc that is placed between the poles of two electromagnets and allowed to freely rotate. The primary and secondary windings are carried by the higher electromagnet. The lower magnet's winding is connected to the secondary winding, which carries the primary winding's relay current I1. A current called I2 is circulated in the secondary as a result of the main current inducing e.m.f. in it. The current in the upper magnet's secondary winding will cause the flux φ2 to be induced in the lower magnet, which will lag φ1 by an angle. A driving torque on the disc proportional to φ1φ2 sin will be produced by the two fluxes φ1 and φ2, which are out of phase by. The ability to operate this kind of relay by opening or closing the secondary winding circuit is a key feature. If this circuit is broken, the lower magnet cannot create any flux, regardless of how much current is flowing through the primary winding; as a result, no torque will be generated. As a result, the secondary winding circuit of the relay can be opened to render it inactive.

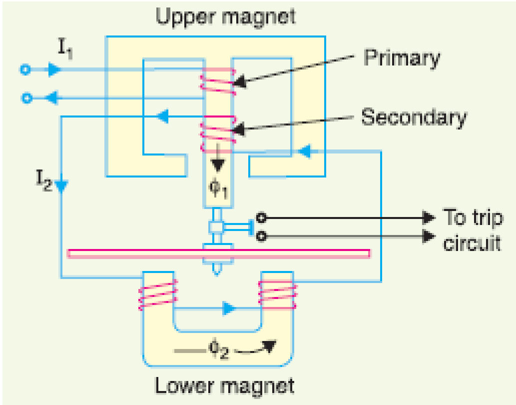


**Figure 2: Watthour-meter structure type induction relay**

**Induction cup structure type induction relay**: a framework with induction cups the general layout of an induction cup construction is shown in Fig. 3. It most closely resembles an induction motor, with the exception that only the rotor conductor is free to move and the rotor iron is immobile. An axis-rotating hollow cylindrical rotor serves as the moving component. Two pairs of coils twisted on four poles as indicated generate the spinning field. To provide the requisite driving torque, the rotating field causes currents in the cup. The torque created is proportional to φ1φ2 sin, where is the phase difference between the two fluxes, if φ1 and φ2 represent the fluxes produced by the respective pairs of poles. To stop the cup's spindle from rotating continuously, a control spring and a back stop for closing the contacts mounted on an arm are attached.

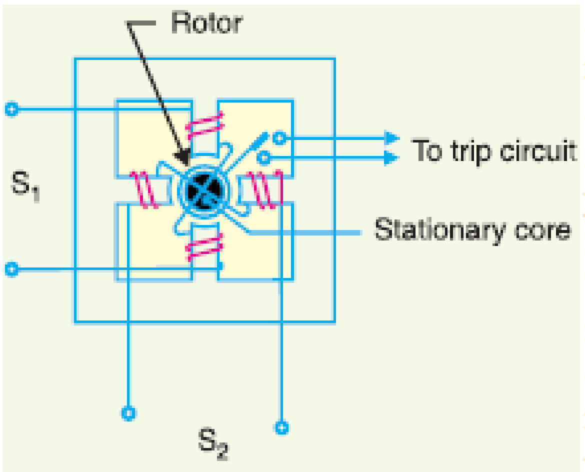


**Figure 3: Induction cup structure type induction relay**

The shaded-pole and watthour metre constructions are less effective at producing torque than induction cup forms. As a result, this kind of relay operates at a very high speed less than one second in time.

**Applications of induction relays**

In electrical power systems, induction relays are used for a variety of protection and control functions. They are essential elements in guaranteeing the dependability and safety of power systems due to their capacity to recognize abnormal conditions and take appropriate action. Here are a few typical uses for induction relays:

Overcurrent Protection: To safeguard electrical systems from excessive current flow brought on by short circuits, overloads, or defective equipment, overcurrent relays are frequently utilised. They detect the amount of current flowing and trigger safety features, including tripping circuit breakers, to isolate the defective area and stop system damage.

Undercurrent Protection: In power systems, undercurrent relays keep an eye on the consistency of the current flow. They identify low or no current conditions, which might be a sign of defects or system breakdowns. Relays for undercurrent situations can be used to restore power or safeguard equipment from harm.

Directional protection: To guard against faults occurring in particular directions, directional relays are used in power systems. They control the flow of current and offer specialized security for transformers, transmission lines, and other vital parts. With the use of directional relays, fault locations can be located more precisely, and faulty sections can be quickly isolated.

Differential Protection: Differential relays are used to guard against internal faults in transformers, generators, motors, and other equipment. They compare the currents or voltages at various system locations and look for any appreciable differences. Differential relays are able to promptly detect internal problems and start procedures to stop additional harm to the protected equipment [7]–[10].

Motor protection: Induction relays are essential for protecting motors from malfunctions and unusual operating circumstances. They track motor temperatures, currents, and other variables to look for problems like overload, phase imbalance, or ground faults. Relays for motor protection have the ability to trip the motor circuit and guard against harm to the motor and connected devices.

Generator Protection: Since generators are essential parts of electrical systems, induction relays are employed to safeguard them from malfunctions and unusual operating circumstances.

These relays keep an eye on the voltages, currents, and other aspects of the generator to look for problems like overloads, short circuits, or imbalanced circumstances. Relays for generator protection can start processes to cut the generator off from the system and stop additional harm.

Protection for Transformers: Induction relays are frequently used to safeguard transformers against errors and unusual circumstances of order to find issues like overloads, short circuits, or insulation failures, they continuously monitor the currents, voltages, and temperature of transformers. Transformer isolation measures can be started by transformer protection relays to guard against equipment and power system damage.

Feeder Protection: To guard against failures and unusual situations in distribution systems, feeders use induction relays. They keep an eye on the voltages and currents and can spot problems like overloads, short circuits, and insulation failures. Feeder protection relays can take steps to isolate the defective area and stop power distribution interruptions.

These are but a few instances of the numerous uses that induction relays can be put to in electrical power systems. They are crucial for safeguarding machinery, reducing downtime, and assuring the dependable and secure operation of power systems. Depending on the features and specifications of the power system in issue, several induction relay applications may be used.

**Advantages and limitations of induction relays**

Robust and Reliable: Induction relays are renowned for their steady performance and sturdy design. They are excellent for a variety of applications in power systems because of their ability to tolerate challenging weather conditions, electrical transients, and mechanical stress.

Broad Range of Protection: Induction relays provide a broad range of protection features, including differential, directional, and overcurrent protection. Because of their adaptability, gearbox lines, transformers, motors and generators can all be completely protected.

Simple and Cost-Effective: Induction relays have a relatively simple design and don't need complicated electrical components or intricate programming, making them simple and cost-effective. They are less expensive than other advanced protection systems because of their simplicity. They are easily installed, run, and maintained and are generally accessible.

Fast Reaction: When there are abnormal conditions in a power system, induction relays react quickly. They can nearly instantly detect changes in current or voltage levels because to the electromagnetic induction theory. This quick reaction reduces damage and stops the system from experiencing cascade failures.

High Sensitivity: Induction relays may be built with high sensitivity, allowing them to pick up on even minute changes in voltage or current. This sensitivity guarantees precise fault and abnormal condition detection, increasing the protection of the power system's overall reliability and effectiveness.

**Relay induction's drawbacks**

Lack of accuracy: Compared to some digital relays, induction relays may not give the same level of accuracy and selectivity. External influences like temperature, vibration, or magnetic interference may have an impact on how they react. This restriction could, in some circumstances, cause false tripping or delayed response. Limited Functionality: Although induction relays offer crucial protection functions, they could be deficient in more sophisticated features and abilities that can be found in digital relays. Induction relays frequently lack sophisticated features like communication interfaces, self-diagnostics, and adaptive protection algorithms. Limited Settings and Adjustability: Induction relays frequently have restricted settings and adjustability, especially when it comes to fine-tuning the relay specifications or adjusting to certain system requirements. This constraint may limit their adaptability in situations requiring specialized protection or those involving sophisticated power system designs.

Limited Communication and Monitoring: Induction relays often lack built-in communication features for remote monitoring and control, leading to limited communication and monitoring. They might not offer integration with sophisticated supervisory control and data acquisition (SCADA) systems or real-time data on system conditions.

## CONCLUSION

Electrical power systems are protected from unusual operating conditions by induction relays. These devices can identify faults and aberrant currents using the electromagnetic induction principle, enabling quick and efficient action to prevent potential equipment damage and guarantee the dependability of the power system. Induction relays have evolved to offer more precise and complex protective measures as a result of technological improvements. However, continuing research and development is required to improve their functionality and flexibility in response to the changing demands of contemporary power systems. Induction relays have an inherent time delay in their response because of their mechanical design. In comparison to digital relays, which employ electronic components and algorithms for quicker processing and decision-making, this delay may be larger. This delay might affect the efficacy of protective measures in some crucial applications. When choosing and implementing induction relays in power systems, it's crucial to take these benefits and disadvantages into account. To choose the best protection strategy, it is important to consider the application's complexity, importance, and special requirements. To maximize the advantages of both technologies, induction and digital relays can frequently be used in tandem.

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# CHAPTER 2

# INVESTIGATING THE ROLE OF FUNCTIONAL RELAY TYPES

Mr. Bishakh Paul
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:bishakhpaul@presidencyuniversity.in

**ABSTRACT:**

Relays are crucial parts of electrical and electronic systems because they give us a way to control circuits using an outside signal. Relays come in a variety of varieties, each intended for certain uses and tasks. The goal of this chapter is to give a general overview of functional relay types while emphasizing their salient features and potential uses. The interaction between the magnetic field created by the current-carrying wire and the induced voltage in a secondary coil forms the foundation of the operation of an induction type overcurrent relay. A magnetic field is produced when the primary coil experiences an excessive current flow. The secondary coil experiences a voltage that is proportional to the current's strength as a result of this magnetic field. The relay can identify if the current exceeds a set threshold by sensing this induced voltage.

**KEYWORDS:**

Distance Impedance Relay, Directional Power Relay, Directional Overcurrent Relay, Electrical Power System, Induction Type Relay.

## INTRODUCTION

Nowadays, the majority of power system relays work on the electromagnetic attraction or electromagnetic induction concept. Regardless of the underlying principle, relays are typically categorized in accordance with the task that needs to be accomplished in order to protect electrical power circuits. For instance, a relay would be referred to as an overcurrent relay regardless of the relay's design if it detects overcurrent in a circuit (i.e., current greater than what may be permitted) and starts to take corrective action. Similar to this, an overvoltage relay is one that detects overvoltage in a circuit and starts the necessary remedial actions. Despite the fact that there are numerous varieties of special function relays, only the following significant varieties will be covered in this chapter:

(i) Induction type overcurrent relays

(ii) Induction type reverse power relays

(iii) Distance relays

(iv) Differential relays

(v) Translay scheme

### Induction type Overcurrent relay

This kind of relay operates on the induction principle and starts remedial actions when the circuit's current exceeds the set limit. A current in the relay's circuit that is supplied by a current transformer serves as the actuation source. These relays can operate for fault current flow in either direction and are exclusively utilised on a.c. circuits.An essential safeguard used in electrical power systems to identify and react to abnormal current levels is the induction type overcurrent relay. It works on the basis of the electromagnetic induction concept and is made to identify circuits with excessive current levels and start the necessary preventive measures. This page offers a thorough explanation of the induction type overcurrent relay, covering its operation, design, distinguishing characteristics, and applications [1]–[3].

A magnetic core, primary and secondary windings, a moving element, and a restraint element make up the construction of an induction type overcurrent relay. While the secondary winding is linked to a measuring circuit, the primary winding is connected in series with the circuit being protected. The magnetic field produced by the primary current acts as an actuator for the moving element, which is typically a disc or plunger. Under typical current settings, the restraint element acts as a counteracting force to avoid false operation. The sensitivity, selectivity, and time-current characteristics of the induction type overcurrent relay are among its key properties. Sensitivity is the relay's capacity to precisely identify minute variations in current and react as necessary. By limiting false trips, selectivity makes sure that the relay only activates for faults that occur within its protected zone. Time-current characteristics define the relay's operation time at various current levels, allowing for the system's other protective devices to be properly coordinated.

The induction type overcurrent relay is used in many different electrical power system components. It frequently serves to safeguard busbars, motors, generators, transformers, feeders, and transformers. In feeder protection, the relay recognizes defects like overloads or short circuits and starts tripping activities to isolate the problematic area. In order to spot anomalies and stop transformer damage, transformer protection includes keeping an eye on the current flowing through the primary and secondary windings. The relay is used in motor protection to keep track of the motor's current and offer overload and short circuit protection. The relay is also used for busbar and generator protection to find problems and guarantee the secure operation of these parts.

Induction type overcurrent relays are crucial safeguard components in electrical power systems, to sum up. Its electromagnetic induction-based operating concept enables precise and reliable detection of high current levels. This relay offers efficient protection against faults and anomalies in different system components because to its sturdy design, sensitivity, selectivity, and time-current characteristics. The induction type overcurrent relay is still a key component in keeping electrical power systems secure, stable, and reliable.

Construction information: The key structural components of a typical nondirectional induction type overcurrent relay are depicted in Fig. 1. A metallic (aluminium) disc that may freely revolve between the poles of two electromagnets makes up the device. The primary and secondary windings of the higher electromagnet are present. The protected line's primary is periodically tapped and connected to the secondary of a C.T. By adjusting the number of active turns on the relay working coil through the tappings, which are connected to a plug-setting bridge, the desired current setting can be obtained.

The lower magnet's winding is connected in series with the secondary winding, which is powered by induction from the primary. A spiral spring provides the regulating torque. When the disc rotates through a predetermined angle, a moving contact on the spindle of the disc spans two fixed contacts (attached to the trip circuit). You can change this angle's value to any number between 0o and 360o.

The moving contact's travel can be changed by modifying this angle, which enables the relay to be configured to any desired timing.

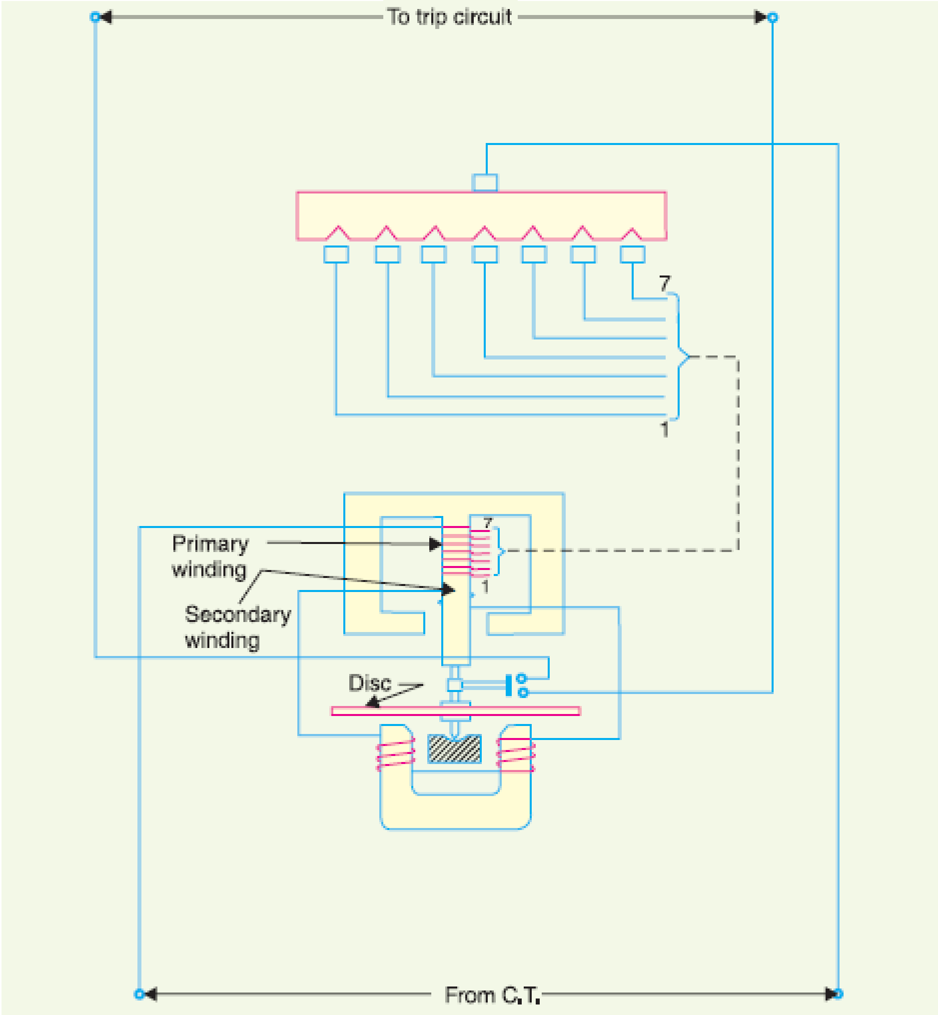


**Figure 1: Induction type Overcurrent relay**

Operation: The induction principle, as mentioned, is what sets up the driving torque on the aluminum disc. The restraint torque that the spring provides opposes this torque. Under typical operating circumstances, the driving torque generated by the relay coil current is smaller than the restraining torque. The aluminum disc stays in place as a result. However, the driving torque becomes greater than the restraining torque if the current in the protected circuit exceeds the pre-set value.

As a result, after the disc has spun over a predetermined angle, the moving contact bridges the fixed contacts. The circuit breaker is operated by the trip circuit, isolating the defective component.A number of steps are involved in the operation of an induction type overcurrent relay, including the detection of current, comparison with a predetermined threshold, and the start of protective measures. An explanation of how an induction type overcurrent relay works is provided below:

Current Sensing: The relay's primary winding is linked in series with the circuit that needs to be protected. A magnetic field is created around the primary winding as current flows through it. The strength of the current is exactly proportional to the strength of the magnetic field.

Induced Voltage: The primary current's magnetic field causes a voltage to be induced in the relay's secondary winding. The secondary winding is wired to a relay coil or a measurement circuit. The magnitude of the main winding's current determines the secondary winding's induced voltage.

Comparison: A predetermined voltage threshold is used to compare the secondary winding's induced voltage to. Based on the required amount of overcurrent protection, this threshold is set. If the induced voltage is higher than the threshold, the primary winding's current has gone over the set limit.

Tripping Mechanism: The relay's tripping mechanism is activated when the induced voltage exceeds the threshold. Depending on how the relay is specifically designed, the tripping mechanism may change. It might entail the movement of a plunger or disc, which actuates the contacts on the relay to start the protective processes.

Protective Measures: The induction type overcurrent relay's protective measures are dependent on the application and type of fault. To isolate the defective part, trip a circuit breaker. To warn the operator. Activate an alarm or indicator transmit a signal to a supervisory control system for additional investigation or action.

Resetting: The induction type overcurrent relay needs to be reset when the fault state has been fixed or eliminated. Depending on how the relay is built, this can either be done manually or automatically. Resetting the relay enables it to resume regular operation and be ready to recognize and react to any upcoming overcurrent situations [4]–[6].

It's crucial to remember that an induction type overcurrent relay operates on the electromagnetic induction theory. The relay continuously checks the current flowing through the protected circuit, and if it notices an overcurrent condition, it starts the necessary protective measures to protect the equipment and maintain the stability and safety of the electrical power system.

## DISCUSSION

### Induction Type Directional Power Relay

When power in the circuit moves in a certain direction, this kind of relay turns on. A directional power relay, in contrast to a nondirectional overcurrent relay, is built in such a way that the magnetic fields generated by the circuit it is protecting interact to give it the working torque. The direction of the torque set up in the relay depends on the direction of the current relative to the voltage with which it is related, making this form of relay effectively a wattmeter.An vital safety feature in electrical power systems is the induction type directional power relay, which determines the direction of power flow and starts the relevant operations depending on preset parameters. It provides individualised security in transmission and distribution networks and functions on the electromagnetic induction principle. This article offers a thorough explanation of the induction type directional power relay, covering its operation, design, distinguishing characteristics, and applications.

An induction type directional power relay's operation is based on the interplay of the electromagnetic fields created by the system's current and voltage. A measuring unit and a directional unit are the two major parts of the relay. The directional unit creates a polarised magnetic field with the help of a polarising coil to define the reference direction for power flow. A current coil and a voltage coil are included in the measuring device, and they are positioned to produce electromagnetic forces that are proportional to the product of current and voltage. The induced magnetic forces in the measuring unit line up with the polarised magnetic field in the directional unit when power is directed in the desired direction. No torque is produced as a result of this alignment, and the relay stays inactive, indicating normal power flow. The induced magnetic forces, on the other hand, work against the polarised magnetic field when power is applied in the opposite direction, producing a torque that opens the relay's contacts and starts the desired protective processes.

A polarising coil, a measuring unit with current and voltage coils, a moving element, and contacts for triggering protective actions are all parts of the construction of an induction type directional power relay. While the current and voltage coils detect the system's currents and voltages, the polarising coil establishes the reference direction. The torque created when power is applied in the opposing direction acts to move the moving element, which is typically a disc or plunger. Depending on the precise protective action needed, this movement causes the relay's contacts to close or open. The induction type directional power relay's directional selectivity, programmable settings, and adaptability to various power system designs are some of its key qualities. In order to defend against faults happening in particular areas of the network, the relay can be selectively configured to operate according to the desired direction of power flow. The relay's parameters can be changed to adapt to various system requirements and conditions, guaranteeing flexibility. The induction type directional power relay is suited for a variety of power system applications since it works with both transmission and distribution networks.

Applications for the induction type directional power relay can be found across electrical power systems. It is frequently employed in transmission lines to identify reverse power flow brought on by flaws or unusual circumstances. The relay promotes system stability and aids in preventing equipment damage by starting preventative measures. The relay selectively protects against power flow from distributed generating or other linked sources in distribution feeders. It guarantees that power is directed in the desired direction and prevents unauthorised power infusions. Another important use of the relay is for generator protection, which prevents the generator from acting like a motor when there is a failure.

In order to determine power flow direction and guarantee good coordination between the interconnected networks, the induction type directional power relay is also utilised in interconnection lines between various power systems. Induction type directional power relays are an essential safety feature in electrical power systems, to sum up. The relay provides selective and effective protection against abnormal conditions due to its capability to use electromagnetic induction to determine the direction of power flow. It is a flexible solution for a variety of applications, including transmission lines, distribution feeders, generator protection, and connecting lines. These applications are made possible by its design, core characteristics, and compatibility with various power system setups. Maintaining the security, dependability, and stability of electrical power systems requires the use of induction type directional power relays.

Details of construction: Fig. 2 depicts the main components of a conventional induction type directional power relay. It consists of a free-rotating aluminium disc that sits between the poles of two electromagnets. On its central limb, the top electromagnet has a winding known as a potential coil that is connected to the circuit's voltage source via a potential transformer (P.T.). The secondary of the C.T. in the protected line is connected to a separate winding (referred to as the current coil) on the lower electromagnet.

A variety of tapings connected to the plug setting bridge are available on the current coil (not shown for clarity). Due to this, any desired current setting is possible. A spiral spring provides the restraint torque. When the disc has rotated through a predetermined angle, a movable contact on its spindle connects two fixed contacts. By changing this angle, the relay can be given any desired time setting by altering the movement of the moving disc.

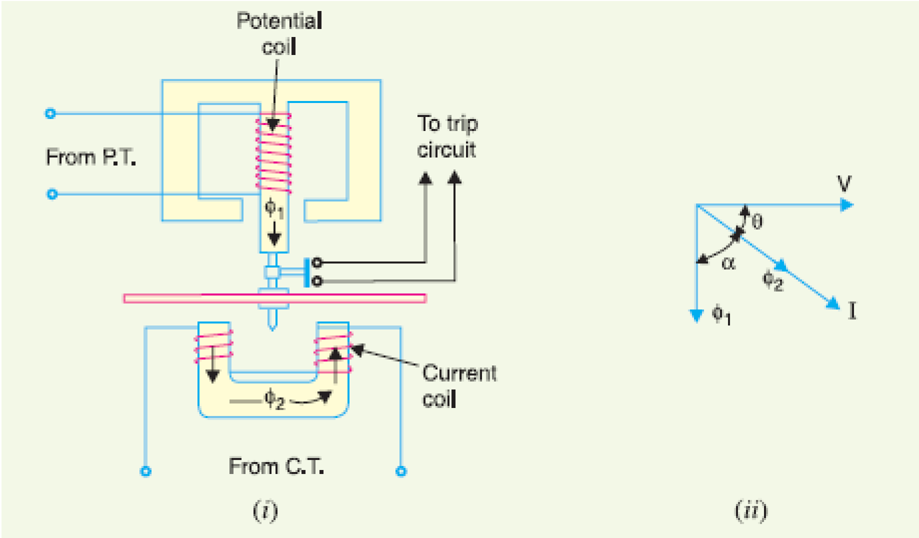


**Figure 2: Induction Type Directional Power Relay**

Operation: The applied voltage V will be roughly 90o behind the flux 1 due to current in the potential coil. The operating current I will be almost in phase with the flux 2 generated by the current coil. Driving torque is produced by the interaction of fluxes 1 and 2 with the induced eddy currents in the disc and is represented as:

$$T \propto \phi_1 \phi_2 \sin\alpha \qquad \text{[See Art. 21.5]}$$

$$\text{Since} \quad \phi_1 \propto V, \quad \phi_2 \propto I \quad \text{and} \quad \alpha = 90 - \theta$$

$$T \propto V I \sin(90 - \theta)$$

$$\propto V I \cos\theta$$

$$\propto \text{power in the circuit}$$

It is obvious that the direction of power flow in the circuit to which the relay is connected determines the driving torque applied to the disc. The driving torque and the restraining torque (caused by the spring) work together to turn the moving contact away from the fixed contacts when the power in the circuit is flowing normally. As a result, the relay is still inactive. However, the direction of the driving torque on the disc is reversed by the circuit's reversal of current flow. The disc rotates in the opposite direction and the moving contact closes the trip circuit when the reversed driving torque is sufficient. This triggers the circuit breaker to operate, disconnecting the defective part.

**Induction Type Directional Overcurrent Relay**

Under short-circuit circumstances, the directional power relay mentioned above is inappropriate for use as a directional protective relay. When a short circuit happens, the system voltage drops to a low level, and the relay may not be able to operate because of a lack of torque. The directed overcurrent relay, which is made to be virtually completely independent of system voltage and power factor, solves this problem.

An essential safety feature in electrical power systems is the induction type directional overcurrent relay, which detects abnormal current situations and reacts while taking the direction of current flow into account. It is a useful tool for selective and reliable fault detection since it combines the directional control and overcurrent protection features. By quickly identifying and isolating faults in certain areas of the network, this relay is essential in ensuring the safety, stability, and dependability of the electrical system. Overcurrent events in power systems can happen as a result of faults such short circuits or overloads, which can cause equipment damage, power outages, and safety risks. The induction type directed overcurrent relay is made to recognise these aberrant current conditions and start coordinated, targeted protection measures. The relay offers selective fault detection, enabling it to distinguish between faults occurring in various parts of the power system by taking into account the direction of current flow.

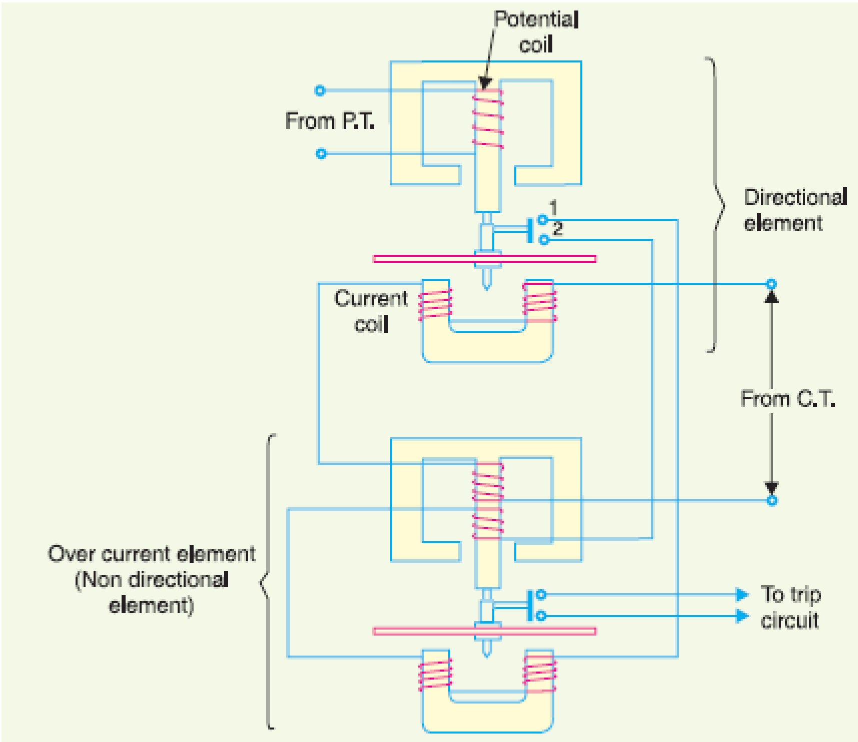


**Figure 3: Induction Type Directional Overcurrent Relay**

The relay can swiftly isolate the defective area with the least amount of network damage thanks to its selective action. The possibility of unneeded tripping during normal operation or during fault conditions in other areas of the system is decreased by the relay's directional control feature, which makes sure that protective actions are only executed when the fault condition occurs in the intended direction. The electromagnetic induction theory serves as the foundation for how the induction type directional overcurrent relay operates. In order to establish the reference direction for current flow and to produce torque based on the alignment of the current with the reference direction, it makes use of current transformers to measure the amount of current as well as polarising and torque-producing coils. The relay can identify the presence of a fault state and start the necessary preventive measures by comparing the current's magnitude with a predetermined threshold and taking the directional information into account [7]–[10].

Current transformers, polarising coils, torque-producing coils, tripping mechanisms, and changeable settings are frequently used in the building of induction type directional overcurrent relays. Together, these parts make sure that aberrant current situations are accurately detected, that fault locations are pinpointed, and that the operation of other system protection devices is coordinated. Transmission lines, distribution feeders, transformers, motors and generators are just a few of the electrical power systems components where the induction type directed overcurrent relay is used. It is a crucial part of protective schemes since it offers accurate and targeted fault detection and reaction. The relay's prompt fault detection and tripping actions save equipment damage, increase system dependability, and guarantee worker and asset safety. Induction type directed overcurrent relays are crucial safeguard components in electrical power systems, to sum up. This relay allows directional control and overcurrent protection, allowing for selective and trustworthy fault detection. Accurate fault localization and coordinated protection are made possible by its capacity to detect abnormal current conditions while taking the direction of current flow into account. The integrity and stability of power systems are significantly maintained by the induction type directed overcurrent relay, enabling the effective and secure transmission of electricity to customers.

Construction information: The construction information for a typical induction type directional overcurrent relay is shown in Fig. 3. It consists of two relay elements a directional element and a non-directional element mounted on a single casing.

(i) The element of direction. It functions like a directional power relay when power is directed in a certain way. Through a potential transformer (P.T.), this element's potential coil is connected to the system voltage. The circuit current powers the element's current coil through a C.T. The non-directional element's upper magnet is covered by this winding.

The secondary circuit of the overcurrent element is linked in series with the trip contacts (1 and 2) of the directional element. The completion of the latter element's secondary circuit is therefore required before it may start operating. In other words, in order to operate the overcurrent element, the directional element must first operate (contacts 1 and 2 should close).

(ii) An element without direction. It is an overcurrent component identical to the non-directional overcurrent relay defined in all aspects. After the directional element has operated, a moving contact on the spindle of the disc of this element shuts the fixed contacts (trip circuit contacts).

It should be noted that the plug-setting bridge, which is a feature of the relay that allows for current setting, has been left out of the image for simplicity and clarity. On the upper magnet of the overcurrent element, tapings are available and connected to the bridge.

Operation: Power flows normally in the circuit that the relay protects when everything is operating as it should. As a result, the overcurrent element (lower element) remains energized and the directional power relay (upper element) does not function. The current or power may, however, prefer to flow in the opposite way when a short circuit occurs. If this occurs, the *upper element's disc spins to span the fixed contacts 1 and 2. The circuit for the overcurrent element is now complete. The moving contact coupled to this element's rotating disc shuts the trip circuit. This turns on the circuit breaker, isolating the defective part. The two relay elements are set up so that the final trip of the current they control doesn't occur until the following conditions are met:

(i) Current moves in a way that the directed element can be operated.

(ii) The reverse current exceeds the predetermined value.

(iii) Excessive current continues for a time frame consistent with the overcurrent element's time setting.

**Distance or Impedance Relays**

The amount of current or power in the protected circuit determined how the relays discussed thus far operated. There is another kind of relays, though, whose functionality is determined by the protected circuit's applied voltage to current ratio. Relays of this type are sometimes known as distance or impedance relays. The torque produced by a voltage element opposes the torque produced by a current element in an impedance relay. When the ratio V/I is below a set limit, the relay will turn on.

An impedance relay's fundamental mode of functioning is depicted in Fig. 4. Through a potential transformer (P.T.) connected to the line that has to be protected, the voltage element of the relay is stimulated. A current transformer (C.T.) in series with the line excites the relay's current element. The protected zone is the line's segment AB. The protected zone has an impedance of ZL when working normally. When the impedance of the protected portion falls below the predetermined value, in this case ZL, the relay is built in such a way that it closes its connections.

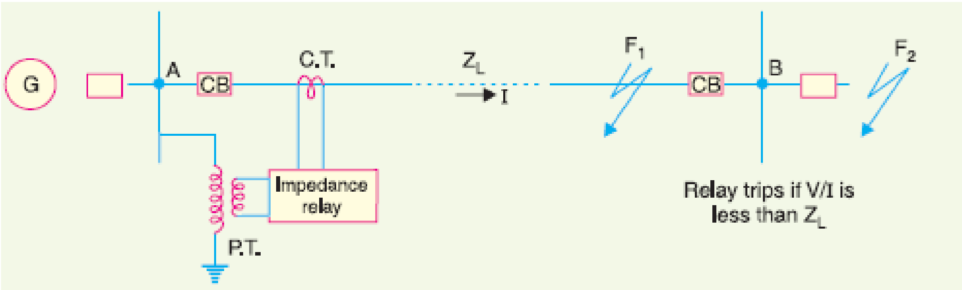


**Figure 4: Distance or Impedance Relays**

Let's say that point F1 in the protected zone experiences a problem. The relay will function because the impedance Z (= *V/I) between the relay's installation point and the point of failure is less than ZL. The relay will not work if the fault occurs outside of the protected zone (at, say, point F2) since the impedance Z will be higher than ZL. Types: When the impedance of the protected zone drops below a set threshold, a distance or impedance relay, which is simply an ohmmeter, activates. For the purpose of protecting the power supply, there are two different types of distance relays in use:

(i) Definite-distance relays, which work instantly for faults up to a predetermined distance from the relay.

(ii) Time-distance relay, whose operating time is inversely correlated with the distance between the relay site and the fault. A fault that is closer to the relay will activate it before a fault that is further away. It should be noted that the balance beam or the induction disc are the two basic relay types that are modified to create the distance relays.

