2.6 Over current, Directional, Distance, Differential, Negative sequence and Under frequency relays:

2.6.1 over current relay:

In an over current relay or o/c relay the actuating quantity is only current. There is only one current operated element in the relay, no voltage coil etc. are required to construct this protective relay.

Principle:

- In an over current relay, there would be essentially a current coil. When normal current flows through this coil, the magnetic effect generated by the coil is not sufficient to move the moving element of the relay, as in this condition the restraining force is greater than deflecting force.
- But when the current through the coil increased, the magnetic effect increases, and after certain level of current, the deflecting force generated by the magnetic effect of the coil, crosses the restraining force, as a result, the moving element starts moving to change the contact position in the relay.
- Although there are different types of over current relays but basic working principle of over current relay is more or less same for all.

Types of Over Current Relay

Depending upon time of operation, there are various types of Over Current relays, such as,

1. Instantaneous over current relay.
2. Definite time over current relay.
3. Inverse time over current relay.

Inverse time over current relay or simply inverse OC relay is again subdivided as inverse definite minimum time (IDMT), very inverse time, extremely inverse time over current relay or OC relay.

1. Instantaneous Over Current Relay:

- Here generally a magnetic core is wound by current coil. A piece of iron is so fitted by hinge support and restraining spring in the relay, that when there is not sufficient current in the coil, the NO contacts remain open.
- When current in the coil crosses a present value, the attractive force becomes sufficient to pull the iron piece towards the magnetic core and consequently the no contacts are closed. The preset value of current in the relay coil is referred as pick up setting current.
- This relay is referred as instantaneous over current relay, as ideally, the relay operates as soon as the current in the coil gets higher than pick up setting current.
- There is no intentional time delay applied. But there is always an inherent time delay which cannot be avoided practically. In practice the operating time of an instantaneous relay is of the order of a few milliseconds.

2. Definite Time Over Current Relay:

- This relay is created by applying intentional time delay after crossing pick up value of the current. A definite time over current relay can be adjusted to issue a trip output at definite amount of time after it picks up.
- Thus, it has a time setting adjustment and pick up adjustment.

3. Inverse Time Over Current Relay

- Inverse time is a natural character of any induction type rotating device. This means the speed of rotation of rotating art of the device is faster if input current is increased. In other words, time of operation inversely varies with input current. This natural characteristic of electromechanical induction disc relay in very suitable for over current protection.
- This is because, in this relay, if fault is more severe, it would be cleared faster. Although time inverse characteristic is inherent to electromechanical induction disc relay, but the same characteristic can be achieved in microprocessor based relay also by proper programming.

Inverse Definite Minimum Time Over Current Relay or IDMT O/C Relay:

- Ideal inverse time characteristics cannot be achieved, in an over current relay. As the current in the system increases, the secondary current of the current transformer is increased proportionally.
- The secondary current is fed to the relay current coil. But when the CT becomes saturated, there would not be further proportional increase of CT secondary current with increased system current.
- From this phenomenon it is clear that from trick value to certain range of faulty level, an inverse time relay shows exact inverse characteristic. But after this level of fault, the CT becomes saturated and relay current does not increase further with increasing faulty level of the system. As the relay current is not increased further, there would not be any further reduction in time of operation in the relay.
- This time is referred as minimum time of operation. Hence, the characteristic is inverse in the initial part, which tends to a definite minimum operating time as the current becomes very high.
- That is why the relay is referred as inverse definite minimum time over current relay or simply IDMT relay.

2.6.2 Directional Relay:

Principle

- This is also a special type of over current relay with a directional features. This directional over current relay employs the principle of actuation of the relay, when the fault current flows into the relay in a particular direction.
- If the power flow is in the opposite direction, the relay will not operate. Normally, the conventional over current relay (non- direction) will act for fault current in any direction.
- The directional over current relay recognizes the direction in which fault occurs, relative to the location of the relay. The principle of directional protection is as under:

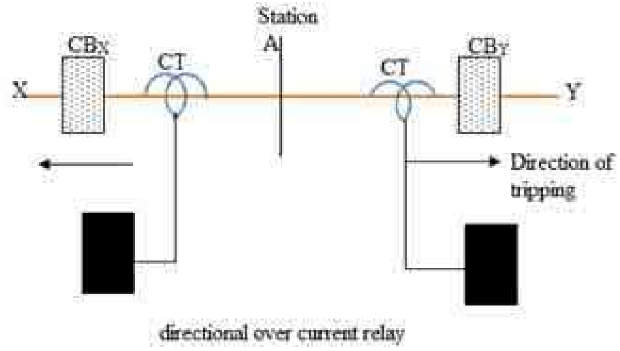


Figure: Basic diagram of directional over current relay
[Source: "Principles of Powersystem" by V.K.Mehta, Page: 292]

- Consider a feeder XY, passing through station A. The circuit breaker in feeder AY is provided with a directional relay R, which will trip the breaker CB_Y, if the fault power flow is in the direction AY alone.
- Therefore, for faults in feeder AX, the circuit breaker CB_Y, does not trip unnecessarily. However, for faults in feeder AY, the circuit Breaker CB_Y trips, due to direction feature of the relays, set to act in the direction AY.
- This type of relay is also called reverse power relay, So far as the direction of fault current (power) flow is concerned. Reverse power flow relays with directional features, not only senses the direction flow, but also measures magnitude of power flow.

Construction and Operation:

- Whenever a near or close-up fault occurs, the voltage becomes low and the directional relay may not develop sufficient torque for its operation. To get sufficient torque during all types faults, irrespective of locations with respect to relays, the relays connections are to be modified.
- Each relay is energized by current from its respective phase and voltage. One of the methods of such connections is 30^{o} connection and other is 90^{o} connection.

30^{o} Connection phasor Diagram:

- In this type of 30^{o} connections, the current coil of the current coil of the relay of phase A is energized by phasor current I_A and the line voltage V_{AC}. Similarly, the relay in phase B by I_B and V_{BA} and in phase C by I_C and V_{CB}.

- The relay will develop maximum torque when its current and voltage are in phase.

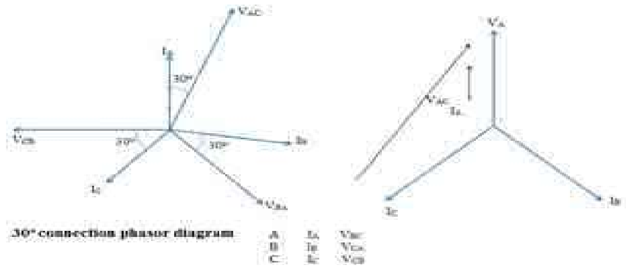


Figure: **30^{o} Connection phasor Diagram**

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 294]

90^{o} Connection Phasor Diagram:

- In the 90^{o} connection, relay in phase A is energized by I_A and V_{BC}, relay in phase B, by I_B and V_{CA} and the relay in phase C by I_C and V_{AB}.
- The relay is designated to develop maximum torque when the relay current leads the voltage by 45^{o}.

