DEPARTMENT OF ELECTRICAL ENGINEERING

Syllabus

Power System Protection

III Year - VI Semester: B. Tech. (Electrical Engineering)

1. Introduction: Objective, scope and outcome of the course.

2. Introduction and Components of a Protection System: Principles of Power System Protection, Relays, Instrument transformers, Circuit Breakers.

3. Faults and Over-Current Protection: Review of Fault Analysis, Sequence Networks. Introduction to over current Protection and over current relay co-ordination.

4. Equipment Protection Schemes: Directional, Distance, Differential protection. Transformer and Generator protection. Bus bar Protection, Bus Bar arrangement schemes.

5. Digital Protection: Computer-aided protection, Fourier analysis and estimation of Phasors from DFT. Sampling, aliasing issues.

6. Modeling and Simulation of Protection Schemes: CT/PT modeling and standards, Simulation of transients using Electro-Magnetic Transients (EMT) programs. Relay Testing.

7. System Protection: Effect of Power Swings on Distance Relaying. System Protection Schemes. Under-frequency, under-voltage and df/dt relays, Out-of- step protection, Synchro-phasors, Phasor Measurement Units and Wide-Area Measurement Systems (WAMS). Application of WAMS for improving protection systems.

Power System Protection

UNIT-IV

Equipment Protection Scheme

1. **Directional Relay:** Directional relay operates when the fault is driving power to flow in particular direction. It senses the direction of current flowing. For example, consider a three phase synchronous motor. Assume fault on the system. Power supply to motor is not available. But 3-phase armature is rotating in magnetic field due to inertia. So motor starts generating power, which feeds fault. To avoid this, Directional Relay is used.

- Directional relay:-works when current direction is from one side only(load or source)

- Non directional relay:-works when current direction is from any side(load or source)

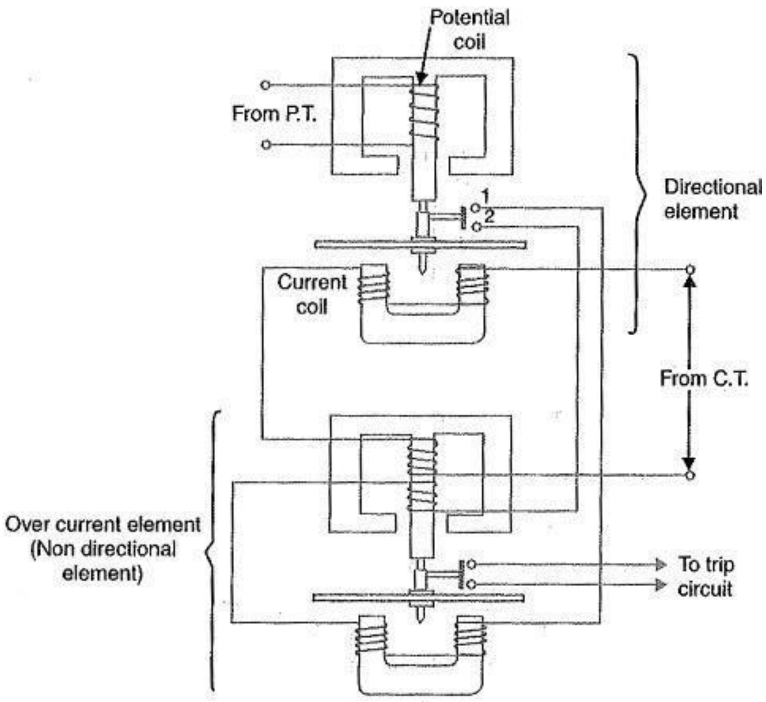
2. Non Directional relay: When there is fault in power system, power flows through fault. Non directional relays operate irrespective of direction of flow of current.

- For example, breaker at generator ends. If there is fault on generator secondary relay has to operate to open GT breaker.

- If there is fault in windings of generator and it's drawing power from grid then also GT breaker has to operate. So we use a non-directional relay. It has to operate in fault conditions irrespective of direction of power flow.

Induction Type Directional Overcurrent Relay:

The directional power relay is unsuitable for use as a directional protective relayunder short-circuit conditions. When a short-circuit occurs, the system voltage falls to a low value and there may be insufficient torque developed in the relayto cause its operation. This difficulty is overcome in the Induction Type Directional Overcurrent Relay which is designed to be almost independent of system voltage and power factor.



Constructional details: Fig. shows the constructional details of a typical Induction Type Directional Overcurrent Relay. It consists of two relay elements mounted on a common case viz.

1. **Directional element and**
2. **Non-directional element.**

1. **Directional element:** It is essentially a directional power relay which operates when power flows in a specific direction. The potential coil of this element is connected through a potential transformer (P.T.) to the system voltage. The current coil of the element is energized through a

   C.T. by the circuit current. This winding is carried over the upper magnet of the non-directional element. The trip contacts (1 and 2) of the directional element are connected in series with the secondary circuit of the overcurrent element. Therefore, the latter element cannot start to operate until its secondary circuit is completed. In other words, the directional element must operate first (i.e. contacts I and 2 should close)in order to operate the overcurrent element.

2. **Non-directional element:** It is an overcurrent element similar in all respects to a non-directional overcurrent relay. The spindle of the disc of this element carries a moving contact which closes the fixed contacts (trip circuit contacts) after the operation of directional element.

It may be noted that plug-setting bridge is also provided in the relay for current setting but has been omitted in the figure for clarity and simplicity. The tapping's are provided on the upper magnet of overcurrent element and are connected to the bridge.

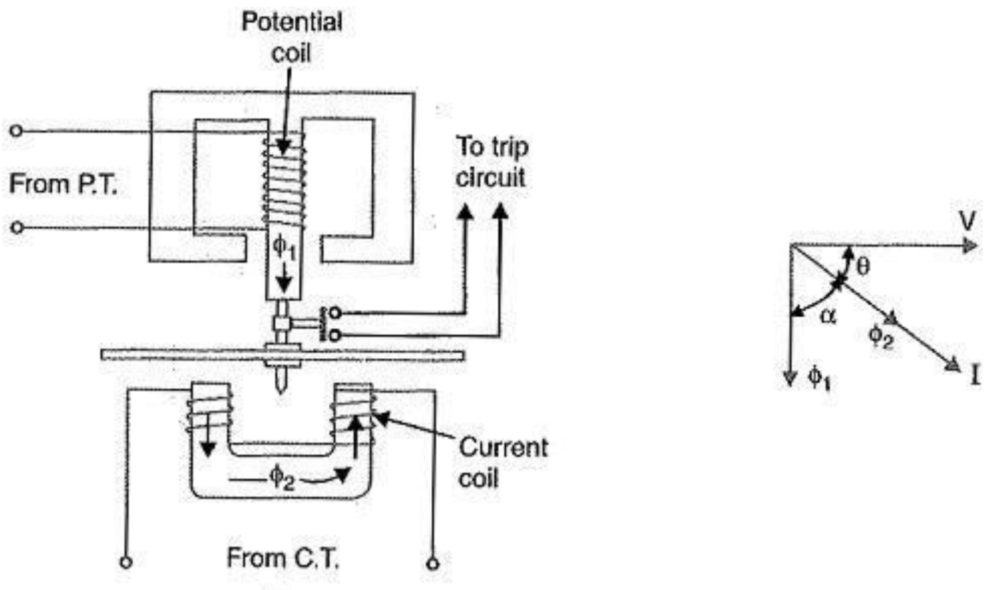
Operation: Under normal operating conditions, power flows in the normal direction in the circuit protected by the relay. Therefore, Induction Type Directional Overcurrent Relay (upper element) does not operate, thereby keeping the overcurrent element (lower element) un-energized. However, when a short-circuit occurs, there is a tendency for the current or power to flow in the reverse direction. Should this happen, the disc of the upper element rotates to bridge the fixed contacts 1 and 2. This completes the circuit for overcurrent element.

The disc of this element rotates and the moving contact attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section. The two relay elements are so arranged that final tripping of the current controlled by them is not made till the following conditions are satisfied:

1. Current flows in a direction such as to operate the directional element.
2. Current in the reverse direction exceeds the pre-set value.
3. Excessive current persists for a period corresponding to the time setting ofovercurrent element.

Induction Type Directional Overcurrent Relay:

This Induction Type Directional Power Relay operates when power in thecircuit flows in a specific direction unlike a non-directional overcurrent relay, a directional power relay is so designed that it obtains its operating torque by the interaction of magnetic fields derived from both voltage and current source of the circuit it protects. Thus this type of relay is essentially a wattmeter and the direction of the torque set up in the relay depends upon the direction of the current relative to the voltage, with which it is associated.



(i) (ii)

Constructional details: The essential parts of a typical induction type directional power relay. It consists of an aluminum disc which is free to rotate in between the poles of two electromagnets. The upper electromagnet carries a winding (**called potential coil**) on the central limb which is connected through a potential transformer (P.T.) to the circuit voltage source. The lower electromagnet has a separate winding (called current coil) connected to the secondary of C.T. in the line to be protected. The current coil is provided with a number of tapping's connected to the plug-setting Midge (not shown for clarity). This permits to have any desired current setting. The restraining torque is provided by a spiral spring.

The spindle of the disc carries a moving contact which bridges two fixed contacts when the disc has rotated through a pre-set angle. By adjusting this angle, the travel of the moving disc can be adjusted and hence any desired time- setting can be given to the relay.

Operation: The flux Φ_1 due to current in the potential coil will be nearly 90° lagging behind the applied voltage V. The flux Φ_2 due to current coil will be nearly in phase with the operating current I.

[See vector diagram in Fig.]. The interaction of fluxes Φ_1 and Φ_2 with the eddy currents induced in the disc produces a driving torque given by :

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

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

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

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

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

It is clear that the direction of driving torque on the disc depends upon the direction of power flow in the circuit to which the relay is associated. When the power in the circuit flows in the normal direction, the driving torque and the restraining torque (due to spring) help each other to turn away the moving contact from the fixed contacts. Consequently, the relay remains inoperative. However, the reversal of current in the circuit reverses the direction of driving torque on the disc. When the reversed driving torque is large enough, the disc rotates in the reverse direction and the moving contact closes the trip circuit. This causes the operation of the circuit breaker which disconnects the faulty section.

Directional Over Current & Non Directional Over Current Protection Working Principle:

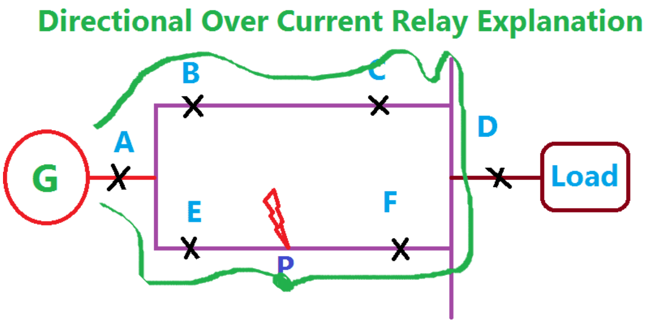
Directional Earth Fault Relay is used to protect the transformer/generator/alternator from over current fault. The relay sense the fault current in only one direction, the relay does not operate when the current in opposite direction. Due to high cost, the Directional Earth fault Relays are used only of high sensitive electrical machine such as alternator & High voltage transmission lines.

Working Principle of Non Directional & Directional Over Current Protection:

First of all, what is over current relay? The relay operates when the fault current exceeds the pickup current. For Directional Over current relay, the fault current can flow in both the directions through the relay either forward or reverse, depending upon fault location. Therefore, it is necessary to make the relay respond for a particular defined direction, so that proper discrimination is possible. This can be achieved by introduction of directional control elements. During the opposite flow of current the CT polarity reverses, the power measuring device in which the system voltage is used as a reference for establishing the relative phase of the fault current.