**Definite – Distance Type Impedance Relay**

The schematic layout of an impedance relay of the definite-distance type is shown in Fig. 5. It is made up of a pivoting beam F and two electromagnets that are powered by a current transformer and a voltage transformer in the protected circuit, respectively. On the opposing sides of the fulcrum, the armatures of the two electromagnets are mechanically connected to the beam. The trip contacts are bridged by a component on the beam. The two electromagnets that make up the relay produce torques that are directed in the opposing directions.

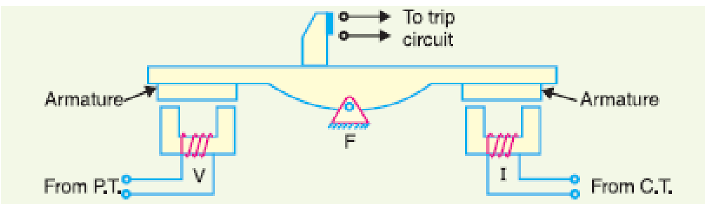


**Figure 5: Distance Type Impedance Relay**

Operation: Under typical operating circumstances, the voltage element's pull is greater than the current elements. Relay contacts stay open as a result. The applied voltage to the relay lowers while the current increases when a fault develops in the protected zone. Impedance, or the ratio of voltage to current, is lower than the target value. As a result, the voltage element's pull will be greater than the current element's pull, which causes the beam to tilt in the direction necessary to close the trip connections.

**Time-Distance Impedance Relay**

In order to identify and react to defects in electrical power systems, particularly in transmission lines, the time-distance impedance relay is a crucial safety device. Impedance, or the ratio of voltage to current in a circuit, provides the basis for how it functions. This relay offers dependable and selective fault detection capabilities, enabling effective fault location and isolation by monitoring the impedance at several points along the transmission line.

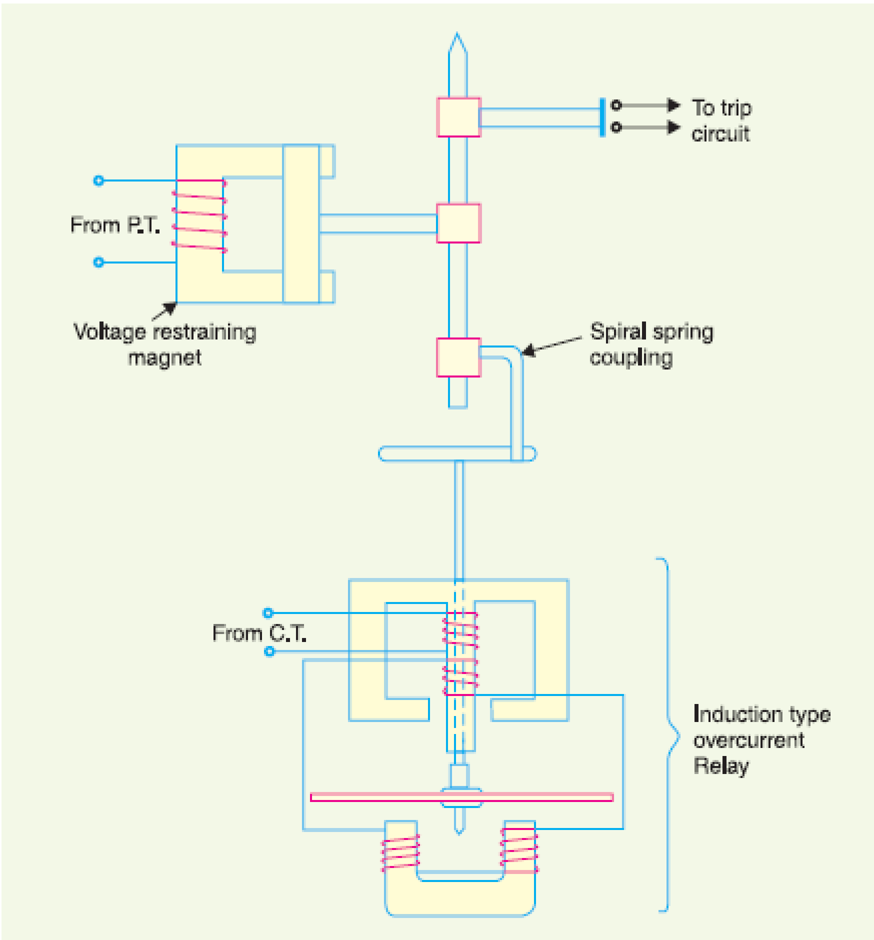


**Figure 6: Time-Distance Impedance Relay**

Transmission line faults in power networks can happen for a number of causes, including short circuits, conductor problems, or insulation failures. To keep the system stable and reliable, it is essential to identify these errors as soon as possible. This need is especially met by the time-distance impedance relay, which continually measures the impedance along the line and compares it to preset values. The idea of measuring impedance serves as the foundation for the time-distance impedance relay's operation. The relay calculates the voltage to current ratio along the gearbox line at various points. When everything is working normally, the impedance stays within reasonable bounds. The impedance, however, alters when a defect happens and deviates from the typical values. The relay can recognise the onset of a defect by detecting these variations from the impedance. A time-distance curve is used by the relay to achieve selective protection. The relay's time to identify a fault at various separations from its location is described by this curve. It is tailored to fit the intended protection plan and is dependent on the transmission line's parameters, such as length. The relay can determine the approximate location of the fault along the line by comparing the measured time and distance to the curve. With the help of this knowledge, circuit breakers or other protective devices can be selectively tripped, allowing for quick fault isolation and little system disturbance. A time-distance impedance relay is made up of a number of parts that work together to enable precise fault detection. To measure the line current and voltage, it has current transformers and voltage transformers. Based on these measurements, impedance measuring circuits compute the impedance. The impedance data is processed, compared to the preset parameters, and choices on fault detection and protective measures are made by a microprocessor-based relay unit. Through communication interfaces, the relay can share data with other safety equipment and control systems, promoting coordination and improving system performance.

The time-distance impedance relay has a number of benefits for safeguarding power systems. Its capacity to monitor impedance at various distances enables selective protection and offers accurate problem detection. The relay's programmable time-distance curve makes it possible to estimate the exact site of a defect, which speeds up fault isolation and lowers downtime. Its interaction with communication interfaces also improves coordination with other security measures and permits remote control and monitoring. To sum up, the time-distance impedance relay serves as an essential safety feature in electrical power systems, particularly in transmission lines. This relay offers precise and targeted fault detection capabilities by tracking impedance and comparing it to predetermined values. It ensures quick fault isolation by using a time-distance curve to estimate the location of the problem accurately. A crucial component in preserving the stability and dependability of power networks, preventing disruptions, and ensuring effective electricity distribution is the time-distance impedance relay.

The relay's distance from the fault, or its operating time,

$$T \propto V/I$$

$$T \propto Z$$

$$T \propto \text{distance.}$$

Similar to the doublewinding type induction overcurrent relay, it is composed of a current-driven induction element. Through a spiral spring connection, the spindle holding this element's disc is joined to another spindle carrying the bridging component of the relay trip contacts. An armature placed against the pole face of an electromagnet stimulated by the voltage of the circuit to be protected typically holds the bridge in the open position. The trip circuit contacts remain open under typical load conditions because the armature's pull is greater than the induction elements.

However, when a short circuit occurs, the induction current element's disc begins to revolve at a rate determined by the operating current. The spiral spring coupling is wound up as the disc rotates until the spring tension is strong enough to draw the armature away from the pole face of the voltage-excited magnet. The moment this happens, the spring tension causes the spindle bearing the armature and bridge piece to move quickly, closing the trip contacts. In order to isolate the defective component, this flips the circuit breaker.

## CONCLUSION

In electrical and electronic systems, relays are essential for controlling circuits. To choose the best relay for a given application, it is crucial to comprehend the various functional relay types. The functional relay types covered in this article have been summarized, together with information on their features and uses. Engineers and technicians may select relays with confidence by taking into account elements including contact type, coil voltage, switching capacity, and environmental conditions. Relays are still essential parts in many different sectors because they provide effective and dependable circuit control. Without taking into account the influence of the control spring, the operating current and the disc's rotational speed are roughly proportionate. Additionally, the voltage-excited magnet's pull and, consequently, the line voltage V at the location where the relay is connected, which determines how long the relay operates for. As a result, the relay's operating time would vary as V/I, or as Z or distance.

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# CHAPTER 3

# DIFFERENTIAL RELAY

Mr. Veerappa Ravi
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:raviangadi@presidencyuniversity.in

**ABSTRACT:**

Differential relays are safety tools frequently used in electrical power systems to find and fix defects. They work by continuously comparing the currents going into and coming out of a protected area, such a transformer or generator, and activating the tripping mechanism if a sizable difference is found. This chapter gives a general introduction of differential relays, covering their main components, uses, and operating principle. The benefits and drawbacks of employing differential relays for protection are also covered. By protecting against failures and assuring the safe and dependable operation of various equipment, including transformers, generators, and motors, differential relays serve a crucial role in electrical power systems. These safeguards work by continuously comparing the currents entering and leaving a protected zone in order to identify and isolate flaws. An overview of differential relays, their significance, and their workings are given in this introduction.

**KEYWORDS:**

Biased Beam Relay, Current Differential Relay, Differential Relay, Power System Protection, Voltage Balance Differential Relay.

## INTRODUCTION

Electrical power systems are intricate networks that transmit and distribute electrical energy to satisfy the needs of numerous enterprises, industries, and homes. To enable the transfer of electricity throughout these power networks, several components are coupled. However, these parts are prone to errors that could ruin the system, harm the tools, and endanger the security of the workers [1]–[3]. Insulation failure, equipment failure, or external factors like lightning strikes or tree interactions are only a few of the causes of power system faults. A fault causes the system to experience aberrant currents and voltages as well as other abnormal situations. Faults can result in system instability, equipment damage, and even cascading failures if they are not quickly identified and isolated. A vital line of defense against problems in power systems is provided by differential relays. They are made to continuously compare the currents entering and leaving a protected zone in order to find internal flaws inside that zone. The protected zone usually corresponds to crucial parts, such as transformers, generators, or motors, where failures might have serious repercussions if they are not promptly identified and separated.

Kirchhoff's current law, which stipulates that the total current flowing into and out of a particular location in an electrical circuit is equal, serves as the foundation for the operation of differential relays. Current transformers (CTs) are used to scale down the currents to a quantifiable level so that the differential relay can monitor the current entering and exiting a protected zone. The input and output sides of the protected zone are connected to these CTs, which give the relay the data it needs to do a current comparison. Depending on the relay's design, the differential relay compares the currents using a comparison element, which may be an analogue or digital circuit. The relay remains in a non-operating state if the currents entering and leaving the protected zone are equal or nearly equal, signifying normal operation. However, if a defect develops inside the protected zone, it leads to a current imbalance and causes the relay to turn on the tripping mechanism.

A differential relay's tripping mechanism is in charge of starting the processes required to isolate the problematic area. This normally entails sending a trip signal to the connected circuit breaker, which opens the contacts and stops the flow of current to the malfunctioning equipment. The differential relay assists in limiting downtime, preventing more damage, and preserving the integrity of the power system by isolating the issue. Transformers, generators, motors, and busbars are just a few of the power system components that differential relays are used in. Differential relays are used in transformer protection to find internal winding problems such turn-to-turn faults or phase-to-phase faults. Comparative relays can also detect stator or inter-turn defects in generator protection. In order to avoid damage from rotor or stator problems, differential relays are also essential for motor safety. Differential relays have many benefits when used for power system protection. First off, they offer exceptional sensitivity, making it possible for them to identify even minor flaws that other protection mechanisms would miss. Second, differential relays provide selectivity, which enables them to precisely pinpoint the fault's position within the protected zone. This chosen procedure aids in reducing unwanted tripping and focusing on the precise area of the defect to facilitate quicker troubleshooting.

The speed at which differential relays operate is another benefit. These relays can quickly respond to abnormal conditions by detecting faults and starting the tripping mechanism within a few moments. This quick process contributes to improving the overall stability of the power system and minimizing any damage brought on by malfunctions. Additionally, differential relays are adaptable and can be used with a variety of power system parts. No matter what type of equipment is being safeguarded, their operational premise is the same. Power system design and execution are made simpler and standardized protective schemes are made possible by this flexibility. Differential relays do have some advantages, but there are also some drawbacks that must be taken into account. One drawback is its vulnerability to outside influences like current transformer (CT) saturation. When the current magnitude surpasses the CT's measuring range, CT saturation happens, resulting in false readings and perhaps jeopardizing the differential relay's dependability.

The coordination between the protection devices in the power system is complicated, which is another restriction. To achieve adequate discrimination and the coordination of protection mechanisms, differential relays must be coordinated with other relays, such as overcurrent or distance relays. In order to prevent needless tripping or inefficient fault isolation, this coordination necessitates careful consideration of settings, time delays, and fault detection logic. Differential relays are essential parts of the defense of the power system. These relays can quickly identify problems and start the necessary processes to isolate the problematic equipment by continually monitoring the currents entering and leaving a protected zone. High sensitivity, selectivity, and operational speed are benefits of differential relays. They are used in many different parts of power systems and add to the overall dependability and safety of electrical power systems. However, it is critical to recognize the drawbacks of differential relays, including their vulnerability to outside influences and the requirement for adequate coordination with other safety measures. The performance of differential relays in power system protection is now being improved as a result of ongoing research and development efforts to solve these constraints.

The majority of the relays that have been discussed so far operated by using too much current. Due to their inability to accurately distinguish between scenarios involving huge loads and minor faults, such relays are less sensitive. Differential relays are utilised to get around this problem. When the phasor difference of two or more similar electrical quantities exceeds a certain threshold, a differential relay will turn on. Therefore, a current differential relay is one that contrasts the current entering with the current exiting a certain system portion. The two currents are equal when everything is working properly, but this condition is no longer true when a fault happens. The functioning coil of the relay is designed to conduct the difference between the incoming and outgoing currents. In order to isolate the defective portion, the relay will work and open the circuit breaker if the differential current is equal to or greater than the pickup value. It should be noted that practically any form of relay may be made to function as a differential relay by connecting them in a certain method. In other words, what distinguishes a relay as a differential relay is not so much its design as it is how it is wired up in a circuit. There are two fundamental systems of differential or balanced protection viz. Protection against current imbalance and voltage imbalance.

## DISCUSSION

### Current differential relay

A protective relay called a current differential relay works by comparing the currents entering and leaving a protected zone. It is frequently used in power systems to locate defects and launch preventative measures, like tripping circuit breakers, to isolate the problematic area. Kirchhoff's current law, which states that the sum of currents entering a point in an electrical circuit is equal to the number of currents leaving that point, serves as the foundation for the operation of a current differential relay. The relay analyses the currents entering and leaving a protected zone, such as a transformer or a generator, and compares them to see if there is a substantial difference. Current transformers, or CTs, are employed to measure the currents. CTs are tools that accurately reflect the principal currents by stepping down the currents to a measurable level. The protected zone's input and output sides are connected to these CTs, which enable the relay to gather the appropriate current data for comparison [4]–[6].

The comparison element, which may be an analogue or digital circuit depending on the design, and the tripping mechanism make up the majority of current differential relays. The comparison component contrasts the currents flowing into and out of the protected area. The relay does not operate if the currents are equal or substantially equal, indicating normal operation. The relay triggers the tripping mechanism if there is a sizable difference between the currents, which points to the possibility of a fault within the protected zone. The operations required to isolate the defective section are started by a current differential relay's tripping mechanism. This frequently entails sending a trip signal to the connected circuit breaker, which opens the contacts and stops the flow of current to the malfunctioning equipment. The differential relay assists in limiting downtime, preventing more damage, and maintaining the stability of the power system by isolating the fault. Transformers, generators, motors, and busbars are just a few of the components in power systems that are frequently protected by current differential relays. They are particularly good at finding internal flaws, such as turn-to-turn or phase-to-phase problems, within these components. The differential relay can immediately identify these faults and start the required protective measures by continuously monitoring the currents.

The high sensitivity of current differential relays is one of their main benefits. They can find even minor flaws that conventional protection mechanisms might miss. Due to this sensitivity, problems may be identified early and quickly isolated, minimizing the risk of equipment damage and improving the stability of the power system as a whole. The constraints of current differential relays must also be taken into account. External factors, such as current transformer (CT) saturation, which can result in false readings and consequently jeopardize the differential relay's dependability, can have an impact on them. To address this problem, the CTs' saturation properties must be carefully thought out and designed. In order to identify faults and safeguard vital components in power systems, current differential relays are crucial safety equipment. These relays offer sensitive and quick fault detection abilities by comparing currents entering and departing a protected zone. They are used in many different parts of power systems and add to the overall dependability and safety of electrical power systems.

A configuration of an overcurrent relay coupled to function as a differential relay is shown in Fig. 1. On either end of the segment that needs to be protected (in this case, the alternator winding), two identical current transformers are installed. In order to convey the induced currents in the same direction, the secondaries of CTs are linked in series. The CT secondary circuit is linked across the working coil of the overcurrent relay. The alternator winding's current at its two ends is compared by this differential relay.

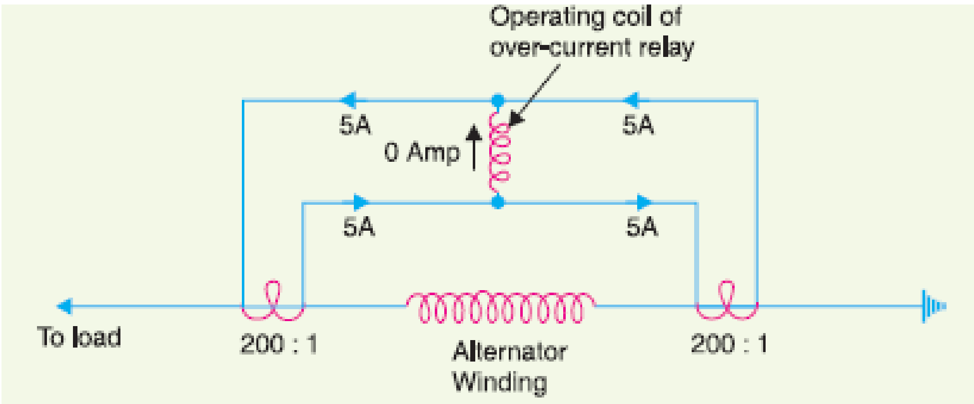


**Figure 1: Current differential relay**

Let's assume that the alternator winding carries a normal current of 1000 A during normal operation. The currents in the two CT secondaries are then equivalent [See Fig. 1]. These currents won't actually flow through the differential relay; instead, they'll only go back and forth between the two CTs. As a result, the relay is still inactive. The two secondary currents will not be equal in the event of a ground fault on the alternator winding, as indicated in Fig. 2 (i), and the current will pass through the relay's operational coil, causing the relay to function. Depending on how the fault is supplied, the relay's ability to conduct current will vary.

(i) If, as illustrated in Fig. 2(i), a smaller current (500 A in this case) flows out of one side while a larger current (2000 A) enters the other side, then the relay will conduct the difference of the CT secondary currents, or 10 - 2.5 = 7.5 A.

(ii) If both sides of the fault experience current flow, as in Fig. 21.24 (ii), then the sum of CT 10 + 5 = 15 A in secondary currents will pass through the relay.

Disadvantage:

(i) Typically, the impedance of the *pilot cables results in a small differential in current between the two ends of the portion that needs to be protected. If the relay is particularly sensitive, even in the absence of a malfunction, it might still work due to the slight differential current passing through it.

(ii) When a significant through-current flows, pilot cable capacitance results in improper relay operation.

(iii) Pilot circuit impedance prevents precise matching of current transformers. Biased beam relay greatly reduces the aforementioned drawbacks.

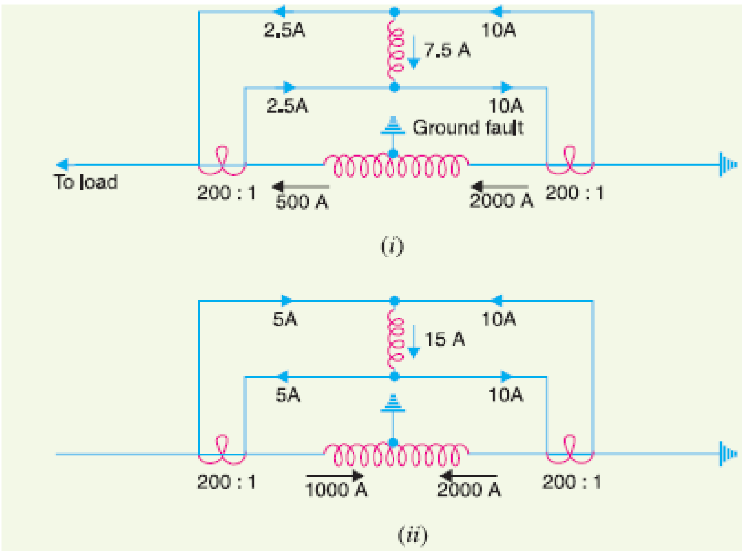


**Figure 2: Current differential relay**

**Biassed Beam Relay**

The biassed beam relay, also known as a percentage differential relay, is made to react to differential currents in proportion to how much of them there are compared to the shielded section's current. The basic layout of a biassed beam relay is shown in Fig. 3. A second restraint coil basically makes it an overcurrent balanced beam relay type. An opposing bias force to the operating force is generated by the restraint coil.The bias force resulting from the restraining coil is greater than the working force under normal and under load circumstances. As a result, the relay is still inactive. The operating force is greater than the bias force when an internal problem occurs. In order to open the circuit breaker, the trip connections are consequently closed. By altering the number of turns on the restraining coil, the bias force can be changed.

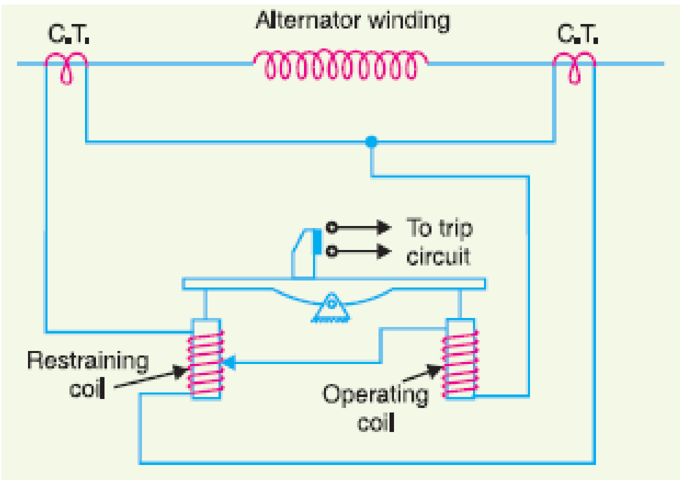


**Figure 3: Biased relay**

Fig. 4 depicts the equivalent circuit of a biassed beam relay. Since the working coil is connected to the midpoint of the restraining coil, the equivalent current in the restraining coil is proportional to (i1 + i2)/2, whereas the differential current in the operating coil is proportional to i2 i1.

It is obvious that the higher the current required in the operational winding to trip the relay, the greater the current flowing through the restraining coil. Therefore, a greater differential current through the relay operating coil is needed for operation when there is a heavy load than when there is a small load. Because the operating current needed to trip can be stated as a proportion of load current, this relay is also known as a percentage relay.

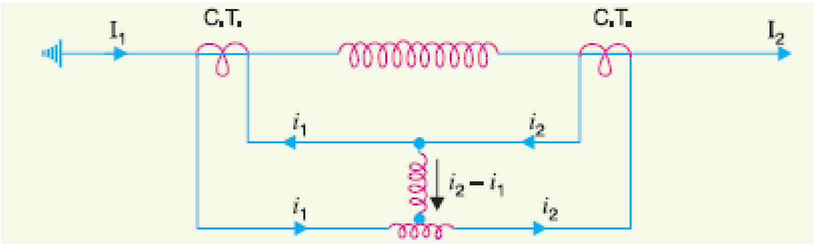


**Figure 4: mathematical illustration of biassed relay**

**Voltage Balance Differential Relay**

The layout of the voltage balance protection is shown in Fig. 5. In this protection method, pilot wires are used to connect two similar current transformers at either end of the element that has to be protected (in this case, an alternator winding). Current transformer secondaries are wired in series with a relay so that, in a neutral state, their induced e.m.fs are in opposition. Both primary windings flow equal currents ($I_1 = I_2$) when everything is in order. As a result, no current will flow because the secondary voltages of the two transformers are balanced against one another through the operational coil of the relay. The two primary' currents will diverge ($I_1$, $I_2$) and their secondary voltages will no longer be in phase when a fault occurs in the protected zone balance. A current will pass through the operational coil of the relay as a result of this voltage differential, closing the trip circuit[7]–[10].

Drawbacks: The voltage balance system has the following shortcomings:

(i) In order to achieve an appropriate balance between current transformer pairs, a multi-gap transformer construction is necessary.

(ii) Due to the pilot wires' capacitance, the technique is appropriate for protecting relatively short cables. Even if a perfect balance of current transformers is achieved, the relay may still be able to work on lengthy connections thanks to the charging current. The Translay (modified) balanced voltage system has been designed to address the aforementioned drawbacks.

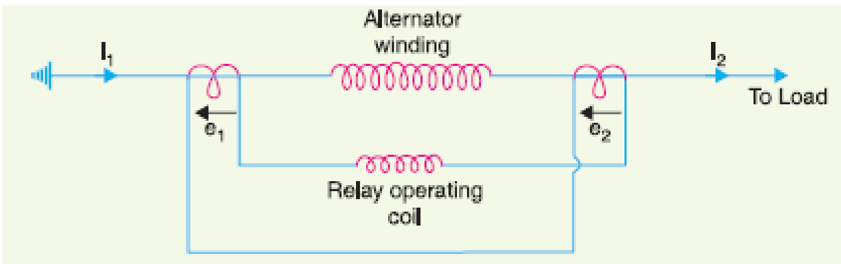


**Figure 5: Voltage Balance Differential Relay**

**Types of protection**

Any time a fault develops in the electric power system, it needs to be fixed right away to prevent further damage and/or interference with the rest of the system. The protection plan is typically divided into two types, namely primary protection and backup protection.

(i) Primary Protection: This protection strategy is intended to safeguard the power system's constituent parts. With reference to Fig. 6, each line is thus protected by an overcurrent relay. Any line that develops a fault will have its relay and circuit breaker reset it. This acts as the initial line of defence and forms the main or primary protection. With far over 90% of all operations being successful, main relaying has an excellent service record. However, occasionally issues with the relay, wire system, or breaker prevent errors from being resolved by the primary relay system. Back-up protection performs the necessary function under these circumstances.

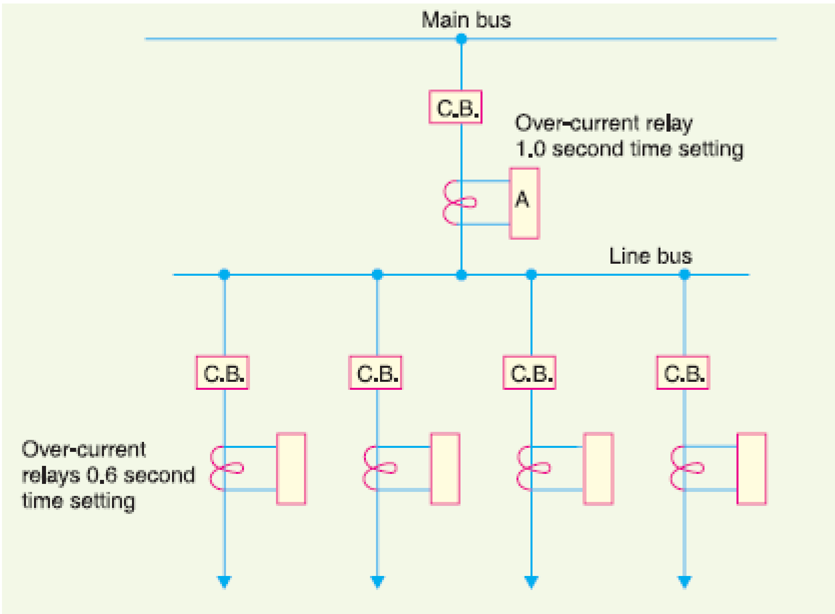


**Figure 6: Primary protection**

(ii) Backup protection: This is the second line of protection in the event that the initial defence fails. It is intended to operate with a long enough time delay to provide primary relaying, assuming it is capable, enough time to work. Relay A thus offers backup security for each of the four lines in Fig. 6. If a line fault is not resolved by its relay and breaker, the group breaker's relay A will activate after a predetermined amount of time and resolve the issue for the entire group of lines. It is clear that a bigger portion is disconnected when backup relaying operates correctly compared to when primary relaying runs smoothly. Therefore, improved primary relaying maintenance should receive more attention.

## CONCLUSION

Finally, it should be noted that differential relays are essential to the dependable and secure operation of electrical power systems. These relays can quickly identify faults and start the necessary measures, including isolating the malfunctioning equipment, by continually monitoring the currents entering and leaving a protected zone. Differential relays have a number of benefits, such as high sensitivity, selectivity, and operation speed. They can also be used on a variety of power system parts, including transformers, generators, and motors. It is crucial to recognize the drawbacks of differential relays, such as their vulnerability to outside influences like CT saturation and the difficulty of coordinating them with other safety measures. Overall, differential relays continue to be a crucial instrument for power system protection, and continuous research and development efforts are aimed at improving their functionality and addressing their drawbacks.

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# CHAPTER 4

# EXPLORING THE PROTECTION METHODS OF ALTERNATORS

Mr. Vesapogu Joshi
Associate Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:joshimanohar@presidencyuniversity.in

**ABSTRACT:**

The protection of alternators, which are crucial parts of systems used to generate electricity, is the main topic of this study. Alternators are susceptible to a number of problems and failures that can seriously harm the equipment and interrupt the power supply. Therefore, adopting efficient protection plans is essential to guarantee the alternators' dependable performance and guard against potential dangers. The chapter examines methods for fault isolation, fault detection, and fault mitigation as they relate to alternator protection. The significance of synchronization with various protection mechanisms inside the power system is also covered. This chapter offers insights into the cutting-edge methods for alternator protection by examining recent research and business practices. A variety of components, such as alternators, transformers, station bus-bars, gearbox lines, and other machinery, make up the contemporary electric power system. Each element should be protected from a variety of fault circumstances that could happen at any time. This is both desirable and required. The protective relays covered in the previous chapter can be effectively used to identify any circuit element's faulty conduct and launch corrective action.

**KEYWORDS:**

Balanced Earth Fault Protection, Differential Protection of Alternators, Protection Of Alternators, Power Generation System, Stator Inter-Turn Protection.

## INTRODUCTION

For ease of reading, just the safety of transformers and alternators is covered in this chapter. The stator winding defects on alternators are the most critical flaws that demand prompt correction. Short circuits in the transformers or their connections are the main causes of problems on transformers. Due to the differential character of measurements, which makes this system considerably more sensitive than other protective systems, the differential relay scheme is the fundamental system utilised for protection against these failures [1]–[3]. To maintain dependable operation and avoid potential risks, alternator protection is crucial in electrical power generation systems. These systems' essential alternators are prone to a variety of errors and malfunctions that can seriously harm the machinery and disrupt the power supply. Implementing efficient protection plans is therefore essential. An overview of alternator protection is given in this article, along with approaches for fault isolation, mitigation, and synchronization with other protection mechanisms in the power system.

A crucial component of alternator protection is fault detection. In order to spot unusual conditions that could point to a fault, it includes continuously monitoring the alternator's parameters, including voltage, current, temperature, and vibration. These parameters are measured using a variety of sensing tools, including relays, sensors, and instruments, which then sound alarms or take other preventive measures when there are deviations from the norm. Advanced methods can be used to improve the accuracy and speed of defect detection, allowing quick response to possible problems. These methods include digital signal processing and artificial intelligence algorithms.

To stop a failure from spreading to other areas of the alternator or the power system after it has been identified, it is crucial to isolate the problematic area or component. Circuit breakers or isolators, which swiftly cut off the defective part of the system from the rest of the system, are the mainstay of isolation approaches. Rapid isolation lessens the influence on the entire power generation system and helps to limit the damage caused by the malfunction. In order to provide selective isolation, where just the defective area is isolated while ensuring an uninterrupted power supply to the healthy components of the system, coordination between the protective devices, such as relays and circuit breakers, is essential. Techniques for fault mitigation seek to minimize the impact of a malfunction and soon resume regular functioning. Different tactics can be used, depending on the fault's nature. For instance, protection mechanisms can be made to automatically limit the alternator's output power or to temporarily disconnect it from the grid in the event of an overvoltage or overcurrent malfunction. The use of backup systems, such as redundant alternators or emergency power supplies that can take over the load in the case of a fault is another strategy for fault mitigation.

To ensure comprehensive protection, coordination with various protective mechanisms within the power system is essential. Within the network of power generation and distribution, alternators are connected to other pieces of machinery including transformers, circuit breakers, and relays. Through coordinated protection, defects in one area of the system are quickly identified, isolated, and addressed without impairing the functionality of other parts. Coordination algorithms that take into account the characteristics and response times of different protective devices in the system are used in conjunction with appropriate settings to achieve this coordination. Sustaining the stability and dependability of electrical power generation systems depends on the protection of alternators. Techniques for fault isolation, mitigation, and cooperation with other protection mechanisms are crucial components of alternator protection. The danger of alternator problems and failures can be reduced by putting in place efficient protection measures, providing an uninterrupted power supply and avoiding equipment damage. Developing cutting-edge and trustworthy alternator protection systems is the subject of ongoing research and industrial practices. To handle new issues and incorporate cutting-edge technologies into alternator protection schemes, further work is still required. By putting alternator protection first, electrical power generation systems perform better overall and are more resilient, resulting in an effective and consistent supply of electricity for consumers.

**Protection of Alternators**

The smaller and more expensive producing units are relatively uncommon compared to other pieces of equipment. As a result, it is both desirable and required to offer protection against the vast range of problems that a contemporary producing plant may experience. Important alternator defects include some of the following:

Failures of the prime mover, the field, overcurrent, over speed, overvoltage, unbalanced loading, and stator winding defects are only a few examples.

(i) Prime-mover failure: The alternator operates as a synchronous motor and takes some current from the supply system when the input to the prime-mover fails. "Inverted running" is the term used to describe this driving situation.

(A) Inverted running may occur with turbo-alternator sets if the steam supply fails. The alternator will take on load without upsetting the system if the steam supply is progressively restored. The machine can be securely separated by the control room attendant if the steam failure is anticipated to last for an extended period of time because it is a generally benign condition. Therefore, automated defence is not necessary.

(b) For hydro-generator sets, mechanical mechanisms are installed on the water-wheel to prevent inverted running. The alternator is unplugged from the system when the water flow becomes too low to maintain the electrical output. Therefore, electrical protection is not required in this situation either.

(c) Diesel engine powered alternators consume a significant amount of power from the supply system when operating inverted, hence it is customary to offer protection against motoring to prevent damage from a potential mechanical seizure. This is accomplished by connecting the alternators to reverse power relays, which isolate the latter while they are operating. Reverse power relays must operate with a time delay in order to avoid accidentally tripping them during system disruptions brought on by improper synchronizing and phase swinging.

(ii) Field failure: Alternators have incredibly slim possibilities of experiencing a field failure. Even if it does happen, there won't be any immediate harm from letting the alternator run briefly without a field. It is adequate to rely on the control room employee to manually separate the defective alternator from the system bus-bars. As a result, it is common practice to refrain from offering "automatic protection against this contingency".