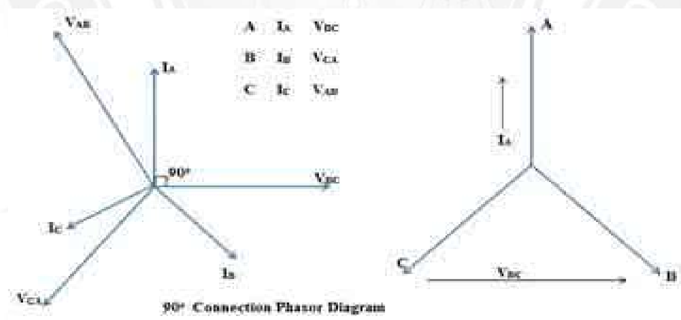


Figure: **90^{o} Connection Phasor Diagram**

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 295]

Construction:

- It has a metallic disc free to rotate between the poles of two electromagnets (EM).The spindle of this disc carries a moving contact which bridges two fixed contacts when the disc rotates through an angle, which is adjustable between 0^{o} to 360^{o}.

- By adjusting this angle, the travel of moving contact can be adjusted so that the relay can be given any desired time setting which is indicated by a pointer, The dial is calibrated from 0-1.
- The relay time from name plate curve is to be multiplied by time multiplier setting.

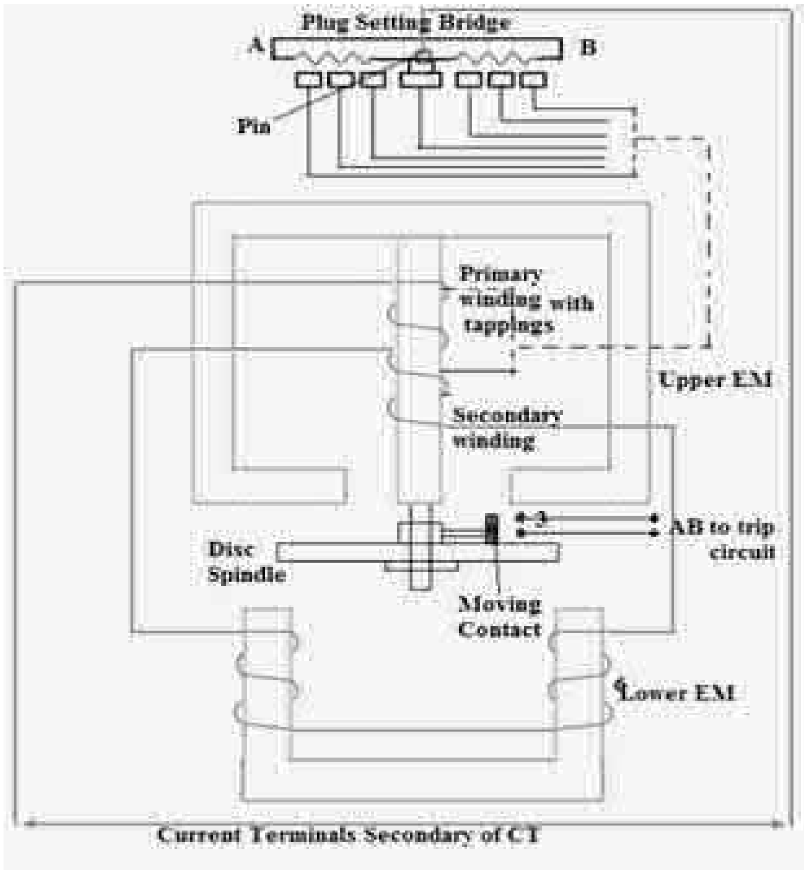


Figure: **Directional over Current Relay**
[Source: "Principles of Powersystem" by V.K.Mehta, Page: 298]

- The upper magnet has two windings. The primary coil is connected to the secondary of CT through tapping in it. Theses tapings are connected to plug setting bridge.
- The secondary is connected to the lower electro magnet; the torque exerted on the disc is due to the interaction of eddy currents produced therein by the flux from the upper EM and the lower EM. The relay setting is 50% to 200% in steps of 25%.

Constructional Details and Operation of Directional Over Current Relay (Wattmeter Type):

- A directional over current relay operates when the current exceeds a specified value in a specified direction. It contains two relaying units, over current units and the other a directional unit.
- For directional unit, the secondary winding of the over current (relay) unit is kept open (AB). When the directional unit operates, it closes the open contacts of the secondary winding of the relay may be either wattmeter or shaded pole type.

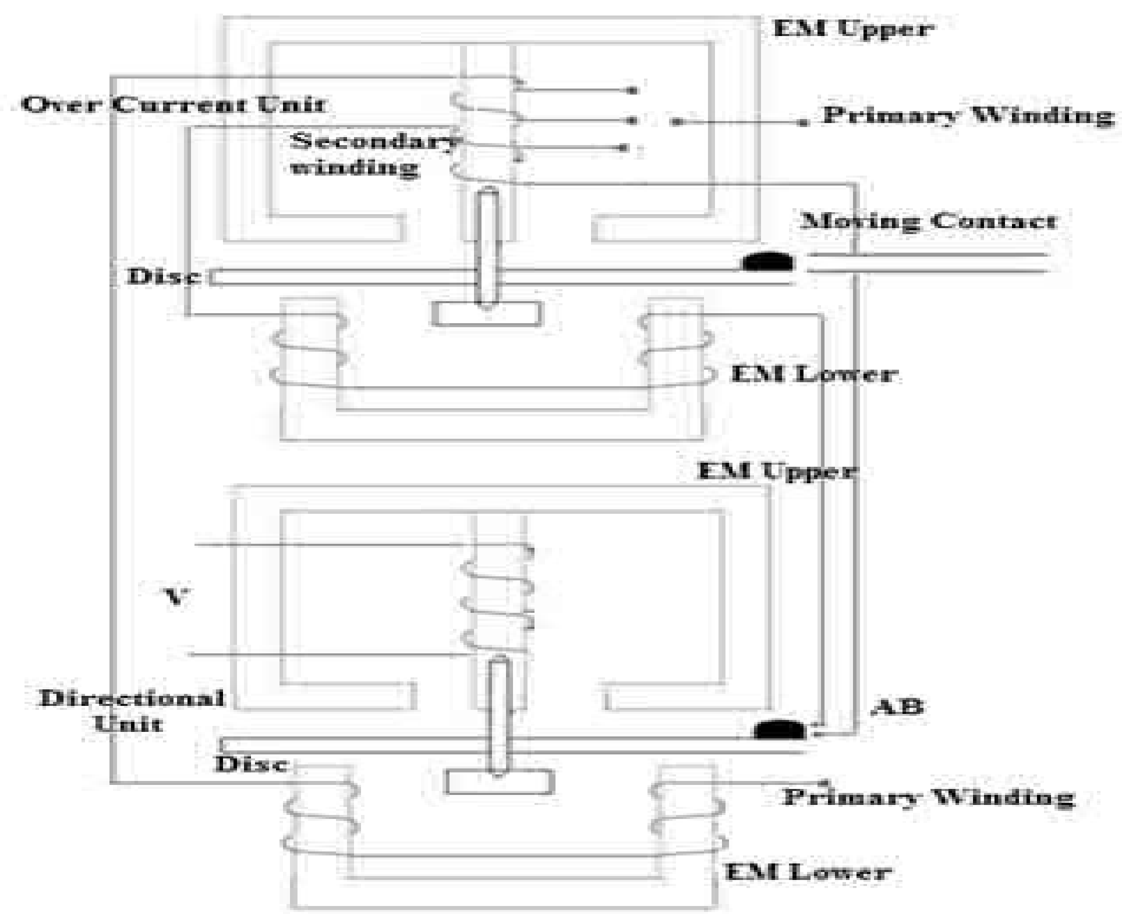


Figure: **Directional over Current Relay**
[Source: "Principles of Powersystem" by V.K.Mehta, Page: 301]

- Under normal operating conditions, power flows in the normal direction in the circuit, protected by the relay and therefore, the directional unit does not operate.
- When a short circuit occurs, there is a tendency for the current or power to flow in the reverse direction. In such a case, the disc of the directional unit rotates to bridge he fixed contacts A and B, completing the circuit for the over current unit.
- The disc of the over current unit rotates consequently and the moving contacts attached to it closes the trip circuit. This operates the circuit breaker which isolates the faulty section.
- The directional unit is made very sensitive so that with the lowest value of voltage which may be anticipated under severe fault conditions, sufficient torque is produced by the current to complete the operation and allow its contacts to close.