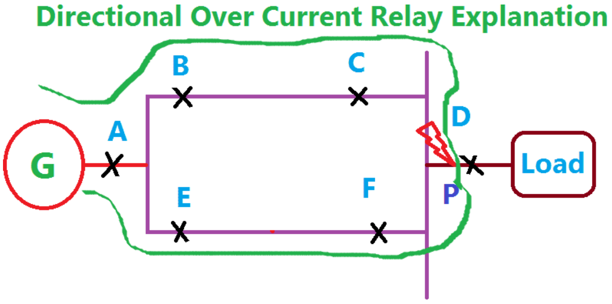
Non Directional & Directional Over Current Relay Explanation:

Case: 1



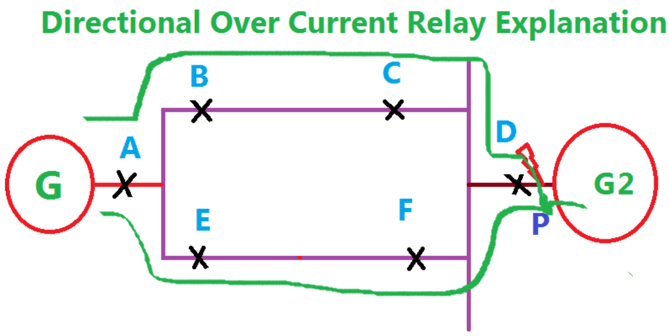
Consider a Power system consists of 6 circuit breaker A, B, C, D, E and F. In this, A, B, C, E are the Non directional over current relays and D, F is a directional over current relay. Consider a fault occurs at a point P. You should remember one thing first, the current always flow through the low impedance path. Hence the fault current flows from the generator G through the breaker A and E. Also the fault current comes from the breaker series A, B, C, and F. In this, the directional relay F operates the breaker of F, but the remaining all relay operates the respective circuit breaker in non-directional relay. Here the directional Relay D become in operative, because the load only observes the current.

Case 2:



Now the fault occurs at a point P which is nearer to the load. In this case, the fault current flow from the generator through A, B, C, P, & A, E, F, P. In this condition, the relay A, B, C & E operates their respective breaker in Non- directional operation. D & F become in operative.

Case 3:



Now we are using another generator G2, in place of load. Consider the fault occurs in P nearer to the generator G2. Now the current flow from G2 & A, B, C, D, P, & A, E, F, D, P. In this condition, the relay A, B, C & E operates their respective breaker in Non-directional operation. D operates the Circuit Breaker D on directional over current. F become in operative because the current direction remains unchanged.

Distance Protection Relay

Distance protection relay is the name given to the protection, whose action depends on the distance of the feeding point to the fault. The time of operation of such protection is a function of the ratio of voltage and current, i.e., impedance. This impedance between the relay and the fault depends on the electrical distance between them. The principal type of distance relays is impedance relays, reactance relays, and the reactance relays.

Distance protection relay principle differs from other forms of protection because their performance does not depend on the magnitude of the current or voltage in the protective circuit but it depends on the ratio of these two quantities. It is a double actuating quantity relay with one of their coil is energized by voltage and the other coil is energized by the current. The current element produces a positive or pick-up torque while the voltages element has caused a negative and reset torque.

The relay operates only when the ratio of voltage and current falls below a set value. During the fault the magnitude of current increases and the voltage at the fault point decreases. The ratio of the current and voltage is measured at the point of the current and potential transformer. The voltage at potential transformer region depends on the distance between the PT and the fault.

If the fault is nearer, measured voltage is lesser, and if the fault is farther, measured voltage is more. Hence, assuming constant fault impedance each value of the ratio of voltage and current measured from relay location comparable to the distance between the relaying point and fault point along the line. Hence such protection is called the distance protection or impedance protection.

Distance zone is non-unit protection, i.e., the protection zone is not exact. The distance protection is high-speed protection and is simply to apply. It can be employed as a primary as well as backup protection. It is very commonly usedin the protection of transmission lines.

Distance relays are used for both phase fault and ground fault protection, and they provide higher speed for clearing the fault. It is also independent of changes in the magnitude of the short circuits, current and hence they are not much affected by the change in the generation capacity and the system configuration. Thus, they eliminate long clearing times for the fault near the power sources required by overcurrent relay if used for the purpose.

Application of Distance Protection Relay

Distance protection relay is widely spread employed for the protection of high- voltage AC transmission line and distribution lines. They have replaced the overcurrent protection because of the following reasons.

- It provides faster protection as compared to overcurrent relay.
- It has a permanent setting without the need for readjustments.
- Direct protection relay has less effect of an amount of generation and faultlevels.
- Their fault current magnitude permits the high line loading.

Distance protection schemes are commonly employed for providing the primary or main protection and backup protection for AC transmission line and distribution line against three phase faults, phase-to-phase faults, and phase-to- ground faults.

Impedance Type Distance Relay

Definition: The relay whose working depends on the distance between the impedance of the faulty section and the position on which relay installed is known as the impedance relay or distance relay. It is a voltage controlled equipment.

The relay measures the impedance of the faulty point, if the impedance is less than the impedance of the relay setting; it gives the tripping command to the circuit breaker for closing their contacts. The impedance relay continuously monitors the line current and voltage flows through the CT and PT respectively. If the ratio of voltage and current is less than the relay starts operating then the relay start operating.

Principle of Operation of Impedance Relay

In the normal operating condition, the value of the line voltage is more than the current. But when the fault occurs on the line the magnitude of the current rises and the voltage becomes less. The line current is inversely proportional to the impedance of the transmission line. Thus, the impedance decreases because of which the impedance relay starts operating.

The figure below explains the impedance relay in much easier way. The potential transformer supplies the voltage to the transmission line and the current flows because of the current transformer. The current transformer is connected in series with the circuit.

Consider the impedance relay is placed on the transmission line for the protection of the line AB. The Z is the impedance of the line in normal operating condition. If the impedances of the line fall below the impedance Z then the relay starts working.

Let, the fault F1 occur in the line AB. This fault decreases the impedance of the line below the relay setting impedance. The relay starts operating, and its send the tripping command to the circuit breaker. If the fault reached beyond the protective zone, the contacts of the relay remain unclosed.

Operating Characteristic of an Impedance Relay

The voltage and the current operating elements are the two important component of the impedance relay. The current operating element generates the deflecting torque while the voltage storage element generates the restoring torque. The torque equation of the relay is shown in the figure below

$$T = k_1 I^2 - k_2 V^2 - k_3$$

The $-K_3$ is the spring effect of the relay. The V and I are the value of the voltage and current. When the relay is in normal operating condition, then the net torque of the relay becomes zero.

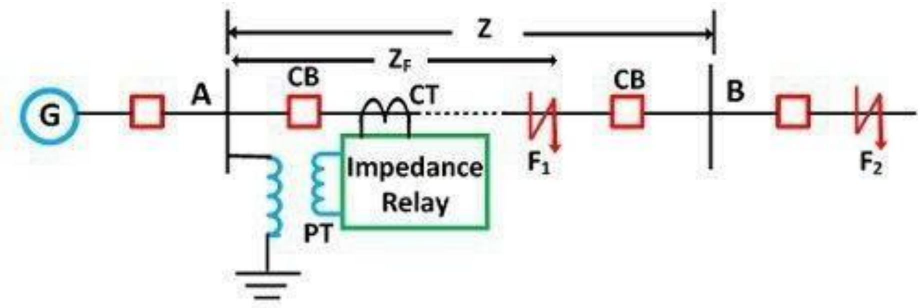
$$k_2 V^2 = k_1 I^2 - k_3$$

$$\frac{V}{I} = Z = \sqrt{\frac{k_1}{k_2} - \frac{k_3}{k_2 I^2}}$$

If the spring control effect becomes neglected, the equation becomes

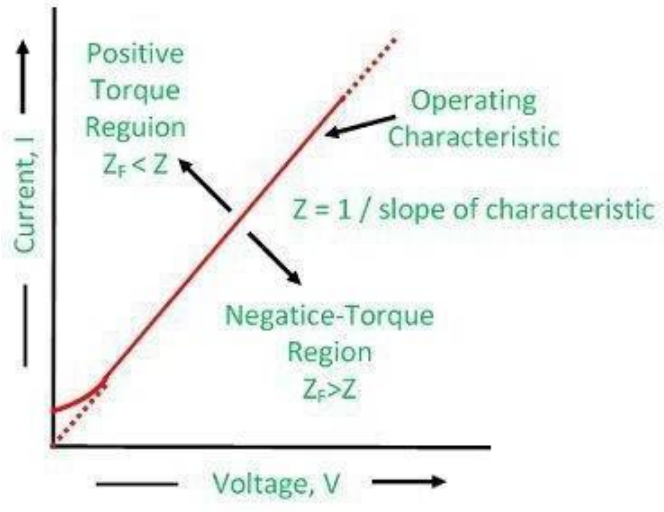
$$Z = \sqrt{\frac{k_1}{k_2}} = Constant$$

The operating characteristic concerning the voltage and current is shown in the figure below. The dashed line in the image represents the operating condition at the constant line impedance.



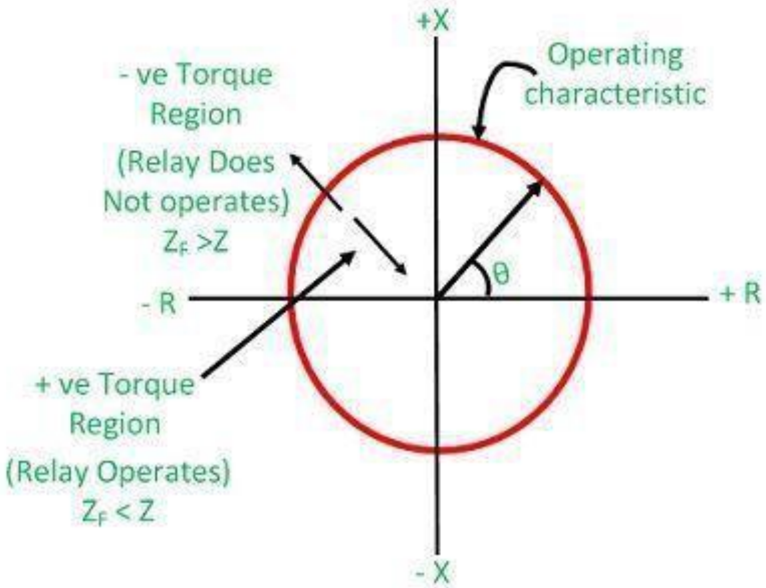
Principle of operation of an Impedance Relay

The operating characteristic of the impedance relay is shown in the figure below. The positive torque region of the impedance relay is above the operating characteristic line. In positive torque region, the impedance of the line is more than the impedance of the faulty section. Similarly, in negative region, the impedance of the faulty section is more than the line impedance



Opening Characteristic of an Impedance Relay

The impedance of the line is represented by the radius of the circle. The phase angle between the X and R axis represents the position of the vector. If the impedance of the line is less than the radius of the circle, then it shows the positive torque region. If the impedance is greater than the negative region, thenit represents the negative torque region.