(iii) Overcurrent: This problem typically results from an overload on the supply system or a partial failure of the insulation on the windings. Due to the following factors, overcurrent protection for alternators is viewed as unnecessary:

(a) In order for alternators to withstand a complete short-circuit at their terminals for an extended period of time without experiencing major overheating, it is now common practice to design them with extremely high internal impedance values. In the event of an overload, the alternators can be manually detached.

(b) The drawback of using overload protection for alternators is that it may cause them to be disconnected from the power plant bus due to brief problems occurring outside the plant, which would disrupt the continuity of electric service.

(iv) Overspeed: The rapid loss of all or most of the load on the alternator is the main cause of overspeed. Modern alternators typically include mechanical centrifugal devices attached on their driving shafts to trigger the prime-mover's main valve when a risky overspeed occurs.

(v) Over-voltage: Modern alternators' field excitation systems are built in such a way that overvoltage conditions cannot exist when the alternator is working normally. However, when the alternator load suddenly disappears, speed of the prime mover increases, resulting in overvoltage in the alternator. The control governors for alternators powered by steam turbines are extremely sensitive to changes in speed. They continuously exercise control over overspeed to avoid overvoltage on the generating unit. As a result, turbo-alternator sets are not equipped with over-voltage protection. Since hydro-generators have control governors that are significantly less sensitive, it may take some time before the increase in speed caused by a loss of load is detected. During this period, the over-voltage might reach a level that would overstress the stator windings and cause insulation breakage.

Therefore, installing over-voltage protection on hydro-generator units is standard practice. A voltage supply derived from the generator terminals is used to power the over-voltage relays. The relays are set up so that they operate to (a) trip the main circuit breaker and separate the defective alternator from the system (b) disconnect the alternator field circuit when the generated voltage increases 20% over the normal value.

(vi) Unbalanced loading: When the alternator is under unbalanced loading, there are various phase currents. Unbalanced loads are caused by faults to the ground or faults between phases on the alternator's external circuit. If the imbalanced currents are allowed to continue, they could seriously burn the rotor core's mechanical fasteners or harm the field winding. The schematic layout for the alternator's safety against unbalanced loads is shown in Fig. 1. The system consists of three-line current transformers, one installed in each phase, with parallel connections between the secondaries of each transformer. The transformer secondaries are crossed by a relay that is connected in parallel. Equal currents pass through the alternator's various phases during normal operation, and their algebraic sum is zero [4]–[6].

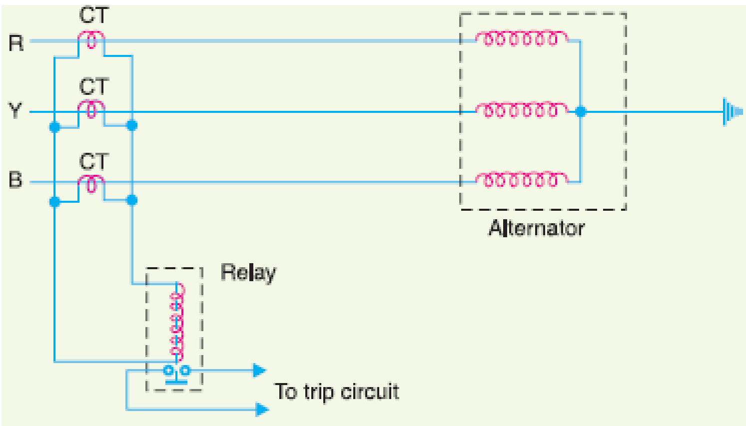


**Figure 1: Unbalance loading**

As a result, there is no current flowing through the operational coil of the relay and the sum of the currents flowing in the secondaries is also zero. The currents created in the secondaries, however, will differ if unbalancing takes place, and the resulting currents will travel via the relay. The circuit breaker will be tripped by the relay's activity, disconnecting the alternator from the system.

(vii) Stator winding faults: These faults primarily result from the stator windings' insulation failing. The two most significant stator winding fault types are:

(a) Fault between phase and ground.

(b) Fault between phases.

(c) A defect that occurs between turns on the same phase winding.

The most hazardous flaws are those in the stator winding, which can seriously harm the pricey equipment.

Therefore, automatic protection is unavoidably required to eliminate such errors as soon as feasible in order to lessen the amount of harm. Due to its increased sensitivity and dependability, differential method of protection, also known as Merz-Price system, is most frequently used to protect alternators against such problems. The section that follows talks about this defence mechanism.

## DISCUSSION

### Differential Protection of Alternators

Circulating-current theory is utilised most frequently in systems for stator winding fault protection. Currents at the two ends of the shielded segment are compared in this protection method. These currents are equal while everything is working normally, but they might not be if there is a defect in the protected section. Under fault conditions, the functioning coil of the relay is configured to pass through the difference in currents. In order to cut off the protected part from the system, the relay then closes its contacts. Alternatively called the Merz-Price circulating current scheme, this method of defence.

The schematic layout of current differential protection for a 3-phase alternator is shown in Fig. 2. On either side of each phase of the stator windings are identical current transformer pairs CT1 and CT2, which are arranged in pairs. The two neutral points and associated terminals of the two-star groups are connected together by a four-core pilot cable, and the secondaries of each set of current transformers are connected in a star configuration. As a result, the currents flowing through each pair of current transformers and the corresponding pilot P have their own separate path.

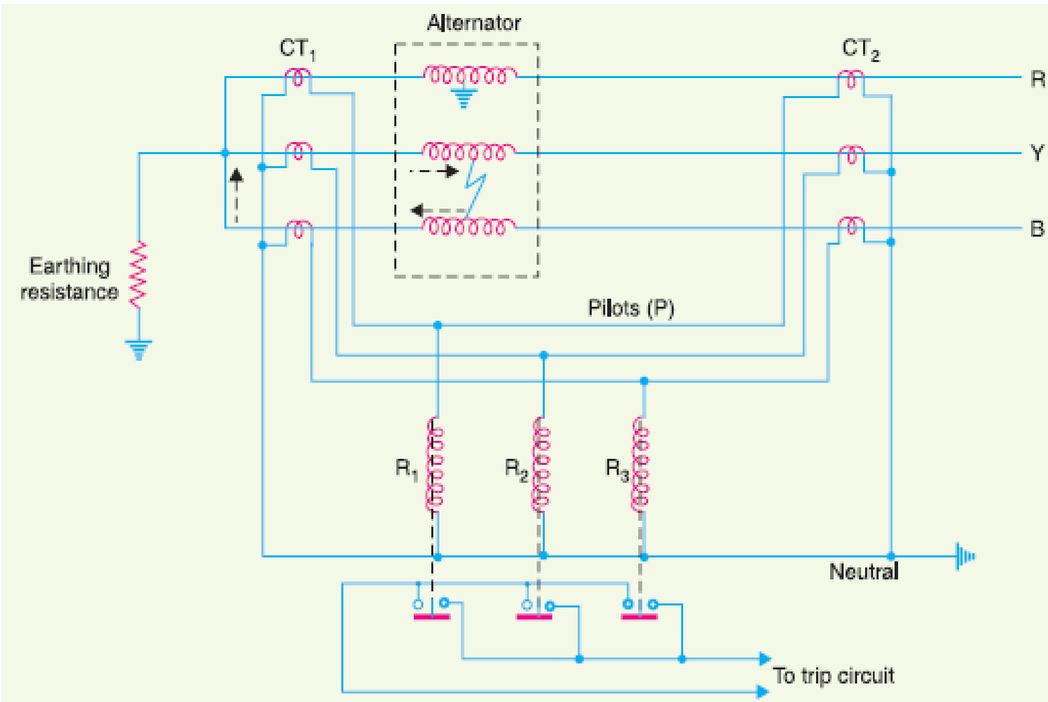


**Figure 2:Differential Protection of Alternators**

The relay coils are wired in a star pattern, with one of the outer ends connected to each of the other three pilots and the neutral point attached to the common neutral of the current transformer. The relays are connected across the three pilot wires' equipotential points, which are logically in the middle of the pilot wires and ensure that the load on each current transformer is the same. The relays are often electromagnetic in nature and set up for instantaneous action because the problem needs to be fixed as soon as feasible.

The relays are connected in shunt across each circulation channel, as shown in Fig. 2. So, in Fig.3, the circuit of Fig. 2 can be represented in a more straightforward manner. The currents in the secondaries of two CTs connected in any phase will also be identical under typical operating conditions since the current at both ends of each winding will be equal. As a result, there is no current flowing through the operating coils (R1, R2, and R3) of the relays and there is balanced circulating current in the pilot wires. This condition is no longer valid in the event of an earth fault or phase-to-phase fault, and the relay is activated to trip the circuit breaker by the differential current flowing through the relay circuit.

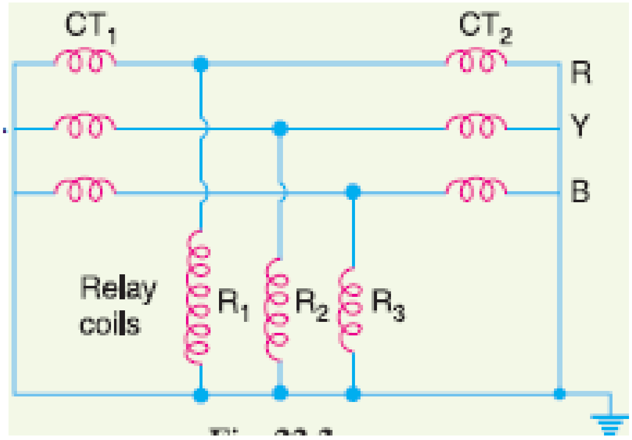


**Figure 3: protection of alternators**

(i) Assume that phase R experiences an earth fault as a result of the failure of its insulation to the earth, as depicted in Fig. 2. The machine's core and frame will conduct the afflicted phase winding's current to earth, completing the circuit with the neutral earthing resistance. Phase R will see an imbalance in the currents flowing through the secondaries of the two CTs, causing the difference to pass through the matching relay coil (R1) and return via the neutral pilot. This causes the relay to activate and trip the circuit breaker.

(ii) Assume that a short-circuit fault has now developed between phases Y and B, as depicted in Fig. 2. The dotted arrows depict how the short-circuit current travels through the two windings, the fault, and the neutral end connection. The differential current will flow via the working coils of the relays (i.e., R2 and R3) connected in these phases as a result of the currents in the secondaries of two CTs in each affected phase becoming unequal. In order to trip the circuit breaker, the relay then closes its connections.

It should be noticed that the relay circuit is set up so that when it is powered on, the alternator's field circuit and the breaker connecting it to the bus bars both open. Current transformers CT1 are commonly mounted in the neutral connections (typically in the alternator pit) and CT2 are mounted in the switch-gear equipment. In other instances, the switchgear and alternator are positioned rather far apart. It is not practical to connect the relay coils to the real physical midpoints of the pilots since the relays are near to the circuit breaker. To ensure that the relay tapping points divide the total secondary impedance of two sets of CTs into equal halves, balancing resistances are placed in the shorter lengths of the pilots in this situation. This configuration is depicted in Fig. 4. Typically, these resistances can be changed to get the ideal balance.

Limitations: Each of the two alternator protection circuits is depicted above has specific restrictions. Neutral earthing resistance is typically used to reduce the harmful effects of earth-fault currents. A star-connected alternator's stator windings cannot be completely protected in such a scenario against earth disturbances. If an earth-fault develops close to the neutral point, there may not be enough voltage across the shorted area to drive the relay's required current around the fault circuit. The size of the unprotected zone is influenced by the value of relay setup and earthing resistance. The phrase "protecting 80% of the winding" used by manufacturers of protective equipment the 20% of the winding that is close to the neutral point is unprotected and cannot trip someone. Due to the consistent insulation of the winding throughout, it is standard practice to only safeguard 85% of the winding because the likelihood of an earth fault happening close to the neutral point is quite remote.

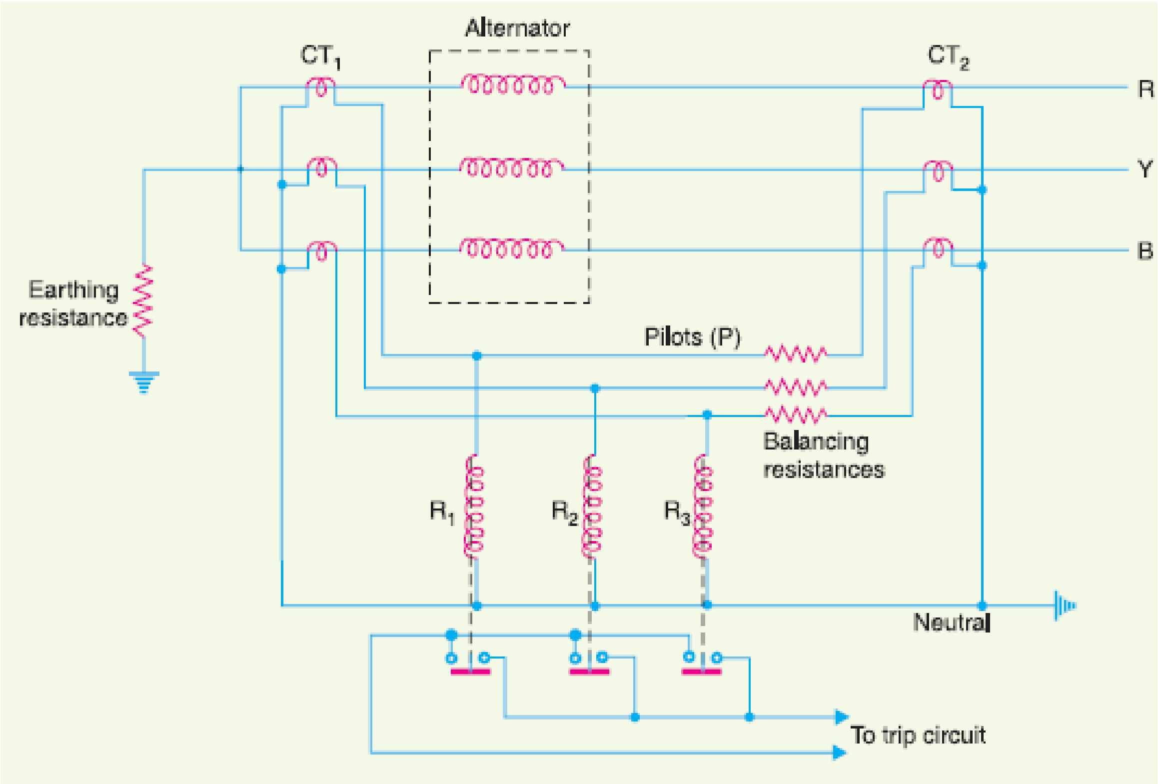


**Figure 4: Alternator protection**

**Modified Differential Protection for Alternators**

The protection strategies shown in Figs. 2 and 4 will not be sensitive enough to detect earth faults if the neutral point of a star-connected alternator is earthed through a high resistance. It is because a sufficient section of the generator winding must be protected, low current setting relays are required since a high earthing resistance will limit the earth-fault currents to a low value. However, for dependable stability on heavy via phase-faults, a relay setting that is too low is not ideal.

A modified type of differential protection is employed to get around this problem, reducing the setting of earth faults without sacrificing stability. Fig.5 depicts the updated configuration. The changes involve connecting two relays for phase-fault protection and a third relay for exclusive earth-fault protection, and they solely alter the relay connections. The earth relay (ER) is linked between this star point and the fourth wire of the circulating current pilot-circuit. The two phase components (PC and PA), balancing resistance (BR), and earth relay (BR) are connected in a star configuration.

Operation: The currents at the two ends of each stator winding will be equal under typical operating circumstances. As a result, the phase pilot wires have a balanced circulating current and there is no current flowing into the operational coils of the relays. As a result, the relays are still inactive.The out-of-balance secondary current in CTs in that phase will travel through the earth relay ER and via pilot S1 or S2 to the neutral of the current transformers if an earth fault occurs on any one phase.

Only the earth relay will operate as a result of this. If there is a fault between two phases, the out-of-balance current will travel through any two of the coils PA, BR, or PC (the pair is determined by the two defective phases) and around the two transformer secondaries without going through the earth relay ER. Only the phase-fault relays will therefore function.

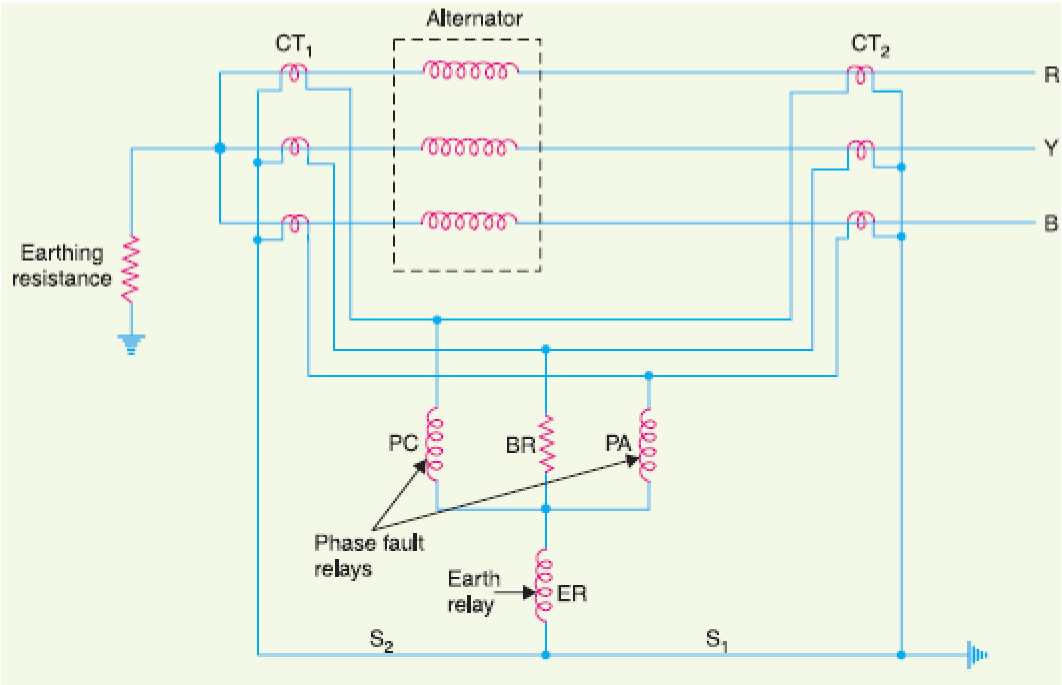


**Figure 5: Modified Differential Protection for Alternators**

**Balanced Earth fault protection**

The neutral ends of the three-phase windings are frequently internally connected to a single terminal in small-size alternators. Therefore, because there are no facilities for housing the requisite current transformers in the neutral connection of each phase winding, it is not possible to employ the Merz-Price circulating current principle mentioned above. Under these conditions, it is deemed sufficient to just use a balanced earth-fault protection method to give protection against earth-faults. Phase-to-phase faults are not protected by this plan, and the majority of them will eventually become earth faults [7]–[10].

Schematic organisation: The balanced earth-fault protection for a 3-phase alternator is shown schematically in Fig. 6. It is made up of three line current transformers—one positioned in each phase whose secondaries are coupled in parallel with those of a single current transformer in the circuit connecting the alternator's star point to ground. The secondaries of the transformers are linked to a relay. The area between the neutral and the line current transformers is the only area that is protected against earth faults.

Operation: Under typical operating circumstances, there is no current flowing through the relay because the currents flowing in the alternator leads and, by extension, the secondaries of the line current transformers, sum to zero. Additionally, in these circumstances, the neutral wire's current is at zero, and the relay receives no current from the secondary of the neutral current transformer. The total of the currents at the alternator's terminals is precisely equal to the current in the neutral connection if an earth-fault develops at F2 outside of the protected zone, therefore no current flows through the relay. These currents are no longer equal in the event of an earth-fault at F1 or inside the protected zone, and the differential current passes through the relay's operational coil. When the alternator is disconnected from the system, the relay then closes its contacts.

**Stator inter-turn protection**: Phase-to-ground and phase-to-phase faults are guarded against via the Merz-Price circulating-current scheme. It does not offer protection from turn-to-turn faults on the stator's same phase winding. This sort of problem does not induce a difference between the currents entering and leaving the winding at its two ends where current transformers are applied since the current flows in a local circuit between the affected turns. However, because inter-turn faults always become earth-faults, it is typically believed that protection should not be offered.

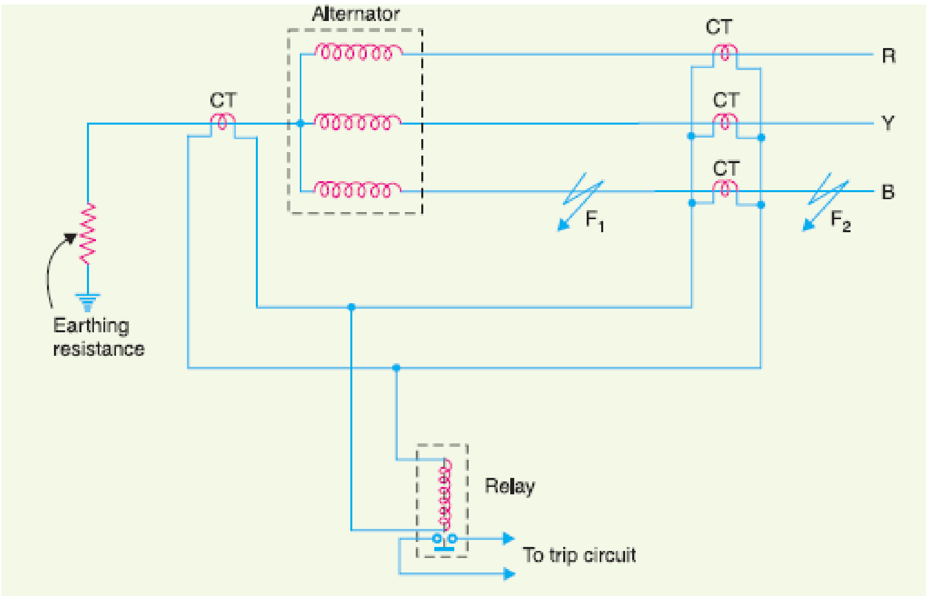


**Figure 6: Balanced Earth fault protection**

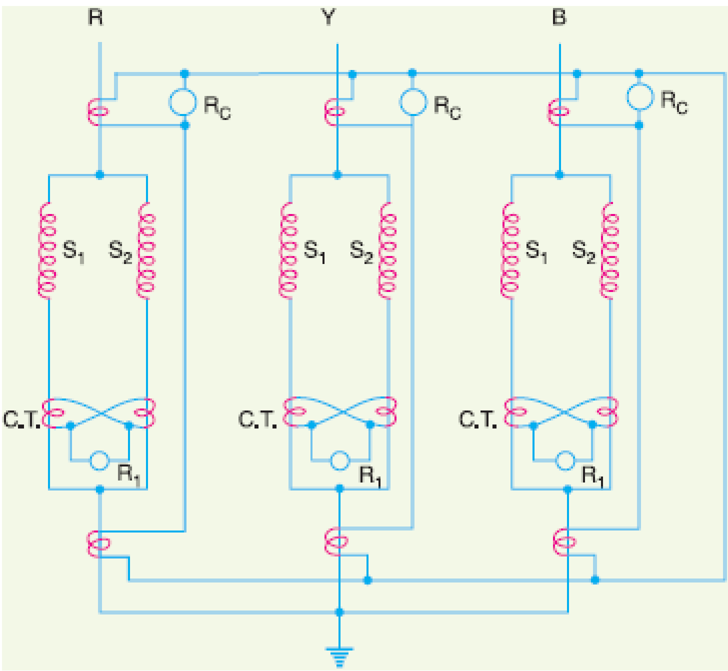


**Figure 7: Stator inter-turn protection**

There is no need for inter-turn fault protection in single turn generators, such as big steam turbine generators. For multi-turn generators, such as hydroelectric generators, inter-turn protection is included. Due to the extremely strong currents that these generators must handle, each phase winding is divided into two halves, resulting in double-winding armatures. This need can be used to one's advantage to safeguard inter-turn failures on the same winding. A 3-phase double wound generator's schematic circulating-current and inter-turn protection are shown in Fig. 7. Relays R1 guard against inter-turn faults, while relays RC protect against phase-to-ground and phase-to-phase faults.

The duplicate stator windings S1 and S2 of a single phase alone are shown in Fig. 8 together with a safeguard against inter-turn failures. The circulating-current idea is used to connect two current transformers. The currents in the secondaries of the two CTs will be equal under normal circumstances as will the currents in the stator windings S1 and S2. Since no current flows via the relay R1, the secondary current through the loop is the same at all places.

The currents in the stator windings S1 and S2 will no longer be equal if a short-circuit forms between neighbouring turns, let's say on S1. As a result, the secondaries of CTs will experience uneven currents, and the difference between these two currents will flow through relay R1. In order to remove the generator from the system, the relay then closes its contacts.

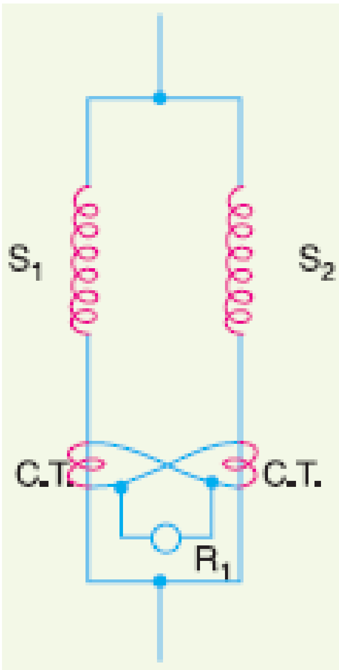


**Figure 8: Stator winding**

**CONCLUSION**

In order to keep electrical power generation systems stable and reliable, alternator protection is essential. The strategies for fault isolation, detection, and mitigation have all been covered in this study along with other aspects of alternator protection. The danger of alternator problems and failures can be reduced by putting in place efficient protection measures, providing an uninterrupted power supply and avoiding equipment damage. To provide thorough system protection, coordination with various protection mechanisms within the power system is also crucial.

The studies and business practices discussed in this paper show the continued efforts to create sophisticated and dependable alternator protection systems. To solve new issues and incorporate cutting-edge technologies into alternator protection systems, more study and development are still required. In order to improve the overall performance and resilience of electrical power generation systems, this study emphasizes the significance of giving alternator protection first priority.

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# CHAPTER 5

# ROLE OF TRANSFORMER IN EFFICIENT TRANSMISSION AND DISTRIBUTION

Mrs. Ramya
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id: ramyak@presidencyuniversity.in

**ABSTRACT:**

Natural language processing problems have been revolutionised by the Transformer model, which has achieved cutting-edge results across several disciplines. However, because of its popularity, malevolent actors who want to weaken the system have also become interested in it. The protection of Transformer models from potential assaults is the main topic of this chapter, which also makes various recommendations for improving their security. The objective is to create strong defence systems that can reduce dangers including adversarial attacks, model stealing, and data poisoning. We establish a system for protecting Transformer models and maintaining their integrity using a combination of architectural changes, adversarial training, input sanitization, and model watermarking. Experimental analyses show how our suggested techniques are successful for boosting Transformer model security while keeping them functional.

**KEYWORDS:**

Earth Fault Protection, Leakage Overload Protection, Power Transformer's Turn Ration, Transformer Protection, Transformer Models.

## INTRODUCTION

Transformers play a key role in the efficient transmission and distribution of electrical energy in electric power systems. They perform the crucial task of increasing or decreasing voltage levels to fulfil the particular needs of diverse electrical networks. Transformers must be protected against faults and irregularities due to their crucial function and expensive cost in order to assure their dependable operation and avoid catastrophic failures. In order to protect transformers, a wide range of techniques, tools, and systems must be used. These techniques must be able to identify faults, isolate the problematic machinery, and lessen the damage the fault causes to the transformer and the entire power system. Transformer protection systems are made to react to unexpected situations quickly and precisely, minimising damage to the transformer, averting power outages, and protecting crew safety [1]–[3].

Transformers are completely enclosed, static, and typically submerged in oil. Therefore, it is quite unlikely that they would develop flaws. However, if the transformer is not immediately unplugged from the system, even a minor problem could have disastrous results. This calls for effective automatic protection against potential failures for transformers. Instead of using circuit breakers, small distribution transformers are typically connected to the supply system using series fuses. As a result, no automatic protective relay machinery is needed. However, there is unquestionably a higher likelihood of problems with power transformers, therefore automatic protection is essential. Typical transformer faults. The only abnormal circumstances that can occur in power transformers, as opposed to generators, are: (i) open circuits; (ii) overheating; and (iii) winding short-circuits, such as earth faults, phase-to-phase faults, and inter-turn faults.

Unwanted heating may result from an open circuit in one of a three-phase transformer's phases. Due to the relative safety of open circuits, relay protection is not typically offered against them. When such a fault occurs, the transformer can be manually unplugged from the system. Transformer overheating is typically brought on by prolonged overloads or short circuits, while the breakdown of the cooling system does occur very infrequently. Thermal accessories are typically utilised to activate an alarm or manage fan banks; relay protection is not given against this scenario.

Transformer winding short-circuits, also known as internal defects, are caused by the winding insulation deteriorating through overheating or mechanical damage. A rapid disengagement from the system is required when a transformer experiences an internal fault because a protracted arc inside the transformer could result in an oil fire. Relay protection is thus unavoidably required for internal failures.

**Types of Transformer Faults**

Before discussing the necessity of transformer protection, it is crucial to understand the different types of faults that can develop inside a transformer. Overcurrent Faults: Excessive load currents, short circuits, or ground faults can result in overcurrent circumstances. These defects stress the transformer mechanically and thermally by exposing it to high currents that exceed its design capability. A transformer's insulation may deteriorate over time through exposure to overcurrent circumstances, which can also lead to overheating and eventually physical harm to the transformer.

Overvoltage Faults: Overvoltage circumstances can develop as a result of switching activities, lightning strikes, or system flaws. High voltages can result in insulation failures and damage to the transformer as a result of insulation breakdown. To maintain the safe operation of transformers and avoid failures due to insulation, overvoltage protection is essential. Transformer Internal Faults: Internal flaws in the transformer, such as failing winding insulation, core faults, or tap changer issues, can result in serious damage if not swiftly identified and fixed. These flaws may be the result of poor maintenance, ageing, or manufacture flaws. To limit the possibility of cascading failures and avoid the transformer from suffering severe damage, it is essential to identify and isolate internal faults.

**Protective Devices and Schemes**

Transformer protection systems use a variety of protective devices and strategies to identify faults quickly and respond appropriately. Several frequently employed safety measures and plans include:

Buchholz Relay: For the safety of oil-filled transformers, Buchholz relays are frequently used. By keeping an eye on the flow of gas and oil inside the transformer tank, they can spot internal issues and take action. Depending on the severity of the malfunction, the relay sends alarm or trip signals, enabling prompt isolation of the defective transformer.

Differential Protection: One of the most popular and efficient transformer protection strategies is differential protection. In order to identify internal faults, it compares the current flowing into and out of the transformer windings. Differential protection strategies provide rapid internal fault separation and identification, minimising the harm done.

Overcurrent Protection: To safeguard transformers from overcurrent failures, overcurrent relays and fuses are used. In order to protect the transformer from heat and mechanical damage, these devices are programmed to trip whenever the current reaches a specific threshold. To accomplish correct discrimination and selectivity, overcurrent protection devices are often coordinated with other protective devices. Voltage Protection: Transformers are protected against overvoltage circumstances brought on by lightning strikes or switching surges using voltage relays and surge arresters. By diverting too much voltage away from the transformer, these devices safeguard its insulation and stop insulation breakdown.

Restricted Earth Fault Protection: Systems for detecting ground faults inside transformer windings are known as restricted earth fault protection. This system offers dependable protection against winding insulation failures by keeping track of the differential current between the primary and secondary windings. Advanced Techniques for Transformer Protection: New and more advanced methods for transformer protection have emerged as a result of technological breakthroughs. Transformer protection systems are more dependable and effective thanks to these cutting-edge technologies. Some significant developments include: Transformer Thermal Monitoring: Temperature sensors inserted into the transformer's windings and fluid allow for real-time monitoring of the temperature of the transformer. This system offers proactive maintenance and prompt identification of abnormal operating circumstances, reducing thermal damage to the transformer by continuously monitoring the temperature rise. Dissolved Gas Analysis (DGA): To find potential problems, DGA examines the gases dissolved in the transformer oil. Certain gases are produced as faults grow inside the transformer, signalling deterioration in the insulation or internal arcing. Early fault identification made possible by DGA permits the implementation of preventative measures prior to significant harm. Intelligent Electronic Devices (IEDs): IEDs offer improved coordination and communication capabilities by combining numerous protection functions into a single device. Advanced fault detection techniques, remote monitoring, and quick information transmission are made possible by them. IEDs facilitate quicker fault identification, isolation, and restoration, which enhances overall transformer protection and system reliability.

Condition Monitoring Systems: Condition monitoring systems can be used to continuously monitor variables including winding currents, voltages, oil levels, and moisture content. These devices offer useful information about the transformer's condition, enabling proactive maintenance and lowering the possibility of unanticipated breakdowns. Condition monitoring systems enable proactive actions to be taken, reducing the chance of transformer failure by identifying early indicators of degradation or irregularities [4]–[6].

To ensure their dependable performance, avoid damage, and preserve the overall stability of electric power systems, transformers must be protected. Transformers can be protected against a variety of defects, including overcurrent, overvoltage, and internal faults, by combining protective devices, plans, and cutting-edge technology. The creation of more effective and dependable protection systems is facilitated by ongoing improvements in protection approaches, allowing for the uninterrupted and smooth flow of electrical energy while ensuring the durability and integrity of transformers.

## DISCUSSION

### Protection system for transformer

Merz-Price circulating-current system is without a doubt the best option for generator protection. Despite the fact that this is generally true for transformer protection, there are some situations in which circulating current systems are either not significantly superior to other systems or are simply not feasible due to the challenging conditions imposed by the wide range of voltages, currents, and earthing conditions that are inextricably linked with power transformers. In such cases, alternative preventative measures. It is common to employ systems that are just as efficient as the circulating-current system. The main systems and relays for protecting transformers are:

(i) Buchholz devices that offer protection against all types of incipient failures, or defects that take time to manifest, such as winding insulation failure, core heating, a drop in oil level as a result of leaking joints, etc.

(ii) Earth-fault relays that exclusively offer protection from earth-faults.

(iii) Overcurrent relays, which offer protection primarily from overloading and phase-to-phase problems.

(iv) A differential system (also known as a circulating-current system) that offers defence against phase and earth faults.

Typically, a combination of these systems is needed for total transformer protection. The choice of a certain system combination may be influenced by a number of variables, including (a) the size of the transformer, (b) the cooling method, (c) the placement of the transformer in the network, (d) the type of load delivered, and (e) the significance of the service for which the transformer is needed. The aforesaid systems of protection will be covered in detail in the sections that follow.

**Buchholz relay**

For protection against all fault types, Buchholz relays are gas-actuated relays fitted in oil-immersed transformers. It is used to disconnect the transformer from the supply in the event of serious internal defects and to sound an alarm in the case of incipient (slow-developing) problems in the transformer. Buchholz is the name of the device's creator. As depicted in Fig. 1, it is typically fitted in the conduit that connects the conservator to the main tank. Use of Buchholz relays is standard procedure for any such oil-immersed transformers with ratings in excess of 750 kVA.