2.6.3 Distance Relay:

- Distance protection is a widely used protective scheme for the protection of high or an extra high voltage transmission lines.
- The operation of the conventional over current relays either direction or non directional, depend on the magnitude of current or power in the protected circuit, where as the distance protection relay operate on the principle of the ratio of applied voltage to current in that circuit.
- This ratio is proportional to the distance along the line, and the relay that measures the distance is called distance protection relay. It is not unit system of protection. A single scheme provides both primary and backup protections.

Principle:

- The working principle of distance relay **or** impedance relay is very simple. There is one voltage element from potential transformer and a current element fed from current transformer of the system.

- The deflecting torque is produced by secondary current of CT and restoring torque is produced by voltage of potential transformer.
- In normal operating condition, restoring torque is more than deflecting torque. Hence relay will not operate. But in faulty condition, the current becomes quite large whereas voltage becomes less.
- Consequently, deflecting torque becomes more than restoring torque and dynamic parts of the relay starts moving which ultimately close the No contact of relay.
- Hence clearly operation or working principle of distance relay depends upon the ratio of system voltage and current. As the ratio of voltage to current is nothing but impedance a distance relay is also known as impedance relay.
- The operation of such relay depends upon the predetermined value of voltage to current ratio. This ratio is nothing but impedance.
- The relay will only operate when this voltage to current ratio becomes less than its predetermined value. Hence, it can be said that the relay will only operate when the impedance of the line becomes less than predetermined impedance (voltage / current).
- As the impedance of a transmission line is directly proportional to its length, it can easily be concluded that a distance relay can only operate if fault is occurred within a predetermined distance or length of line.

Torque equation:

- The impedance relay is a double actuating relay and essentially consists of two elements operated voltage element and the current operated element. The current operate elements produce a positive (pick up torque) while the voltage elements develop a negative or reset torque. Taking spring control effects as –K3, the torque equation of the relay is:

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

Where V and I are the RMS value of voltage and current respectively. At balance point, when the relay is on the extreme of operating the net torque is zero.

$$k_2V^2 = k_1I^2 - k_3$$

The effect of control spring magnitude is negligible. Its effect is noticeable only at current, magnitude well below those normally encountered. Hence, taking K3 = 0 the relay torque equation becomes

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

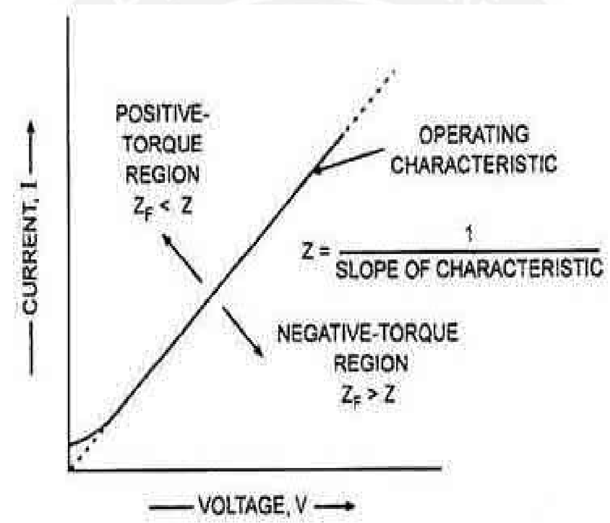


Figure: operating characteristic of V and I

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 304]

- The operating characteristic regarding voltages V and current I is shown in the figure, causing a notable bend in the characteristic only at the current low end.
- The dashed line represents an operating characteristic which represents a constant value of Z, may be considered as operating characteristic.

Types of Distance Protection Relay

The distance protection relay family consists of the following types of Relays:

1. Impedance Relays
2. Reactance Relays
3. MHO Relays or Admittance Relays

1. Impedance Relay:

➔ An impedance relay measures the impedance of the line at the relay location. When a fault occurs in the protected line section the measured impedance is the impedance of the line section between the relay location and the point of fault.

➔ It is proportional to the length of the line and hence to the distance along the line as shown below:

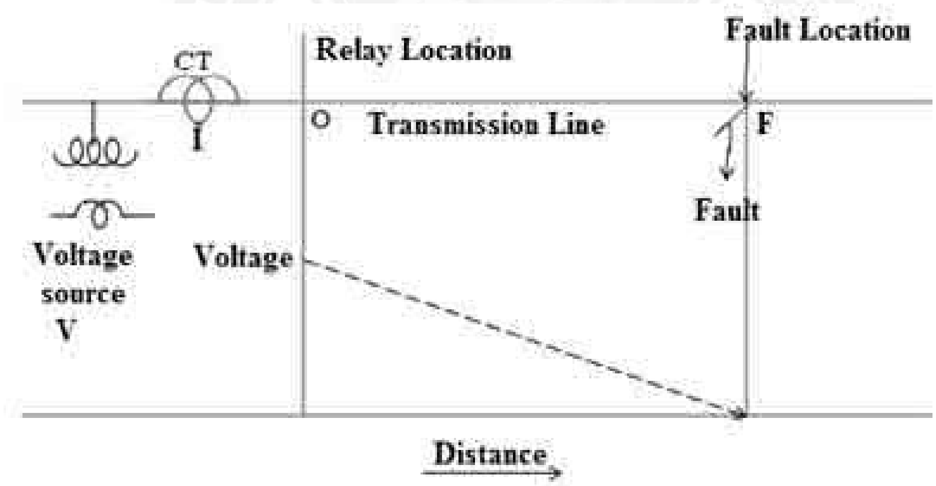


Figure: Impedance of the transmission line
[Source: "Principles of Powersystem" by V.K.Mehta, Page: 306]

➔ OF is the distance along the line between the relay location and the fault location, the voltage drop along OF and the current I flowing in the line are taken for measurement by the relay and the ratio of the both quantities is nothing but impedance.

Construction of Impedance Relay

The figure shows the simple arrangement of impedance relay operates based on the distance of the fault.

Here, balanced beam type EM relay is used as impedance relay. The CT and PT are energized by the current and voltage of the circuit which is to be protected.