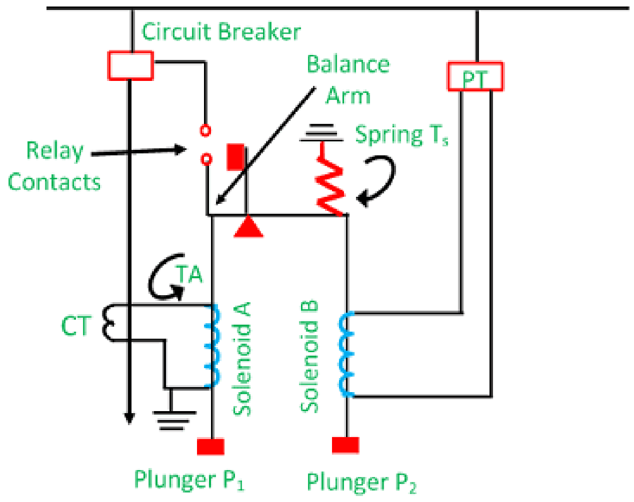
Operating Characteristic of an Impedance Relay on an R-X Diagram

Electromagnetic Type Induction Relay

In such type of relay, the torque is induced by the electromagnetic action on the voltage and current. This torques is compared and considers the circuit of the electromagnetic type induction relay. The solenoid B is excited by the voltage supplied of the PT. This voltage develops the torque in the clockwise direction, and it pulls the plunger P_2 in the downward direction. The spring connects to theplunger P_2 apply the restraining force on it. This spring generates the mechanical torque in the clockwise direction.

The solenoid A generates the other torque in the clockwise direction and thus moves the plunger P_1 downwards. The solenoid one is excited by the CT of the lines. This torque is called the deflecting or pick up torque.

When the system is free from fault, the contacts of the relay become open. When the fault occurs in the protective zone, the current of the system rises because of which the current across the relay also increases. The more torque developed on the solenoid A. The restoring torque because of the voltage decreases. The balance arms of the relay start rotating in the opposite direction, thus closed their contacts.



Electromagnetic Type Impedance Relay

The pull of the solenoid A, i.e., (current element) is proportional to I_2 and that due to solenoid B (voltage element) to V_2. Consequently, the relay will operatewhen

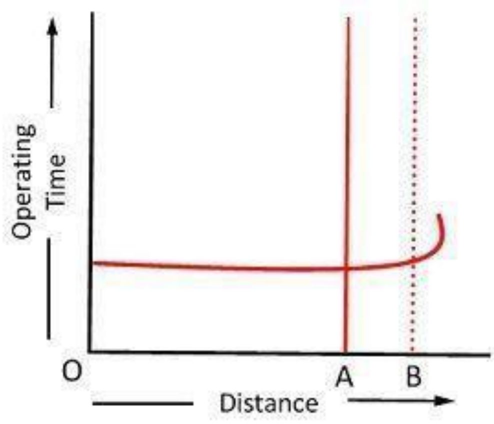
$$K_1 I^2 > k_2 V^2$$

$$\frac{V}{I} < \sqrt{\frac{k_1}{k_2}}$$

$$Z = \sqrt{\frac{k_1}{k_2}}$$

The value of the constants k_1 and k_2 depend on the ampere-turns of the two solenoids, and the ratios of the instrument transformers. By providing tappings on the coil, the setting of the relay can be changed.

The y-axis shows the operating time of the relay and the X-axis represents their impedances. The operating time of the relay remains constants. The value of the voltage and current becomes constant at the predetermined distance and after that their value becomes infinite.

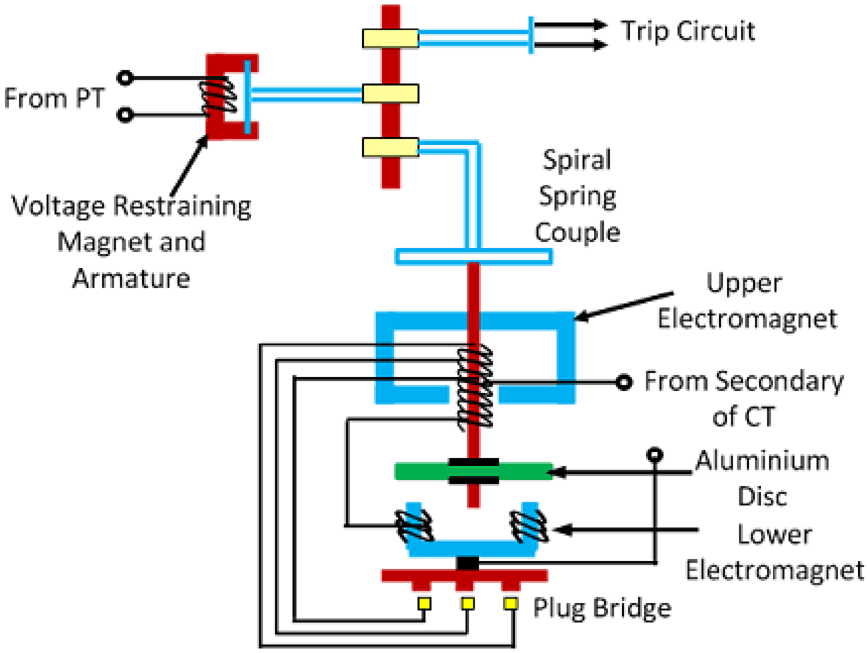


Operating Time Impedance Characteristic

Induction Type Impedance Relay

The circuit diagram of the induction type impedance relay is shown in the figure below. This relay consists current and voltage element. The relay has an aluminum disc, which is rotating between the electromagnets.

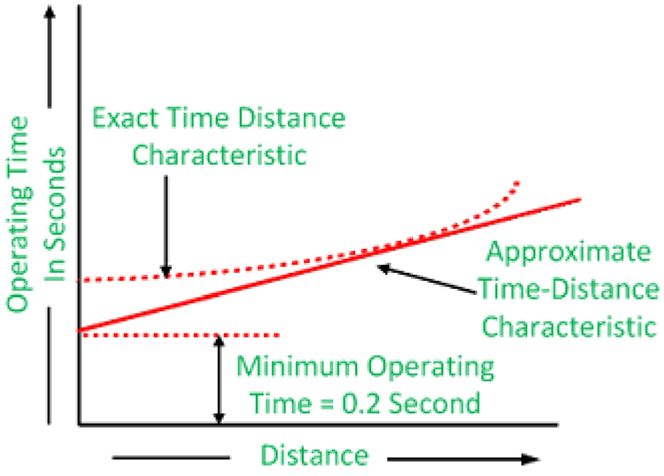
The upper electromagnet has two separate windings. The primary winding is connected to the secondary coil of the current transformer. The current setting of the winding is varied by the help of the plug bridge placed below the relay.



Connection Diagram of Induction Type Impedance Relay

The electromagnetic of the relay connects in series with each other. The flux induce between the electromagnets produces the rotational torque, which rotates the aluminum disc of the relay. The permanent magnet provides the controlling and braking torque.

In normal operating conditions the force exerted on the armature is more than the induction element which keeps the trip contacts open. When the fault occurs in the system, then the aluminum disc starts rotating, and their rotation is directly proportional to the current of the electromagnet.

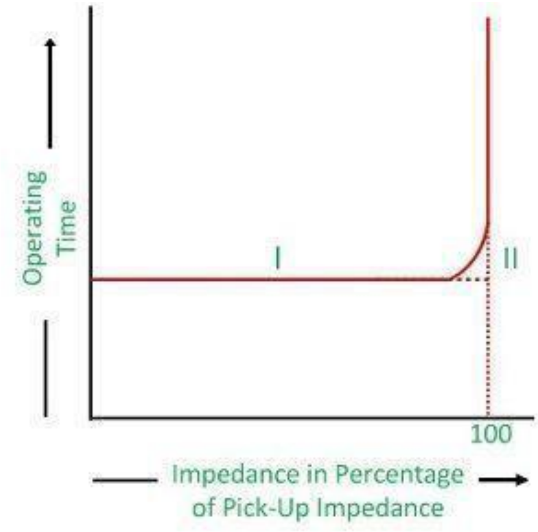


Operating Time Impedance Characteristic

The angle of the rotation of the disc for relay operation depends on the force acting on their armature. The force acting on the armature is directly proportional to the applied voltage. Thus, the angle of rotation also depends on the voltage.

Time-Characteristic of High-Speed Type Impedance Relay

The figure below shows that the relay does not operate for the value more than the 100 percent pickup value. The curves 1 is the actual characteristic, and the curve 2 is the simplified characteristic of the curve 1.



Operating-Time V/s Impedance Characteristic of a High Speed Impedance Relay For One Value of current.

Drawbacks of Plan Impedance Relay

The following are the disadvantages of the impedance relay.

1. It gives the response on both the side of the CT and PT. Thus, it becomes difficult for the breaker to determine whether the fault is external or internal.
2. The relay is easily affected by the arc resistance of the line.
3. It is very sensitive to the power swing. The powerful wings generate the faults on the line because of which the impedances of the line vary.

The relay always operates when the impedance of the line is less than the relay settings.

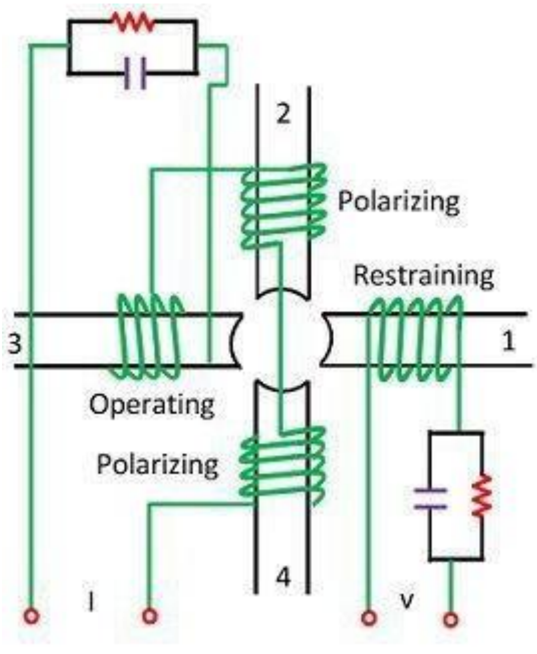
Reactance Relay

The reactance relay is a high-speed relay. This relay consists of two elements anovercurrent element and a current-voltage directional element. The current element developed positive torque and a current-voltage developed directional element which opposes the current element depending on the phase angle between current and voltage.

Reactance relay is an overcurrent relay with directional limitation. The directional element is arranged to develop maximum negative torque when its current lag behinds its voltage by 90°. The induction cup or double induction loop structures are best suited for actuating reactance type distance relays.

Construction of Reactance Relay

A typical reactance relay using the induction cup structure is shown in the figure below. It has a four-pole structure carrying operating, polarizing, and restraining coils, as shown in the figure below. The operating torque is developed by the interaction of fluxes due to current carrying coils, i.e., the interaction of fluxes of 2, 3 and 4 and the restraining torque is produced by the interaction of fluxes due to poles 1, 2 and 4.