Construction: A Buchholz relay's construction is depicted in detail in Fig. 2. It takes the shape of a dome-shaped vessel that is inserted into the conduit that connects the conservator and main tank. The gadget consists of two parts. An attached float and a mercury-type switch make up the upper component. A mercury switch installed on a hinged flap in the lower element is in the direct path of the oil flow from the transformer to the conservator. The bottom element is designed to trip the circuit breaker in the event of serious internal faults, whilst the upper element is designed to close an alert circuit during impending failures.

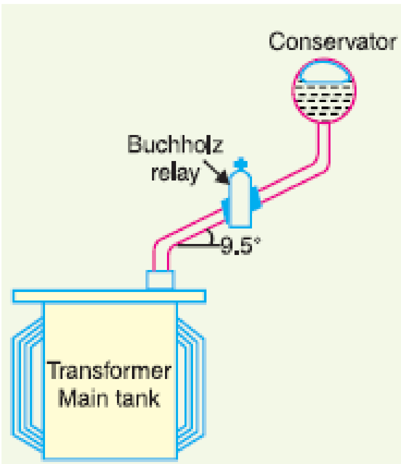


**Figure 1: Buchholz relay**

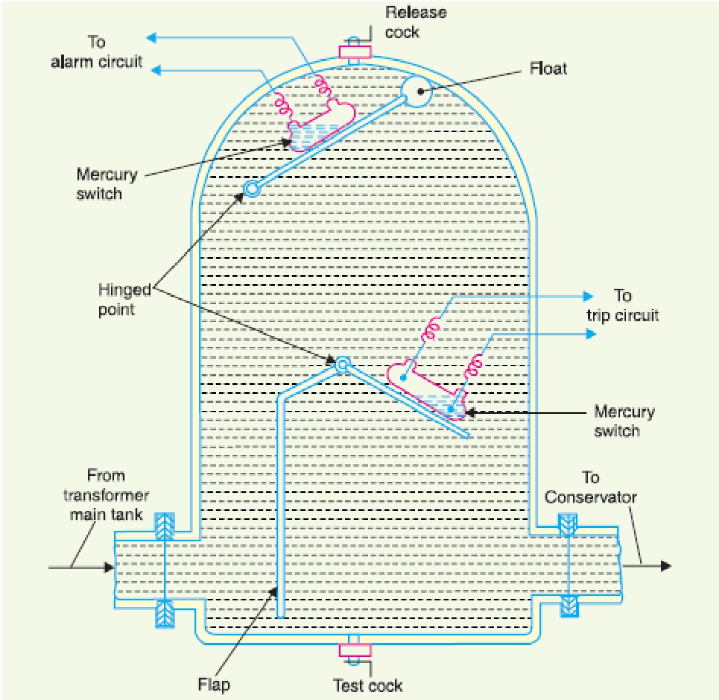


**Figure 2:Buchholz relay construction**

Operating: The Buchholz relay functions as follows:

(i) In the event of transformer faults in the early stages, the heat generated by the fault leads to the breakdown of some transformer oil in the main tank. More than 70% of the hydrogen gas in decomposition's byproducts is hydrogen. Being light, the hydrogen gas seeks to enter the conservator but becomes stuck in the top portion of the relay chamber. When a specific volume of gas builds up, it presses down on the float to the point where it tilts and closes the contacts on the mercury switch that is connected to it. The alarm circuit is now complete, and an alarm will now sound.

Advantage:

(i) The main tank produces a significant volume of gas if the transformer develops a serious problem. Through the Buchholz relay, the oil from the main tank rushes towards the conservator, tilting the flap to seal the connections on the mercury switch. The circuit trip that opens the circuit breaker controlling the transformer is now complete.

(ii) Benefits include the fact that it is the most basic type of transformer protection.

Disadvantage:

(i) It identifies potential problems considerably earlier than other forms of protection are able to.It can only be used with oil-immersed transformers that have conservator tanks.

(ii) The instrument can only identify defects in the transformer below the oil level. As a result, special protection is required when connecting cables.

**Earth fault or leakage protection**

An earth fault typically involves some degree of insulation breakdown in the windings leading to the earth. Leakage current as a result is far lower than short-circuit current. Before becoming a short-circuit and being eliminated from the system, the earth-fault may continue for a long period and do significant harm. Employing earth-fault relays to ensure the early disconnection of an earth-fault or leak is profitable in these instances. When an earth-fault or leak forms, an earth-fault relay, which is effectively an overcurrent relay with a low setting, activates. The core-balance leakage protection shown in Fig.3 is one technique for shielding a transformer against earth-faults.

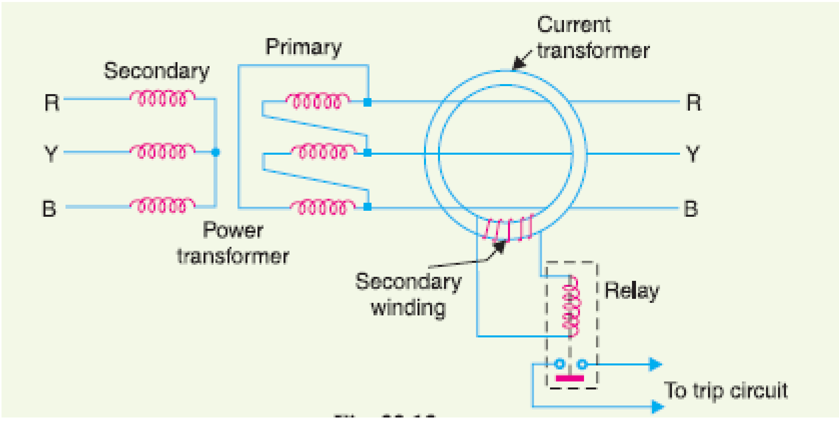


**Figure 3: Earth fault or leakage protection**

The core of a current transformer, which carries a single secondary winding, is passed through by the three leads of a power transformer's primary winding. This secondary is wired up to a relay's operational coil. No matter how much the load is out of balance, there is no consequent flux in the core of the current transformer under normal circumstances (i.e., no fault to earth), when the vector sum of the three phase currents is equal to zero. As a result, there is no current passing through the relay, and it is inactive. But when an earth fault occurs, the vector sum of the three phase currents is no longer zero. The resulting current induces e.m.f. in the secondary winding by creating flux in the C.T.'s core. The relay is activated, tripping the circuit breaker and removing the defective transformer from the system.

**Combined Leakage and Overload Protection**

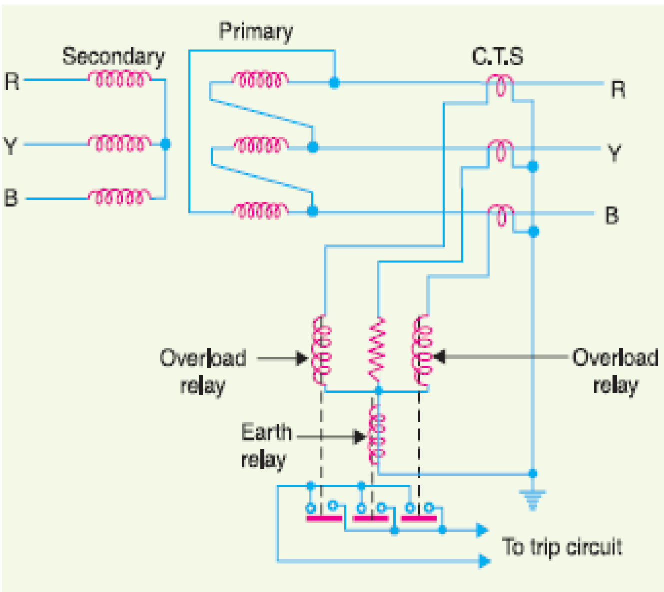


**Figure 4: Combined Leakage and Overload Protection**

The limitation of the core-balance protection mentioned above is that it cannot offer overload protection. The core-balance relay won't work if there is a failure or leakage between phases. Combining leakage and overload protection for transformers is standard procedure. The earth relay only functions when there is an earth or leakage fault and has a low current setting. The overload relays are set up to function against faults between the phases and have high current settings. The schematic layout of the combined leakage and overload protection is shown in Fig. 4. Two overload relays and one leakage or earth relay are linked as indicated in this protective system. Phase-to-phase fault protection can be provided by the two overload relays. Overload relay trip contacts and earth fault relay trip contacts are connected in parallel. The circuit breaker will trip as a result of the overload relay or earth relay being activated.

**Applying circulating current system to transformers**

Power transformers are frequently protected against earth and phase defects using the Merz-Price circulating-current method. Although there are certain complicating factors that are not present in the generator application, the system as it applies to transformers is fundamentally the same as that for generators. Below is a brief summary of the problematic elements and their corrective actions:

(i) Currents in the primary and secondary of a power transformer should be compared. Due to the fact that these two currents are often different, using identical transformers with the same turn ratio will provide differential current and enable the relay to work even when there is no load. Different turn ratios of CTs are used to make up for the variation in the number of currents in the primary and secondary of the power transformer. If T is the power transformer's turn-ratio, then the turn-ratio of the CTs on the low-voltage side is T times that of the CTs on the high-voltage side. If this requirement is met, under typical load conditions, the secondaries of the two CTs will carry identical currents. As a result, the relay won't receive any differential current and stays inoperative [7]–[9].

(ii) The primary and secondary currents of a 3-phase power transformer often have a phase difference. A differential current may pass through the relay under normal circumstances and cause relay operation, even when CTs with the right turn ratio are utilised.

By properly connecting CTs, the phase discrepancy can be corrected. The power transformer's CTs on one side are wired together so that the resulting currents fed into the pilot wires are out of phase with the individual phase currents in the same direction as the phase shift between the power-transformer's primary and secondary currents, and by an angle equal to that phase shift. The sort of connections for CTs that should be used to account for the phase difference between the primary and secondary currents of power transformers are shown in the table below.

(iii) The fact that most transformers have the ability to change the tap makes this issue much more challenging. Even in normal operation, tap altering will result in differential current flowing through the relay. By modifying the turn-ratio of CTs on the side of the power transformer equipped with taps, the aforementioned issue is resolved.

(iv) The magnetising in-rush current also adds complexity to transformer protection. The magnetising current is quite tiny under typical load circumstances. However, the magnetising or in-rush current can be quite high for a brief period of time when a transformer is activated after it has been taken out of service. Magnetising current appears to differential relays as a fault current and may result in relay operation because it indicates a current entering the transformer without an equal amount leaving. Differential relays are configured to work at a somewhat high level of unbalance in order to overcome the aforementioned challenge. The relays' sensitivity is decreased by using this technique. In actuality, the presence of a strong second-harmonic component in the early in-rush currents is exploited. As a result, it is possible to create a scheme that uses second-harmonic bias features that, because they are only tuned to the second harmonic, practise restraint during energising to prevent malfunction. The aforementioned safety measures are required when using the circulating current principle to protect transformers in order to prevent accidental relay activation.

**Circulating current scheme for transformer protection**

The Merz-Price circulating-current protection strategy for a three-phase delta/delta power transformer against phase to ground and phase-to-phase faults is shown in Fig. 5. Keep in mind that the CTs on the transformer's two sides are connected in a star pattern. This corrects the phase discrepancy between the main and secondary of the power transformer. One relay is utilised for each pair of CTs, which are connected to each other on the two sides by pilot wires [10].

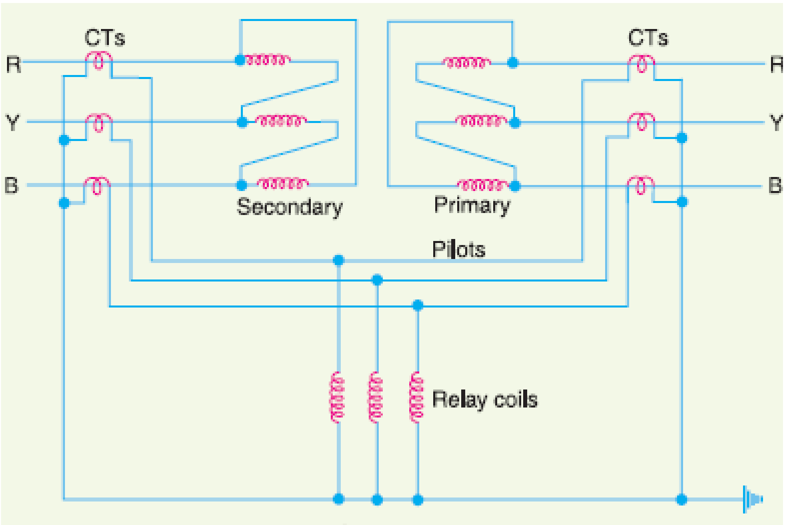


**Figure 5: Circulating current scheme for transformer protection.**

The secondaries of CTs operate under identical current conditions under normal working settings. As a result, no current flows through the relays because the currents entering and leaving the pilot wires at both ends are identical. The currents in the secondaries of CTs will no longer be equal in the event of a ground or phase-to-phase fault, and the differential current flowing through the relay circuit will trip the breaker on both sides of the transformer. The area between the CTs on the power transformer's high-voltage side and low-voltage side constitutes the protected zone.It's important to remember that this system also protects against short circuits occurring between turns on the same phase winding. The power transformer's turn-ratio changes when a short-circuit happens between the turns, which throws off the balance between the current transformer pairs. A substantial differential current may flow through the relay to activate it if the power transformer's turn-ratio is adjusted. Buchholz relays, however, are more effective at preventing such short-circuits.

## CONCLUSION

The vital problem of safeguarding Transformer models from potential attacks has been covered in this study. To increase the security of Transformer models while maintaining their performance, we have provided a thorough framework that integrates various defence strategies. Our experimental assessments have shown that the suggested strategies are effective in reducing adversarial attacks, preventing model theft, and reducing data poisoning. We have created a strong defence system that can defend Transformer models against multiple security attacks by including architectural changes, adversarial training, input sanitization, and model watermarking. In order to guarantee the dependability and credibility of natural language processing systems, Transformer models must be protected. Transformer-based models will likely continue to be important in many different applications, hence it is essential to invest in proactive security measures to protect these models from any weaknesses. Future studies may examine different methods and tactics to boost the security of Transformer models and fend against new dangers. By doing this, we may encourage the creation and use of reliable Transformer models that are secure and resilient for a variety of real-world applications.

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# CHAPTER 6

# PROTECTION OF BUSBARS AND LINES: AN ANALYSIS

Mrs. Ragasudha Chundampunathil
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:ragasudha@presidencyuniversity.in

**ABSTRACT:**

Busbars and lines, which transport and distribute electricity to different loads, are essential parts of electrical power networks. To maintain the dependability and stability of the power system, busbars and lines must be protected. This chapter presents an overview of the protection strategies used for busbars and lines, as well as several methods for fault isolation and detection. To reduce the effects of failures and provide a constant supply of power, coordination and selectivity in protection systems are crucial. The improvements in protection technologies such as numerical relays and communication-based protection schemes—that improve the precision and speed of fault detection and make effective monitoring and control possible are also covered in this paper. The importance of adequate protective measures is emphasized throughout this work in order to improve the functionality and durability of busbars and lines in electrical power systems.

**KEYWORDS:**

Definite Time Relays, Inverse Time Relays, Protection Of Busbar, Protection Of Lines, Pilot Wire Protection, Voltage Balance System.

## INTRODUCTION

Busbars and lines are crucial components of the electric power system, and protection engineers must pay them urgent attention to take precautions against any faults on them. With a few minor adjustments, the techniques used to protect transformers and generators can also be applied to busbars and lines. The adjustments are required to address the protection issues brought on by longer lines and many more circuits connected to a busbar. Although differential protection is a viable option, longer lines cannot afford it due to the longer pilot wires needed. Fortunately, there are less expensive techniques that can safeguard the busbars and wires fairly effectively. We will concentrate on the various busbar and line protection strategies in this chapter [1]–[3].

### Busbar Protection

Busbars are a crucial link between the incoming and outgoing circuits in generating stations and sub-stations. If a busbar develops a defect, there will be significant damage and a supply disruption unless a quick-acting automatic protection is offered to isolate the damaged busbar. For the purpose of protection, the busbar zone also comprises the accompanying connections, isolating switches, and circuit breakers in addition to the busbars themselves. All of the circuit equipment linked to that portion of the busbar must be stripped out in order to provide complete isolation in the event of a problem there. Bus faults are extremely uncommon as a result of the very high grade of construction used for busbars. The risk of harm and service interruption from even a rare bus breakdown, however, is so high that this type of protection is now given more consideration. Relaying techniques have been improved, lowering the likelihood of malfunction. The two busbar protection schemes that are most frequently utilised are (i) differential protection and (ii) fault bus protection. The differential scheme, in which currents entering and exiting the bus are totaled, is the fundamental technique for busbar protection. When the load is normal, the total of these currents equals zero.

When a fault develops, the fault current throws off the equilibrium and generates a differential current that can be used to drive a relay. The single line schematic of the current differential scheme for a station busbar is shown in Fig. 1. A generator feeds the busbar, which provides power to two lines. The generator lead, lines 1 and 2, and the secondaries of the current transformers are all linked in parallel. Across this parallel connection, the protective relay is attached. Regardless of the capabilities of the individual circuits, all CTs in the scheme must have the same ratio. The sum of the currents entering and leaving the bus are equal under normal load conditions or when there is an external fault, therefore no current flows through the relay. The currents entering and leaving the bus will no longer be equal if a fault develops within the protected zone. The relay will open the generator, circuit breaker, and each of the line circuit breakers as a result of the differential in these currents flowing through it.

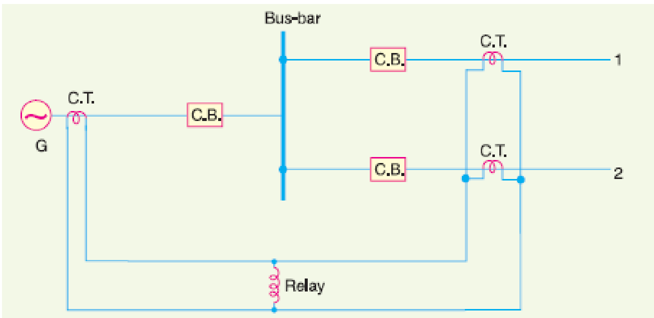


**Figure 1: Busbar protection**

**(ii) Protection for bus faults:** It is feasible to construct a station so that the majority of the faults that form are earth faults. This can be done by including an earthed metal barrier, or fault bus, all the way around each conductor in the bus structure. Every defect that can arise in this configuration necessitates a link between a conductor and an earthed metal component. It is feasible to find the faults and pinpoint their locations by controlling the flow of earth-fault current. Fault bus protection is the name for this form of defence.

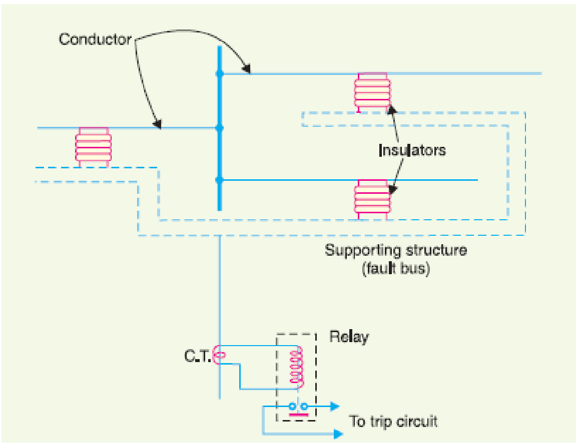


**Figure 2:Protection for bus faults**

The schematic layout of the fault bus protection is shown in Fig. 2. Through a current transformer, the metal supporting structure or fault bus is grounded. This CT's secondary is connected to a relay. The relay is inactive when working normally since there is no current flowing from the fault bus to ground. When there is a problem with the connection between a conductor and an earthed support structure, current will flow via the fault bus to ground, activating the relay. All breakers connecting equipment to the bus will trip during relay operation.

## DISCUSSION

### Protection of lines

Due to their larger length and exposure to environmental factors, the lines have a significantly higher potential of developing faults. This has led to the need for numerous precautionary measures that are useless in the comparatively straightforward cases of transformers and alternators. The following are the specifications for line protection:

(i) In the case of a short circuit, the circuit breaker closest to the fault should open, with all other circuit breakers remaining in the closed state.

(ii) The nearby circuit breakers should offer backup protection in the event that the nearest breaker to the problem is unable to open.

(iii) To prevent superfluous circuit trips and maintain system stability, the relay working time should be kept to a minimum.

The difficulty of protecting lines is very different from that of protecting station equipment like generators, transformers, and busbars. Although differential protection is the best strategy for lines, it is significantly more expensive to employ. A pricey pilot-wire circuit is needed to compare the two currents because a line's two ends may be many kilometres apart. Although this cost can be acceptable, less expensive alternatives are frequently employed. The standard techniques for line protection are:

(i)Time-graded overcurrent protection.

(ii)Differential protection

(iii) Distant defence

### Time graded overcurrent protection

This overcurrent protection plan incorporates time discrimination. In other words, the relays' time settings are graded in such a way that, in the case of a malfunction, the system is isolated to the absolute minimum. We'll talk about a few significant situations.

**1. Radial feeder:** A radial system's defining feature is that electricity can only travel in one direction, from the generator or supply end to the load. Its drawback is that, in the event of a problem, the recipient cannot maintain supply continuity. A radial feeder can be protected in stages throughout time by employing (i) definite time relays and (ii) inverse time relays.

(i) Using definite time relays: Figure 3 depicts definite time relays protecting a radial feeder from overcurrent. Each relay has a predetermined operating time that is unaffected by the operating current. As a result, relay D operates for 0–5 seconds, whereas other relays experience a time delay that gradually grows by 0–5 seconds. Because all other relays have longer operating times, if a fault arises in section DE, it will be fixed in 0–5 seconds by the relay and circuit breaker at D. Only the system's sector DE will be isolated in this way. If the relay at D does not trip, the relay at C will operate 0–5 seconds later, or 1 second after the fault occurred. The drawback of this system is that it has a high (2 second) tripping time for failures near the supply end if there are several feeders connected in series. The most common requirement is to keep the maximum tripping time to 2 seconds. Inverse-time relays can help to some extent to address this drawback [4]–[6].

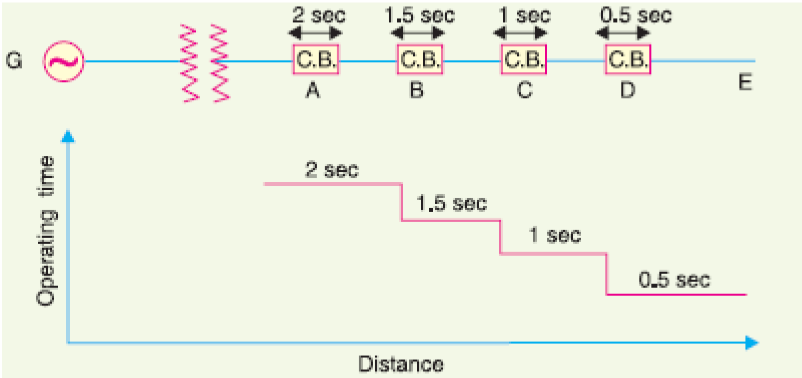


**Figure 3: Radial feeder protection using definite time relays.**

**(ii) Using inverse time relays:** Inverse time relays, whose working time is inversely proportional to operating current, are used in Fig. 4 to safeguard a radial feeder against overcurrent. With this configuration, the circuit breakers relay operating time decreases with distance from the generating station. It is assumed that the three relays at locations A, B, and C exhibit inverse-time characteristics. Due to a failure in section BC, the breaker at B will trip before the breaker at A due to relay timings.

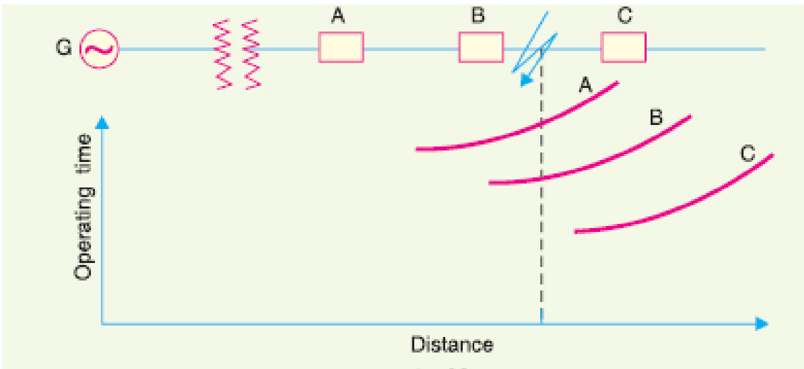


**Figure 4: Radial feeder protection using inverse time relays**

**2. Parallel feeders:** Two parallel feeders may be built in areas where supply continuity is very important. If there is a problem with one feeder, it can be unplugged from the system so that the other feeder can continue to produce power. It is not possible to protect parallel feeders alone with non-directional overcurrent relays. For selective trips, it is required to grade the time setting of relays and to use directional relays as well.

Two feeders are linked in parallel between the producing station and the sub-station, as shown in Fig. 5. Each feeder must have a non-directional overcurrent relay at the generator end for the system to be protected (i). These relays ought to have an inverse-time property. (ii) At the sub-station end of each feeder is a reverse power or directional relay. These relays ought to be instantaneous types that only turn on when power is applied in the opposite direction, that is, in the direction indicated by the arrows at P and Q. Let's say that feeder 1 experiences the earth fault seen in Fig. 23.6. To guarantee supply continuity, it is preferred that just the circuit breakers at A and P open to remove the fault. Feeder 2 should stay intact. The above configuration actually makes this happen. There are two ways to feed the fault in the diagram: (a) directly from feeder 1 through the relay A; and (b) from feeder 2 through B, Q, the sub-station, and P. As a result, power flow will be regular in relay Q but reversed in relay P. As a result, the circuit breaker at P opens. Relay A will also be in operation while Relay B is not. The reason is that current flowing in relay A is greater than current flowing in relay B due to the inverse-time properties of both relays. Only the problematic feeder is isolated in this manner.

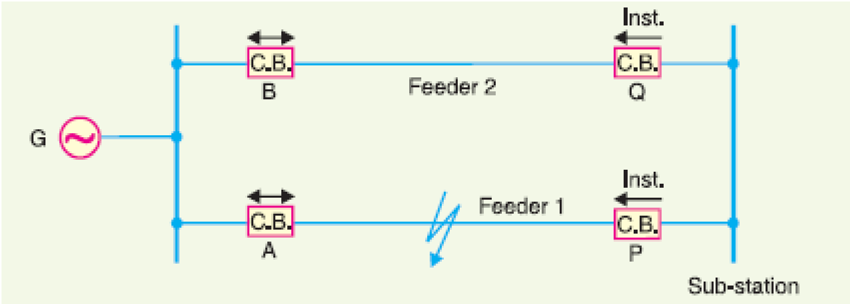


**Figure 5: Parallel feeder protection**

**3. Ring main system:** The ring main system connects several power stations or sub-stations via detours to create a closed ring. Any piece of the ring that sustains damage may be disconnected for repairs, and power will still be provided from both ends of the ring, maintaining supply continuity. A typical ring main system is depicted in Fig. 6 as a single line diagram, with one generator G powering four sub-stations (S1, S2, S3, and S4). Power can move both ways in this configuration under faulty circumstances. As a result, grading in both directions around the ring is required, as well as the usage of directional relays. To ensure that only the defective portion of the ring is isolated when there is a failure, The following relay configurations and times should be used.

(i) Non-directional overcurrent relays should be installed on the two lines that leave the producing station (in this case, the relays at A and J).

(ii) At each sub-station, directional or reverse power relays ought to be installed on both the incoming and the outgoing lines (in this case, relays at B, C, D, E, F, G, and H).

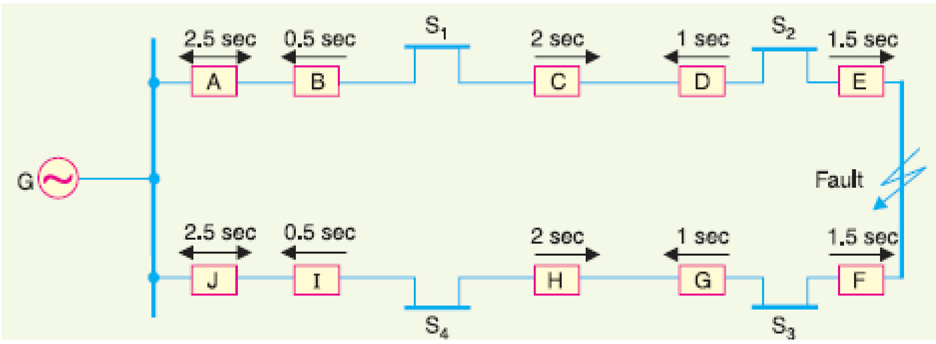


**Figure 6: Ring main system protection**

Let's say a short circuit happens at the location in Fig. 6. Only the circuit breakers at E and F should open to clear the fault in order to ensure selectivity, while the other parts of the ring should remain intact to maintain supply continuity. The above configuration actually makes this happen.

Two paths will be used to supply power to the fault: (i) from G near S1 and S2, and (ii) from G near S4 and S3. Relays at points A, B, C, and D, as well as J, I, H, and G, won't trip, it is obvious. Due to their lower time-setting, only the relays at E and F will activate before any other relay does.

**Differential pilot wire protection**

The differential pilot-wire protection is based on the idea that, ordinarily, the current flowing into one end of a line is equal to the current flowing out of the other. The difference between the incoming and outgoing currents is set up to flow through a relay, which activates the circuit breaker to isolate the faulty line, as soon as a fault develops between the two ends. For the lines, many differential protection strategies are in use. Only the next two schemes, nevertheless, will be covered:

1. Merz-Price voltage balance system.

2. The translay system

1. The voltage balance system by Merz-Price: The single line diagram 7 of the Merz-Price voltage balance system for a 3-phase line's protection. At both ends of the line, identical current transformers are positioned in each phase. Each line's pair of CTs is coupled in series with a relay so that, under normal operating conditions, their secondary voltages are equal and in opposition, or they counterbalance one another.

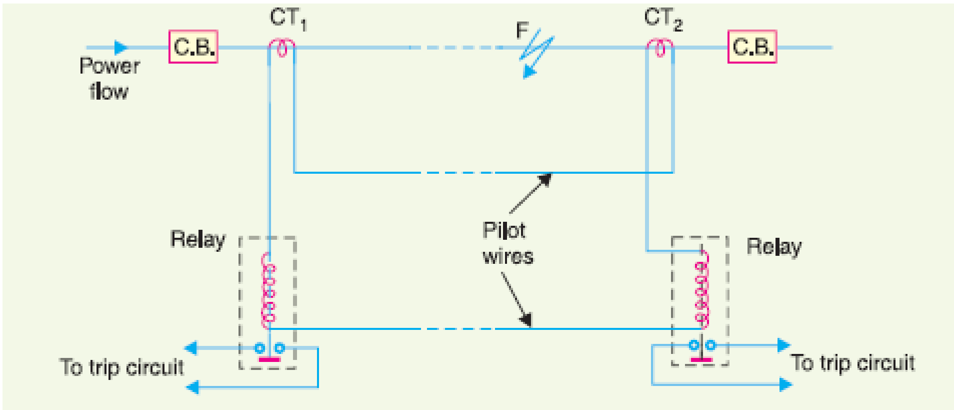


**Figure 7: SLD of Merz-price Voltage balance system**

When everything is in order, the current entering the line at one end is equal to the current exiting it at the other. As a result, at the line's two ends, the secondaries of the CTs are induced with equal and opposing voltages. As a result, the relays experience no current flow. Assume a fault develops at position F along the line in Figure 7. As a result, CT1 will experience a larger current flow than CT2. As a result, their secondary voltages diverge, causing circulating current to pass via the relays' pilot wires. The line's circuit breakers will trip out at both ends, isolating the defective line. The connections for the Merz-Price voltage balance method are shown in Fig. 8 for all three phases of the line.

Benefits:

(i) Both parallel feeders and ring mains can use this technology.

(ii) This technology offers immediate ground fault prevention. This lessens the chance that these problems will affect other phases.

(iii) This method offers instantaneous relaying, which lessens the amount of harm that arcing faults do to overhead wires.

Drawbacks:

(i) It's crucial to match current transformers precisely.

(ii) The system won't function if the pilot-wire circuit is broken.

(iii) Because longer pilot wires are needed, this technique is quite expensive.

(iv) In the case of long lines, charging current resulting from pilot-wire capacitance effects may be enough to activate a relay even under standard circumstances.

(v) Due to construction issues with the current transformer matching, this system cannot be used for line voltages above 33 kV.

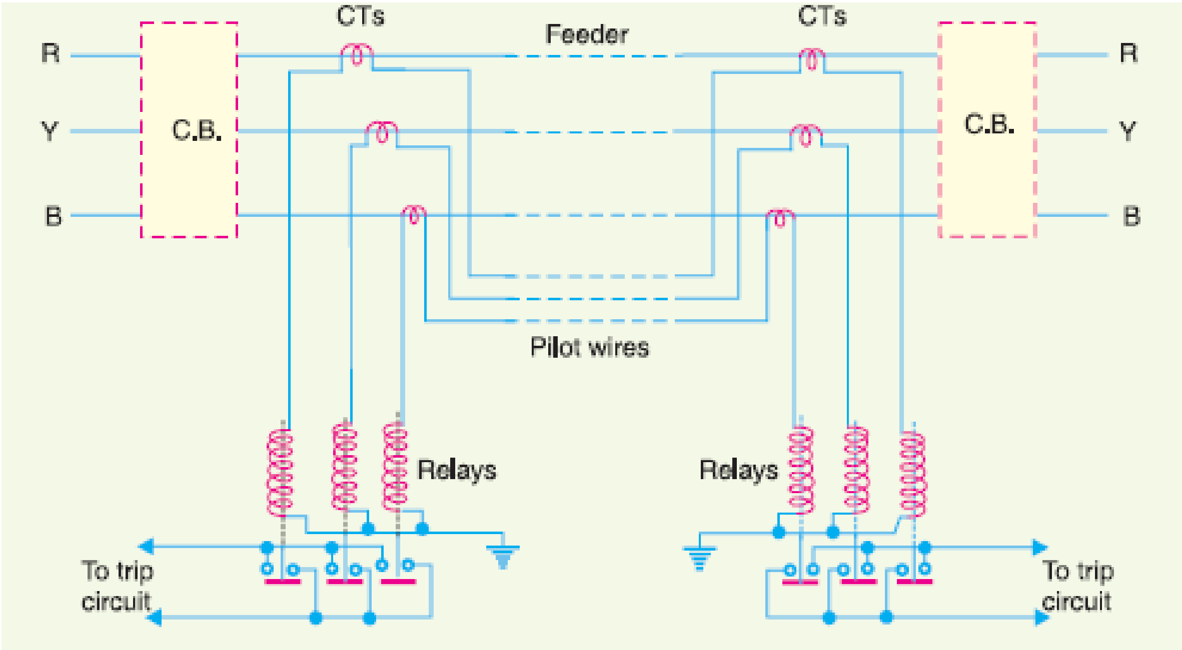


**Figure 8: pilot wire protection**

**2. Translay scheme:** This system is similar to a voltage balance system, with the exception that in this case the opposition or balance is between voltages that are induced in secondary windings wound on relay magnets rather than secondary voltages of line current transformers.