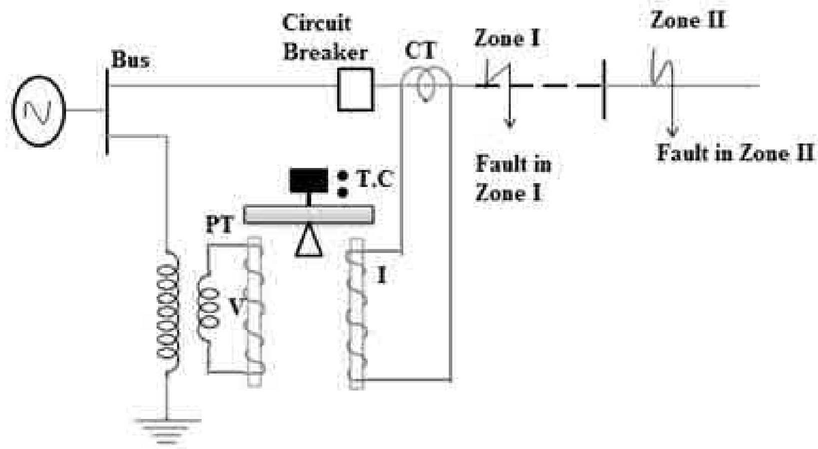


Figure: Impedance relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 310]

Operating Principle of Impedance Relay:

- ✓ A simple form of EM balanced beam impedance relay is shown in the fig. It has a fixed beam and two electromagnets (EM). One EM is energized by voltage of the zone through PT and the other EM is energized by current of the zone through CT.
- ✓ Under no fault condition, the pull due to voltage element will be more than the pull due to current element and the trip circuit (TC) remains open. Since this type of relay operates based on the impedance of the circuit which in turn depends upon the distance of the fault from the relay location, it is called distance relay.
- ✓ In operating characteristics of an impedance of the circuit is compared with voltage at relay location. The current produces a positive torque, called Operating Torque and the voltage produces a negative torque called Restraining Torque.
- ✓ This equation for the operating torque of an electromagnetic relay is:

$$T = K1\, I^2 - K2V^2 - K3$$

Where K_1, K_2, K_3 are constants, K_3 being the torque due to control spring effect. Neglecting the effect of the spring used, which is very small, the torque equation can be written as:

$$T = K_1 I^2 - K_2 V^2$$

For the operation of the relay, the following condition should be satisfied.

$$K_1 I^2 > K_2 V^2 \text{ or } K_2 V^2 < K_1 I^2$$

$$V_2/I^2 < K_1/K_2$$

$V/I < K$ where K is a constant. as V/I is Z, Z<K.

The above expression explains that the relay is on the verge of operation when the ratio of V to I i.e., the measured value of line impedance is equal to a given constant. The relay operates, if the measured Z is less than the given constant. This given constant, is a design value depending on the total length of the HT / EHT feeder to be protected.

A distance relay can also be called as an Ohmmeter, measuring the impedance of the line in ohms.

Operating Characteristic of an Impedance Relay (V-I and R-X Diagram)

V-I Diagram

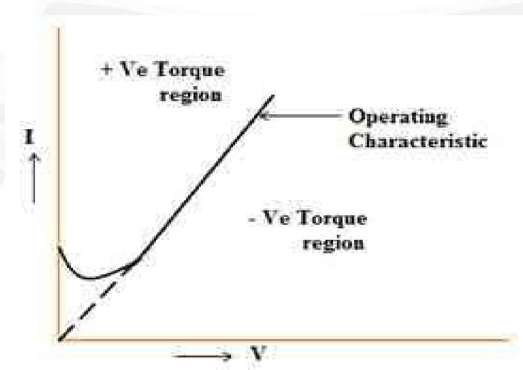


Figure: V-I Diagram of Impedance relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 316]

- The above figure shows the operating characteristic of impedance relay in terms of voltage and current. Hence the above is termed as V-I diagram.

- The operating characteristic is slightly bent near the origin due to the effect of the control spring. If the relay is of static relay type, the characteristic would have been a straight line, as there is no control spring in the relay.
- The positive torque region is the relay operating zone (above the characteristic curve) and the negative torque region below the curve is the relay non-operating zone.

R-X Diagram

Another and more useful way of representing the operating characteristic of the relay is an R-X diagram as shown below:

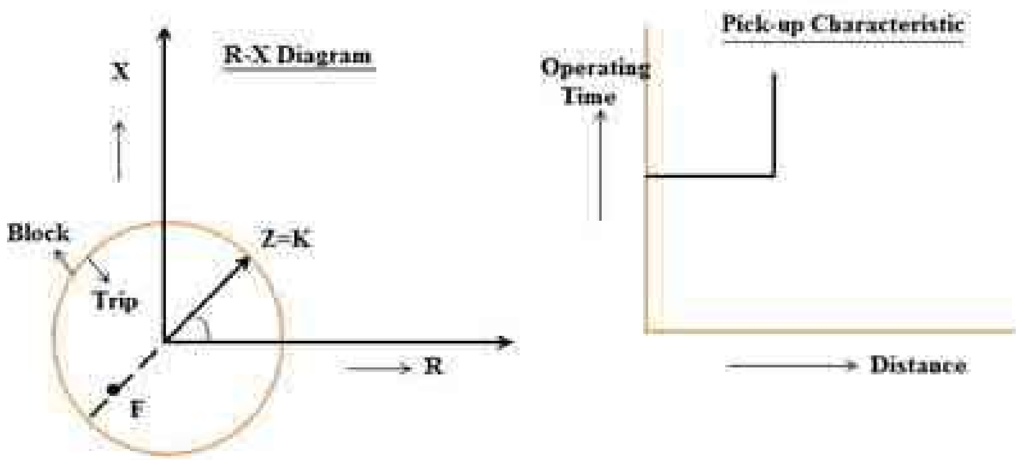


Figure: R- X Diagram of Impedance relay
[Source: "Principles of Powersystem" by V.K.Mehta, Page: 317]

- Z = K = radius of the circle. When Z, i.e., the impedance of the line up to fault location measured from the relay location is less than K, the relay will operate i.e., the fault location lies inside the circle. If it is outside the circle, the relay will not sense it and hence, that zone is the Blocking zone.
- The operations of the relay depends upon the magnitude of Z and not on angle Φ, as Z is the radius of the circle, having equal magnitude along the circumference of the circle, from the centre.
- It is also seen that the impedance relay, basically a non-directional relay, as it operates on the magnitude of the operating quantity and not on its direction of

flow, The figure indicates that the operating time of this relay is constant irrespective of the distance within the protective zone.

2. Reactance relay:

A simplest form of electromagnetic induction type reactance relay (Induction Cup) is shown in the figure.

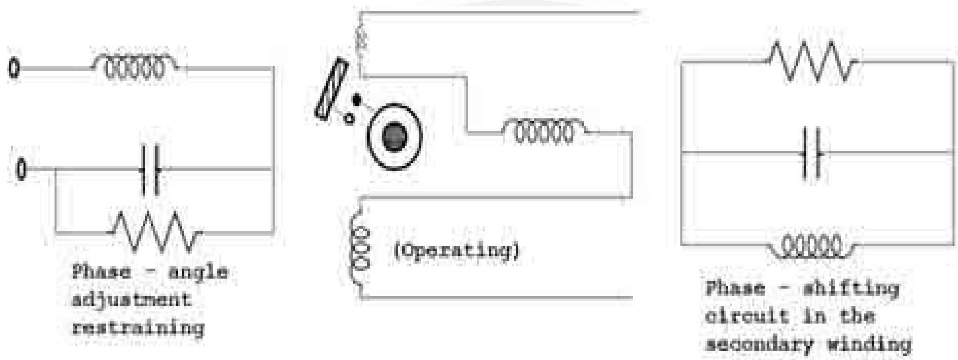


Figure: Induction type reactance relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 316]

- The current is the operating quantity. It produces flux in the upper, lower and right hand side poles. The right hand side pole flux is out of phase with the flux in the lower and upper poles because of the secondary winding which is closed by a phase shifting circuit and is placed on the right hand side pole.
- The polarizing flux and the right hand side pole flux interact to produce the operating torque K_1I^2. The interaction of left hand side pole flux and the polarizing flux produces the restraining torque. The phase angle adjustment circuit is connected in series with the voltage coil.
- A reactance relay measures the reactance of the line at the relay location. This induction type reactance relay performance is not affected by arc resistance during the occurrence of the fault. In case of a fault, the relay measures the reactance of the line up to the fault point from the relay location.