Reactance Type Distance Relay

The operating torque will be proportional to the square of the current while the restraining torque will be proportional to VI cos (Θ – 90°). The desired maximum torque angle is obtained with the help of resistance-capacitance circuits, as illustrated in the figure. If the control effect is indicated by $-k_3$, the torque equation becomes

$$T = K_1 I^2 - K_2 VIcos(\theta - 90^{\circ}) - K_3$$

$$T = K_1 I^2 - K_2 sin\theta - K_3$$

where Θ, is defined as positive when I lag behind V. At the balance point net torque is zero, and hence

$$K_1 = K_2 \frac{V}{I} sin\theta + \frac{K_3}{I^2}$$

$$\frac{V}{I} sin\theta = \frac{K_1}{K_2} - \frac{K_3}{K_2 I^2}$$

$$Zsin\theta = \frac{K_1}{K_2}$$

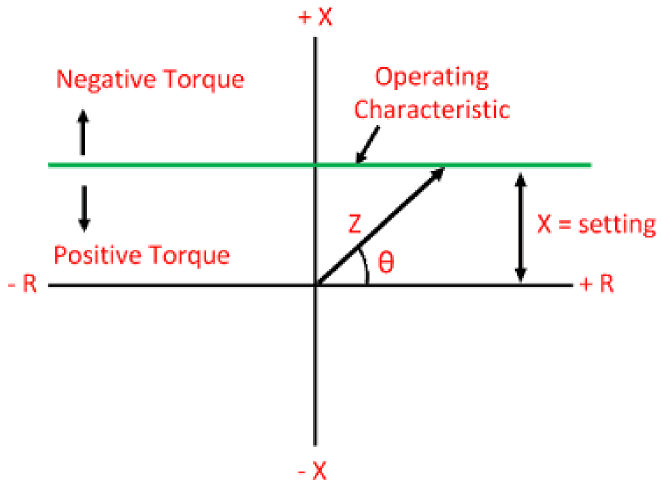
$$K_1 I^2 - K_2 VIcos(\theta - 90^{\circ}) - K_3$$

$$K_1 I^2 = K_2 VIsin\theta + K_3$$

The spring control effect is neglected in the above equation, i.e., $K_3 = 0$.

Operating Characteristic of Reactance Relay

The operating characteristic of a reactance relay is shown in the figure below. X is the reactance of the protected line between the relay location and the fault point, and R is the resistance component of the impedance. The characteristic shows that the resistance component of the impedance has no consequence on the working of the relay, the relay reacts solely to the reactance component. The point below the operating characteristic is called the positive torque region.



Operating Characteristic of Reactance Type Distance Relay

If the value of τ, in the general torque equation, expressed below is made any other 90º, a straight line characteristic will still be obtained, but it will not be parallel to R-axis. Such a relay is called an angle impedance relay.

$$T = K_1 I^2 - K_2 VIcos(\theta - \tau) - K_3$$

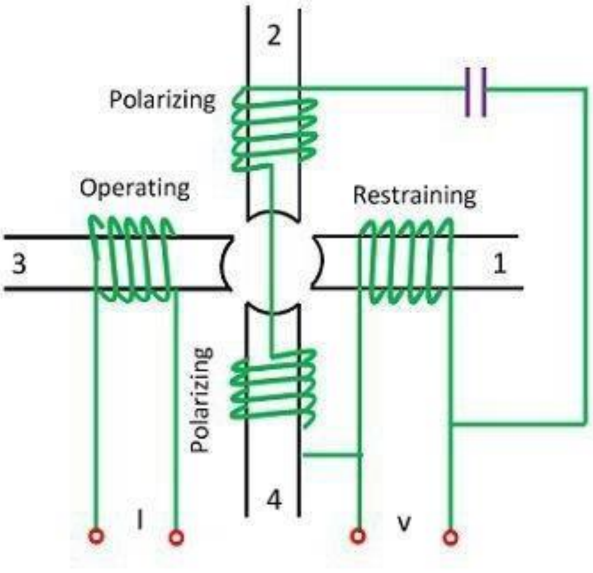
This type of relay is not capable of selecting whether the fault has taken place inthe section where the relay is located, or it has taken place in the adjoining section when used on the transmission line. The directional unit used with the reactance relay will not be same as used with the impedance type relay because the restraining reactive volt-ampere, in that case, will be nearly equal to zero.

Therefore the reactance type distance relay needs a directional unit that is inoperative under load conditions. Reactance type relay is very suitable as a ground relay for ground fault because its reach is not affected by fault impedance.

Mho Relay

A mho Relay is a high-speed relay and is also known as the admittance relay. In this relay operating torque is obtained by the volt-amperes element and the controlling element is developed due to the voltage element. It means a mho relay is a voltage controlled directional relay.

A mho relay using the induction cup structure is shown in the figure below. The operating torque is developed by the interaction of fluxes due to pole 2, 3, and 4 and the controlling torque is developed due to poles 1, 2 and 4.



Schematic Diagram of Mho Relay

If the spring controlling effect is indicated by $-K_3$, the torque equation becomes,

$T = K_1 VI cos(\theta - 90°) - K_3$ Where Θ and τ are defined as positive when I lag behind V. At balance point, the net torque is zero, and hence the equation becomes

$$\frac{K_1}{K_2} \text{Cos}(\theta - \tau) - \frac{K_3}{K_2 VI} = \frac{V}{I} = Z$$

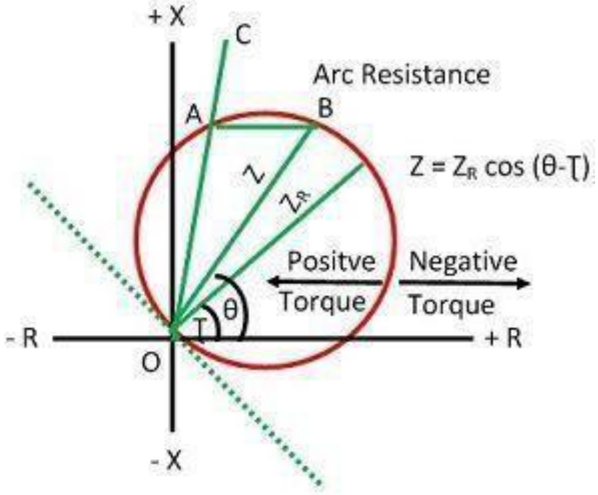
$$K_1 VI cos(\theta - \tau) - K_2 V^2 - K_3 = 0$$

$$Z = \frac{K_1}{K_2} \text{Cos } (\theta - \tau)$$

If the spring controlled effect is neglected i.e., $k_3 = 0$.

Operating Characteristic of Mho Relay

The operating characteristic of the mho relay is shown in the figure below. The diameter of the circle is practically independent of V and I, except at a very low magnitude of the voltage and current when the spring effect is considered, which causes the diameter to decrease. The diameter of the circle is expressed by the equation as $Z_R = K_1 / K_2$ = ohmic setting of the relay

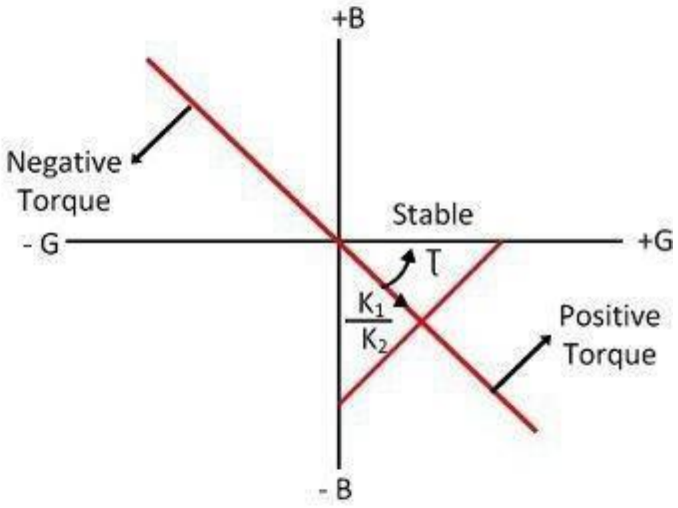


Operating Characteristic of Mho Relay

The relay operates when the impedance seen by the relay within the circle. The operating characteristic showed that circle passes through the origin, which makes the relay naturally directional. The relay because of its naturally directional characteristic requires only one pair of contacts which makes it fast tripping for fault clearance and reduces the VA burdens on the current transformer.

The impedance angle of the protected line is normally 60º and 70º which is shown by line OC in the figure. The arc resistance R is represented by the length AB, which is horizontal to OC from the extremity of the chord Z. By making the τ equal to, or little less lagging than Θ, the circle is made to fit around the faulty area so that the relay is insensitive to power swings and therefore particularly applicable to the protection of long or heavily loaded lines.

For a given relay the τ is constant, and the admittance phasor Y will lie on the straight line. The characteristic of mho relays on the admittance diagram is, therefore, a straight line and is shown in the figure below.



Characteristic of Mho Type Relay on Admittance Diagram

Mho relay is suitable for EHV/UHV heavily loaded transmission lines as its threshold characteristic in Z-plane is a circle passing through the origin, and its diameter is Z_R. Because of this, the threshold characteristic is quite compact enclosing faulty area compactly and hence, there is lesser chance to operate during power swing and also it is directional.

Differential Protection Relay

Definition: The relay whose operation depends on the phase difference of two or more electrical quantities is known as the differential protection relay. It works on the principle of comparison between the phase angle and the magnitude of the same electrical quantities.

For example: Consider the comparison of the input and output current of the transmission line. If the magnitude of the input current of the transmission lineis more than that of output current that means the additional current flows through it because of the fault. The difference in the current can operate the differential protection relay.

The following are the essential condition requires for the working of the differential protection relay.

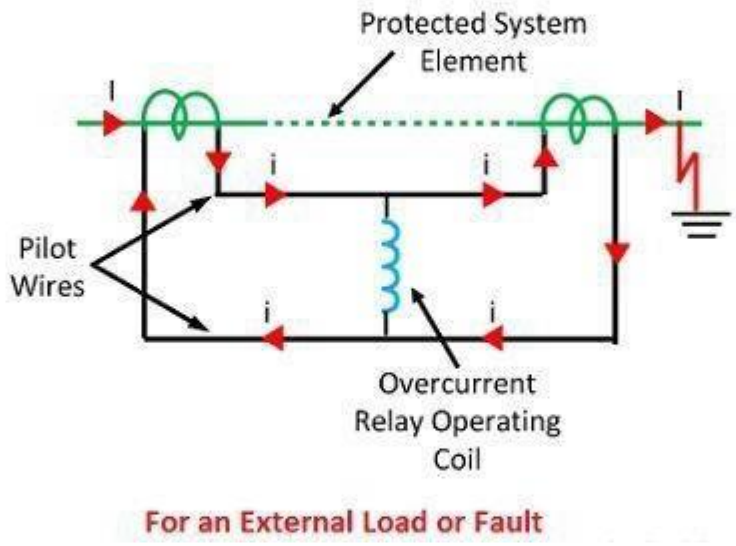
- The network in which the relay use should have two or more similarelectrical quantities.
- The quantities have the phase displacement of approximately 180º.

The differential protection relay is used for the protection of the generator, transformer, feeder, large motor, bus-bars etc. The following are the classification of the differential protection relay.

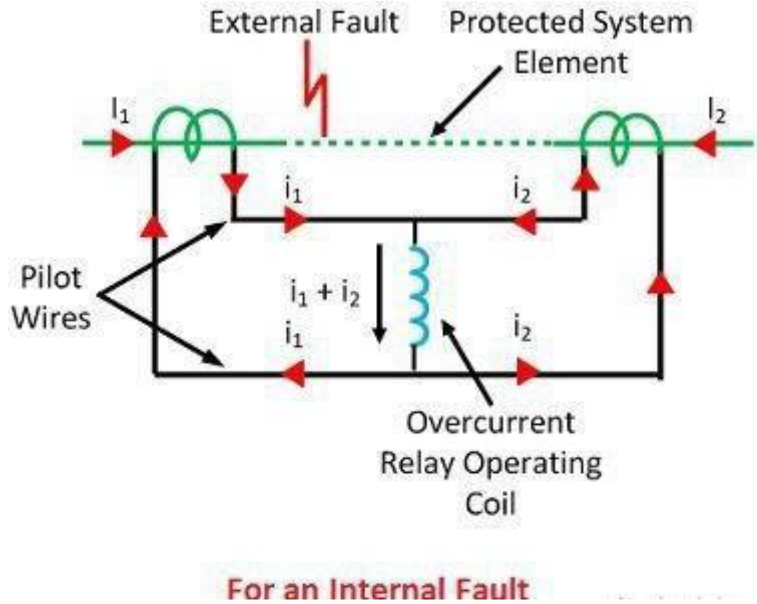
- Current Differential Relay
- Voltage Differential Relay
- Biased or Percentage Differential Relay
- Voltage Balance Differential Relay

Current Differential Relay

A relay which senses and operates the phase difference between the current entering into the electrical system and the current leaving the electrical systemis called a current differential relay. An arrangement of overcurrent relay connected to operate as a differential relay is shown in the figure below.