This removes one of the original voltage balance system's most important constraints, which was its restriction to the system functioning at voltages not exceeding 33 kV, and allows the use of current transformers of standard design.

We've already talked about using the Translay technique on a single-phase line. By adding a relay to either end of each phase of the 3-phase line, this can be expanded to a 3-phase system. However, using the summation transformer principle, it is possible to further simplify the system by integrating currents from all phases in a single relay at either end (See Fig. 9). Using a summation transformer, a polyphase line's currents can be replicated as a single-phase quantity.

The tapped primary of the summation transformer is where the three lines of CTs are linked. With a single-phase output as a result, each line CT energizes a different number of turns (from line to neutral).

The usage of a summation transformer has two benefits: (i) phase faults can be repaired using primary windings 1 and 2, while earth faults can be repaired using winding 3. (ii) There are only two necessary pilot wires [7]–[10].

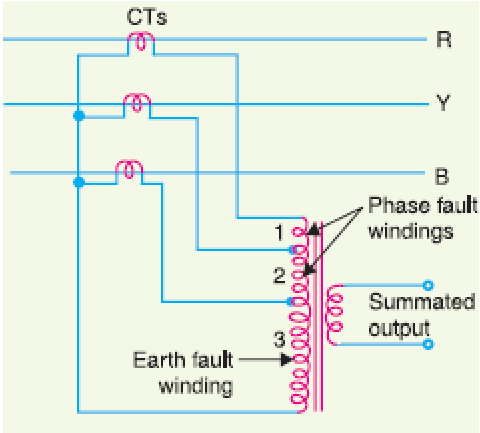


**Figure 9: Translay scheme**

Operation: The secondary currents in both sets of CTs are equal when the feeder is operating properly since the currents at its two ends are equal. As a result, the currents flowing in the primary and secondary windings of the relay, 11, respectively, will be equal, resulting in equal voltages in the secondary windings, 12, and 12, respectively. There is no current flowing in these windings or in the functioning windings 13 and 13a because they are connected in opposition. The line current at one end of the protected line must carry a higher current than the line current at the other end in the case of a fault. As a result, the current will flow through the working coils 13, 13a, and the pilot circuit, and there will be a difference in the voltages induced in the secondary windings 12 and 12 a. In these circumstances, the upper and bottom elements of each relay are both activated, and each relay disc is subjected to a forward torque. The circuit breakers at both ends of the line will be opened by the relays' action.

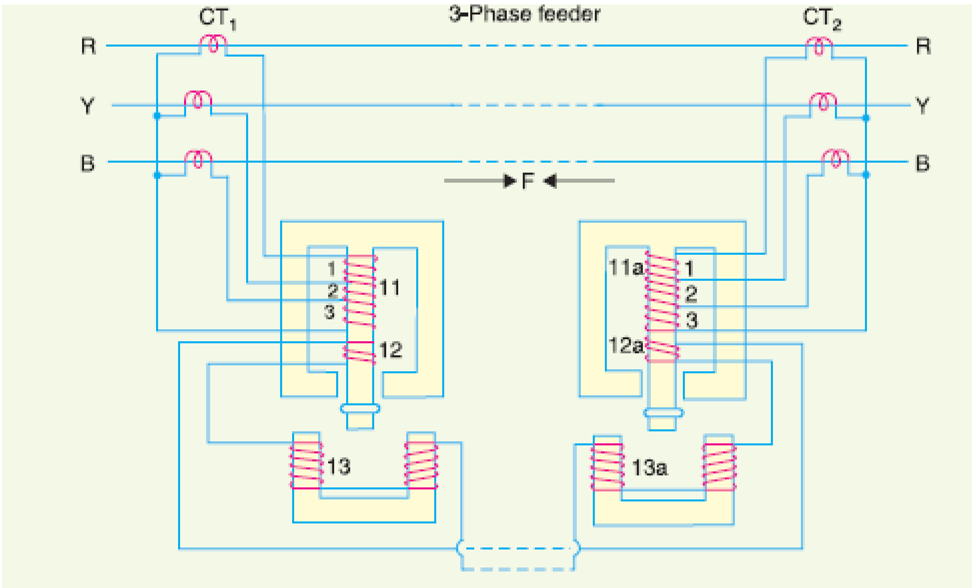


**Figure 10: Operation of Translay scheme**

(i) Assume a fault F, shown in fig. 10, develops between phases R and Y and is fed from both sides. Only section 1 of primary windings 11 and 11a will be powered by this, while secondary windings 12 and 12a will experience voltage induction. Therefore, current will flow through the operating coils 13, 13a, and the pilot circuit because these voltages are now additive*. The circuit breakers at both ends will be opened and the relay connections will close as a result. Section 2 of primary windings 11 and 11a is powered by a fault between phases Y and B, whereas Sections 1 and 2 are powered by a fault between phases R and B.

(ii) Now envision phase R experiencing an earth fault. Sections 1, 2, and 3 of the primary windings 11 and 11a will be powered by this. The voltages induced in the secondary windings 12 and 12a are additive once more if the fault is fed from both ends, and they cause a current to flow through the working coils 13, 13a. The circuit breakers at both ends of the line are so opened by the relays. Sections 2 and 3 of primary windings 11 and 11a will be electrified in the event of an earth fault on phase Y, activating the relays. Relay primary windings 11 and 11a will only be powered up in section 3 in the event of an earth fault on phase B.

Advantages:

(i) The system is cost-effective since a 3-phase line can be protected with just two pilot wires.

(ii) Regularly designed current transformers may be employed.

(iii) Pilot wire capacitance currents have no impact on how relays function.

**Distance protection**

For the safety of very long high voltage transmission lines, neither the time-graded system nor the pilot-wire system are appropriate. When there are more than four or five sections, the former results in an excessively long time delay in fault clearance at the producing station end, while the pilot-wire system becomes too expensive due to the longer length of pilot wires required. Due to this, distance protection has been developed, in which the relay's response is based on the impedance (or distance) between the relay's installation site and the source of the problem. Without using pilot wires, this technique protects against discrimination.

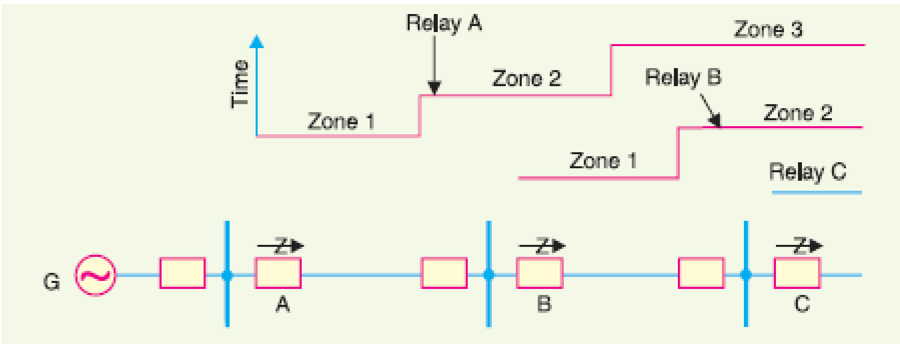


**Figure 11: Distance protection**

The basics of how distance relays work have already been covered. We'll now talk about how it can be used to safeguard transmission lines. a straightforward setup with lines connected in series such that power can only flow left to right. Relays at locations A, B, and C are programmed to operate for corresponding impedances of Z1, Z2, and Z3, respectively. If a fault develops between sub-stations B and C, power station and sub-station A and B will experience fault impedances of Z1 + Z and Z, respectively. It is obvious that only relay at B will function for the portion depicted. Similarly, only the relay at A will turn on if a fault develops in section AB. In this way, it is possible to get immediate protection under any operational circumstances.

Due to errors in the relay components and instrument transformers, it is actually not possible to obtain instantaneous protection over the entire length of the line. In order to distinguish between a fault at 99% of the distance AB and one at 101% of the distance AB, the relay at A would not be particularly accurate. The 'three-zone' distance protection method, as depicted in Fig. 11, helps to solve this challenge. Three distance elements are employed at each terminal in this protection technique. The zone 1 element is designed to trip instantly for defects in the first 90% of the line, which it covers. The zone 2 element trips for faults in the remaining 10% of the line and for faults in the subsequent line section; however, if the fault is in the subsequent line section, a time delay is added to prevent the line from being tripped Section. In the event that the next section's breaker is unable to resolve a problem, the zone 3 element offers backup protection.

## CONCLUSION

In order to ensure the dependability and stability of electrical power systems, busbars and lines must be protected. An overview of the numerous protection strategies used for busbars and lines has been provided in this work, with a focus on the value of fault detection, isolation approaches, coordination, and selectivity. Numerical relays and communication-based protection schemes are two examples of improvements in protection technologies that have considerably increased the accuracy and speed of fault detection and made it possible to monitor and regulate busbars and lines effectively. Effective protection strategies provide a constant supply of electricity, reduce the effects of failures, and improve the overall efficiency and resilience of busbars and lines. Further research and development in protection technologies are required to handle new difficulties and improve the protection capabilities as power systems continue to develop and become more complicated. Power system operators can reduce risks, boost system dependability, and guarantee the effective operation of busbars and lines in electrical power systems by putting in place reliable protective measures and embracing cutting-edge technologies.

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# CHAPTER 7

# APPROACHES AND STRATEGIES FOR OVERVOLTAGE PROTECTION

Mr. Sreekanth Kondreddy
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:ksreekanthreddy@presidencyuniversity.in

**ABSTRACT:**

Overvoltage is a serious problem that can seriously harm electronic devices and systems. This chapter investigates numerous approaches and strategies for overvoltage protection. It offers an overview of the various protection systems and talks about the significance of overvoltage protection. The chapter also identifies important factors to take into account when deciding on the best protection method for various applications. For engineers, designers, and researchers working in the subject of electrical system protection, the study's findings offer useful insights. A sizable portion of these overvoltages are severe enough to destroy the insulation of the power system's equipment. As a result, power system experts constantly devise strategies to reduce the severity of produced overvoltages and to manage their impact on the operational equipment. We will focus on the numerous power system overvoltage reasons in this chapter, paying particular attention to the protective equipment that is employed to address these issues.

**KEYWORDS:**

Cause of Over Voltage, Lightning, Mechanism of Lightning, Switching Surge, Voltage Surge.

## INTRODUCTION

The components of a power system, such as generators, transformers, gearbox lines, insulators, etc., are frequently exposed to overvoltages, or voltages higher than the typical value. These power system overvoltages can occur for a variety of reasons, including lightning, the tripping of a circuit breaker, the grounding of a conductor, etc. The majority of overvoltages have small magnitudes, yet they could nevertheless be significant due to their impact on the effectiveness of circuit interrupting machinery and protective devices. A voltage surge or transient voltage is a sudden increase in voltage that lasts just a very brief time on the power system.

Although transients and surges are momentary in nature and last only a few hundred nanoseconds, they generate overvoltages in the power system. Although they can be induced by switching or other factors, lightning strikes to transmission lines are by far the most significant source of transients. Similar to how a flow of water rushes along a small valley when the retaining wall of a reservoir at its head suddenly breaks way, when lightning strikes a line, the surge rushes along the line.

In the majority of situations, such surges can destroy surrounding transformers, generators, or other connected equipment if they are not adequately protected, as well as the line insulators (near the spot where lightning has struck). A typical lightning surge's waveform is depicted in Fig. 1. The time is measured along the x-axis and the voltage buildup along the y-axis. It is evident that lightning creates waves with a steep front. At any point in the network, voltage builds up more quickly the steeper the wave front. The majority of the time, this build-up is relatively quick, taking between 1 and 5 seconds. Voltage surges are typically described in terms of the time it takes for them to rise (t1) and for them to reach half their peak value (t2). A 1/50-s surge, for instance, achieves its peak value in 1 s and declines to 50% of that value in 50 s [1]–[3].

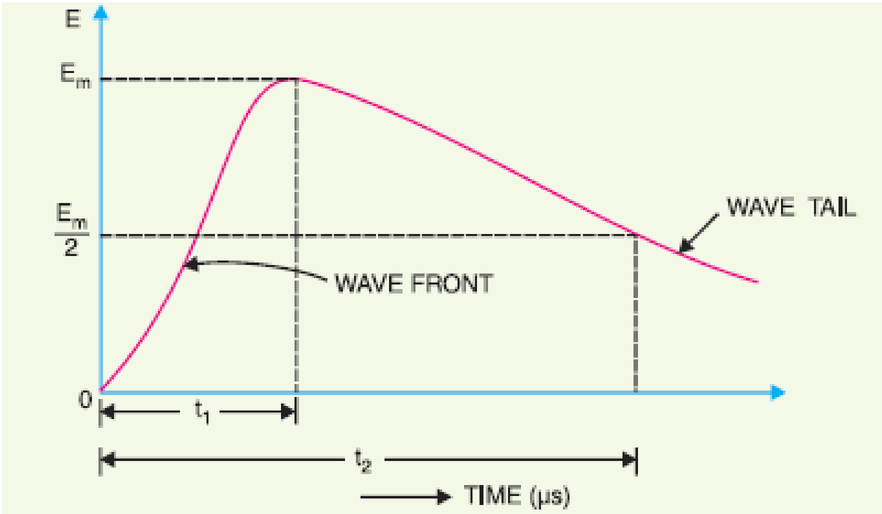


**Figure 1: voltage surge graph**

**Cause of overvoltage**

A power system's overvoltages can be roughly classified into two categories:

1. Internal causes, which include switching surges, insulation failure, arcing ground, and failure of other components, Resonance.

2. Outside factors, such as lightning

Large-scale surges are not caused by internal factors. Experience has shown that surges resulting from internal causes hardly ever double the system voltage. Surges caused by internal factors are often addressed by giving the equipment in the power system the appropriate insulation.

Lightning-related surges, on the other hand, can significantly boost system voltage to levels many times higher than average.

The equipment in the power system may sustain significant damage from lightning surges if it is not shielded from them. In actuality, lightning surges are primarily handled by the protection mechanisms against overvoltages provided in a power system.

**Internal cause of Overvoltage**

The oscillations caused by the abrupt changes in the circuit conditions are the main internal sources of overvoltages on the power system. This circuit shift could be caused by a fault event, such as the grounding of a line conductor, or it could be a regular switching procedure like opening a circuit breaker. The typical system insulation is effectively built to tolerate such surges in practice. We'll talk briefly about what causes internal overvoltages.

**1. Switching Surges:** Switching surges are overvoltages that are caused by switching processes on the electrical grid. The following cases will be used as examples:

(i) Case of an open line: Travelling waves are created during switching operations on an unloaded line, causing overvoltages on the line. Consider, as an example, the connection of an unloaded line to a voltage source.

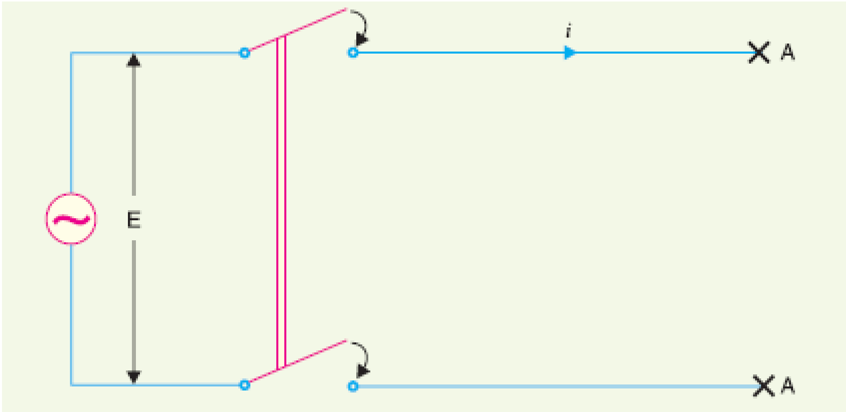


**Figure 2: Switching surges**

A voltage wave is created and propagates along the line after the unloaded line is connected to the voltage source. It is unaltered when it returns to the supply end after passing the terminal point A. This results in voltage doubling, when the voltage on the line doubles from its initial value.

The instantaneous voltage that the line must tolerate is $2\sqrt{2}$ E if Er.m.s. is the supply voltage. This overvoltage is only transient. It happens because line losses reduce the wave's intensity, and the line quickly returns to its typical supply voltage E. Similar to this, when an unloaded line is turned off, it briefly reaches a voltage of $2\sqrt{2}$ E before returning to its normal value.

(ii) A loaded line case: Additionally, when a loaded line is switched, overvoltages will be generated. Let's say a loaded queue is abruptly terminated.

This will create a voltage of 2 Zn i across the break (or switch), where i is the current at that precise moment the line was opened, and Zn is the line's natural impedance. Consider a scenario in which the break occurs while the current is at its peak and the line with Zn = 1000 carries a current of 100 A (r.m.s.). The voltage across the switch, or breaker, is equal to $2\sqrt{2}$ x 100 x 1000/1000, or 282.8 kV. The highest voltage that a line can withstand is equal to (Vm + 282.8) kV if Vm is the voltage's peak value in kV.

(iii) Current chopping: Current chopping causes the air blast circuit breaker to produce high voltage transients across its contacts. Here, it is briefly discussed. Air-blast circuit breakers keep the same extinguishing strength regardless of the magnitude of the current being interrupted, in contrast to oil circuit breakers, which depend on the magnitude of the current being interrupted for their effectiveness. When using an air-blast breaker to break low currents (such as transformer magnetizing current), the current falls sharply to zero much before the natural current zero is reached due to the air-blast's potent de-ionizing impact. Current chopping is the name of the phenomena, which results in high transient voltage across the breaker contacts. Resistance switching prevents overvoltages brought on by current hopping.

**2. Insulation failure:** The grounding of conductor, or the failure of the insulation between the line and the earth, is the most typical instance of insulation failure in a power system and may result in overvoltages. Consider earthing a line at potential E at point X. Two equal voltages of E, carrying currents of E/Zn and +E/Zn, respectively, travel down XQ and XP as a result of the line being grounded. Both of these currents go via X to the earth, resulting in a current of 2E/Zn.

**3. Arcing ground:** To achieve two benefits, the neutral of three phase lines was not earthed in the early days of transmission. First off, a line-to-ground fault does not render the line inoperable. The interference with communication lines is reduced as a result of the second elimination of zero sequence currents. With short lines and relatively low voltages, insulated neutrals provide no issues. However, a major issue known as arcing ground is frequently observed when the lines are long and run at high voltages. Three to four times the usual voltage oscillations are produced by the arcing ground. Arcing ground is a word used to describe the intermittent arc that occurs in a line-to-ground fault of a three-phase system and the transients that are produced as a result. The cumulative transients caused by an arcing ground can seriously harm the power system's equipment by causing insulation to fail. Earthing the neutral will stop arcing ground.

**4. Resonance:** In an electrical system, resonance happens when the circuit's inductive reactance and capacitive reactance are equal. Under resonance, the circuit's impedance and resistance are equal, and the p.f. is one. High voltages in the electrical system are a result of resonance. Because the capacitance in typical transmission lines is so low, resonance at the fundamental supply frequency doesn't happen very often. However, if the generator e.m.f. wave is warped, underground cables may also have resonance issues caused by 5th or higher harmonics [4]–[6].

## DISCUSSION

### Lightning

Lightning is an electric discharge between a cloud and the earth, another cloud, or the charge centres of the same cloud. When clouds are charged to such a high potential (+ve or -ve) with regard to earth or a neighbouring cloud that the dielectric strength of the surrounding medium (air) is broken, lightning, which is a massive spark, occurs. To explain how the clouds gain charge, there are many hypotheses in existence.

The most widely recognized theory holds that when warm, humid air rises from the earth, friction between the air and the minuscule water particles causes charges to build up. In the formation of water drops, the larger drops acquire a positive charge while the smaller drops acquire a negative charge.

Depending on the charge of the water drops they contain, the accumulated water drops give rise to clouds, which can have either a positive or negative charge. When a cloud's charge builds up enough, it may release onto another cloud or the earth, and we refer to this as lightning. Thunder occurs when lightning strikes because the air is instantly heated and expands, resulting in thunder. The expanding air is pushed back and forth by the surrounding air, creating the air wave motion that we associate with thunder.

### Mechanism of lightning discharge

Now let's talk about how a lightning discharge happens. The ground below receives an equal and opposite charge when a charged cloud passes over it. In Fig. 3, a negatively charged cloud causes the soil beneath it to become positively charged. As a cloud's charge rises, the potential between it and the earth rises as well, increasing the gradient in the air. The lightning stroke begins when the potential gradient is high enough (5 kV/cm to 10 kV/cm) to destroy the surrounding air. The following is the stroke mechanism:

(i) As soon as the air in the vicinity of the cloud collapses, a leader streamer, also known as a pilot streamer, shoots out of the cloud towards the earth while carrying charge, as seen in Fig. 3 (i). As long as the cloud from which it emanates feeds it with enough charge to keep the gradient at the tip of the leader streamer above the force of air, the leader streamer will continue on its course towards the ground. The leader streamer ends and the charge dissipates without forming a full stroke if this gradient is not maintained. To put it another way, the leader streamer won't touch down on the planet. The leader streamer is shown to be unable to reach the earth in Fig. 3 (i) because the gradient at its end cannot be maintained above the strength of the air. It should be noted that the leader streamer's current is low (less than 100 A), and its propagation speed is only slightly faster than that of light. Additionally, the leader's brightness is likewise relatively low.

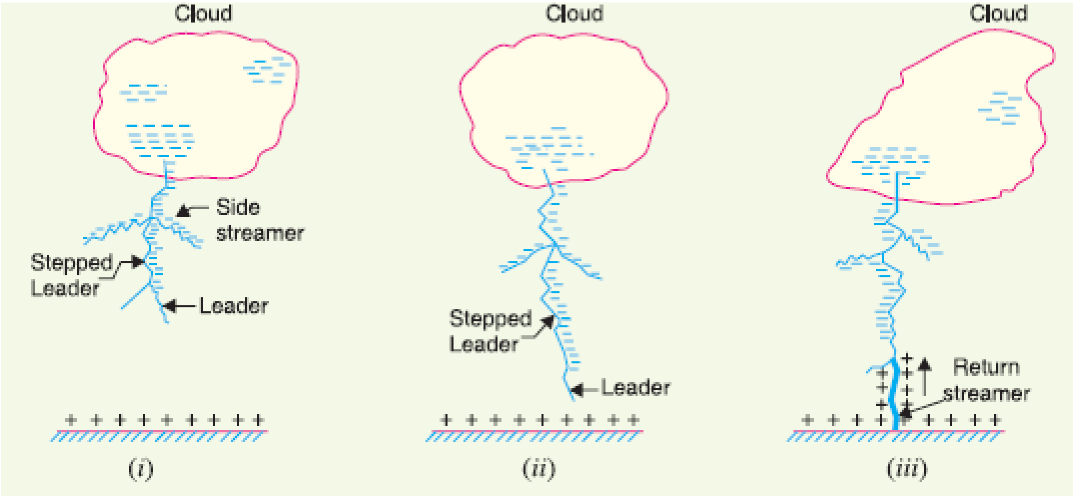


**Figure 3: Mechanism of lightning discharge**

(ii) The leader streamer frequently travels further towards the earth [See Fig. 3 (ii)] until it comes into contact with the earth or an object on the earth. Stepped leaders are created as the leader streamer approaches the earth and is accompanied by points of luminescence that move in jumps. Stepped leaders travel at speeds greater than one-sixth the speed of light and cover around 50 m in each stride. There is a possibility that stepped leaders have sufficient luminance and cause the first visual discharge occurrence.

(iii) The leader streamer's route is one of ionization and, as a result, of total insulation breakdown. A return streamer emerges from the earth to the cloud [See Fig. 3 (iii)] when the leader streamer approaches the earth and travels along the same direction as the main channel of the downward leader. The downward leader has a negative charge and the return streamer has a positive charge, therefore the action can be equated to closing a switch between the positive and negative terminals. A sudden spark caused by this event is what we refer to as lightning. Any additional discharge from the cloud may need to come from another area of it because a large percentage of the negative charge on the cloud has been neutralized as a result.

The following details of lightning discharge may be noted:

(a) Although a lightning discharge normally appears to the eye as a single flash, it is actually composed of several distinct strokes that follow the same path. The time difference between them ranges from 0 to 5 seconds. Each individual stroke begins with a leader that descends from the cloud.

(b) It has been discovered that just 13% of all lightning strikes come from positively charged clouds, while 87% of all lightning strikes are caused by negatively charged clouds.

(c) It has been calculated that there are roughly 100 lightning strikes every second worldwide.

(d) Currents in a lightning discharge can range from 10 kA to 90 kA.

**Types of Lightning strokes**

There are two primary methods that lightning can strike the electrical grid, including overhead lines, towers, substations, etc.

1. Direct movement 2. Indirect movement

**1. Direct stroke:** In a direct stroke, lightning discharge (i.e., current path) travels straight from the cloud to the target equipment, such as an overhead line. The current path from the line may travel over the insulators, down the pole, and then to the ground. The stroke-induced overvoltages may be significant enough to cause a flashover along this channel straight to the ground. There are two different sorts of direct strokes: strokes A and B.

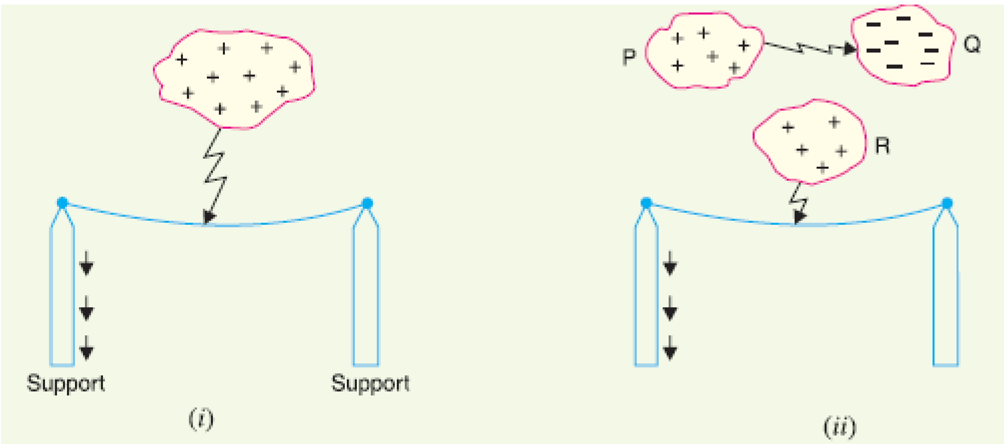


**Figure 4: Direct stroke Lightning**

(i) As seen in Fig. 4 (i), the lightning discharge in stroke A is from the cloud to the apparatus in question, in this case an overhead line. The tall item, in this case an overhead line, will experience an opposite sign charge as a result of the cloud. Lightning discharges happen between clouds and lines when the potential between them is greater than the breakdown value of air.

(ii) As seen in Fig. 4 (ii), stroke A between the clouds results in stroke B, which is when discharges on the overhead wire lightning. There are three clouds with positive, negative, and positive charges, referred to as P, Q, and R, respectively. The cloud R is responsible for tying the charge to the cloud Q. Lightning discharge will occur between the clouds P and Q if the cloud P moves too close to them, and charges on both of these clouds will vanish swiftly. As a result, the charge on cloud R abruptly breaks free, discharging quickly to earth while oblivious to tall objects.

Regarding direct strikes, there are two things to consider. First off, direct hits to the power system are quite uncommon. Second, since towering objects will always be the site of stroke A, protection can be offered. Stroke B, however, fully disregards the object's height and has the potential to even hit the ground. As a result, there is no way to offer protection against stroke B [7]–[10].

2. Indirect stroke: Because charged clouds are present, indirect strokes are caused by electrostatically generated charges on the conductors. Fig. 5 is an illustration of this. Electrostatic induction causes a positively charged cloud above the line to induce a negatively charged line.

However, this negative charge will only apply to the section of the line directly beneath the cloud; the rest of the line will be positively charged, as shown in Fig. 5. Through the insulators, the induced positive charge progressively escapes to earth. The negative charge on the wire is isolated when the cloud discharges to earth or to another cloud because it can't travel quickly to earth across the insulators. As a result, negative charge rushes in both directions along the line as travelling waves. It might be important to note that the majority of transmission line surges are produced by indirect lightning strikes.

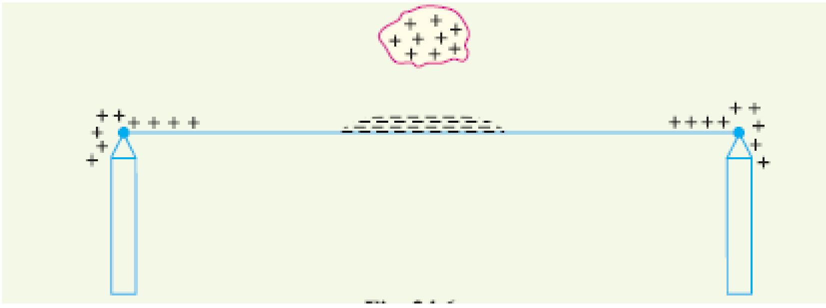

**Figure 5: Indirect Stroke Lightning**

**Harmful effects of Lightning**

A steep-fronted voltage wave is created on a transmission line by a direct or indirect lightning strike. This wave's voltage may increase from zero to its peak value (perhaps 2000 kV) in approximately one second and then decline to half its peak value in about five seconds. A voltage wave with such a steep front will start travelling waves along the line in both directions, with the velocity depending on the line's L and C characteristics.

(i) The travelling waves caused by lightning surges will damage poles and break insulators.

(ii) A transformer or generator's windings may sustain significant damage if the travelling waves caused by lightning strike them. Any quick passage of electric charge is resisted by the windings' inductance. Electric charges "pile up" against the transformer (or generator) as a result. This creates a pressure between the windings that is so high that insulation may fail, causing an arc to form. When insulation has failed and an arc has been generated by a brief overvoltage, the normal voltage between the turns is never enough to start an arc; nevertheless, the line voltage is typically adequate to maintain the arc long enough to seriously harm the machine.If a lightning strike initiates an arc in any area of the power system, this arc will cause extremely unsettling oscillations in the line. This could harm other linked equipment a queue.

## CONCLUSION

In order to prevent potential harm to electrical systems and equipment, protection against overvoltage is crucial. Voltage surges and transients, which are overvoltage occurrences, can cause system failure, component failure, and data loss. The usage of transient voltage suppressors, voltage regulators, and surge protectors are a few of the efficient techniques for overvoltage protection that have been covered in this work. By restraining the voltage at a safe level, transient voltage suppressors can deflect excessive voltage away from delicate components, preventing damage. On the other hand, voltage regulators maintain the input voltage and deliver a constant output, protecting the system against voltage changes. Surge protectors combine numerous protection strategies, including as clamping and filtering, to provide thorough protection.

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# CHAPTER 8

# EXAMINING LIGHTNING PROTECTION STRATEGIES AND EFFICACY

Mr. Bishakh Paul
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:bishakhpaul@presidencyuniversity.in

**ABSTRACT:**

Lightning strikes pose a serious risk to both infrastructure and people's safety. This essay tries to examine the various lightning protection strategies and their efficacy. The chapter looks at the fundamentals of lightning creation and the dangers it might pose. The article then explores several lightning protection techniques, including surge protectors, grounding systems, surge arresters, and lightning rods. The relevance of lightning protection system installation and maintenance is also covered in the article. The results of this study help us understand lightning protection strategies better and facilitate the creation of more dependable and durable solutions. An accumulation of electrical charges in the environment can result in lightning, a natural occurrence. It poses serious threats to human safety and has the potential to seriously harm infrastructure. Consequently, it is essential to put in place strong security measures. This article examines various lightning prevention strategies, highlighting their value in reducing the dangers brought on by these high-energy discharges.To protect human life and limit damage to infrastructure, lightning protection is essential.

**KEYWORDS:**

Expulsion-Type Arresters, Horn Gap Arrester, Lightning arrester, Multigap Arrester, Protection Against Lightning, Rod Gap Arrester, Surge Absorber, Valve Type Arresters.

## INTRODUCTION

An efficient lightning protection system must include surge arresters, surge protectors, grounding systems, and lightning rods. Lightning rods direct lightning strikes away from buildings, surge protectors guard against voltage spikes on sensitive electronics, grounding systems release electrical energy safely into the earth, and surge arresters direct excess energy away from vital equipment. For these protection measures to be reliable and efficient, proper installation and routine maintenance are essential. Technology will progress as a result of ongoing study and innovation in lightning protection, improving our capacity to safeguard infrastructure and human life from the catastrophic impacts of lightning strikes. Individuals and organizations can reduce hazards, improve safety, and save priceless assets by putting in place complete lightning protection systems.

### Understanding Lightning

It is important to have a fundamental understanding of how lightning happens before talking about lightning protection techniques. The imbalance of positive and negative charges in the atmosphere leads to lightning. A cloud and the ground can be on opposite sides of a cloud, or there may be an imbalance between them. A discharge takes place when the electrical potential difference is large enough to produce a lightning bolt. A huge amount of energy is released during the discharge in the form of heat, light, and electromagnetic radiation [1]–[3].

Installation and Upkeep: For lightning protection systems to work effectively, proper installation and ongoing maintenance are essential. Professionals with the necessary training should install products in accordance with accepted norms and recommendations. Lightning rods, surge protectors, grounding systems, and surge arresters all need to be installed properly and connected in accordance with the system design. To make sure the system stays in good operating order, routine inspections and maintenance should be carried out. To do this, look for corrosion, damage, or loose connections, and replace any defective parts as soon as possible.

The Risks of Lightning: The dangers of lightning: Lightning strikes can cause several problems for people and property. The main dangers are as follows:

a) Electrical Shocks: Direct lightning strikes can result in powerful electrical shocks that can be lethal or cause serious damage. Lightning's high voltage and current are potentially fatal.
b) Fire dangers: Lightning can start flames when it strikes flammable objects like trees, buildings, or other materials. A fire may be started by the lightning bolt's high heat, which has the potential to spread quickly and do great harm.
c) Structural Damage: Building, towers, and other structures are susceptible to structural damage as a result of lightning strikes. Lightning carries a tremendous amount of energy that can lead to building collapses, rips, and harm to electrical equipment and systems
d) Electrical Surges: Lightning strikes can cause high voltage surges in electrical systems, including power lines. These surges have the potential to harm electrical and electronic equipment, resulting in failures, data loss, and monetary losses.

**Systems for lightning protection**

Several safety precautions can be taken in order to reduce the risks of lightning strikes:

1. Lightning Rods (Air Terminals): Air terminals, commonly referred to as lightning rods, are a crucial component of lightning protection systems. They are made to give lightning a preferred route to go, rerouting the electrical discharge away from buildings. Buildings, towers, and other structures frequently have lightning rods put on their highest points. The lightning rod gathers the electrical charge as a lightning strike approach and securely transfers it to the ground through a system of conductors.
2. Surge Protectors (Transient Voltage Surge Suppressors): Surge protectors are tools used to guard against voltage surges brought on by lightning in electrical and electronic equipment. Power lines may experience high voltage surges caused by lightning strikes, which could harm or even destroy delicate equipment. To reduce voltage spikes and safely redirect surplus energy to the earth, surge protectors are installed at the locations where electrical systems enter the building. They serve as a barrier, protecting the equipment by preventing the surge from getting to it.
3. Grounding systems: Effective lightning protection depends on proper grounding. Lightning currents can safely flow into the ground using grounding systems' low resistance channel. Deeply buried conductive elements, like copper or aluminum, make up the grounding system. To ensure the dissipation of electrical energy, it connects numerous lightning protection system elements such surge protectors, equipment grounding, and lightning rods. The potential for damage to structures, the risk of electrical shock, and the protection of equipment are all reduced by adequate grounding.