The relays operating characteristic on R-X diagram, is a straight line parallel to X axis as indicated below in figure.

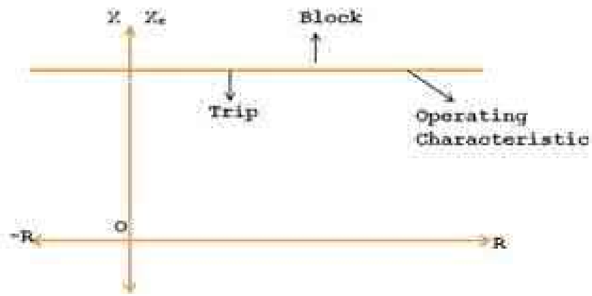
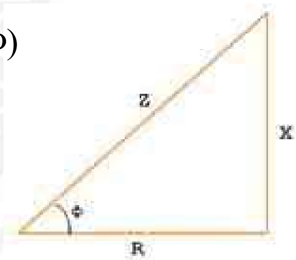


Figure: operating characteristic of R-X diagram

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 319]

- The operating torque is by current and the Restraining torque is by current –voltage directional element. The Reactance relay may also be called as over current relay with directional restraint.
- The directional element is arranged to develop maximum negative torque, when the current lags its voltage by 90^o. If the spring control effect is K_3, the torque T is given by:

$T = K_1 I^2 - K_2 VI \sin\Phi - K_3$ where $\sin\Phi = \cos(90 - \Phi)$



As the value of K_3 is very small, it can be neglected.

$T = K_1 I^2 - K_2 VI \sin\Phi$.

$VI\sin\Phi$ indicates reactive volt-amperes.

As the start of relay operation, $K_1 I^2 =$

$K_2 VI\sin\Phi$

$K_1 I = K_2 V \sin\Phi$

$(V/I) = K_1 / K_2 \sin\Phi$

$Z \sin\Phi = K_1/K_2 = X = \text{Constant}$

Operating torque will be more than the Restraining torque for relay operation. In other words the Restraining torque should be less than the operating torque.

i.e., $K_2 VI\sin\Phi < K_1 I^2$

$K_2 V\sin\Phi < K_1 I$

$V/I \sin\Phi < K_1/K_2 < K$, a constant

$X < K$, as $X = Z \sin\Phi$ and $Z = V/I$

The reactance relay will operate, when the measured value of the reactance is less than the predetermined or design value of K.

- The directional unit used with the reactance relay is not the same as the one used with the impedance type relay because the reactance relay will trip under normal load conditions when the power factor of the load is unity or near zero.
- This is because; the restraining reactive volt-ampere at U.P.F or near U.P.F will be near zero. Therefore, we must have directional unit is called Mho unit or Mho relay, having a circular characteristic.
- Reactance relay are used for protection of short lines having fault currents less than 20 KA. In such lines, the effect of fault resistance or arc resistance is predominant.

3. Mho relay:

A simple form of Mho relay | Admittance or angle admittance relay shown in the figure below:

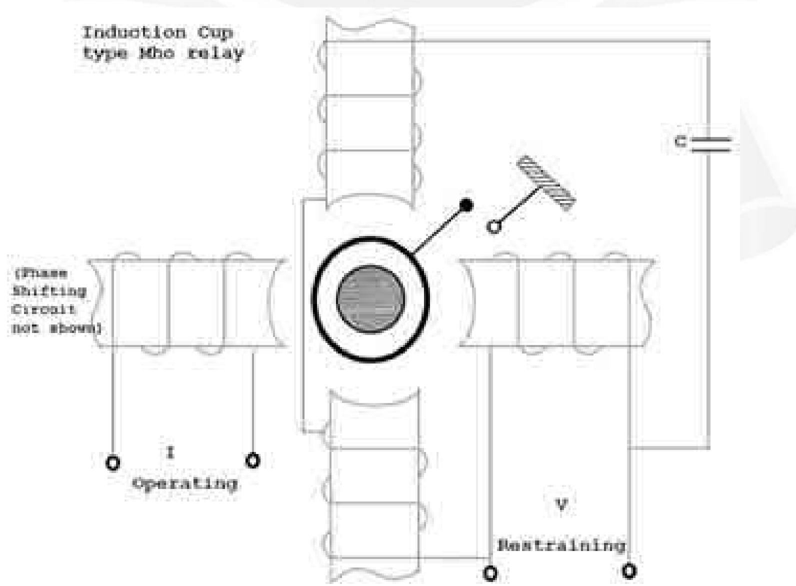


Figure: Induction cup type Mho relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 322]

It is an electromagnetic induction cup type mho relay.

The torque equation is given by $T = K_1 \; VI \,(\Phi - \alpha) - K_2V^2 - K_3$

- The upper and lower poles are energized by a voltage V to produce a polarizing flux. The capacitor connected in series provides memory action. The left is energized by a current is the operating quantity. The left pole due to current I interacts with the polarized flux due to V produce the operating torque $K_1VICos(\Phi - \alpha)$.
- The angle α can be varied by adjusting the resistance in the phase shifting circuit provided on the left pole. The right hand side pole is energized by the voltage and the flux produced by it interacts with the polarizing flux for producing the restraining torque, K_2V^2.

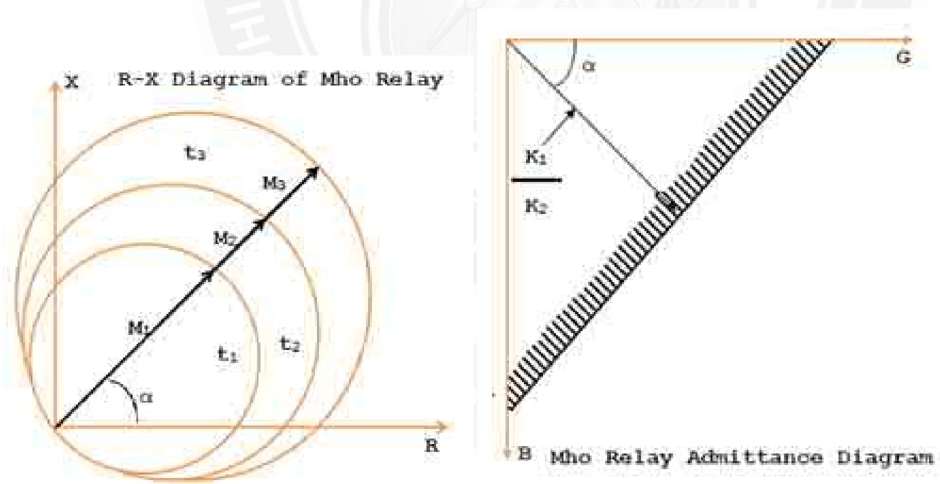


Figure: R-X diagram of Mho relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 324]

- A Mho relay measures a component of admittance |Y| ∠θ. But its characteristic when plotted on the impedance diagram (i.e., R-X diagram) is a circle passing thro' the origin shown in the fig.

