2.6.1 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 $-K_3$, the torque equation of the relay consists of 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. The effect of control spring magnitude is negligible. Its effect is noticeable only at current, magnitude well below those normally encountered.

- 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:

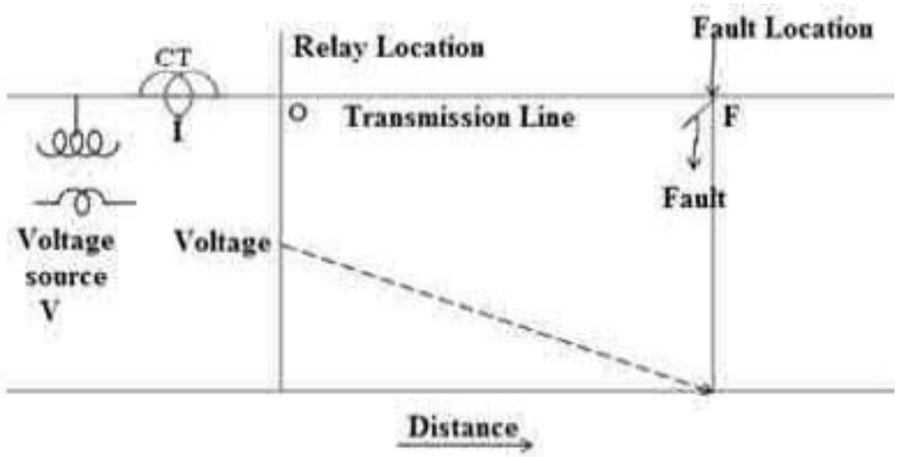


Figure: Impedance of the transmission line

[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.

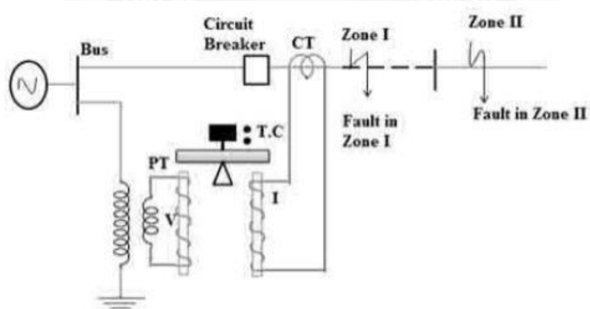


Figure: Impedance relay

[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 negati ve torque called Restraining Torque.
- ✓ This equation for the operating torque of an electromagnetic relay is:

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

where K1, K2, K3 are constants, K3 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:

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

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

$$K1I^2 > K2V^2 \text{ or } K2V^2 < K1I^2$$

$$V2/I^2 < K1/K2$$

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

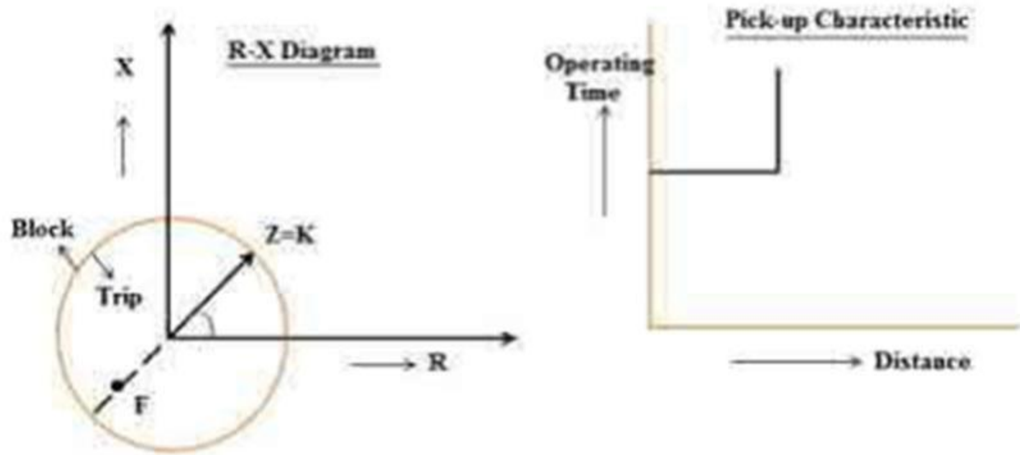


Figure: V-I Diagram of Impedance relay

[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:

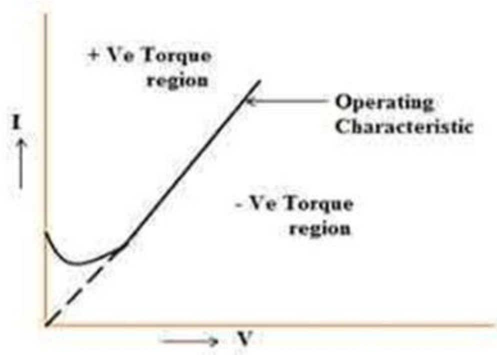


Figure: R- X Diagram of Impedance relay

[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.