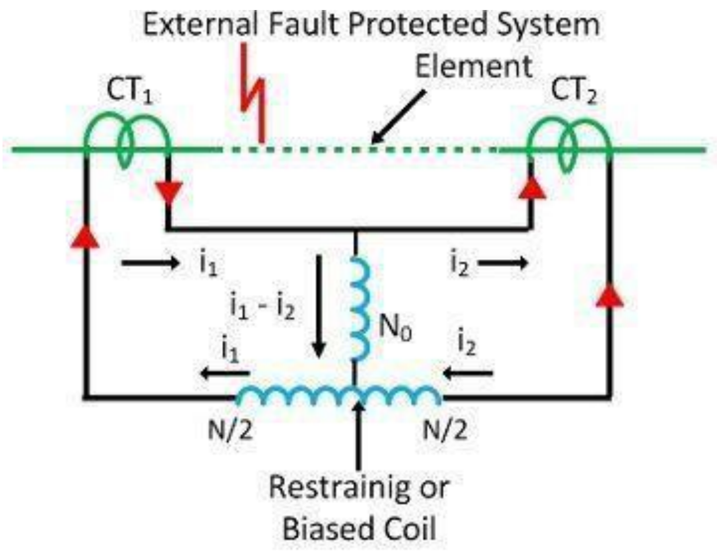
The arrangement of the overcurrent relay is shown in the figure below. The dotted line shows the section which is used to be protected. The current transformer is placed at both the ends of the protection zone. The secondary of the transformers is connected in series with the help of the pilot wire. Thereby, the current induces in the CTs flows in the same direction. The operating coil of the relay is connected on the secondary of the CTs.



In the normal operating condition, the magnitude of current in the secondary of the CTs remains same. The zero current flows through the operating coil. On the occurrence of the fault, the magnitude of the current on the secondary ofCTs becomes unequal because of which the relay starts operating.

Biased or Percentage Differential Coil

This is the most used form of differential relay. Their arrangement is same as that of the current differential relay; the only difference is that this system consists an additional restraining coil connected in the pilot wires as shown in the figure below.

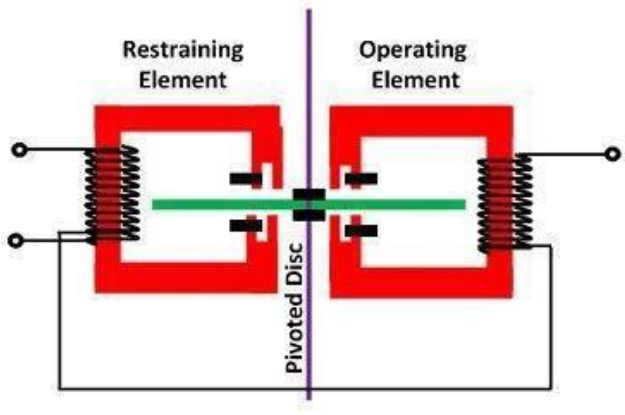


Biased or Percentage Differential Relay

The operating coil connects in the centre of the restraining coil. The ratio of current in the current transformer becomes unbalance because of the fault current. This problem is resolved by the use of the restraining coil.

Induction Type Biased Differential Relay

This induction type relay consists a disc which freely rotates between the electromagnets. The each of the electromagnet consists the copper shading ring. The ring can move in or out of the electromagnet. The disc experiences a force because of the restraining and the operating element.



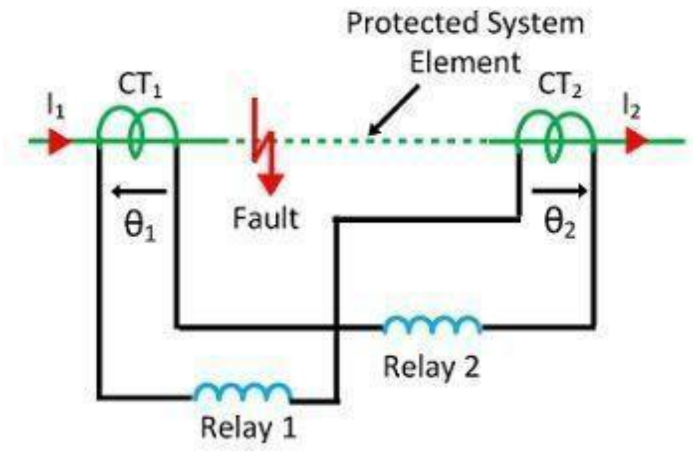
Induction Type Biased Differential Relay

The resultant torque on the shaded ring becomes zero if the position of the ring is balanced for both the element. But if ring moves towards the iron core then the unequal torques acting on the ring because of the operating and restraining coil.

Voltage Balance Differential Relay

The current differential relay is not suitable for the protection of the feeders. For the protection of the feeders, the voltage balance differential relays are used. The voltage differential relay uses two similar current transformer places across the protective zone with the help of pilot wire.

The relays are connected in series with the secondary of the current transformer. The relays are connected in such a way that no current flows through it in the normal operating condition. The voltage balance differential relay uses the air core CTs in which the voltages induces regarding current.



Balance Voltage Differential Protection

When the fault occurs in the protection zone, the current in the CTs become unbalance because of which the voltage in the secondary of the CTs disturbs. The current starts flowing through the operating coil. Thus, the relay starts operating and gives the command to the circuit breaker to operate.

Differential Protection of a Transformer

The transformer is one of the major equipment in power system. It is a static device, totally enclosed and usually oil immersed, and therefore the fault occurs on them are usually rare. But the effect of even a rare fault may be very serious for a power transformer. Hence the protection of power transformer against possible fault is very important.

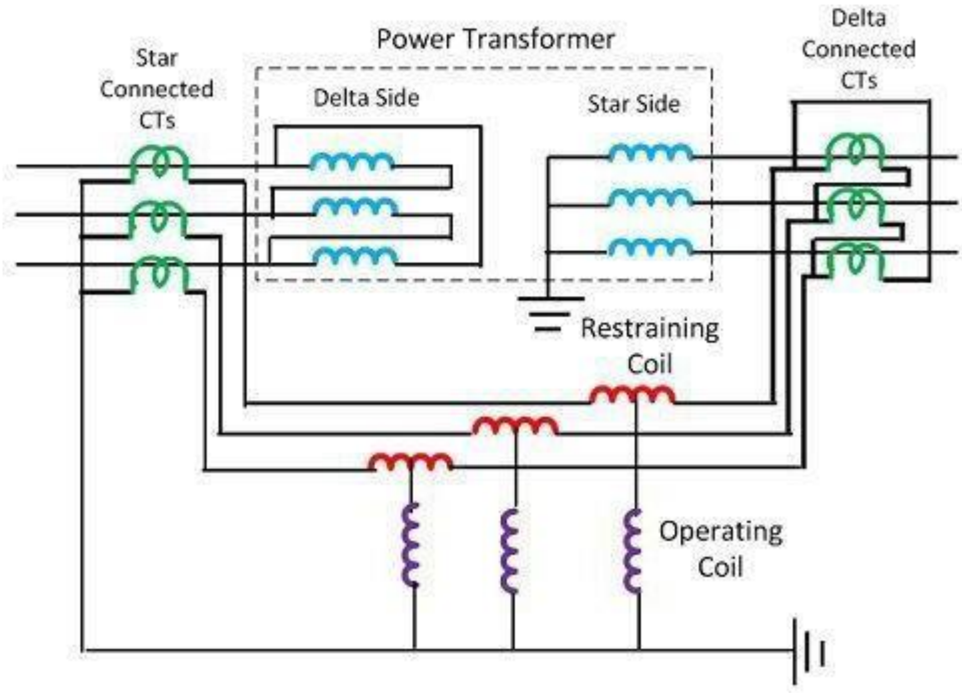
The fault occurs on the transformer is mainly divided into two type external faults and internal fault. External fault is cleared by the relay system outside the transformer within the shortest possible time in order to avoid any danger to the transformer due to these faults. The protection for internal fault in such type of transformer is to be provided by using differential protection system.

Differential protection schemes are mainly used for protection against phase-to- phase fault and phase to earth faults. The differential protection used for power transformers is based on Merz-Prize circulating current principle. Such types of protection are generally used for transformers of rating exceeding 2 MVA.

Connection for Differential Protection for Transformer

The power transformer is star connected on one side and delta connected on the other side. The CTs on the star connected side are delta-connected and those on delta-connected side are star-connected. The neutral of the current transformer star connection and power transformer star connections are grounded.

The restraining coil is connected between the secondary winding of the current transformers. Restraining coils controls the sensitive activity occurs on the system. The operating coil is placed between the tapping point of the restraining coil and the star point of the current transformer secondary windings.



Differential Protection for Power Transformers

Working of Differential Protection System

Normally, the operating coil carries no current as the current are balanced on both the side of the power transformers. When the internal fault occurs in the power transformer windings the balanced is disturbed and the operating coils of the differential relay carry current corresponding to the difference of the current among the two sides of the transformers.Thus, the relay trip the main circuit breakers on both sides of the power transformers.

Problem Associated with Differential Protection System

When the transformer is energizing the transient inrush of magnetizing current is flows in the transformer. This current is as large as 10 times full load current and its decay respectively. This magnetizing current is flows in the primary winding of the power transformers due to which it causes a difference in current transformer output and it makes the differential protection of the transformer to operate falsely.

To overcome this problem the kick fuse is placed across the relay coil. These fuses are of the time-limit type with an inverse characteristic and do not operate in short duration of the switch in the surge. When the fault occurs the fuses blow out and the fault current flows through the relay coils and operate the protection system. This problem can also be overcome by using a relay with an inverse and definite minimum type characteristic instead of an instantaneous type.

Differential Protection of a Generator

Differential protection for a generator is mainly employed for the protection of stator windings of generator against earth faults and phase-to-phase faults. The stator winding faults are very dangerous, and it causes considerable damage to the generator. For the protection of stator winding of the generator, the differential protection system is used for clearing the fault in the shortest possible time for minimizing the extent of a damage.