- It is inherently a directional relay as it detects the fault only in the forward direction. The relay is called Mho relay because its characteristic is a straight line, when plotted on an admittance diagram (G-B axes i.e., conductance – susceptance axes) as in the figure.
- The operating torque for a Mho relay is by V-I element and restraining torque is by voltage element. Therefore, a Mho relay can be called as a voltage restrained directional relay.

$T = K_1 VI \cos(\Phi - \alpha) - K_2V^2$, neglecting the effect of the spring.

$K_2V^2 < K_1VI \cos(\Phi - \alpha)$

$K_2V < K_1I \cos(\Phi - \alpha)$

$(V/I \cos(\Phi - \alpha)) < K_1/K_2$ or $(V/I) < (K_1/K_2) \cos(\Phi - \alpha)$ or $Z < (K_1/K_2)\cos(\Phi - \alpha)$

At balance conditions, the operating torque is equal to restraining torque. i.e., $K_1VI\cos(\Phi - \alpha) = K_2V^2$

$(I/V)\cos(\Phi - \alpha) = (K_2K_1) = K$

$(1/Z) = (K / \cos(\Phi - \alpha)) = Y$

$Y = K / \cos(\Phi - \alpha)$ = admittance in mho.

- There units of mho relays are used for the protection of a section of the line. I unit is a high speed unit to protect 80% to 90% of the line section. The II unit protects the rest of the line section and its reach extends up to 50% of the adjacent line section.
- The III unit is meant for backup protection of the adjacent line section. The II and III units operate with a preset time delay, usually 0.2 sec to 0.5 sec and 0.4 sec to 1sec respectively. The time distance characteristic is a stepped one as shown in figure.

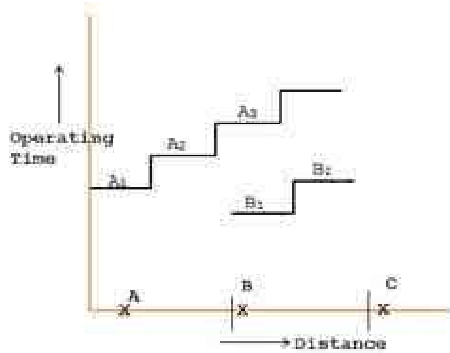


Figure: Time distance characteristics of Mho relay
[Source: "Principles of Powersystem" by V.K.Mehta, Page: 326]

Comparisions of distance relay

S. No	Type of Relay	Operating Torque Element	Restraining Torque Element	Used for Protection
1	Impedance Relay (Z)	Current (I)	Voltage (V)	Phase faults in medium length lines
2	Reactance Relay (X)	Current (I2)	Voltage – Current SinΦ (V – I sin Φ)	Ground faults in short lines
3	Admittance Relay (Y)	VI Cos (Φ – α)	V	Phase faults in long Lines

2.6.4. Differential Relay:

Definition

A differential relay is defined as the relay that operates when the phase difference of two or more identical electrical quantities exceeds a predetermined amount.

From the definition the following aspects are known; -

1- The differential relay has at least two actuating quantities say I_1, I_2

2- The two or more quantities should be similar i.e. current/current.

3- The relay responds to the vector difference between the two i.e. to I_1-I_2, which includes magnitude and/or phase angle difference.

Differential protection is generally unit protection. The protected zone is exactly determined by location of CT's and VT's. The vector difference is achieved by suitable connections of current transformer or voltage transformer secondary.

Types:

1. Current Differential Relay
2. Merz Price or Biased or Percentage Differential Relay
3. Voltage Balance Differential Relay

1. Current Differential Relay

Principle Operation of differential relay:

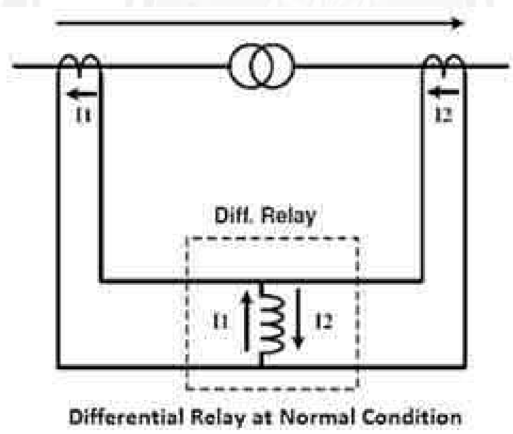


Figure: Current Differential Relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 324]

- Let assume a power transformer with transformation magnitude (ratio) relation 1:1 and (Y/Y) connection and therefore the CT1 and CT2 ensure a similar transformation magnitude relation as shown.
- The current flows within the primary side and secondary side of power transformer are equal, presumptuous ideal power transformer. The secondary current I1 and I2 are same in magnitude and reverse in direction.
- Therefore, the net current within the differential coil is nil at load situation (without any fault), and therefore the relay won't operate.

External Fault Condition in Differential Relay:

- Assigning the previous one the power transformer with an external fault F is shown in figure.
- During this case the 2 currents I1, and I2 can increase to terribly high magnitudes values however there's no modification in phase angle.
- Hence, net current within the differential coil continues to be zero and therefore the relay won't operate.

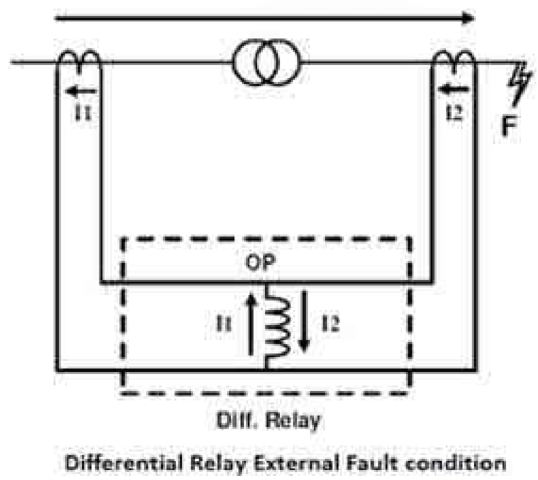


Figure: Current Differential Relay(External fault conditions)

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 326]

Internal Fault Condition in Differential Relay:

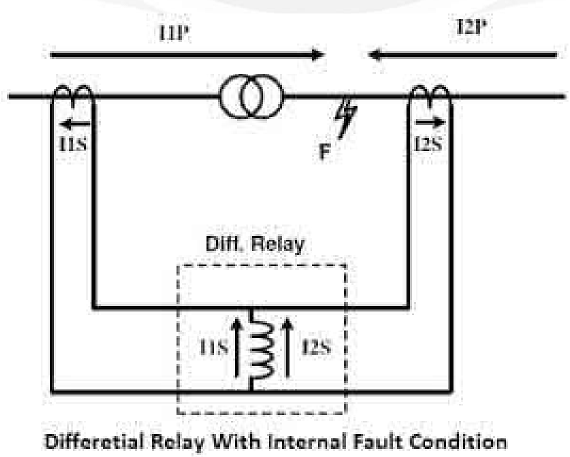


Figure: Current Differential Relay(Internal fault conditions)

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 326]

An internal fault F is shown in this figure. Now, there are 2 anticipated conditions:

There's other supply to feed the fault thus I2P includes a nonzero value Idiff = I1S + I2S which can be terribly high and sufficient to function the differential relay.

Radial system, I2P = 0. So, Idiff = I1S and additionally the relay can work and disconnect the breaker.