4. Lightning Arresters: Lightning arresters, often referred to as surge arresters, are devices fitted at electrical entry points to prevent surges caused by lightning. They recognize voltage spikes and safely direct extra electrical energy to the earth. Surge arresters serve as a barrier, keeping the surge from destroying equipment and entering the electrical system. They give an extra degree of security, especially for delicate and important equipment.
5. Installation and Upkeep: For lightning protection systems to work effectively, proper installation and frequent upkeep are required. Here are some crucial things to remember:
6. Professional Installation: Lightning protection systems should only be installed by trained experts who are familiar with the regulations and criteria for lightning protection. Installation must follow accepted industry norms, such as International Electrotechnical Commission (IEC) Standard IEC 62305 or National Fire Protection Association (NFPA) Standard NFPA 780.
7. Lightning Risk Assessment: A complete evaluation of the lightning risk should be done prior to implementing a lightning protection system. It is important to consider elements such the geographic location, building height, environment, and electrical systems. The proper design and elements of the lightning protection system will be determined with the aid of this assessment.
8. Regular Inspections: To make sure lightning protection systems are still in good working order, they should be examined on a regular basis. Corrosion, damage, loose connections, and any other indicators of wear should all be looked for during inspections. Immediately fix or replace any deteriorating components that are visible.
9. Upkeep and Maintenance: In order to retain the efficiency of lightning protection devices, they need be regularly maintained. This include keeping grounding systems clean of debris or obstructions, ensuring clear paths for lightning rods, and routinely testing surge protection equipment.

Lightning protection is essential to protect human life and limit damage to infrastructure. An efficient lightning protection system must include surge arresters, surge protectors, grounding systems, and lightning rods. The dependability and efficiency of these protective measures are largely dependent on proper installation, adherence to regulations, and routine maintenance. Individuals and organizations can reduce hazards, improve safety, and save priceless assets by putting in place complete lightning protection systems. Our capacity to protect infrastructure and human life from the deadly effects of lightning strikes will be improved through ongoing research and technical advancements in lightning protection.

## DISCUSSION

### Protection Against Lightning

Switching and other factors can create transients or surges on the power grid, but lightning-related surges are the most significant and destructive. The expensive equipment in the power system (such as generators, transformers, etc.) may sustain catastrophic damage as a result of lightning surges, either directly striking the equipment or striking transmission lines that send waves to the equipment. Protection against both types of surges must be provided. The three most popular lightning surge prevention tools are:

(i) Earthing screens (ii) Overhead ground cables (iii) Lightning arresters or surge diverters.

While overhead ground wires shield transmission lines from direct lightning strikes, earthing screens protect power plants and sub-stations from such strikes. However, lightning arresters or surge diverters shield the station's equipment from both direct strikes and waves that enter the equipment indirectly. We'll talk briefly about various defense strategies.

**The earthing screens**

Usually, expensive equipment is housed in the power stations and sub-stations. By installing an earthing screen, these stations can be shielded from direct lightning strikes. It is made up of a network of copper conductors, commonly referred to as shield or screen, installed on every piece of electrical machinery in the sub-station or power plant. Through a low impedance, the shield is appropriately connected to earth at least twice. When a direct strike occurs on the station, the screen offers a low resistance channel for conducting lightning surges to the ground. The station's equipment is shielded from harm in this way. This method's drawback is that it offers no defence against travelling waves that might get to the station's equipment.

**Overhead ground wires**

The use of overhead ground wires, as depicted in Fig. 1, is the most efficient way to shield transmission lines from direct lightning strikes. One ground wire and one line conductor are presented for simplicity's sake. The ground wires (also known as ground wires) are positioned above the line conductors in such a way that they practically catch every lightning strike. At every tower or pole, the ground wires are grounded with the least amount of resistance. The ground wires will absorb all lightning strikes because of their strategic placement, preventing them from striking line conductors [4]–[6]. The ground wires will absorb the direct lightning strike that strikes the transmission line.

The ground wire's significant lightning current (10 kA to 50 kA) flows to the ground, shielding the line from the destructive effects of lightning. It should be noted that the ground wires' level of protection is influenced by the tower's footing resistance. Assume, for instance, that the lightning current from the tower to the ground is I amperes and the tower-footing resistance is R1 ohms. The tower then rises to a potential Vt determined by, where Vt = I1R1. This is also the voltage that will be visible across the string of insulators because Vt (= I1R1) is about the voltage between the tower and line conductor.

If Vt's value falls short of what's needed to generate an insulator flashover with no consequences. On the other hand, insulator flashover could happen if Vt is too high. Since the tower-footing resistance R1 determines the value of Vt, it is imperative to keep this resistance as low as possible to prevent insulator flashover.

**Benefits:**

(i) It significantly protects transmission lines from direct lightning strikes.

(ii) A grounding wire functions as a short-circuited secondary and dampens any disturbance that travels along the line.

(iii) It offers some electrostatic shielding protection from outside forces. As a result, it lessens the voltages that a nearby cloud's discharge causes in the line conductors.

Drawbacks:

(i) It incurs additional expenses.

(ii) It might shatter and fall across the conductors of the line, resulting in a short-circuit fault. Galvanized stranded steel conductors have significantly reduced this problem when used as ground wires. The ground wires are strong enough as a result.

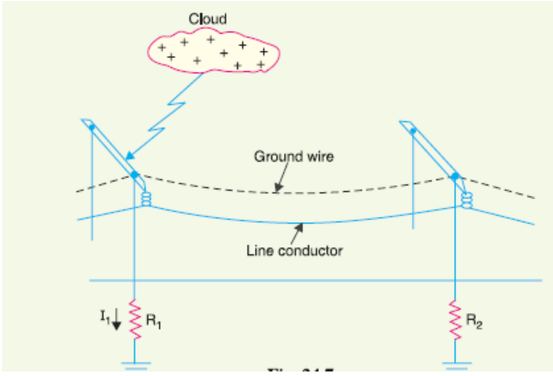


**Figure 1: Overhead ground wires**

### Lightning arresters

The earthing screen and ground wires can effectively shield the electrical system from direct lightning strikes, but they are ineffective against waves that could travel and strike the terminal device. Surge diverters or lightning arresters offer defence against these surges. A surge diverter, also known as a lightning arrester, is a safety measure that transmits high voltage surges on the electrical system to the ground.

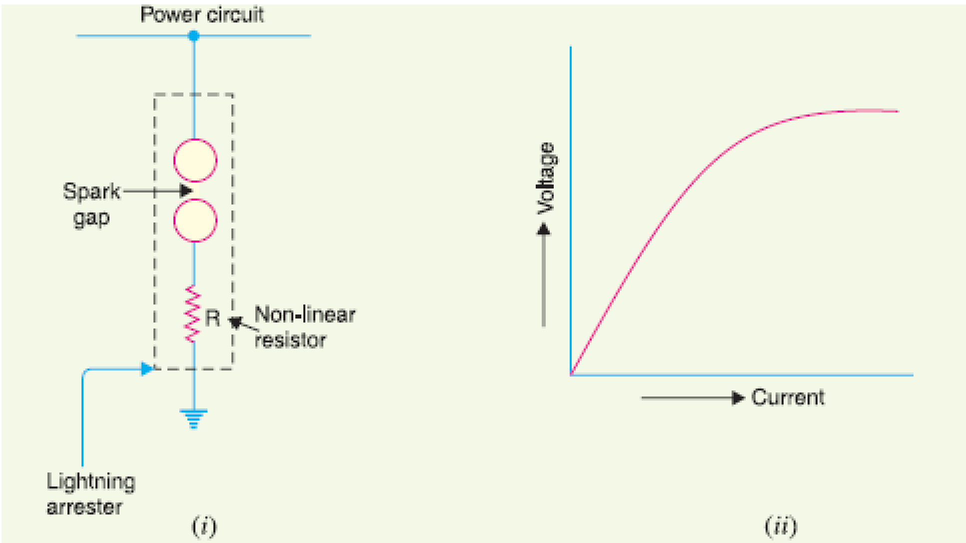


**Figure 2: Lightning arrester**

The fundamental design of a surge diverter is depicted in Fig. 2 (i). It consists of a non-linear resistor in series with a spark gap. The equipment to be protector's terminal is attached to one end of the diverter, while the other end is effectively grounded. Due to the predetermined length of the gap, a standard line voltage will not be adequate to break down the air insulation and create an arc across the gap, but a dangerously high voltage will.

The non-linear resistance has the property that when the voltage (or current) rises, so does its resistance, and the opposite is also true. This is evident from the resistor's volt/amp characteristic illustrated in Fig. 2 (ii) Action. The surge diverter or lightning arrester works as follows:

(i) The lightning arrester is off the line, conducting no current to earth, or the gap is not conducting, during normal operation.

(ii) When overvoltage occurs, the air insulation across the gap disintegrates, forming an arc that offers a low resistance path for the surge to the ground. This prevents the surge's excess charge from being sent back over the line and instead safely conducts it through the arrester to the ground.

(iii) It is important to emphasize the role of the non-linear resistor in the operation of the arrester in subparagraph.

The arc would be a short-circuit on the power system and might result in power-follow current in the arrester as the gap sparks over as a result of overvoltage. A short-circuit is avoided because of the resistor's ability to provide high resistance to high voltage (or current). Following the surge, the resistor provides a high resistance to stop the gap from conducting.

A lightning arrester's design must take into account two factors. First, the arc in the gap should stop once the surge is over. The resistor and gap may both be destroyed if the arc does not end. This is because electricity would keep flowing through the resistor if it did not. Second, the I R drop over the arrester, where I is the surge current, should not be greater than the breakdown strength of the insulation of the apparatus to be protected. Types of lightning arresters: There are numerous kinds of lightning arresters that are often used. They all work on the same premise of giving surges a low resistance path to the ground; their only structural differences are minor. The following types of lightning arresters will be covered:

1. A rod gap stopper

2. Horn gap arrester

3. Multigap arrester

4. Lightning arrester with expulsion

5. Lightning arrester with a valve

**1. Rod Gap Arrester:** This diverter is made up of two 1.5 cm rods that are bent at a right angle and separated by a gap, as shown in Fig. 3. The line circuit is connected to one rod, while earth is connected to the other rod. In order to prevent the arc from damaging the insulator, the distance between the gap and the insulator (i.e., distance P) cannot be less than one-third of the gap's length. In order to prevent the cascading of extremely steep wave fronts through the insulators, the gap length is often chosen such that breakdown should occur at 80% of spark-over voltage. There is frequently a rod gap across the string of insulators for an overhead line on the transformer bushing. The rod gap across a transformer's bushing is depicted in Fig. 3.

The gap is still non-conducting in normal operating conditions. When a high voltage surge occurs on the wire, the gap ignites and conducts the surge current to ground. In this manner, any extra charge left over after a surge is safely transported to earth.

Limitations:

(i) The arc in the gap is sustained by the normal supply voltage after the surge is over, causing a short-circuit in the system.

(ii) The tremendous heat the arc produces may cause the rods to melt or become damaged.

(iii) The performance of the rod gap arrester is impacted by the meteorological factors (such as rain, humidity, temperature, etc.).

(iv) The polarity of the surge has an impact on how well this arrester works.

The rod gap arrester is only employed as a "back-up" protection in the event of major arresters because of the aforementioned restrictions.

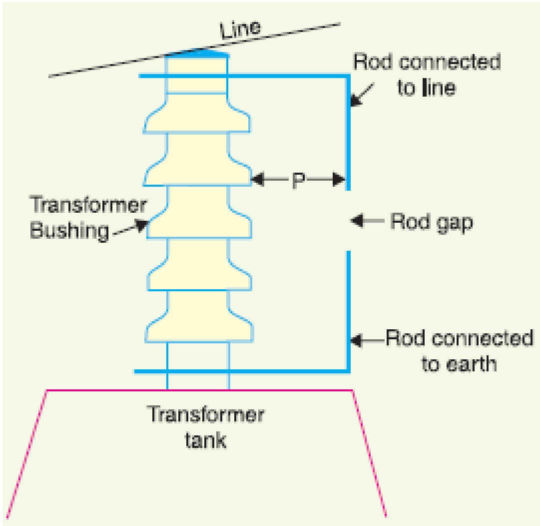


**Figure 3: Rod Gap Arrester**

**2. Horn Gap Arrester:** The horn gap arrester is depicted in Fig. 4. It is made up of two horn-shaped metal rods A and B that are spaced apart by a tiny air gap. The horns are designed so that, as depicted, the space between them gradually widens as they approach the summit. On porcelain insulators, the horns are mounted.

The line is connected to one end of the horn through a choke coil L and resistance R, while the other end is essentially grounded. The resistance R contributes to keeping the follow current at a low level. Because of how it is constructed, the choke coil has a low reactance at power frequency but a very high reactance at transient frequency. As a result, the choke prevents transients from entering the protective device. Because of the way the spacing between the horns is controlled, a standard supply voltage cannot create an arc across the gap [7]–[10]. The gap is not conducting under normal circumstances, meaning that the supply voltage is inadequate to start an arc between the gaps. When an overvoltage occurs, spark-over occurs across the small gap G. The arc moves up the gap as a result of the magnetic pull of the arc and the hot air surrounding it. Gradually, the arc enters places 1, 2, and 3. At a certain point along the arc the distance might be too great for the voltage to keep the arc going (perhaps position 3). As a result, the arc is put out. Thus, the extra charge on the line is transferred to the battery through the arrester ground.

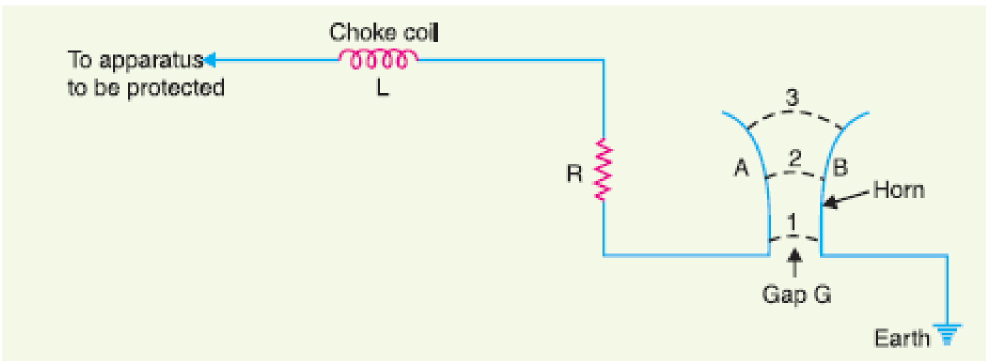


**Figure 4: Horn Gap Arrester**

**Benefits:**

(i) The arc self-clears. As opposed to rod gap arresters, this kind of arrester prevents the system from short-circuiting after the surge has passed.

(ii) Series resistance aids in keeping the follow current to a minimal amount.

Limitations:

(i) The gadget may become worthless if a gap is bridged by an outside force, such as birds.

(ii) Because of corrosion or pitting, the horn gap setting is likely to alter. The arrester's performance is negatively impacted by this.

(iii) The operation takes a rather considerable amount of time—roughly 3 seconds. This period is excessively long when compared to the extremely little operational time of current protection equipment for feeders.

Due to the aforementioned restrictions, this kind of arrester is unreliable and should only be used as a backup defence, similar to the rod gap arrester.

**3. Multigap arrester:** The multigap arrester is depicted in Fig. 5. It is made up of a number of metallic (often zinc alloy) cylinders that are spaced apart from one another and separated by brief air gaps. Through a series resistance, the line is connected to the series' first cylinder (cylinder A), and the ground is connected to the other cylinder. The power arc is restricted by the series resistance. Series resistance is added, which lessens the level of protection from travelling waves. Some of the gaps (B to C in Fig. 5) are redirected by a resistance to get around this challenge.

Point B is at earth potential in typical circumstances; hence the standard supply voltage cannot close the series gaps. The breakdown of series gaps A to B takes place when an overvoltage occurs.

After breakdown, the heavy current will select the direct route to the earth via the shunted gaps B and C over the alternate route through the shunt resistance. The arcs B through C go out after the surge, and any power current that occurs afterward is restricted by the two resistances (shunt resistance and series resistance), which are now connected in series. The arcs in the gaps A to B cannot be maintained by the current, and normal conditions return. Such arresters can be used in situations where the system voltage is less than 33 kV.

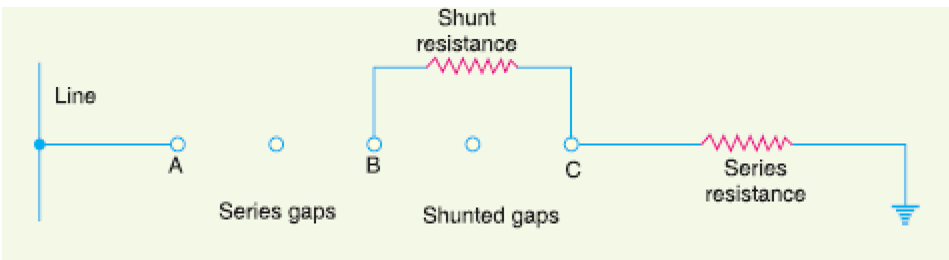


**Figure 5: Multigap arrester**

**4. Expulsion-type arresters:** These arresters, also known as "protector tubes," are frequently utilized on systems that operate at voltages up to 33 kV. The main components of an expulsion type lightning arrester are depicted in Fig. 6 (i). Basically, it is made up of a rod gap A A′ in sequence with a second gap encased in a fibre tube. Two electrodes create the gap in the fibre tube. The lower electrode is connected to the ground, while the higher electrode is connected to the rod gap.

Each line conductor is given its own ejection arrester. The installation of an ejection arrester on an overhead line is shown in Fig. 6 (ii). The series gap A A′ is spanned and an arc is produced between the electrodes in the tube when there is an overvoltage on the line. A neutral gas* is created when the heat from the arc vaporizes some of the fibre in the tube walls.

The gas builds up high pressure in a very brief period of time and is released through the hollow lower electrode. Ionized air from the arc is carried away by the gas as it forcefully exits the tube. Usually, the de-ionizing impact is so severe that the arc terminates at a current zero and cannot be restarted.

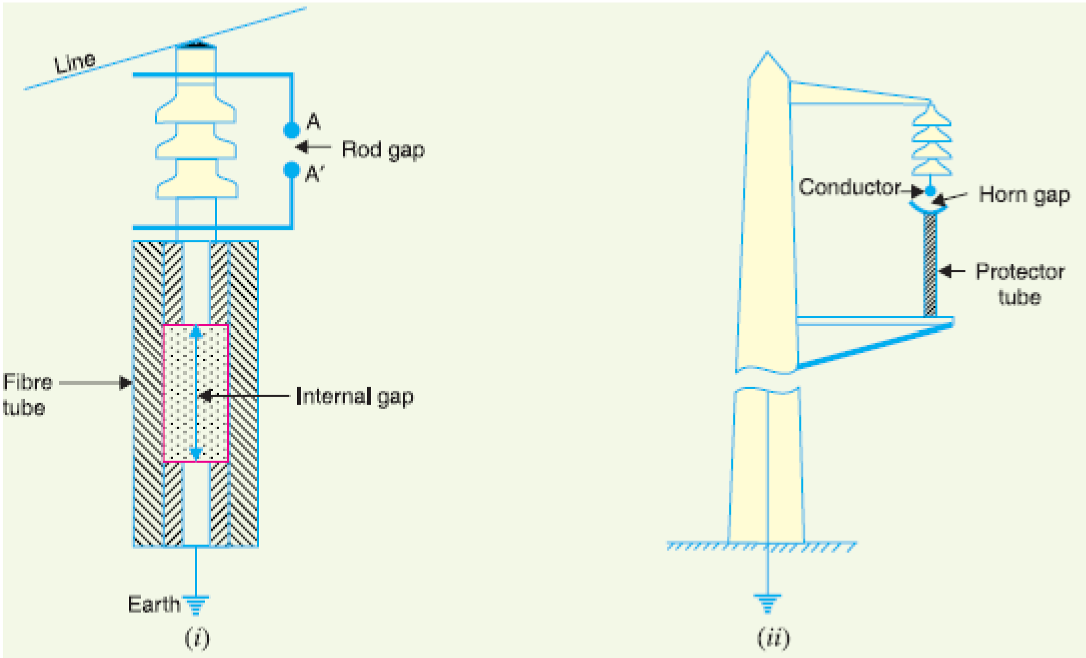


**Figure 6: Expulsion-type arresters**

Advantage:

(i) They are not very expensive.

(ii) They are improved form of rod gap arresters as they block the flow of power frequency.

Limitations:

(i) An ejection type arrester can only execute a certain number of operations because each one depletes a portion of the fibre material.

(ii) Due to gas discharges during operation, this type of arrester cannot be put in an enclosed apparatus.

(iii) The arrester is not appropriate for the protection of expensive equipment because of its weak volt/amp characteristic.

**5. Valve type arrester:** Valve type arresters frequently employed in systems running at high voltages and incorporate non-linear resistors. The various components of a valve-type arrester are depicted in Fig. 7(i). It is made up of two assemblies: series spark gaps in assembly 1 and non-linear resistor discs in assembly 2 made of materials like thyrite or metrosil. The spark gaps are coupled in series with the non-linear components. Both assemblies fit snugly into a porcelain container.

(i) The spark gap is an assemblage of many spark gaps that are identical and are connected in series. Two electrodes with a predetermined gap separation make up each gap. By adding extra resistance components (referred to as grading resistors) across the gaps, the voltage distribution across them is linearized. The series gaps are spaced apart enough to sustain the typical circuit voltage. But an excessive voltage will force the gap to collapse, sending the surge current through the non-linear resistors to the ground.

(ii) The non-linear resistor discs are constructed from an inorganic substance like metrosil or thyrite. The CDs are linked together in a series. When the usual system voltage is applied, the non-linear resistors have the property of providing a high resistance to current flow, but a low resistance to the passage of high-surge currents. In other words, as current through these non-linear parts increases, their resistance falls, and vice versa.

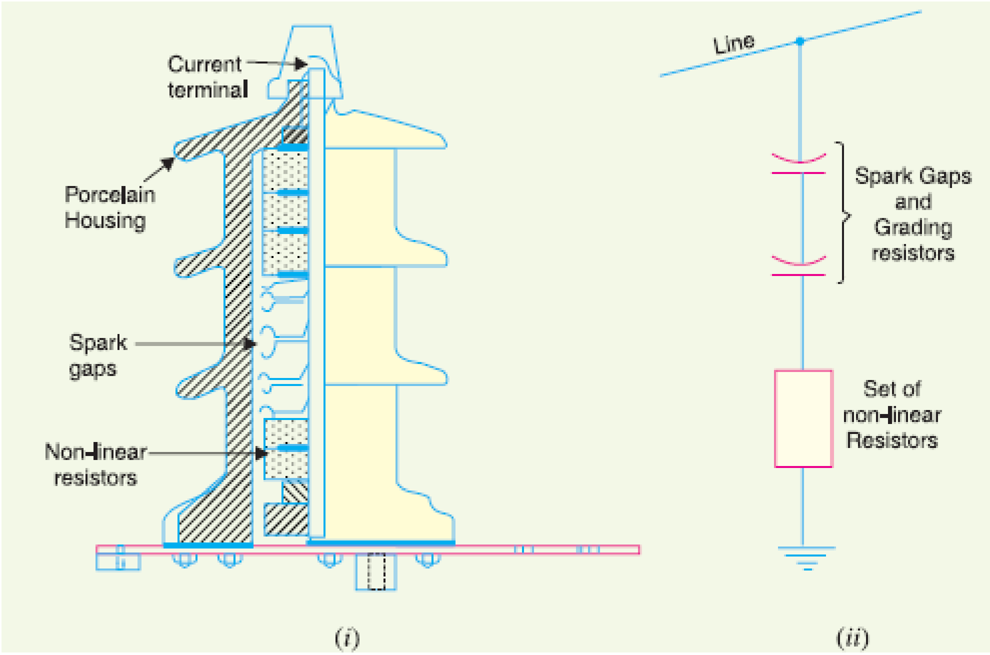


**Figure 7: Valve type arrester**

Working: The usual system voltage is inadequate to cause the failure of the air gap assembly under normal circumstances. When there is an overvoltage, the series spark gap collapses, causing the surge current to be transmitted through the non-linear resistors to ground. The non-linear elements will provide a very low resistance to the flow of surge due to the very huge magnitude of the surge current. The surge won't be pushed back across the line as a result; instead, it will quickly reach Earth. The non-linear resistors take on high resistance once the surge is over to block the current flow.

Advantages:

(i) They offer excellent surge protection, especially for cables and transformers.

(ii) They move very quickly, in under a second.

(iii) The impulse ratio is almost unity.

Limitations:

(i) They might not stop exceptionally steep wave front surges from getting to the terminal apparatus. This necessitates taking extra precautions to look for steep-fronted waves.

(ii) The introduction of moisture into the enclosure has a negative impact on their performance. This demands that the enclosure always be effectively sealed.

Applications: The valve type arresters are divided into two categories: (i) station type and (ii) line type, respectively. The station type arresters are typically employed in power plants that operate on voltages up to 220 kV or greater to protect crucial equipment. The stations that handle voltages up to 66 kV also use line type arresters.

**Surge absorber:** The surges' travelling waves that they create on the gearbox lines may harm the terminals' equipment. The severity of the damage relies on both the surge's amplitude and the steepness of its wave front. The equipment was damaged more severely the steeper the wave front of the surge was. Surge absorbers are typically used to lessen the steepness of a surge's wave front.

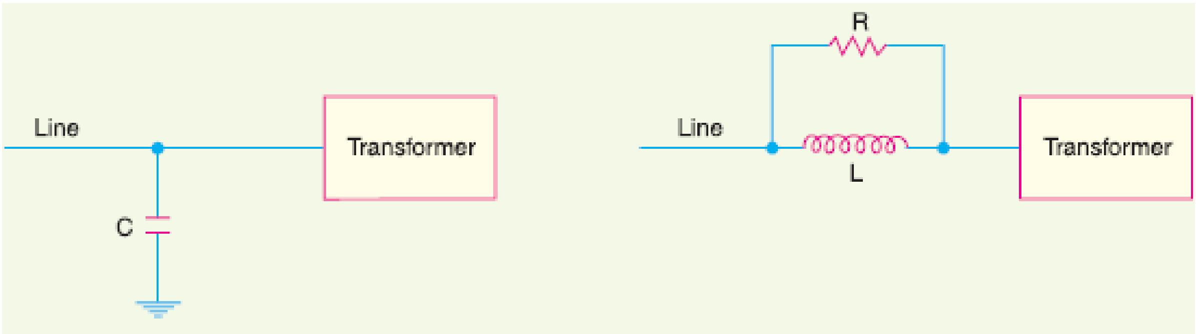


**Figure 8(i): Surge absorber**

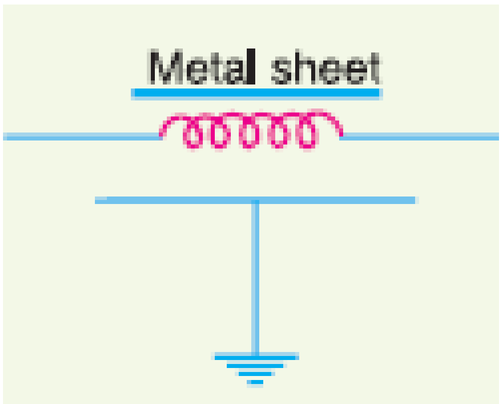


**Figure 8(ii): Metal sheet of Surge absorber**

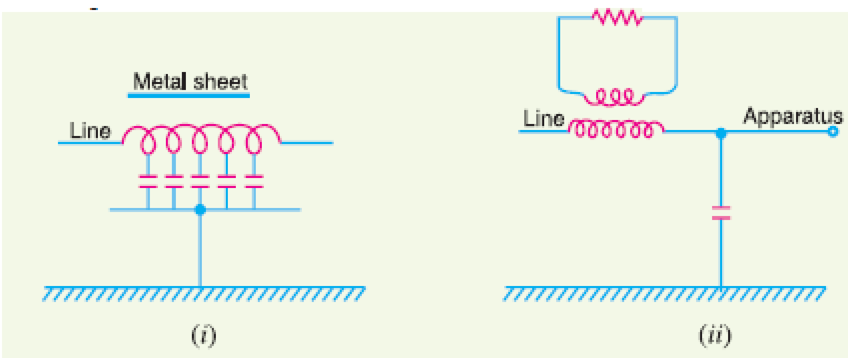


**Figure 9: Connections of Surge absorber**

A surge absorber is a safety measure that, by absorbing surge energy, lessens the steepness of a surge's wave front. Although the surge is eliminated by both the surge diverter and the surge absorber, how it is done varies between the two devices. Surge energy is absorbed by the surge absorber while the surge diverter diverts the surge to earth. Here are a few examples of surge absorption:

(i) The line and earth can be linked to a condenser, which can serve as a surge absorber. The transformer winding is protected by a capacitor, which functions as a surge absorber, as shown in Fig. 8 (i). A condenser's reactance will be low at high frequency and high at low frequency since it is inversely proportional to frequency. The capacitor functions as a short circuit and transmits the high frequency surges directly to ground. However, at power frequencies, the capacitor's reactance is extremely high and essentially no current travels to the ground.

(ii) Another type of surge absorber combines resistance and choke in parallel attached in series to the line in Fig. 8(i). The choke (XL = 2 f L) provides a high reactance to surge frequencies. Consequently, the surges are forced. so that they might get past the resistance R and be released there.

(iii) Another sort of surge absorber is depicted in Fig. 8(ii). Ferranti surge absorber is its name. It comprises of a line connected in series with an air cored inductor. A dissipator, or earthed metallic sheet, surrounds and insulates the inductor. This configuration is comparable to a transformer with a shorted secondary.

The dissipator creates the secondary that is short-circuited, while the inductor creates the primary. Due to the operation of the transformer, the heat produced in the dissipator consumes the energy of the surge. Transformer protection is the primary application for this kind of surge absorber. The equivalent circuit of the 66 kV Ferranti surge absorber is shown in Fig. 9 (ii), while Fig. 9 (i) displays the schematic diagram.

## CONCLUSION

In conclusion, lightning protection is essential for preserving human life and limiting infrastructure damage. This study emphasizes several lightning protection strategies and their value in reducing the risks brought on by lightning strikes. Surge protectors provide protection against lightning-related electrical surges, whereas lightning rods are essential for deflecting lightning strikes away from buildings. Grounding systems make guarantee that electrical energy is dissipated into the ground, which lowers the risk of damage. Surge arresters provide further protection by rerouting excess electrical energy away from delicate machinery. The effectiveness of lightning protection devices depends on proper installation and routine maintenance. Individuals and organizations may improve safety and safeguard priceless assets from the catastrophic impacts of lightning strikes by putting these safeguards into place. Further developments in this important subject will be made possible by ongoing research and invention in the realm of lightning protection.

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# CHAPTER 9

# ESSENTIAL COMPONENTS OF ELECTRICAL POWER DISTRIBUTION SYSTEM

Mr. Veerappa Ravi
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:raviangadi@presidencyuniversity.in

**ABSTRACT:**

Sub-stations are essential components of the electrical power distribution system because they serve as a bridge between the low-voltage distribution networks and high-voltage transmission lines. To provide a reliable and efficient supply of electricity to consumers, they act as important centers for electrical transformation and regulation. The role, components, and operational facets of sub-stations are covered in this chapter's overview. However, there may be times when it is beneficial to go from high amounts of A.C. power to D.C. power, such as when using traction, electroplating, D.C. motors, etc. Once more, the appropriate equipment (such as an ignitron) known as a sub-station handles this task. The kind of equipment required at a sub-station will obviously base on the requested service. Although there are many different kinds of sub-stations, we will focus on those where the incoming and exiting supply are both A.C., i.e., substations that alter the supply of electricity's voltage level.

**KEYWORDS:**

Electric Power, Electrical Power Distribution, Power Factor, Primary Grid Sub-Station, Sub-Station.

## INTRODUCTION

Electricity is created, transmitted, and distributed in the form of alternating current in the modern electrical power system, or a.c. The power stations that generate the electricity are placed in advantageous locations, usually quite a distance from the users. It is distributed across a vast network of transmission and distribution to reach the users. It may be desirable and required to alter a certain electric supply characteristic (such as voltage, a.c. to d.c. conversion, frequency, p.f., etc.) at numerous points along the power system's line. A suitable piece of equipment called a substation carries out this function. For instance, the power plant may step up the generation voltage (11 kV or 66 kV) to a high voltage, such as 220 kV or 132 kV, for the purpose of transmitting electric power. The sub-station is the collection of equipment (such as a transformer, etc.) utilized for this purpose. Similar to this, the voltage may need to be stepped down to utilization level close to the customers' locations. Once more, a suited tool called a substation handles this task [1]–[3].

### Substation

A sub-station is a group of devices used to modify the characteristics of an electric supply, such as voltage, ac to dc conversion, frequency, or phase factor. Sub-stations are a crucial component of the power grid. The efficient operation of sub-stations is largely responsible for supply continuity. Therefore, it is crucial to use the greatest caution when designing and constructing a sub-station. When planning the layout of a sub-station, the following crucial considerations must be made:

(i) It ought to be put in a suitable location. It should be placed as close to the load's centre of gravity as is practical.

(ii) It need to offer a secure framework. The upkeep of regulatory permissions, facilities for doing repairs and maintenance, atypical events like the potential for explosion or fire, etc., must all be taken into account for safety. The provision of proper protective equipment, good design and construction, and other factors must all be taken into account for reliability.

(iii) It must be simple to use and maintain.

(iv) The capital expense should be kept to a minimum.

**Classifications of substation**

There are various sub-station classification schemes. However, the two most crucial methods of categorization are in accordance with constructional traits and service demand.

**Depending on the service requirement**

It may be necessary to use a sub-station to alter the voltage, increase power factor, convert a.c. power to d.c. power, etc. Sub-stations may be categorized into the following groups depending on the service requirement:

(i) Transformer sub-stations: Transformer sub-stations are those sub-stations that modify the voltage level of the electric supply. These power substations take in power at one voltage and output it at another. Transformers will undoubtedly be the primary component of such substations.

This sort of sub-station makes up the majority of them in the power system.

(ii) Switching sub-stations: Incoming and outgoing lines have the same voltage at these sub-stations since they do not vary the voltage level. They just carry out power line switching activities, though.

(iii) Power factor correction sub-stations: These sub-stations are referred to as power factor correction sub-stations since they help the system's power factor. These sub-stations are typically found at the end of transmission lines that receive power. Synchronous condensers are typically used in these sub-stations to improve power factor.

(iv) Frequency changer sub-stations: These sub-stations are referred to as frequency changer sub-stations since they alter the supply frequency. For industrial use, a modification in frequency might be necessary.