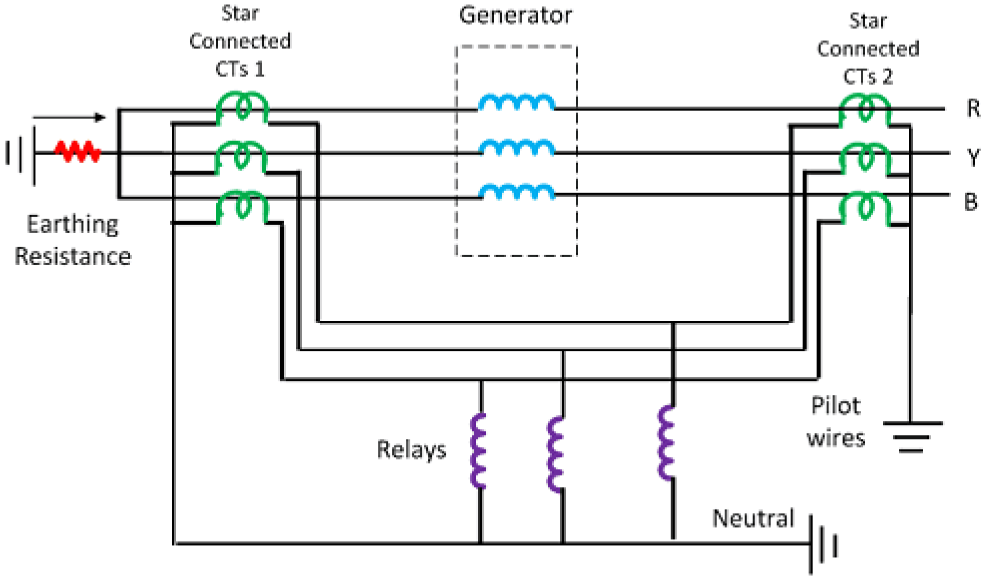
Merz-Prize Circulating Current System

In this scheme of protection, currents at the ends of the protected sections compare. When the system is in normal operating condition, the magnitude of currents is equal on the secondary windings of the current transformers. On the occurrence of the faults, the short-circuit current flows through the system and the magnitude of current become differ. This difference of current under fault conditions is made to flow through the relay operating coil.

The relay then closes its contacts and makes the circuit breaker to trip and thus isolated the protection from the system. Such a system is called a Merz-Prize circulating current system. It is very effective for earth faults and faults betweenphases.

Connection for Differential Protection System

The protection system requires two identical transformers which are mounted on both sides of the protection zone. The secondary terminals of the current transformers are connected in stars, and their end terminals are connected through the pilot wire. The relay coils are connected in delta. The neutral of the current transformer and the relay are connected to the common terminal.



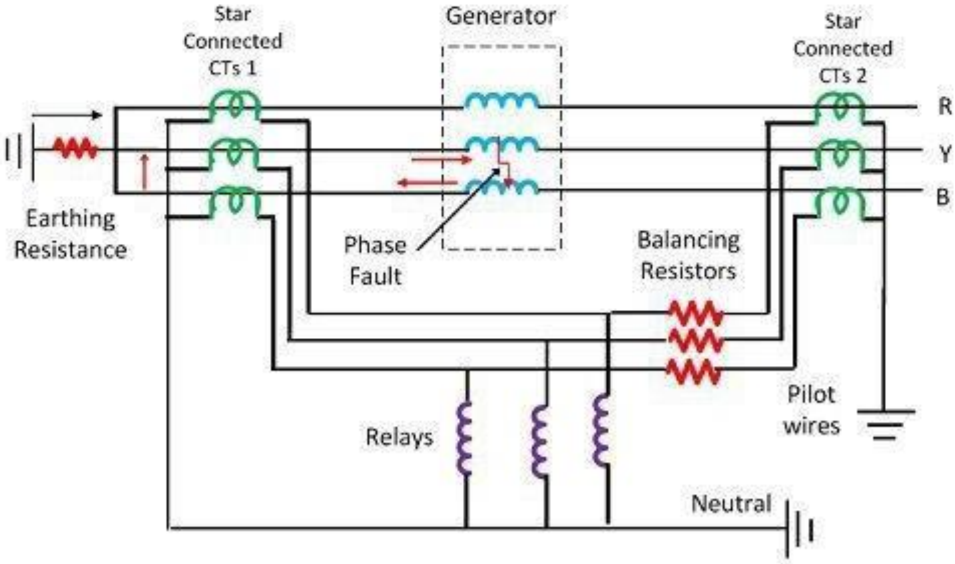
Merz-Price Protection With Relay Being Connected in the Midpoints of Two Sets of CTs.

The relay is connected across equipotential points of the three pilot wires so thatthe burden on each current transformer is same. The equipotential point of the pilot wire is its centre, so the relay is located at the midpoint of pilot wires.

For proper working of the differential protection system, it is essential to locate the relay coils adjacent to the current transformer near the main circuit. This can be done by inserting the balancing resistance in series with the pilot wires to make equipotential points located near the main circuit breaker.

Working on Differential Protection System

Consider the fault occurs on the R phase of the network because of the insulation breakdown. Because of the fault, the current in the secondary of the transformer becomes unequal. The differential currents flow through the relay coil. Thus, the relay becomes operative and gives the command to the circuit breaker for operation.



Merz-Price Protection With Relay Being Connected Adjacent To One Set of CTs

If the fault occurs between any two phases, say Y and B then short-circuit current flows through these phases. The fault unbalanced the current flows through CTs. The differential current flows through the relay operating coil and thus relay trips their contacts.

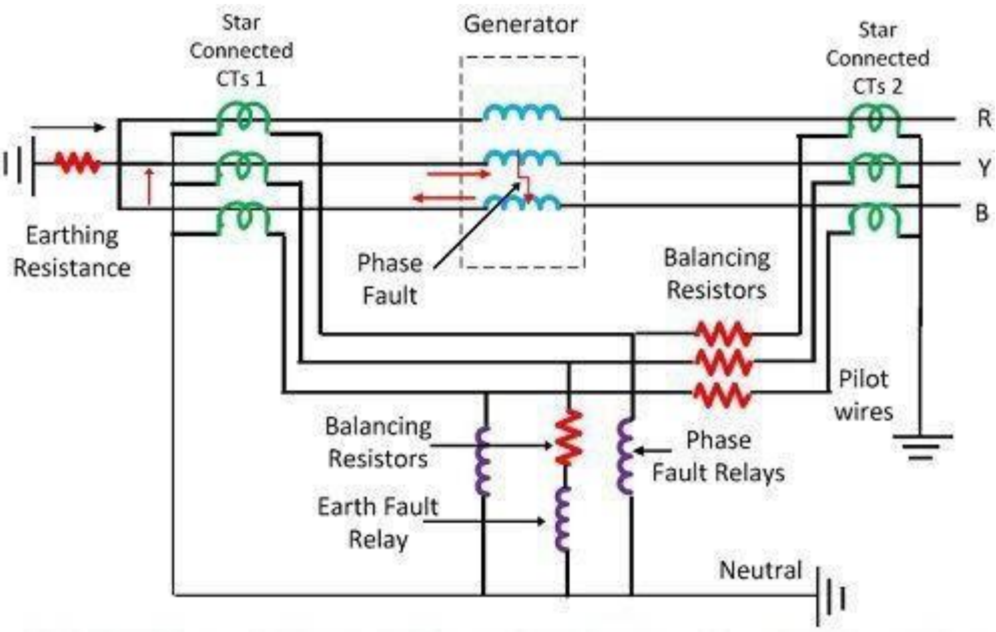
Problem Associated with Differential Protection System

A neutral resistance wire is used in the differential protection system for avoiding the adverse effect of earth fault currents. When an earth fault occurs near the neutral, it will cause a small, short circuit current to flow through the neutral point because of small emf. This current is further reduced by the resistance of the neutral grounding. Thus, the small current will flow through the relay. This small current will not operate the relay coil, and hence the generator gets damage.

Modified Scheme of Differential Protection System.

To overcome the above problem, the modified scheme has been developed. In this scheme two elements are arranged, one for the protection of the phase fault and other for the earth fault protection.

The phase elements are connected in stars along with the resistor. The earth fault relay is kept between the star and neutral. The two-phase elements together with a balancing resistor are connected in star, and the earth fault relay is connected between the star and neutral pilot wire.



Modified Scheme of Differential Protection For Generators Grounded Through High Resistance

The star-connected circuit is symmetrical, and any balanced overflow current from the current circulating point will not flow through the earth fault relay. So in this system, the sensitive earth fault relay will operate at a high degree of stability.

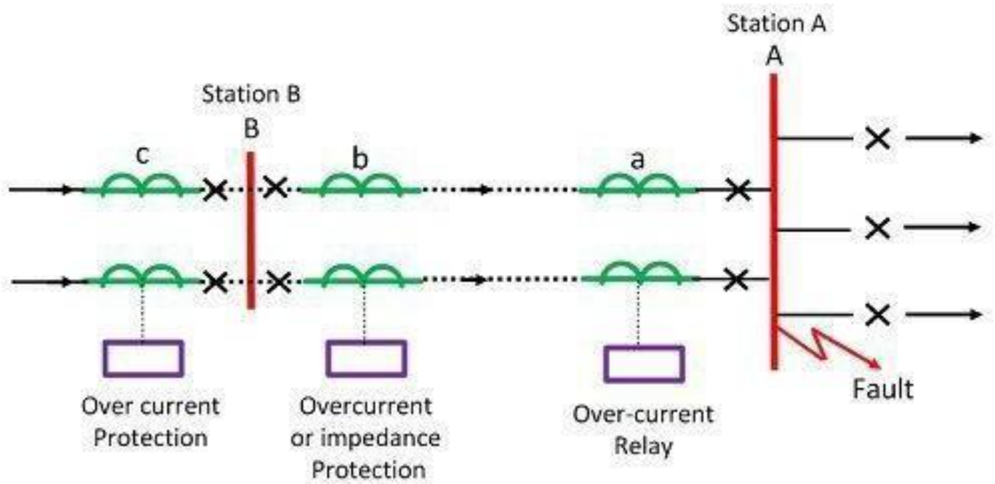
Bus-Bar Protection

When the fault occurs on the bus bars whole of the supply is interrupted, and all the healthy feeders are disconnected. The majority of the faults is single phase in nature, and these faults are temporary. The bus zone fault occurs because of various reasons likes failure of support insulators, failure of circuit breakers, foreign object accidentally falling across the bus bar, etc., The most commonly used schemes for bus zone protection are:

- Backup protection
- Differential Overcurrent Protection
    - Circulating current protection
    - Voltage Overvoltage Protection
- Frame leakage protection.

Backup protection for Bus-Bars

This is the simple way of protecting the bus-bar from the fault. The fault occurs on the bus-bar because of the supplying system. So the backup protection is provided to the supply system. The figure below shows the simple arrangement for the protection of bus-bar. The bus A is protected by the distance protectionof the bus B. If the fault occurs on A, then the B will operate. The operating times of the relay will be 0.4 seconds.



Backup protection for Bus-Bars

The bus-bar protection system has few disadvantages likes the protection system is slow. Such system is mainly used for the protection of the transmission lines. But as the protection system is very economical, thereby it isalso used for the bus-bar protection.

This protective scheme is not used for small switchgear system. The backup protection system has many disadvantages likes delayed in action, disconnections of more circuits for two or more transmission line requires etc.

Frame Leakage or Fault-Bus Protection

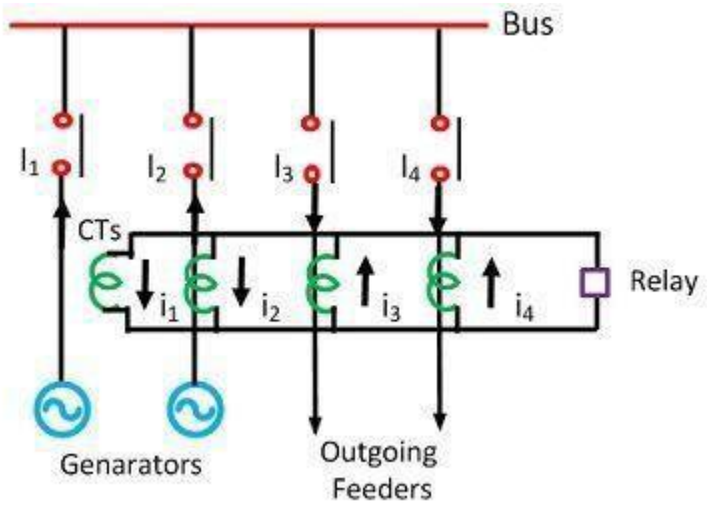
This method insulates the bus-supporting structure and its switchgear from the ground, interconnecting all the framework, circuit breakers tanks, etc. and provided a single ground tank connection through a CT that feeds an overcurrent relay. The overcurrent relay controls a multi-contact auxiliary relay that trips the breakers of all circuits connected to the bus.