2. Merz –price protection:

The reason for using this modification is circulating current current differential relay is to overcome the trouble arising out of differences in CT ratios for high values of external short circuit currents.

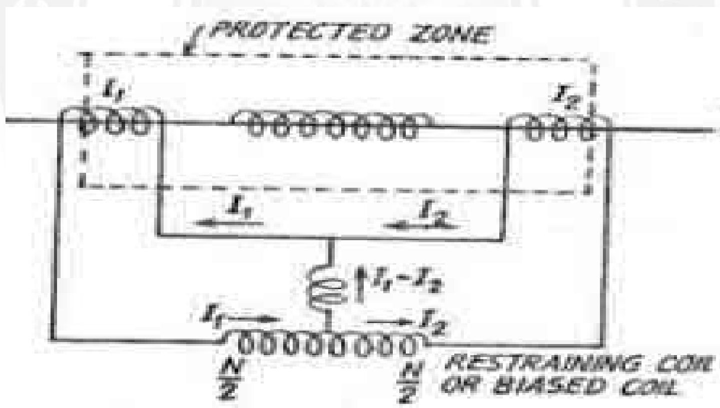


Figure: Percentage differential relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 328]

- The percentage differential relay has an additional restraining coil connected in the pilot wire as shown. In this relay the operating coil is connected to the mid-point of the restraining coil becomes the sum of ampere turns in its two halves, i.e $(I_1N/2) + (I_2N/2)$ which gives the average restraining current of $(I_1 + I_2)/2$ in N turns.
- For external faults both I_1 and I_2 increase and thereby the restraining torque increases which prevents the mal- operation.

- In this relay the operating coil is connected to the mid-point of the restraining coil becomes the sum of ampere turns in its two halves, i.e $(I_1N/2) + (I_2N/2)$ which gives the average restraining current of $(I_1 + I_2)/2$ in N turns.
- For external faults both I_1 and I_2 increase and thereby the restraining torque increases which prevents the mal-operation.

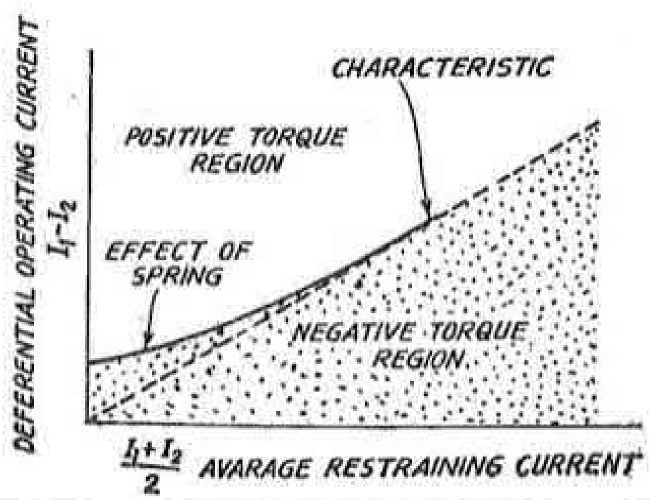


Figure: Operating characteristics differential relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 333]

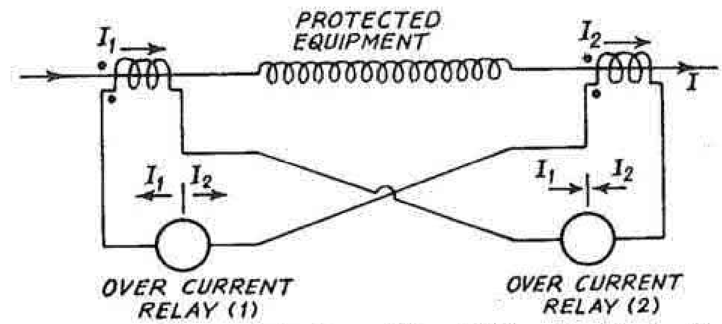
- ✓ The ratio of differential operating current to average restraining current is fixed percentage. Hence the relay is called 'percentage differential relay'.
- ✓ The relay is so called 'Based differential relay' because the restraining coil is also called a biased coil as it provides additional flux.
- ✓ The percentage of biased differential relay has a rising single pick up characteristic. As the magnitude of through current increases, the restraining current decreases.

3. Voltage Balance Differential Relay:

- ➔ The relays are connected in series with the pilot wires, one at each end. The relative polarity of the current transformers is such that there is no current through the relay under normal operating conditions and under fault conditions
- ➔ In this the secondary of CT's are connected such that for normal conditions and through fault conditions, the secondary current of CT's on two sides opposes

each other and their voltage are balanced During internal fault, the condition changes as an equivalent current $(I_1 + I_2)/2$ flows through relay coils at each end.

➔ The current transformer used in such protection is with air gap core so that the core does not get saturated and over voltages are not produced during zero secondary current under working normal condition.



Through fault condition Differential Protection based on balanced voltage principle.

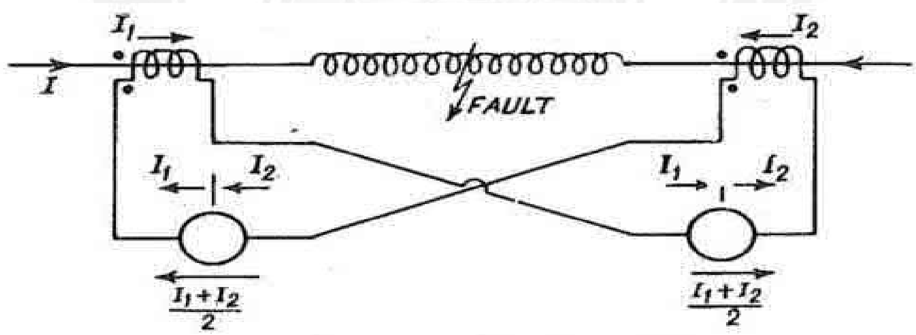


Figure: Voltage Balance Differential Relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 356]

2.6.5 Negative sequence relay:

<u>Principle</u>

- ✓ Negative sequence relays are used to protect electrical machines against overheating due to unbalance currents in stator. These unbalance currents cause heating of rotor and damage it.
- ✓ Unbalance three-phase currents have negative sequence components.
- ✓ These components rotate at synchronous speed in a direction opposite to the direction of rotation of rotor, including double frequency currents in the rotor.

Construction and Operation:

- ✓ The arrangement of negative sequence relay connection is shown in the figure.
- ✓ The relay is connected in parallel across the current transformer secondaries.
- ✓ Under normal conditions, as equal current flows in all the three phases, their algebraic sum is zero. Hence no current flows through the relay.
- ✓ But, if unbalancing occurs, the secondary currents will be different and the resultants current flows through the relay and the operation of the relay trips the circuit breaker to disconnect the generator from the system.