(v) Converting sub-stations: These sub-stations are known as converting sub-stations since they convert a.c. power into d.c. power. These sub-stations accept a.c. power and use the appropriate equipment (such as an ignitron) to convert it to d.c. power for uses like traction, electroplating, electric welding, etc.

(vi) Substations for industry: Industrial sub-stations are those sub-stations that provide power to specific industrial concerns.

**In accordance with structural characteristics**

To ensure continuous and dependable service, a sub-station's numerous components, such as circuit breakers, switches, fuses, instruments, etc., must be adequately housed. The sub-stations are categorized as follows based on their constructional characteristics:

(i) Indoor sub-station (ii) Outdoor sub-station

(iii) Underground sub-station (iv) Pole-mounted sub-station

(i) Indoor sub-stations: Due to financial constraints, the substation's equipment is located indoors for voltages up to 11 kV. However, these sub-stations can be built at voltages up to 66 kV when the air is polluted with pollutants.

(ii) Outdoor sub-stations: Equipment is always installed outdoors at voltages greater than 66 kV. It is not cost-effective to put the equipment indoors because for such voltages, the distances between conductors and the amount of space needed for switches, circuit breakers, and other equipment grow so large.

(iii)Underground sub-stations: The amount of space for buildings and equipment is constrained in densely populated locations, and land is expensive. In such cases, an underground sub-station is built. Further information on underground sub-stations can be found in Art. 25.6.

(iv) Substations installed on poles: Equipment is put above this outdoor sub-station on an H-pole or 4-pole structure. For voltages up to 11 kV (or 33 kV in some cases), it is the least expensive type of sub-station. These substations virtually entirely supply local communities with electricity. The reader may turn to Art. 25.5 for a detailed explanation of pole-mounted sub-stations.

## DISCUSSION

### Transformer substation

The bulk of the power system's sub-stations are worried about the fluctuating voltage level of the electric supply. Because the transformer is the primary device used to modify the voltage level, these are referred to as transformer sub-stations. Transformer sub-stations can be categorized into different groups depending on their intended use: Step-up substation, primary grid substation, secondary substation, distribution substation are the first four.

The location of the aforementioned types of sub-stations are shown in the block diagram of a typical electric supply system in Fig. 1. It should be noted that not all electric supply schemes must incorporate every stage depicted in the diagram. For instance, in one supply scheme, secondary sub-stations might not be there, while in another, the scheme might be so small that only distribution sub-stations are present[4]–[6].

(i) Step-up sub-station: To improve transmission efficiency of electric power, the generation voltage, in this example 11 kV, is stepped up to high voltage (220 kV). Step-up sub-stations are the sub-stations that carry out this task. These are typically found in power plants and are of the outdoor variety.

(ii) Primary grid sub-station: Electricity at a 220 kV voltage is transmitted from the step-up sub-station to the city's outskirts through a 3-phase, 3-wire overhead system. The primary grid sub-station in this location receives electrical power and lowers the voltage to 66 kV for secondary transmission.

Typically, the primary grid sub-station is an outdoor model.

(iii) Secondary sub-station: Electricity is transmitted at 66 kV by a 3-phase, 3-wire system from the principal grid sub-station to a number of secondary sub-stations positioned at key locations across the city. A secondary sub-station further steps down the voltage to 11 kV. The city's major road sides are lined with 11 kV lines. It should be noted that large users (those with demand greater than 50 kW) typically get power at an 11 kV voltage for use in their own substations. The secondary sub-stations are typically outdoor in nature as well.

(iv) Distribution sub-station: Distribution sub-stations receive electricity from 11 kV lines. In order to supply the customers, these sub-stations scale down the voltage to 400 V, 3-phase, and 4-wire. They are situated close to the consumer locations. There is 230 V between any phase and the neutral and 400 V between any two phases. While a 3-phase, 400V motor load is linked directly across 3-phase lines, a single-phase home lighting load is connected between any one phase and neutral. It would be helpful to note that the majority of distribution substations are pole-mounted.

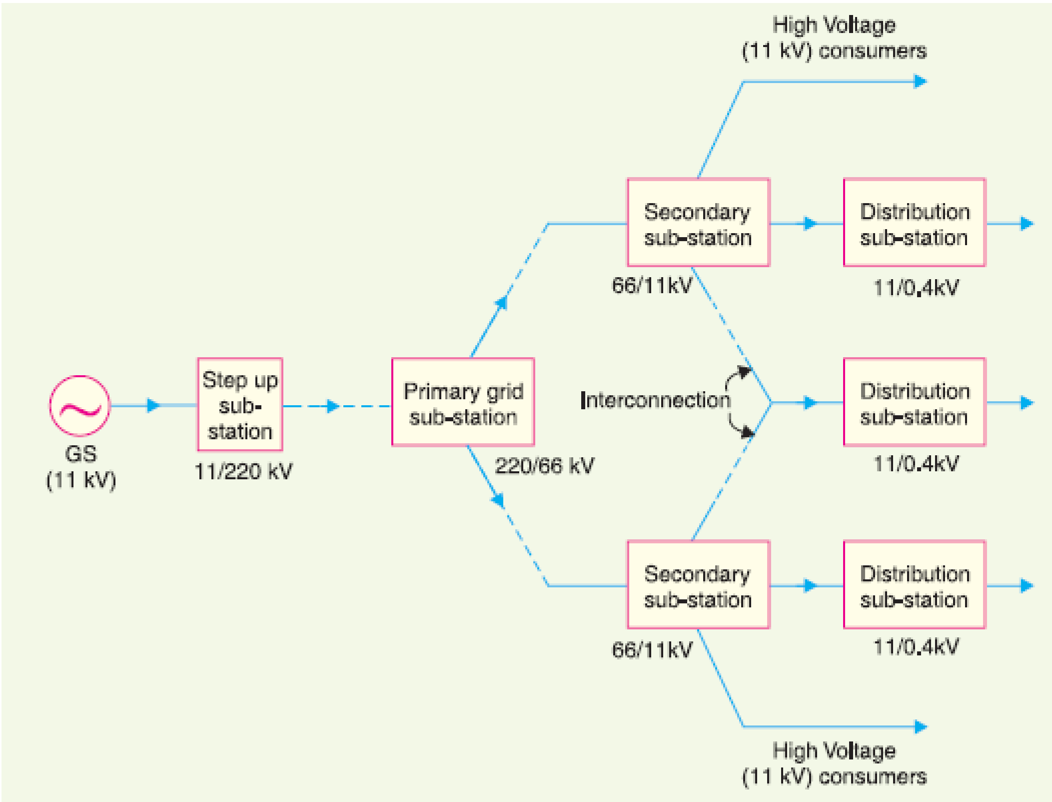


**Figure 1: Transformer substation**

**Pole mounted substation:** It is an overhead sub-station for distribution that is mounted on a pole. Because it doesn't require any construction, it is the least expensive type of sub-station. The pole-mounted sub-station's layout is shown in Fig. 2 (i), while the schematic connections are shown in Fig. 2 (ii). On an H-type pole (or 4-pole structure), further equipment and the transformer are placed.

Through a gang isolator and fuses, the 11 kV line is linked to the transformer (11 kV / 400 V). To guard against lightning strikes, lightning arresters are put on the H.T. side of the sub-station. The voltage is reduced by the transformer to 400V, 3-phase, 4-wire supply. While there is 230 V between any line and the neutral, there is 400 V between any two lines. In the event of a problem, the transformer is automatically isolated from the consumers by the oil circuit breaker (O.C.B.) mounted on the L.T. side. Transformer capacities up to 200 kVA are typically employed for pole-mounted sub-stations. The following details of pole-mounted sub-stations should be noted:

(i) The dielectric strength of the oil in the transformer and O.C.B. should be periodically checked.

(ii) The gang isolator and O.C.B. should both be turned off when a transformer or O.C.B. needs to be repaired.

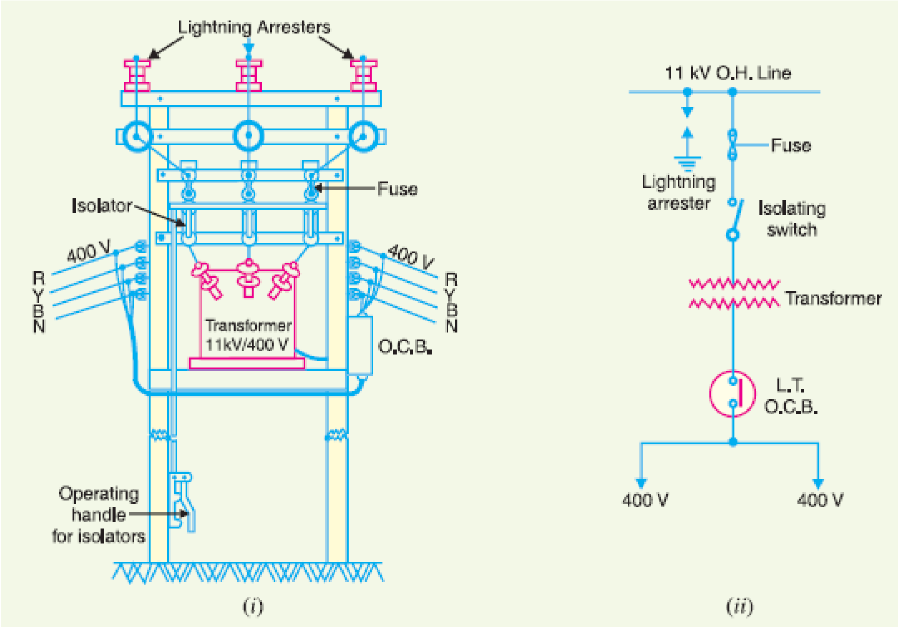


**Figure 2: Pole mounted substation**

**Underground substation**

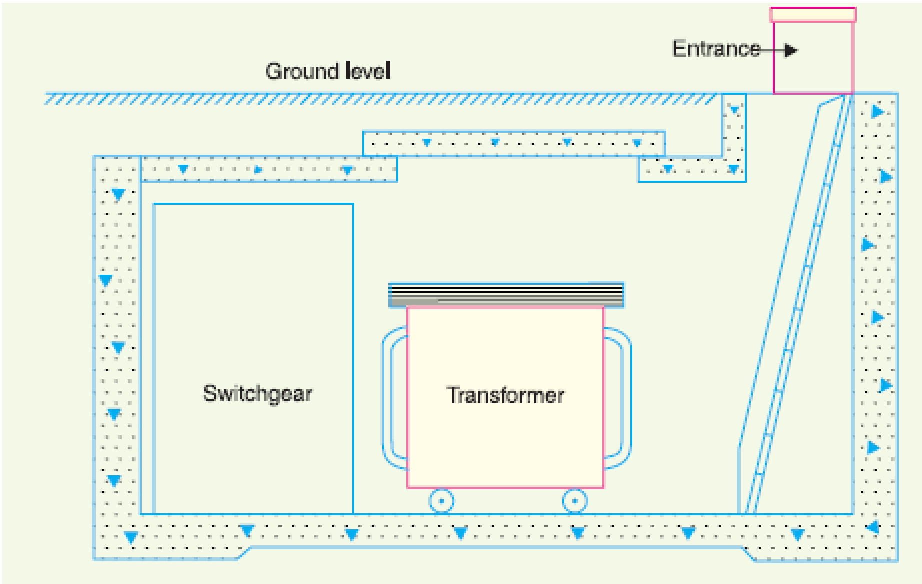


**Figure 3: Underground substation**

There is a shortage of land in densely crowded cities, and the cost of land is very expensive. The creation of underground sub-station is the result of this. In these sub-stations, the machinery is buried. A typical subterranean sub-station is shown in Fig. 3. Compared to other types of substation designs, underground substation design needs more careful attention sub-stations. The following considerations must be made while planning an underground sub-station:

(i) The station's size should be kept to a minimum.

(ii) Equipment and staff should both have easy access.

(iii) There should be provisions for both fire protection and emergency illumination.

(iv) There needs to be adequate ventilation.

(v) It should be possible to remotely detect an excessive temperature rise so that the H.V. supply can be cut off.

(vi) Air cooling is recommended for the fuses, switches and transformers to prevent oil from entering the building.

**Equipment in a Transformer substation**

A transformer sub-station's equipment requirements vary depending on the sub-station's kind, required services, and desired level of protection. However, a transformer sub-station typically has the following primary apparatus:

1. Bus-bars: Bus-bars are utilized as the common electrical component when several lines that operate at the same voltage must be directly connected electrically. Bus-bars are rectangular, usually x-shaped, copper or aluminum bars that run at a constant voltage. A sub-station's incoming and outgoing lines are connected to the bus-bars. The three bus-bar configurations that are most frequently used in sub-stations are (i) the single bus-bar arrangement (ii) the single bus-bar system with sectionalization, and (iii) the double bus-bar configuration. These bus-bar layouts have already been the subject of a thorough discussion. However, it is described how they can be used in sub-stations.

2. Insulators: These components have two functions. By restricting the current to the conductors, they support the conductors (also known as bus-bars). Porcelain is the material that is most frequently used to make insulators. There are numerous varieties of insulators, including pin, suspension, and post types. The sub-station's employment of these components (insulator, etc.) will depend on the level of service required. For bus-bars, for instance, a post insulator is employed. A post insulator's porcelain body and cast iron cap make up the device with a base made of cast iron. Bus-bars can be directly bolted to the cap thanks to the threaded hole in the cap.

3. Isolating Switches: It is frequently desirable to disconnect a portion of the system in sub-stations for routine maintenance and repairs. An isolating switch, often known as an isolator, achieves this. An isolator, which opens a circuit when there is no load, functions much like a knife switch. In other words, isolator switches can only be used when there is no current flowing through the lines to which they are connected.

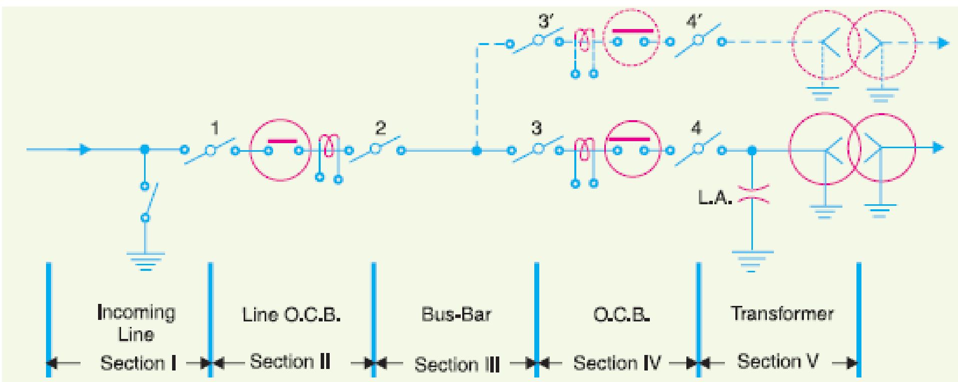


**Figure 4: Isolating switches**

The use of isolators in a typical sub-station is depicted in Fig. 4. There are V sections along the length of the sub-station. With the use of isolators, each section can be separated for repair and maintenance. For instance, if part No. II needs to be repaired, disconnecting this portion will be done as follows. Open isolators 1 and 2 after turning on the circuit breaker in this section. Section II will be disconnected throughout this process to be repaired. Close the isolators 1 and 2 first after the repair is finished, then the circuit breaker.

4. Circuit breaker: A circuit breaker is a piece of equipment that has the ability to open or close a circuit in both normal and malfunctioning circumstances. Its architecture enables manual (or remote control) operation under normal circumstances and automatic operation when there is a problem. A relay circuit combined with a circuit breaker is utilized for the latter operation. For voltages up to 66 kV, bulk oil circuit breakers are typically utilized, while low oil circuit breakers are employed for high voltages (>66 kV). Air-blast, vacuum or SF6 circuit breakers are utilized for even higher voltages. The reader may see chapter 19 for a thorough examination of these breakers [7]–[10].

5. Power Transformers: To increase or decrease voltage in a sub-station, a power transformer is utilized. All succeeding sub-stations, with the exception of the power station, employ step-down transformers to gradually lower the voltage of the electric supply before delivering it at utilization voltage. Although three single phase bank of transformers can also be utilized, the present standard is to employ three phase transformers in sub-stations. There are two benefits to using a 3-phase transformer rather than a bank of three single-phase transformers. One 3-phase load-tap changing mechanism can only be employed, to start. Second, compared to the three single phase transformers, its installation is easier. The power transformer is typically mounted on railings that are fastened to concrete slabs that have1 to 15 m-deep foundations. Oil-immersed, naturally cooled transformers are utilized for ratings up to 10 MVA. Transformers are typically air blast cooled for greater ratings.

Transformers for instruments: Substation lines run at high voltages and can carry thousands of amps of electricity. The measuring tools and safety equipment are made for low voltages (often 110 V) and currents (about 5 A). Therefore, if put directly on the power lines, they will not function properly. By putting instrument transformers on the power lines, this problem is solved. These instrument transformers' job is to convert power line voltages or currents into amounts that are useful for relays and measuring devices to operate on. Instrument transformers come in two different varieties: current transformers (C.T.) and potential transformers (P.T.).

(i) Current transformer: A current transformer (C.T.) is essentially a step-up transformer that steps down current to a predetermined ratio. One or more twists of thick wire linked in series with the line make up the transformer's primary. The secondary, which is made up of numerous twists of tiny wire, supplies current for measurement devices and relays current that is a constant percentage of the line's current. Consider connecting a 100/5 A current transformer to the line to measure the current. If the line current is 100 A, the secondary current will be 5 A. Similar to this, the secondary of a C.T. will have a current of 2.5 A if the line current is 50 A.

As a result, the C.T. under consideration will 20-fold reduce the line current.

(ii) Voltage transformer: This device, which reduces voltage to a predetermined ratio, functions essentially as a step-down transformer. This transformer's primary is made up of several twists of thin wire connected crosswise. A few turns make up the secondary winding, which provides for measuring devices and relays a voltage that is a known percentage of the line voltage. Let's say a power line is connected to a potential transformer with a 66kV/110V rating. The voltage across the secondary will be 110 V if line voltage is 66kV.

7. Metering and Indicating Instruments: Instruments for metering and indicating: A sub-station is equipped with a number of metering and indication devices (such as ammeters, voltmeters, energy metres, etc.) to keep track of the circuit amounts. They are always utilized in conjunction with the instrument transformers for successful operation.

8. Miscellaneous equipment. In addition to above, there may be following equipment in a

Sub-station:

(i) Fuses

(ii) carrier-current equipment

(iii) Sub-station auxiliary supplies

## CONCLUSION

Sub-stations are crucial parts of the electrical power distribution system because they make it possible to supply consumers with electricity in a stable and efficient manner. They guarantee that power may be securely supplied to multiple locations by changing and controlling voltage levels. Transformers, circuit breakers, and protective devices all work together in a sub-station to keep the system stable and guard against errors. Sub-stations are run using monitoring and control systems that allow for effective energy management and quick reaction to any disturbances.

Sub-stations are developing to include smart grid capabilities as a result of continued technological improvements, enabling improved monitoring, automation, and integration of renewable energy sources. In order to satisfy the continuously rising demand for electricity in contemporary society, sub-stations serve a crucial role in preserving the reliability of the electrical power distribution system.

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# CHAPTER 10

# BUSBAR ARRANGEMENT IN SUB-STATION

Mr. Vesapogu Joshi
Associate Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id:joshimanohar@presidencyuniversity.in

**ABSTRACT:**

The effective and dependable distribution of electrical power is greatly influenced by the busbar configuration in a substation. This chapter examines a variety of busbar arrangement-related topics, such as their significance, distinct varieties, and things to keep in mind when building a bus bar system. Additionally, it covers the benefits and drawbacks of various busbar layouts and how they affect the substation's overall performance. This chapter's goal is to give a thorough review of busbar configurations in substations and to assist engineers and designers in making well-informed decisions on the design and implementation of busbar systems. The busbar configuration is an essential component of substation design that affects the electrical power system's efficiency, reliability, and fault-handling capabilities. The many busbar layouts that are frequently utilized in substations are thoroughly discussed in this essay. The importance of bus bars, their function in power transmission and distribution, and the different considerations that affect the decision to choose a particular busbar configuration are all covered in this article.

**KEYWORDS:**

Busbar Arrangement, Busbar Configuration, Power Supply, Single Busbar System, Transmission and Distribution.

## INTRODUCTION

Engineers and operators can optimize substation performance and guarantee a steady power supply by making decisions based on a solid understanding of busbar arrangements.The generators, transformers, circuit breakers, and transmission lines that make up the electrical power system all work together to produce, transfer, and distribute electrical power. Between the transmission and distribution systems, substations serve as transitional locations where voltage levels are changed, managed, and distributed to end customers. Bus bars are essential for connecting and transporting power between various parts of a substation. These conductors' configuration and design are determined by the busbar arrangement, which has an effect on the substation's overall effectiveness and dependability [1]–[3].

Importance of busbar arrangement: Reliable Power Transfer: Within a substation, the busbar configuration has a direct impact on the dependability of power transfer. Bus bars guarantee minimal losses and voltage drop during gearbox by offering a strong and effective channel for power transfer. A well-planned busbar configuration reduces impedance and heat losses, increasing the substation's overall efficiency. In order to satisfy customer demand for electricity and prevent disruptions or voltage swings, reliable power transfer is necessary.A substation's busbar configuration performs a number of vital tasks. First off, it offers a reliable and effective way to transfer power between various devices, including circuit breakers, transformers, and generators. The coupling of these components and the transmission and distribution of electrical power are made possible by the busbars, which serve as a core support system. Second, the busbar configuration influences the substation's ability to handle faults. Busbars are essential in diverting and isolating the faulty parts during faults or abnormal situations, such as short circuits, to keep the rest of the substation operational. The method of busbar arrangement chosen can have a big impact on how quickly and effectively faults are found, isolated, and fixed. Thirdly, the busbar configuration affects the power system's dependability and redundancy. Substations can provide alternate channels for power flow by utilizing the proper configurations, such as twin busbar or ring bus arrangements, which enables selected maintenance, expansion, and problem handling without interrupting the power supply. The busbar configuration also has an impact on the substation's overall operational flexibility. In terms of adding or deleting feeders, modifying the connection points, and accommodating future expansions, different layouts offer differing degrees of flexibility. A well-thought-out busbar configuration makes it possible for the substation to react to shifting demands and changing power demands.

Fault Handling Capabilities: The busbar layout has a considerable impact on the substation's ability to handle and isolate faults in the case of faults or abnormal situations. How quickly and effectively defects can be found, isolated, and fixed depends on the busbars' configuration and design. Numerous busbar configurations provide selective fault handling and fault tolerance, minimizing the effects of errors on the entire system. The power supply can be kept intact in the substation's healthy sections thanks to, for instance, a ring bus configuration that enables sectionalization of faulted areas. Rapid fault isolation and detection help keep downtime to a minimum and keep the power supply reliable.

System Flexibility: Busbar arrangements are crucial in a substation's ability to operate with operational flexibility. Selective power transfer and maintenance are made possible by various configurations, such as double busbar or breaker and a half topology. The ability to switch the power flow between busbars and expand, add, or remove feeders are both made possible by this flexibility. A variable busbar configuration improves the substation's ability to respond to shifting power requirements, potential expansions, and technology developments. Additionally, it makes load shedding, effective load distribution, and the incorporation of renewable energy sources possible.

Maintenance Points: Reliable operation of substations depends on efficient maintenance. The busbar configuration influences how simple and effective maintenance tasks are. Configurations that permit selective maintenance reduce downtime and power supply disturbance. For instance, the double busbar configuration allows for the power to be transferred through the alternative busbar when one busbar is isolated for maintenance. By eliminating the requirement for full substation shutdowns during maintenance procedures, this feature increases the dependability of the power supply.

For effective power transmission and distribution, the busbar configuration in substations is crucial. The busbar configuration has a significant impact on dependable power transfer, fault handling capabilities, system flexibility, and maintenance issues. Engineers and operators can improve the robustness, efficiency, and resilience of substations by optimizing the design and configuration of busbars, which will ultimately result in a steady and uninterrupted power supply. By enabling stakeholders to make educated decisions, understanding the significance of the busbar configuration improves the overall effectiveness and dependability of the electrical power system.

**Factors affecting busbar arrangement selection**

In the construction of substations, choosing a suitable busbar configuration is a crucial choice. This decision is influenced by a number of variables, including the size of the substation, the need for fault handling, long-term planning, maintenance considerations, and cost. This article examines these elements in depth, emphasizing how they affect the selecting procedure. Engineers and operators may optimize the busbar configuration and guarantee effective and dependable power transmission and distribution by having a thorough understanding of these deciding criteria.

Substation Size and Capacity: The right busbar layout is heavily influenced by the size and capacity of the substation. Smaller substations with fewer feeds may use a more straightforward structure, like a single busbar system. This system is simple to use and economical. Larger substations with higher power requirements, on the other side, call for more complicated configurations, like a twin busbar or multiple busbar layout. These set-ups offer the flexibility, fault tolerance, and redundancy required to handle the increased demand.

Fault Handling Requirements: A reliable power supply depends on the substation's ability to handle faults. More sophisticated busbar solutions might be needed for substations that are situated in fault-prone regions or in locations where prompt fault isolation, identification, and restoration are essential. The ring bus and breaker and a half configuration, for example, offer enhanced fault tolerance and selective fault isolation capabilities. By reducing the effects of problems on the power system, these systems guarantee uninterrupted power delivery to unaffected areas.

Flexibility and Future Planning: Busbar arrangements must to be created with future planning in mind. Substations must be flexible enough to accommodate future expansions, changing power needs, and technology improvements. The chosen configuration should make it simple to add or remove feeders, connection points, and equipment without impairing the general flow of power. The flexibility required to adapt the power system to future expansion and modifications is provided by configurations like the double busbar or multi-busbar setups.

Maintenance Considerations: When choosing a busbar configuration, it's important to take maintenance into account as well as how it will affect the power supply. Substations require routine upkeep and sporadic repairs. The double busbar or breaker and a half arrangement, which enable selective maintenance, minimize downtime and guarantee continuous power supply during maintenance procedures. This factor is especially significant in vital infrastructure or sectors where a constant source of power is required. The best performance and the least amount of system disturbances are guaranteed with careful consideration of the maintenance requirements.

Budget & Cost Restraints: When choosing a busbar configuration, installation, and maintenance costs play a big role in the decision. Budget-constrained substations may choose less complex configurations, such as the basic and affordable single busbar configuration. Cost factors must be balanced with the necessary reliability and fault handling skills, though. Higher initial costs may be associated with more complicated setups like twin busbar or multi-busbar systems, but they offer improved redundancy, fault tolerance, and operational flexibility. To ensure the most cost-effective solution for the particular substation, it is crucial to evaluate the long-term benefits and financial repercussions.

Integration with Existing Infrastructure: In some circumstances, the integration with existing infrastructure may have an impact on the choice of busbar arrangement. A substation's compatibility and interoperability with the current setup may need to be taken into account if it is a part of an existing power system or network. In order to achieve seamless integration and minimal interruption to the existing infrastructure, it may be necessary to carefully evaluate the busbar layout while retrofitting or updating old substations.

Environmental issues: The choice of busbar configuration may also be influenced by environmental concerns such as seismic issues, severe weather, or corrosive surroundings. To withstand such conditions, substations located in earthquake-prone or harsh weather locations may need specialized designs or reinforced busbar arrangements. To ensure the longevity and dependability of the busbars in corrosive conditions, it may be necessary to utilize specialized materials or protective coatings.

The choice of an appropriate busbar configuration for substations is a crucial choice that affects the power system's overall efficiency, dependability, and flexibility. Substation size, fault handling needs, long-term planning, maintenance needs, cost, integration with existing infrastructure, and environmental concerns are just a few of the variables that need to be carefully considered. Engineers and operators can choose the best busbar layout by carefully taking into account these deciding elements, providing efficient and dependable power transmission and distribution in substations [4]–[6].

## DISCUSSION

The crucial elements in a sub-station are bus-bars. In a sub-station, there are various bus-bar configurations that can be used.

The selection of a specific configuration is influenced by a number of variables, including system voltage, sub-station location, reliability level, cost, etc. These are the significant bus-bar configurations found in sub-stations:

**(i) Single bus-bar system:** This system has a single bus-bar, to which all incoming and outgoing lines are linked, as the name implies. Low startup costs, little upkeep, and ease of use are this type of arrangement's key benefits. The main drawback of a single bus-bar system is that if a bus-bar needs to be repaired or if a problem develops on the bus, the supply is completely cut off. Voltages greater than 33 kV are not used in this configuration.

The single bus-bar layout is frequently used in indoor 11kV sub-stations. A sub-station's single bus-bar configuration is shown in Fig. 1. Two 11 kV incoming lines are linked to the bus-bar via isolators and circuit breakers. The 11kV/400 V transformers and circuit breakers are used to link the two 400V outgoing lines to the bus bars.

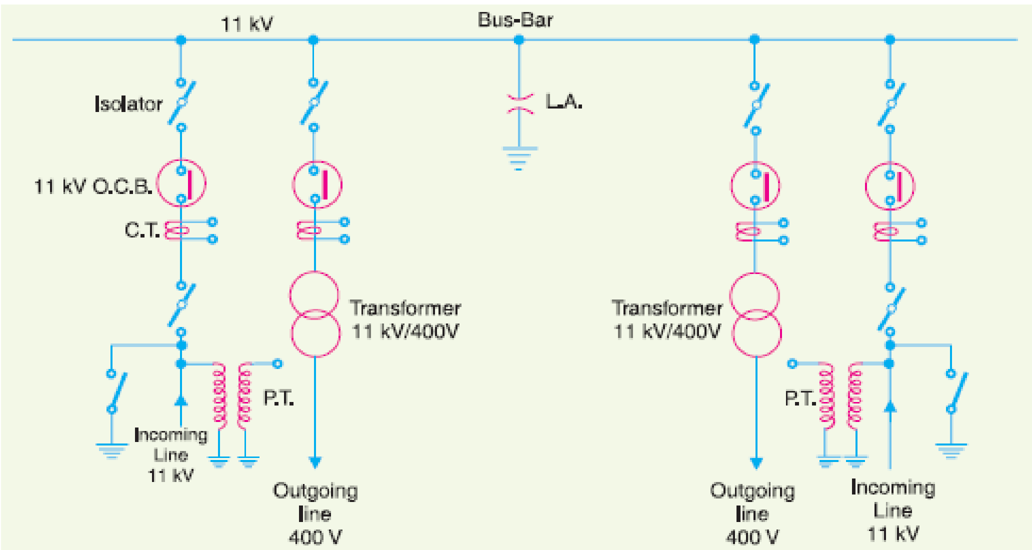


**Figure 1: single busbar system**

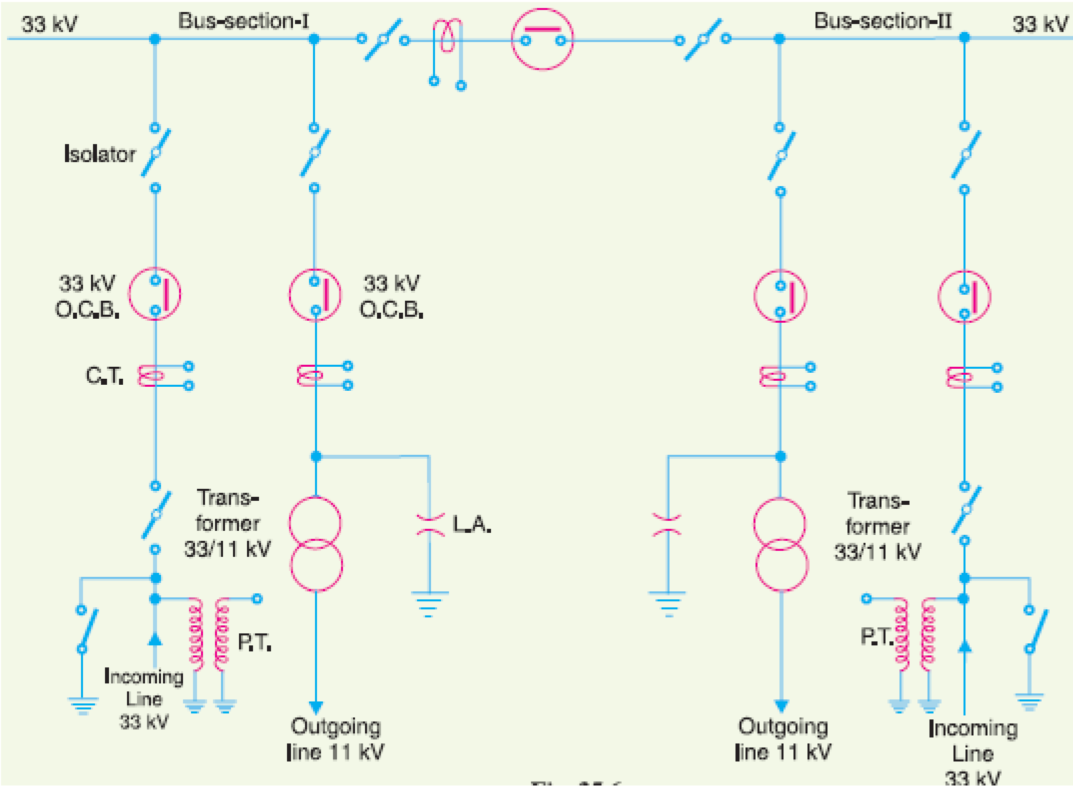


**Figure 2: single bus-bar system that includes sectionalization**

**(ii) A single bus-bar system that includes sectionalization:** In this configuration, a single bus-bar is separated into portions, with load being distributed evenly among each sector. A circuit breaker and isolators connect any two adjacent busbar sections. This configuration is said to have two main advantages.

First off, any piece of the bus can be isolated in the event of a problem without affecting the supply from other sections. Second, complete shutdown is not a possibility because any component of the busbar can be repaired or maintained by just de-energizing that particular section. The application of this configuration ranges up to 33 kV.

The bus has been divided into two portions in Fig. 2's bus-bar with sectionalization. Sections I and II are shown to be connected to two 33 kV incoming lines by circuit breakers and isolators. The connection between each 11 kV outgoing line and one segment is made by a transformer (33/11 kV) and circuit breaker. It is clear that each bus-section functions as a different bus-bar.

**(iii) A duplicate bus-bar system has two bus-bars:** one is the "main" bus-bar, and the other is the "spare" bus-bar. The sub-station load can be carried entirely by each bus-bar. A bus-bar coupler, which comprises of a circuit breaker and isolators, can be used to connect the incoming and outgoing lines to either bus-bar. The incoming and outgoing lines often stay attached to the main bus-bar.

The circuit can still receive power by switching to the backup bus-bar in the event that the primary bus-bar needs to be repaired or experiences a failure. The duplicate bus-bar arrangement is typically utilized for voltages more than 33 kV. The layout of a duplicate bus-bar system in a typical sub-station is shown in Fig. 3.

A bus-bar coupler allows the two incoming 66kV wires to be connected to either bus-bar. Two 11 kV outbound cables Lines are connected to the bus-bars using circuit breakers and 66/11 kV transformers.