In such type of protection, the only metal supporting structure or fault-bus is grounded through a CT, secondary of which is connected to an overcurrent relay. Under normal operating condition, the relay remains inoperative, but fault involving a connection between a conductor and the ground supporting structure will result in current flow to ground through the fault bus, causing the relay to operate. The operation of the relay will trip all the breakers connecting equipment to the bus.

Differential Over Current Protection

The current differential protection scheme works on the principle of the circulating current which states that the current enters into the bus-bar is equal to the current leaving the bus-bar. The sum of the incoming and outgoing junction is equal to zero. If the sum of current is not equal to zero, then the fault occurs in the system. The differential protection scheme is used both for the protection of the phase-to-phase fault and for the ground fault.

Schematic diagram of bus differential protection relay is shown in the figure below. The current transformers are placed on both the incoming and the outgoing end of the bus-bar. The secondary terminals of the current transformer are parallel connected to each other.



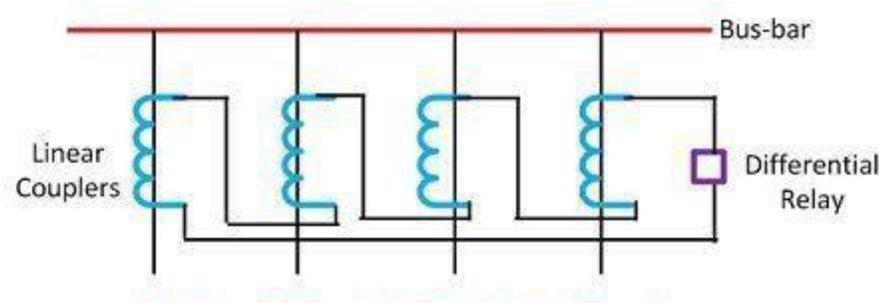
Schematic Diagram of Bus Differential Protection

The summation current of the current transformer flows through the operating coil of the relay. The current flows through the relay coils indicates the short circuit current present on the secondary of the CTs. Thus, the relay sends the signal to the circuit breakers to open the contacts.

The drawback of such types of the scheme is that the iron cored current transformer causes the fault operation of the relay at the time of the external fault.

Voltage Differential Protection Relay

In this scheme, the coreless CTs are used. The linear couplers are used for increases the number of turns on the secondary sides of the CTs. The secondary relays connected in series with the help of the pilot wires. The relay coil is also connected in series with the second terminal.



Voltage Differential Relaying For Bus-bar

When the system is free from fault or external fault occurs on the system, the sum of secondary current of CTs becomes zero. On the occurrence of the internal fault, the fault current flows the differential relay. The relay becomes operative and gives command to the circuit breaker to open their contacts. Thus,protects the system from damage.

Electrical Bus-Bar and its Types

Definition: An electrical bus bar is defined as a conductor or a group of conductor used for collecting electric power from the incoming feeders and distributes them to the outgoing feeders. In other words, it is a type of electrical junction in which all the incoming and outgoing electrical current meets. Thus, the electrical bus bar collects the electric power at one location.

The bus bar system consist the isolator and the circuit breaker. On the occurrence of a fault, the circuit breaker is tripped off and the faulty section of the busbar is easily disconnected from the circuit.

The electrical bus bar is available in rectangular, cross-sectional, round and many other shapes. The rectangular bus bar is mostly used in the power system. The copper and aluminum are used for the manufacturing of the electrical bus bar.

The various types of busbar arrangement are used in the power system. The selection of the bus bar is depended on the different factor likes reliability, flexibility, cost etc. The following are the electrical considerations governing the selection of any one particular arrangement.

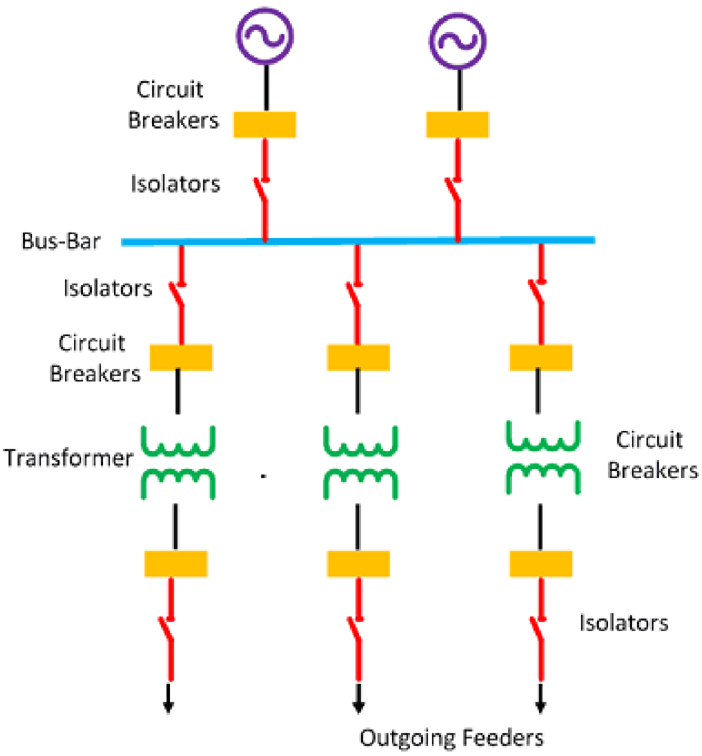
- The bus bar arrangement is simple and easy in maintenance.
- The maintenance of the system did not affect their continuity.
- The installation of the bus bar is cheap.

The small substation where continuity of the supply is not essential uses the single bus bar. But in a large substation, the additional busbar is used in the system so that the interruption does not occur in their supply. The different type of electrical bus bar arrangement is shown in the figure below.

Single Bus-Bar Arrangement

The arrangement of such type of system is very simple and easy. The system has only one bus bar along with the switch. All the substation equipment like the transformer, generator, the feeder is connected to this bus bar only. The advantages of single bus bar arrangements are

- It has low initial cost.
- It requires less maintenance
- It is simple in operation



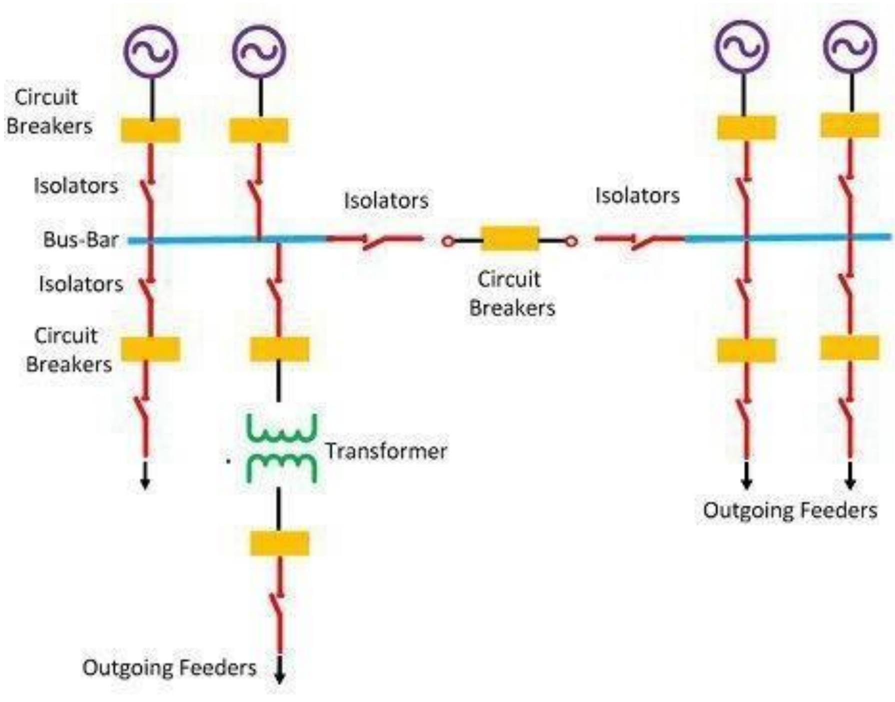
Single Bus-Bar Arrangement

Drawbacks of Single Bus-Bars Arrangement

- The only disadvantage of such type of arrangement is that the completesupply is disturbed on the occurrence of the fault.
- The arrangement provides the less flexibility and hence used in the smallsubstation where continuity of supply is not essential.

Single Bus-Bar Arrangement with Bus Sectionalized

In this type of bus bar arrangement, the circuit breaker and isolating switches are used. The isolator disconnects the faulty section of the bus bar, hence protects the system from complete shutdown. This type of arrangement uses one addition circuit breaker which does not much increase the cost of the system.



Sectionalized Single Bus-Bar System

Advantage of single Bus-bar Arrangement with Bus Section.

The following are the advantages of sectionalized bus bar.

- The faulty section is removed without affecting the continuity of the supply.
- The maintenance of the individual section can be done without disturbingthe system supply.
- The system has a current limiting reactor which decreases the occurrence ofthe fault.

Disadvantages of Single Bus-Bar Arrangement with Section.

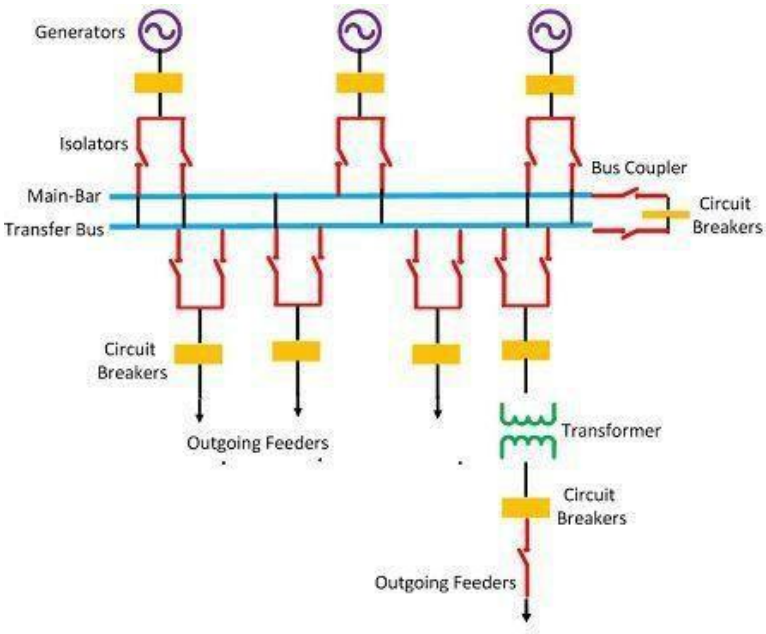
- The system uses the additional circuit breaker and isolator which increasesthe cost of the system.

Main and Transfer Bus Arrangement

Such type of arrangement uses two type of bus bar namely, main bus bar and the auxiliary bus bar. The bus bar arrangement uses bus coupler which connects the isolating switches and circuit breaker to the bus bar. The bus coupler is also used for transferring the load from one bus to another in case of overloading. The following are the steps of transferring the load from one bus to another.