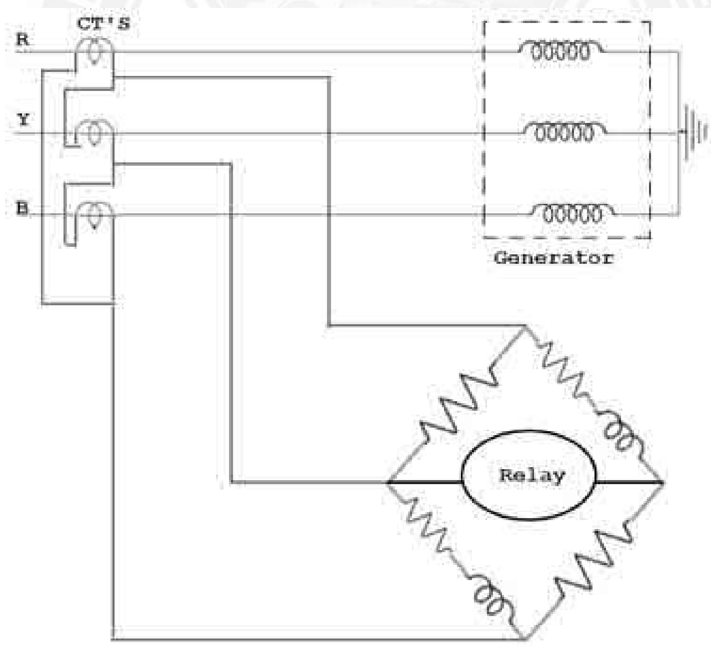


Figure: Negative sequence relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 358]

- ✓ For unbalanced conditions or unsymmetrical faults, negative phase sequence network are used as shown in the figure below.

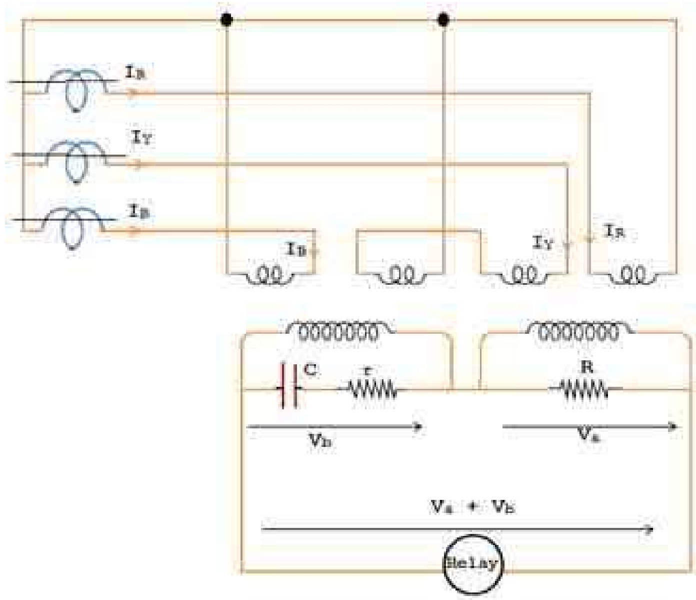


Figure: Negative sequences relay (Un balanced conditions)

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 360]

- ✓ The values of c and r are such as to give a phase shift 60^{o}. It can be seen from the vector diagrams that for the positive sequence currents the output voltage $V_a + V_b$ applied to the relay is zero shown in fig-a below
- ✓ Where for the negative sequence currents, the output voltage $V_a + V_b$ is of considerable magnitude to operate the relay shown in fig-b.

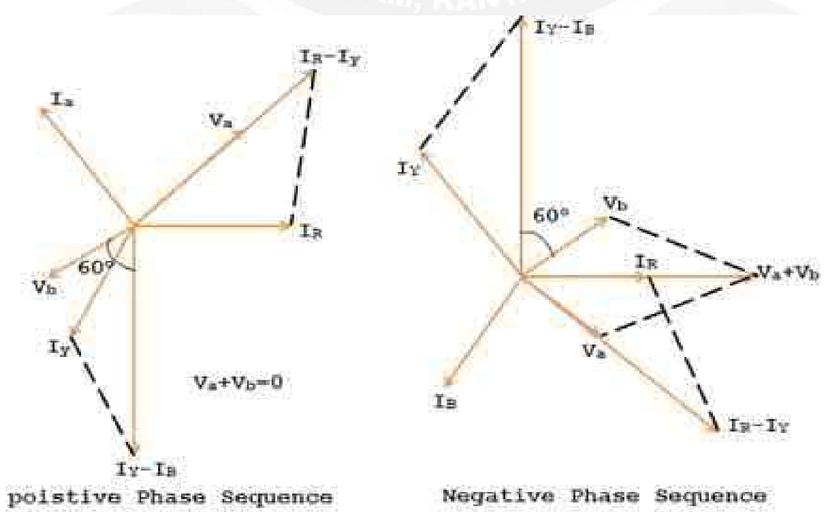


Figure: Pharos diagram of positive and Negative phase sequence relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 364]

The negative sequence relay has the inverse square law characteristic. i.e., $I_2^2 t = K$, a constant. I_2 is the negative sequence component to the current

$$t = K / I_2^2 \text{ i.e., } t \propto 1/I_2^2$$

2.6.6. Under Frequency Relay

The frequency relays are normally used in generator protection and for load- frequency control.

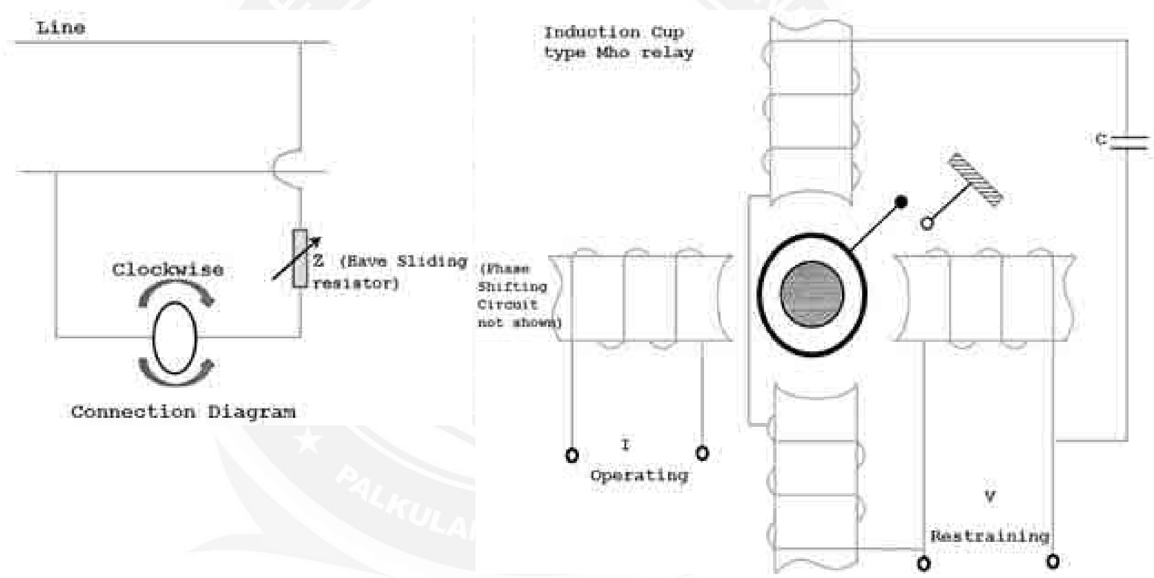


Figure: Under Frequency Relay

[Source: "Principles of Powersystem" by V.K.Mehta, Page: 369]

- ✓ The frequency of induced e.m.f. of synchronous generator is maintained constant by constant speed. Over speeding of the generator occurs due to loss of load and under speeding occurs due to increase in load.
- ✓ In both the cases, the frequency varies from normal value. In order to avoid damage to the generator under the above two conditions, frequency relays are used.

- ✓ Under frequency relay trips the feeder on load at set value of frequency, so as to give relief to the generator, thereby saving the unit. Under frequency relay thus aids load shedding programme to save the grid.