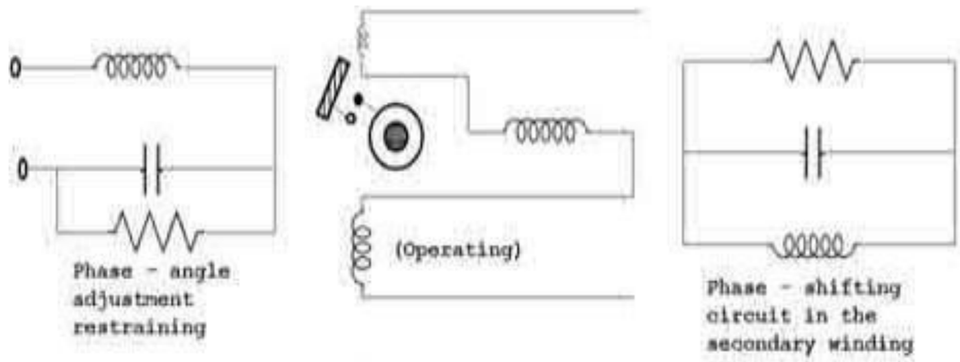


Figure: Induction type reactance relay *[Source: "Principles of Powersystem" by V.K.Mehta, Page: 316]*

- 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 rela by 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.

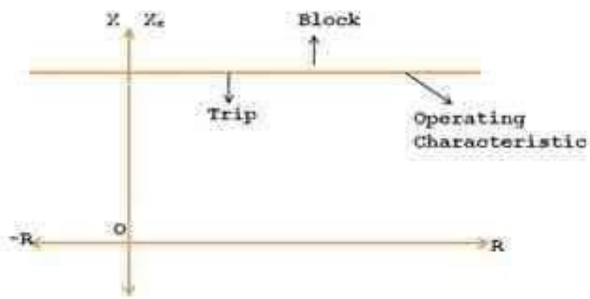
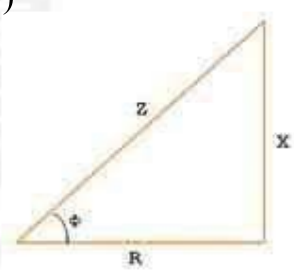


Figure: operating characteristic of R-X diagram

[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:

$T = K_1l^2 - K_2VI \sin \Phi - K_3$ where $\sin \Phi = \cos (90 - \Phi)$



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

$T = K_1l^2 - K_2VI \sin \Phi$.

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

As the start of relay operation, $K_1l^2 = K_2VI\sin\Phi$

$K_1I = K_2 \, V \sin\Phi$

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

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

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., $K_2 \, VI\sin\Phi < K_1I^2 \; K_2V\sin\Phi < K_1I$

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

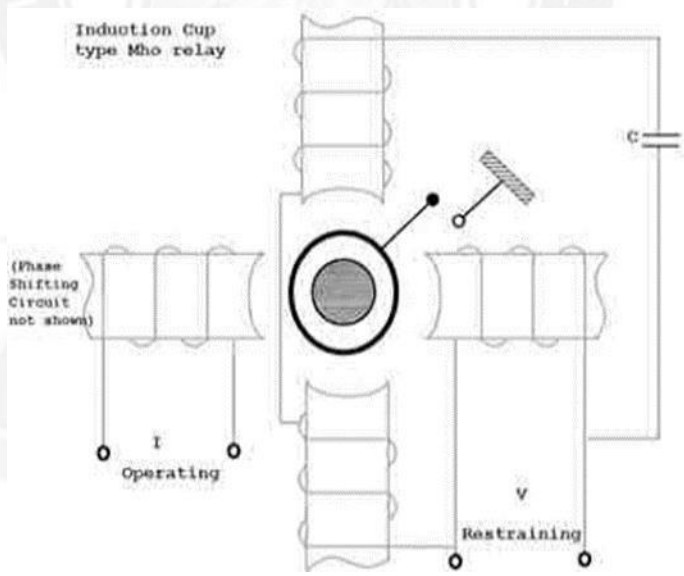


Figure: Induction cup type Mho relay

[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.

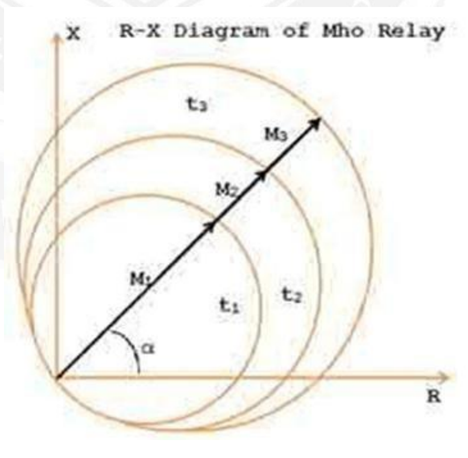


Figure: R-X diagram of Mho relay

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

- A Mho relay measures a component of admittance $|Y| \angle\theta$. But its characteristic when plotted on the impedance diagram (i.e., R-X diagram) is a circle passing through 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 $Z < (K_1/K_2)\cos(\Phi - \alpha)$

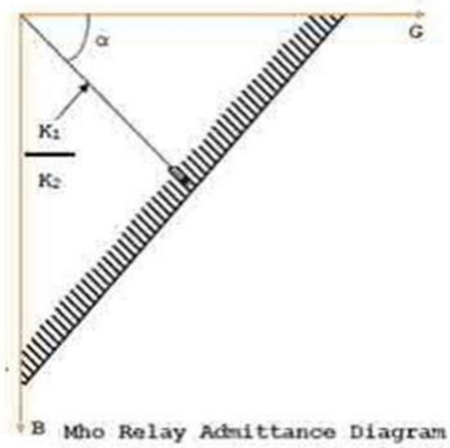
At balance conditions, the operating torque is equal to restraining torque. i.e., $K_1VI\cos(\Phi - \alpha) = K_2V^2$

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

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

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



Mho Relay Admittance Diagram