1. The potential of both the bus bar kept same by closing the bus coupler.
2. The bus bar on which the load is transferred is kept close.
3. Open the main bus bar.

Thus, the load is transferred from the main bus to reserve bus.



Main and Transfer BUS Arrangement

Advantages of Main and Transfer Bus Arrangement

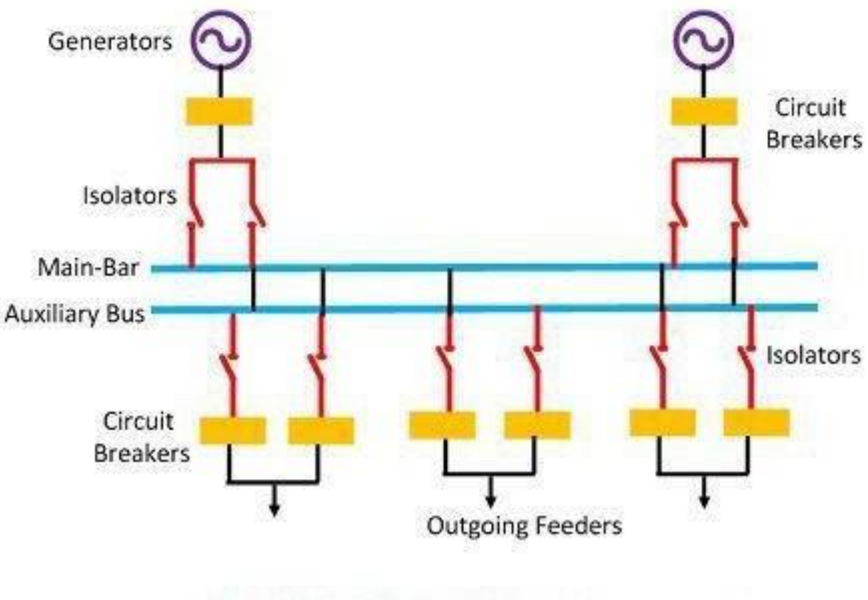
- The continuity of the supply remains same even in the fault. When the faultoccurs on any of the buses the entire load is shifted to the another bus.
- The repair and maintenance can easily be done on the busbar withoutdisturbing their continuity.
- The maintenance cost of the arrangement is less.
- The potential of the bus is used for the operation of the relay.
- The load can easily be shifted on any of the buses.

Disadvantages of Main and Transfer Bus Arrangement

- In such type of arrangements, two bus bars are used which increases thecost of the system.
- The fault on any of the bus would cause the complete shutdown on thewhole substation.

Double Bus Double Breaker Arrangement

This type of arrangement requires two bus bar and two circuit breakers. It does not require any additional equipment like bus coupler and switch.



Double Bus Double Breaker Arrangement

Advantages of Double Bus Double Breaker

- This type of arrangement provides the maximum reliability and flexibility in the supply. Because the fault and maintenance would not disturb their continuity.
- The continuity of the supply remains same because the load is transferrable from one bus to another on the occurrence of the fault.

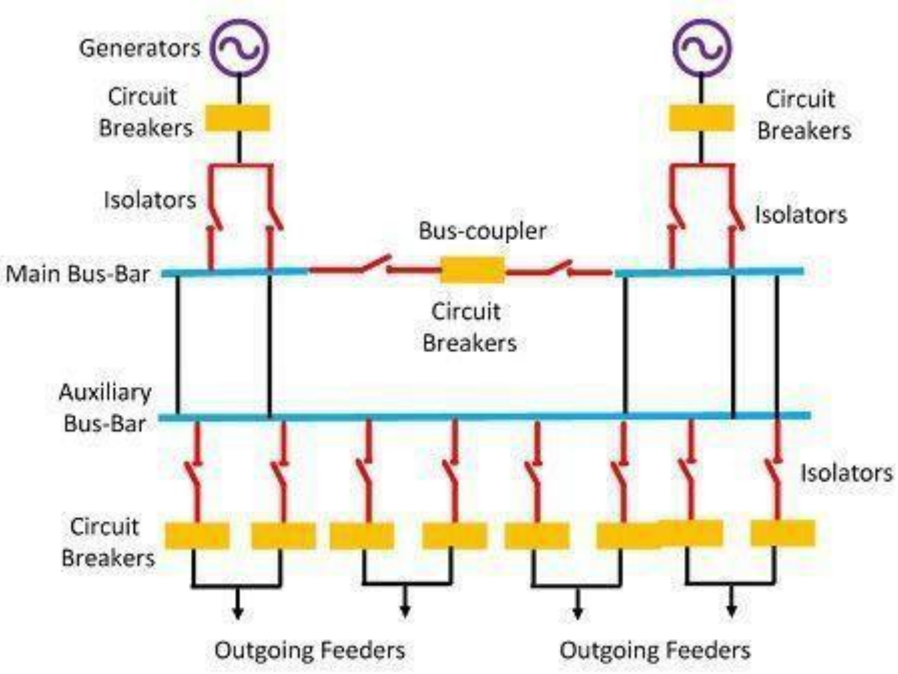
Disadvantages of double bus Double breaker

- In such type of arrangement two buses and two circuit breakers are used which increases the cost of the system.
- Their maintenance cost is very high.

Because of its higher cost, such type of bus-bars is seldom used in substations.

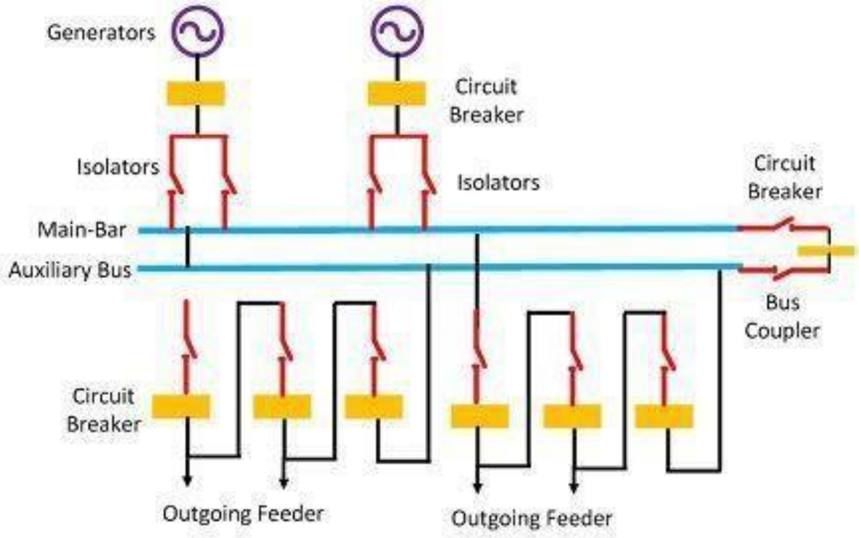
Sectionalized Double Bus Bar Arrangement.

In this type of bus arrangement, the sectionalized main bus bar is used along with the auxiliary bus bar. Any section of the busbar removes from the circuitfor maintenance and it is connected to any of the auxiliary bus bars. But such type of arrangement increases the cost of the system. Sectionalization of the auxiliary bus bar is not required because it would increase the cost of the system.



Sectionalized Double Bus Arrangement

One and a Half Breaker Arrangement



One-and-a-Half Circuit Breaker Arrangement

In this arrangement, three circuit breakers are required for two circuits. The each circuit of the bus bar uses the one and a half circuit breaker. Such type of arrangement is preferred in large stations where power handled per circuit is large.

Advantages of One and a Half Breaker Arrangement

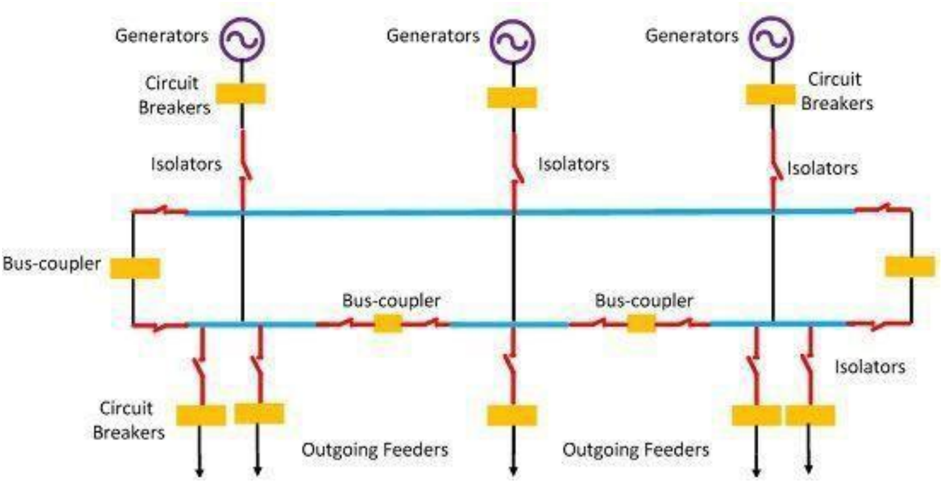
- It protects the arrangement against the loss of supply.
- The potential of the bus bar is used for operating the relay.
- In such type of arrangement, the additional circuits are easily added to thesystem.

Disadvantages of One and a Half Breaker Arrangement

- The circuit becomes complicated because of the relaying system.
- Their maintenance cost is very high.

Ring Main Arrangement

In such type of arrangement, the end of the bus bar is connected back to thestarting point of the bus to form a ring.



Ring Main arrangement

Advantages of Ring Main Arrangement

- Such type of arrangement will provide two paths for the supply. Thus thefault will not affect their working.

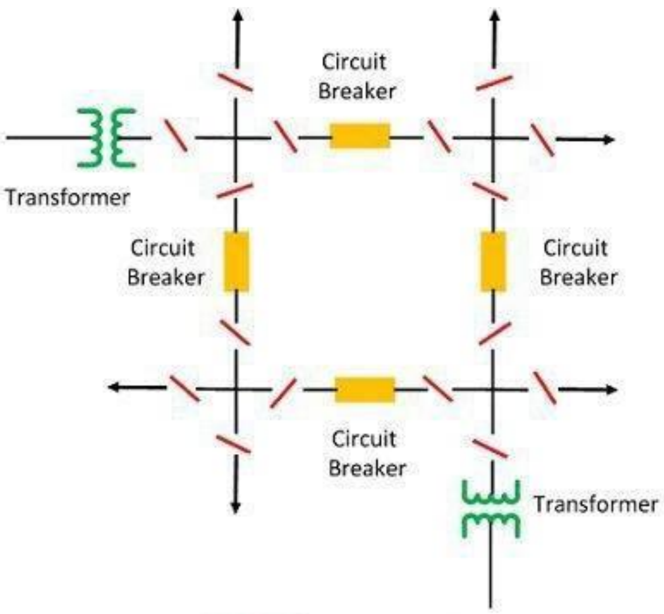
- The fault is localized for the particular section. Hence the complete circuitis not affected by the fault.
- In this arrangement, a circuit breaker can be maintained without interrupting the supply.

Disadvantages of Ring Main Arrangement

- Difficulties occur in the addition of the new circuit.
- Overloading occurs on the system if any of the circuit breakers is opened.

Mesh Arrangement

In such type of arrangement, the circuit breakers are installed in the mesh formed by the buses. The circuit is tapped from the node point of the mesh. Such type of bus arrangement is controlled by four circuit breakers.



Mesh Arrangement

When a fault occurs on any section, two circuit breakers have to open, resulting in the opening of the mesh. Such type of arrangement provides security against bus-bar fault but lacks switching facility. It is preferred for substations having a large number of circuits.