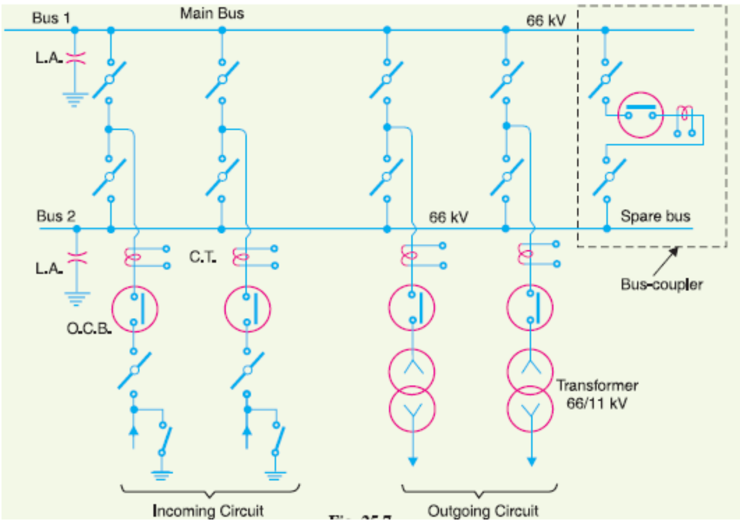


**Figure3: duplicate bus-bar system has two bus-bars**

**Terminal and through substation:**

(i) Terminal sub-station: A terminal sub-station is one where the line supplying power to the substation stops or is cut off. It could be situated at the end of the main line or someplace else other than the main line route. In the latter scenario, a tapping is made to supply the sub-station from the main line. It is obvious that the sub-station is where the incoming 11 kV main line finishes. These are the majority of the distribution sub-stations.

(ii) Through sub-station: A through sub-station is one where the incoming line 'passes through' at the same voltage. In order to lower the voltage to the necessary level, a tapping is often taken from the line and fed to the transformer. The incoming 66 kV line and the outgoing 66 kV line both pass via the sub-station. In addition, the sub-station taps the incoming line to lower the voltage to 11 kV for secondary distribution.

**Key Diagram of 66/11 kV Sub-Station**

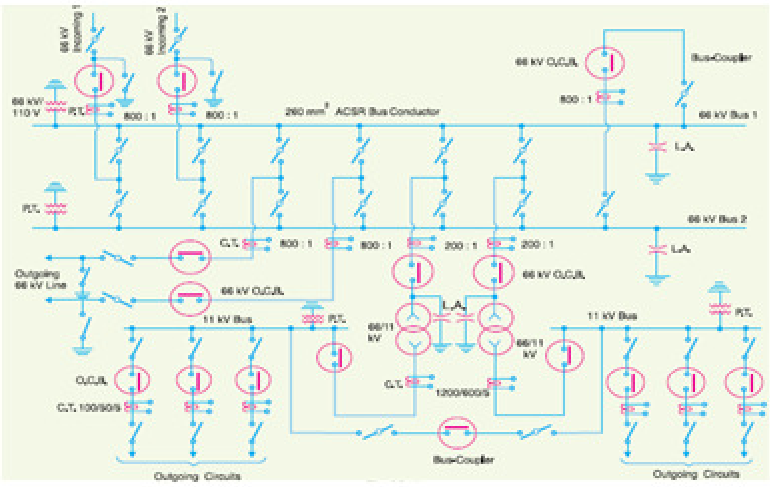

**Figure 4: Key Diagram of 66/11 kV Sub-Station**

The main diagram of a typical 66/11 kV sub-station is shown in Fig. 4. The following explanation explains the main schematic of this substation:

(i) The two incoming 66 kV lines with the designations "incoming 1" and "incoming 2" are connected to the bus-bars. Double circuits are two incoming lines arranged in this manner. The rated sub-station load can be supplied by each incoming line. These two lines could both a single line can be used to handle the entire load and multiple lines can be loaded simultaneously to share the sub-station load. The two circuit configuration makes the system more reliable. In the event that one incoming line fails, the other line can keep the supply flowing continuously.

(ii) The sub-station features two bus-bar systems—one designated as the "main bus-bar" and the other as a backup. A bus-coupler, which comprises of a circuit breaker and isolators, can be used to link the incoming lines to either bus-bar. The benefit of a double bus-bar system is that if a repair needs to be made to one bus-bar, the supply won't need to be stopped because the full load may be moved to the other bus [7]–[10].

(iii) The sub-station has a configuration that allows the same 66 kV double circuit supply to be sent out, meaning that the 66 kV double circuit supply is travelling via the sub-station. It is possible to convert the outgoing 66 kV double circuit line into an incoming line.

(iv) There is also a plan to use two sets of 3-phase transformers to scale down the incoming 66 kV supply to 11 kV, with each transformer feeding to a different bus-bar. Typically, one transformer serves as the standby unit and the other one powers the entire sub-station load. Both transformers can be used to split the sub-station load if necessary. The distribution sub-stations, which are situated close to consumer communities, are fed by the 11 kV outgoing lines.

(v) Circuit breakers with isolators on either end are used to link the incoming and outgoing lines. The line is always switched off before being earthed if maintenance needs to be done over the line towers.

(vi) The current transformers (C.T.) and potential transformers (P.T.) are properly positioned for supply to relay circuits and metering and signalling equipment. These components are not depicted in the image. The P.T. is connected directly at the line's termination. Each circuit breaker's terminals have the CTs linked to it.

(vii) In order to shield the transformer terminals from lightning strikes, lightning arresters are attached close by (on the H.T. side).

(viii) The sub-station also has additional auxiliary parts, such as a capacitor bank for improving power factor, earth connections, local supply connections, d.c. supply connections, etc. For the purpose of simplicity, these have been left out of the essential diagram.

**Key Diagram of 11 kV/400 V Indoor Sub-Station**

The main diagram of a typical 11 kV/400 V indoor sub-station is shown in Fig. 5. Below is an explanation of this sub-station's important diagram:

(i) The 11 kV line with three phases and three wires is tapped and transported to the gang operating switch placed close to the sub-station. Isolators linked to each phase of the three-phase line make up the G.O. switch.

(ii) An underground cable is used to transport the 11 kV line from the G.O. switch to the indoor sub-station. It is fed through the 11 kV O.C.B. to the H.T. side of the transformer (11 kV/400 V). The voltage is reduced by the transformer to 400 V, 3-phase, and 4-wire.

(iii) Through the main O.C.B., the secondary of the transformer serves the bus-bars. 400 V, 3-phase, 4-wire supply from the bus bars is provided to the various customers via 400 V O.C.B. There is 230 V between any phase and the neutral and 400 V between any two phases. While a 3-phase, 400 V motor load is linked directly across 3-phase wires, a single-phase domestic load is connected between any one phase and neutral.

(iv) The CTs are placed in the sub-station circuit and supply at appropriate locations for the metering and relay circuits, as well as signalling devices.

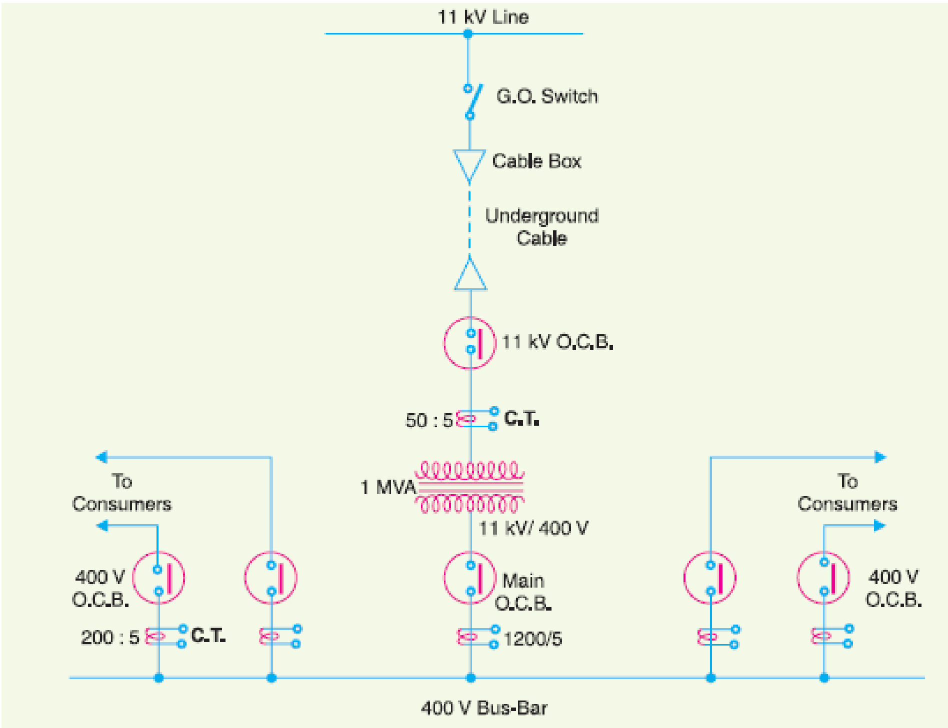


**Figure 5: Key Diagram of 11 kV/400 V Indoor Sub-Station**

## CONCLUSION

One important factor that affects the effectiveness and dependability of electrical power distribution is the busbar configuration at a substation. When building a busbar system, a number of elements must be taken into account, including the type of substation, load requirements, space availability, and fault tolerance.

The performance, operational flexibility, and maintenance needs of the substation are significantly impacted by the busbar layout, whether it is a single bus, double bus, ring bus, or breaker-and-a-half scheme. Each layout has benefits and drawbacks, and the choice should be made after a comprehensive examination of the substation's unique needs and limitations. For a safe and dependable power supply to customers, the busbar system must be properly planned and implemented.

To quickly identify and resolve any possible faults, the busbar system must be continuously monitored and maintained. Overall, an effective busbar configuration that is properly maintained is crucial for a substation's smooth operation and the steady flow of electricity to end consumers.

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# CHAPTER 11

# AN ANALYSIS OF NEUTRAL GROUNDING IN ELECTRICAL POWER SYSTEMS

Mrs. Ramya
Assistant Professor, Department of Electrical and Electronics Engineering,
Presidency University, Bangalore, India.
Email Id: ramyak@presidencyuniversity.in

**ABSTRACT:**

Neutral grounding is a crucial component of electrical power systems that helps to guarantee the equipment's reliability and safety. It entails using a grounding resistor or impedance to connect a power system's neutral point to a reference point, usually the earth. The idea of neutral grounding, its importance, several forms of grounding techniques, and their effects on system performance are all explored in this chapter. In a power system, "grounding" or "earthing" refers to connecting an electrical component, such as a neutral point in a star-connected system, a secondary conductor of a transformer, or some other electrical component, to the earth, or dirt. Depending on the circumstances, this connection to earth might be made by a conductor or another circuit component (such as a resistor, a circuit breaker, etc.). No matter how you connect to the earth, there are two main benefits to grounding or earthing. It first safeguards the electrical system. A substantial fault current will flow via the circuit breaker, for instance, if the neutral point of a star-connected system is grounded through a circuit breaker and a phase to earth fault develops on any one line.

**KEYWORDS:**

Equipment Grounding, Neutral Grounding, Resistance Grounding, System Grounding, Solid Grounding.

## INTRODUCTION

To isolate the defective line, the circuit breaker will trip. By doing this, the electricity system is shielded from the fault's negative repercussions. Second, earthing electrical devices (such as home appliances and handheld). The safety of the individuals using the equipment is ensured by the use of tools, industrial motors, etc. For instance, if insulation fails, the live conductor will come into direct contact with the metallic component (i.e. frame) of the apparatus. Anybody who comes into contact with the metallic component of this apparatus will experience a deadly electrical shock. The significance of earthing, or earthing, in the line of power system will be covered in this chapter, with a focus on neutral earthing [1]–[3].

### Grounding or Earthing

It is known as grounding or earthing to link the metallic frame, or non-current carrying component, of electrical equipment, or some electrical component of the system, such as the neutral point in a star-connected system, one conductor of the secondary of a transformer, etc., to earth (soil). The less understood part of the power system is electrical system grounding, which is weird yet accurate. However, it is a highly significant topic. We can effectively prevent accidents and damage to the equipment of the power system and preserve supply continuity if grounding is done methodically in the lines of the power system. There are two types of grounding or earthing: system grounding and equipment grounding. Equipment grounding involves connecting the metal components of electrical equipment that do not transport current to the earth. System grounding, on the other hand, entails earthing a portion of the electrical system, such as the neutral point of a system connected to a star in generating stations and sub-stations.

**Equipment grounding**

Equipment grounding is the practice of connecting non-current-carrying metal components of electrical equipment (such as the metallic enclosure) to earth (such as soil) so that, in the event of insulation failure, the enclosure effectively remains at earth potential.

Electrical devices of various kinds, from home appliances and handheld tools to industrial motors, are something we constantly interact with. By taking into consideration a single-phase circuit made up of a 230 V source linked to a motor M as illustrated in Fig. 26.1, we will demonstrate the necessity of appropriate equipment grounding. At the service door, you'll see that neutral is firmly grounded. For the sake of clarity, we will break up the topic into three sections, namely. (i) An ungrounding enclosure (ii) A connection to the neutral wire (iii) A connection to the ground wire.

(i) Ungrounded enclosure: An ungrounded enclosure is depicted in Fig. 1 in this situation. If the device is working properly, nothing will happen if a person touches the metal cage. The resistance Re between the motor and enclosure, however, lowers to a low value (a few hundred ohms or less) if the winding insulation develops a defect. The current journey as depicted in Fig. 1 would be completed by a person with a body resistance Rb. The leakage current IL through the person's body could be extremely high if Re is low, which is typically the case when insulation failure of the winding occurs. The consequence would be a significant electric shock that might be lethal. This system is dangerous as a result.

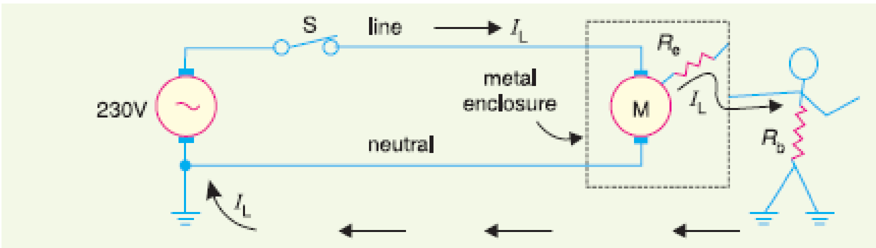


**Figure 1: Equipment Grounding Through Ungrounded Enclosure**

(ii) Enclosure connected to neutral wire: Connecting the enclosure to the grounded neutral wire as illustrated in Fig. 2 may seem to be the solution to the aforementioned issue. The leakage current IL now travels directly from the motor to the neutral wire after passing through the enclosure (see Fig. 2). The enclosure therefore continues to have an earth potential. As a result, the operator wouldn't get shocked by electricity.

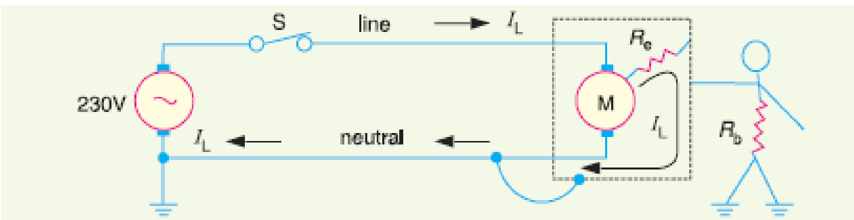


**Figure 2: Equipment grounding through Enclosure connected to neutral wire**

(iii) Ground wire connected to enclosure: As illustrated in Fig. 3, we place a third wire, known as a ground wire, between the enclosure and the system ground to solve this issue. The ground wire could be insulated or left bare. Green indicates that it is insulated.

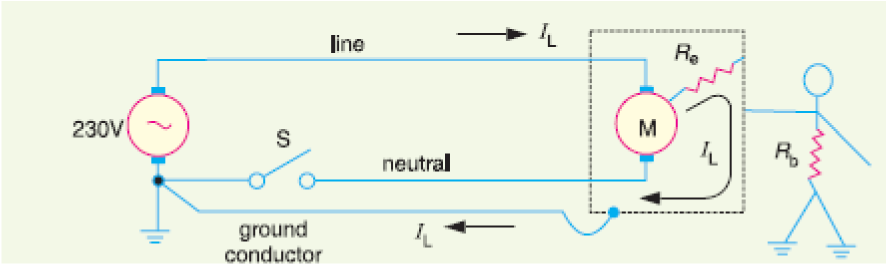


**Figure 3: Equipment grounding through Ground wire connected to enclosure**

## DISCUSSION

### System grounding

System grounding is the process of connecting a certain electrical component of the power system to earth (soil), such as the neutral point of a star connected system, a secondary conductor of a transformer, etc. In the rapidly developing power system, the relevance of system grounding has increased significantly. We can obtain various benefits, including protection, dependability, and safety to the power system network, by adopting correct system grounding schemes. But in order to understand the significance of system grounding, it is preferable to provide two examples before going over the many facets of neutral grounding.

(i) The primary winding of a distribution transformer is shown connected between an 11 kV line's line and neutral in Fig. 4 (i). It would seem that a person could touch either secondary conductor without getting hurt if they were grounded, as there is no ground return. This is untrue, though. The capacitance C1 between the primary and secondary, as well as the capacitance C2 between the secondary and ground, are shown in Fig. 4. A significant voltage difference between the secondary lines and the ground may result from this capacitance coupling. It might be as high as 20% to 40% of the primary voltage, depending on the relative sizes of C1 and C2. Even with small transformers, the capacitive current (IC) that results from touching any of the secondary wires and flows through the body could be harmful [See Fig. 4(ii)]. For instance, if IC is just 20 mA, the individual could receive a lethal electric shock. The capacitive coupling and capacitive current IC virtually reach zero if one of the secondary conductors is grounded. The person won't get an electric shock as a result. This clarifies why system grounding is crucial.

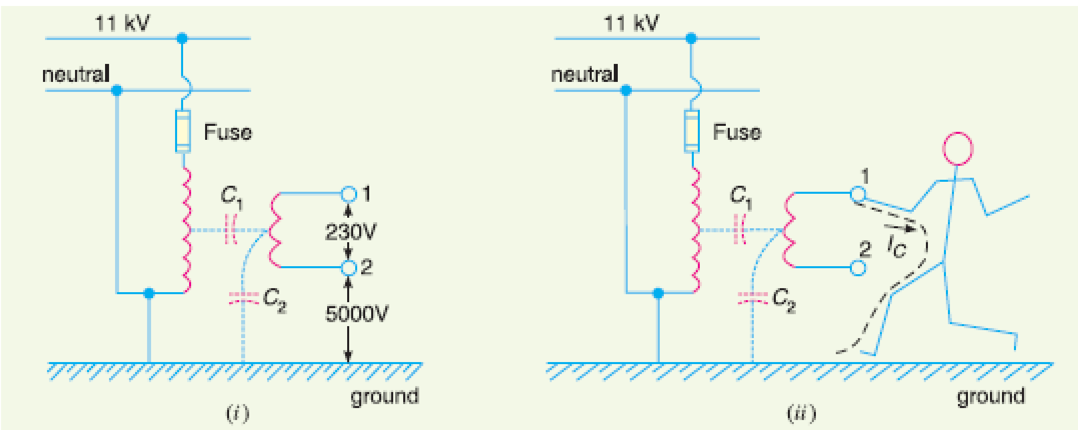


**Figure 4: System grounding**

(ii) Let's move on to a more dire scenario. The primary winding of a distribution transformer positioned between an 11 kV line's line and neutral. Ungrounded secondary conductors are used. Assume that the 230 V conductor is touched by the high voltage line (11 kV in this instance). A branch or tree falling across the 11 kV and 230 V cables or an internal failure in the transformer are both potential causes of this. A very high voltage is applied between the secondary conductors and ground in these conditions. The 230 V insulation would be rapidly damaged, leading to a significant flashover. Anywhere on the secondary network, even perhaps inside a house or factory, could experience this flashover. Because of this, ungrounded secondary in this situation poses a risk of fire and may result in serious accidents under unusual circumstances.

**Underground Neutral system**

The neutral in an ungrounded neutral system is isolated from the ground since it is not connected to the ground. Because of this, this system is also known as a free neutral system or an isolated neutral system. Ungrounded neutral system is seen in Fig. 5. There are capacitances between the line conductors and to ground. The former are connected via delta, whilst the latter are connected via stars. The delta-connected capacitances can be disregarded because they have no impact on the system's grounding characteristics (i.e., they have little impact on the earth circuit) [4]–[6].

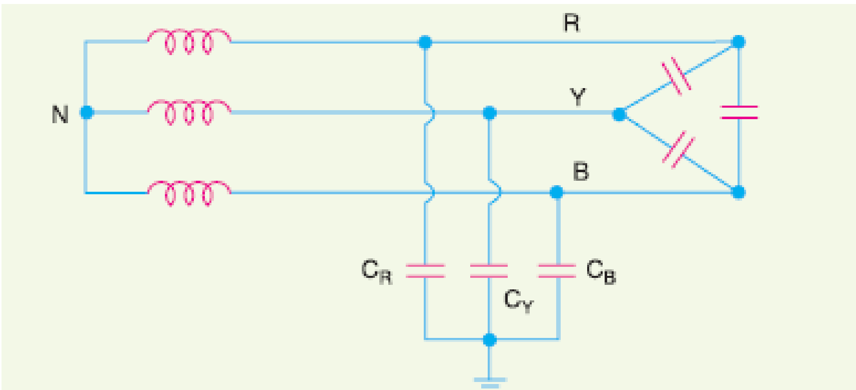


**Figure 5: Underground Neutral system**

**Neutral Grounding**

Neutral grounding is the technique of connecting the neutral point of a three-phase system to the earth (soil), either directly or through a circuit component (such as resistance, reactance, etc.). Personal and equipment are protected by neutral grounding. This is so that the protective devices (such as a fuse, etc.) can function to isolate the faulty conductor from the rest of the system when an earth fault occurs and the current route is completed through the earthed neutral.

Fig. 6 provides an illustration of this point.A 3-phase, star-connected system with an earthed neutral point (neutral point is connected to ground) is shown in Fig. 6. Let's say point F on line R experiences a single line to ground fault. As depicted in Fig. 6, this will result in the current flowing through the ground path. Keep in mind that current travels from R phase to earth, then to neutral point N and finally back to R phase. A significant current flow through this path due to the low impedance.

This substantial current will isolate the problematic line R and explode the fuse in R-phase. This will shield the system from the fault's negative repercussions, such as equipment damage and employee electric shock. The potential difference between the live conductor and ground will not exceed the phase voltage of the system, which means it will remain almost constant. This is a crucial characteristic of grounded neutral.

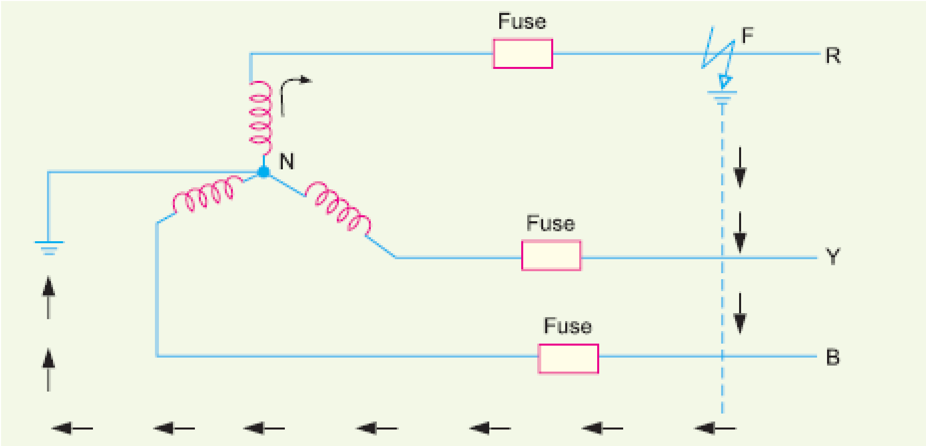


**Figure 6: Neutral grounding**

**Advantage of Neutral grounding**

The benefits of neutral grounding are as follows:

(i) The voltages of the healthy phases are almost constant and do not exceed the voltages from the line to ground.

(ii) Arcing grounds' high voltages are eliminated.

(iii) Earth fault protection can be offered using the protective relays. The protective relay will activate in the event of an earth fault on any line to isolate the problematic line.

(iv) Lightning-related over voltages are dumped to earth.

(v) It increases the safety of the workers and the machinery.

(vi) It offers enhanced service dependability.

(vii) Operating and upkeep costs are decreased.

**Solid grounding**

It is referred to as solid grounding or effective grounding when the neutral point of a three-phase system (such as a three-phase generator, transformer, etc.) is directly connected to earth (i.e. dirt) through a wire with minimal resistance and reactance.

Advantage and disadvantages of solid grounding:

Advantages. The advantages of neutral point's firm grounding are as follows:

(i) Earth potential successfully holds the neutral.

(ii) The capacitive current IC that results from an earth fault on any phase is in phase opposition present fault IF. Both currents totally cancel one another out. As a result, neither an arcing ground nor an over-voltage situation may exist. Take a line-to-ground problem for example B. The capacitive currents IR and IY, respectively, are flowing in the healthy phases R and Y. The phasor sum of IR and IY yields the capacitive current IC. The power supply also provides the fault current, abbreviated IF, in addition to these capacitive currents. This fault current will travel through the faulty phase and from the fault point to earth, neutral point N, and back to the fault point. The IC's path is capacitive, while the IF's path is inductive. The two currents entirely cancel each other out since they are in phase opposition. As a result, neither the arcing ground phenomenon nor over-voltage situations are possible.

(iii) The phase to earth voltage of the faulty phase drops to zero when an earth fault occurs on any phase of the system. However, because the neutral's potential is set at earth potential, the phase to earth voltages of the other two healthy phases continue to be at normal phase voltage. This enables the device to be phase voltage insulated. As a result, the cost of equipment is reduced.

(iv) It becomes simpler to defend the system against the regular earth faults that affect it. A significant fault current flows between the fault site and the grounded neutral whenever an earth fault occurs on any phase of the system. This makes it possible for earth fault relays to operate simply.

Disadvantages: The drawbacks of a firm foundation include the following:

(i) Because phase to earth problems make up the majority of faults on an overhead system, the system must withstand a lot of extremely damaging shocks. The system becomes unstable as a result of this.

(ii) Strong earth fault currents are caused by the solid grounding. Heavy earth fault currents may result in the burning of circuit breaker contacts since the fault must be cleared by the circuit breakers.

(iii) Because of the higher earth fault current, nearby communication links are more likely to experience interference.

Applications: When the circuit impedance is strong enough to maintain the earth fault current within safe bounds, solid grounding is typically used. This grounding system is utilized for voltages up to 33 kV with a maximum total power capacity of 5000 kVA.

**Resistance grounding**

Resistance grounding is a technique used in electrical power systems to control the flow of fault currents and limit the size of the fault current. It entails using a grounding resistor to link a power system's neutral point to the ground. This resistor restricts the current flow during a malfunction, reducing excessive equipment damage and potential worker dangers. The resistance grounding technique has a number of benefits. By causing a voltage drop across the grounding resistor, it first enables the identification of ground defects. This voltage may be tracked, and if it rises beyond a certain threshold, a problem is present.

This makes it easier to quickly identify faults and to schedule maintenance and repairs. Second, resistance grounding reduces the possibility for thermal and mechanical pressures on system components by limiting the ground fault current magnitude. System reliability is increased as a result of reducing equipment damage and extending the life of electrical equipment. Resistance grounding also reduces the possibility of transient over voltages. It prevents equipment from being damaged by voltage surges that can lead to insulation breakage and other electrical problems by giving fault currents a controlled path. Resistance grounding does have some drawbacks, though. In contrast to solid grounding techniques, it does not offer full fault current clearing.

A voltage will also be present between the neutral and ground during a ground fault, raising the risk of electric shock dangers. To summarize, resistance grounding is a useful technique for reducing the size of a fault current and enhancing the security and dependability of electrical power systems. It is a popular grounding technique used in many industrial and commercial applications because it finds a compromise between minimizing equipment damage and protecting against fault currents.

**Benefits and drawbacks of Resistance grounding:**

Resistance grounding has several benefits.

1. Fault Current Limitation: Resistance grounding's capacity to restrict fault currents is one of its key benefits. The neutral path grounding resistor is used to reduce the fault current's overall strength. This lessens heat and mechanical strains, prevents excessive equipment damage, and improves system reliability all around.
2. Fault Detection: Resistance grounding makes it possible to discover ground defects. A voltage drop is produced across the grounding resistor when a fault occurs. Operators can detect the presence of a malfunction and act quickly to perform maintenance and repairs by monitoring this voltage. Early defect detection reduces downtime and raises the power system's overall effectiveness.
3. Transient Overvoltage Mitigation: Resistance grounding reduces the likelihood of transient over voltages during a fault by preventing them. It controls the growth in voltage by giving fault currents a controlled path, shielding equipment from voltage spikes that could lead to insulation breakdown and other electrical problems.
4. Selective Ground Fault Protection: Resistance grounding makes it possible to defend against certain ground faults. Operators can pinpoint the exact position of the defect by measuring the voltage across the grounding resistor. This makes it simpler to isolate and fix the affected area while causing the least amount of inconvenience to the rest of the system [7]–[10].

The drawbacks of resistance grounding include:

1. Hazards of Electric Shock: Because of the grounding resistor's presence, there will be a voltage between the neutral and ground during a ground fault. For anybody working on the system or in close proximity to it, this creates the potential for electric shock hazards. To lessen this risk, appropriate safety precautions must be put in place, such as the use of personal protection equipment and obvious warning signs.
2. Limited Fault Current Clearing: Resistance grounding, in contrast to solid grounding techniques, only offers partial fault current removal. This indicates that, despite their diminished intensity, fault currents will still flow during a fault. Resistance grounding may not be the best choice in some applications where quick fault clearing is necessary, such as in crucial industrial processes.
3. Increased Complexity: Resistance grounding implementation complicates system design and calls for extra parts like the grounding resistor. This can make the system more expensive and demand more upkeep.
4. Potential for Ground Fault Persistence: Resistance grounding has the potential to result in ground fault persistence in some circumstances. A defect may continue to cause problems and potential system damage if its size is not great enough to result in a noticeable voltage drop across the grounding resistor.

When contemplating resistance grounding, it is essential to thoroughly assess the unique requirements and restrictions of the power system, weighing the benefits and drawbacks to make an informed choice.

**Applications of Resistance grounding**

In many different sectors and electrical power systems, where controlled fault current and fault detection are crucial, resistance grounding is used. Here are a few typical examples:

Industrial and Commercial Facilities: Resistance grounding is frequently employed in industrial and commercial settings, including manufacturing plants, refineries, and data centres. It aids in preventing damage from fault currents in sensitive equipment including motors, transformers, and generators. Controlled fault current also helps find ground problems, enabling quick maintenance and reducing downtime.

Hospitals and Healthcare Facilities: Resistance grounding is used in healthcare facilities where electrical systems must perform consistently to support vital medical equipment. This lowers the danger of equipment damage and limits fault currents. It improves patient safety and assists in ensuring an uninterrupted power supply.

Water and Wastewater Treatment Plants: Resistance grounding is frequently used in water and wastewater treatment plants to shield electrical components like pumps and motors from fault currents. It assists in preserving the plants' operating effectiveness and guards against potential harm to vital systems.

Mining: Resistance grounding is used in mining operations to control fault currents and safeguard machinery, such as motors, conveyors, and control systems. It raises reliability, reduces downtime, and raises safety standards for mining operations.

Renewable Energy Systems: To safeguard the machinery and grid infrastructure, resistance grounding is used in renewable energy systems, such as solar and wind farms. It ensures the safe and effective operation of these systems by aiding in the prevention of overvoltage situations and controlling fault currents.

Oil and Gas Sector: To safeguard machinery from fault currents, such as pumps, motors, and generators, the oil and gas sector uses resistance grounding. It improves security, averts harm, and lowers the danger of electrical fires in dangerous settings.

Railway Systems: Resistance grounding is used in railway systems to protect traction systems, signaling apparatus, and other electrical components by limiting fault currents. It promotes the safe and dependable functioning of rail networks.

These are only a few instances of the numerous uses for resistance grounding. The design and execution of the resistance grounding system will depend on the particular needs of each application, including fault current levels, system size, and safety considerations.

**Reactance grounding**

A reactance is introduced between the neutral and ground in this setup. Reactance is used to restrict the earth fault current. The earth fault current can be altered to create conditions akin to solid grounding by altering the earthing reactance. The following drawbacks prevent this strategy from being employed today:

(i) For the identical fault conditions in this system, the fault current needed to activate the protective device is larger than it would be for resistance grounding.

(ii) High transient voltages manifest themselves when there is a fault.

**Voltage transformer Earthing**

The main of a single-phase voltage transformer is connected between the neutral and the earth in this manner of neutral earthing, as depicted in Fig. 7. The secondary of the voltage transformer is linked to a low resistor in series with a relay.

The voltage transformer effectively functions as an ungrounded neutral system by offering a high reactance in the neutral earthing circuit. Any phase that has an earth fault results in a voltage across the relay. This results in the protection gadget functioning.

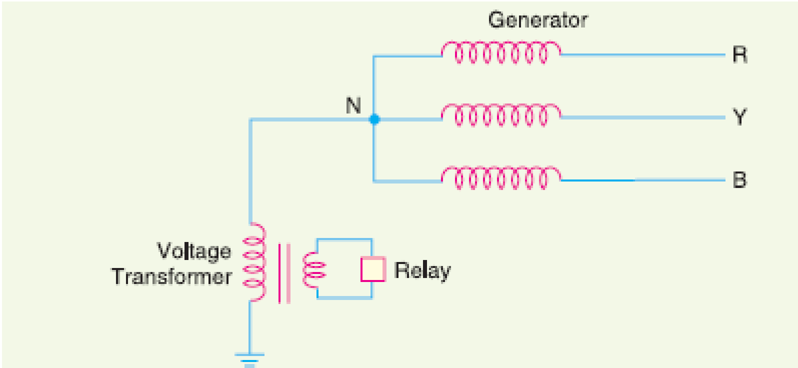


**Figure 7: Voltage transformer Earthing**

The benefits of earthing voltage transformers include the following:

(i) Switching and arcing grounds reduce the system's transient over voltages.

The reason for this is that the ground path of the voltage transformer has a high reactance.

(ii) The benefits of an ungrounded neutral system are all present in this sort of earthing.

(iii) Arcing grounds are removed.

Disadvantages: The following are drawbacks of earthing voltage transformers:

(i) Line voltage is visible across line to earth capacitances when an earth fault occurs on any phase. Overstressing of the system insulation will occur.

(ii) The earthed neutral serves as a point of reflection for waves moving through the machine winding. A buildup of high voltage could arise from this.

Applications: Step-up power transformers that are directly linked to generator equipment are the only devices that typically employ this neutral earthing scheme.

## CONCLUSION

In order to control voltage levels during fault conditions and provide a channel for fault currents, neutral grounding is essential in electrical power systems. The size of the fault current, the system voltage level, and the required level of system reliability all play a role in choosing an acceptable grounding method.

Solid grounding, impedance grounding, and ungrounded systems each have advantages and disadvantages that should be carefully considered in light of the power system's unique needs and limitations. When neutral grounding is carried out correctly, equipment is safeguarded, fault damage is reduced, and the electrical power system's overall security and dependability are improved.

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