Electromagnetic protection:

Principles of Operation and Constsruction of Different Relays

Electromagnetic type attraction relay:-

In this type relays the operation is obtained by the virtue of an armature being attracted to the poles of an electromagnet or a plunger being drawn into a solenoid. These relays are operated on both AC as well as DC.

Characteristics, applications and limitations.

i, These relays are non-directional
ii, simple in construction
iii, Inherently very fast in operation

These relays are normally used for DC operating quantiti but these can also be used for AC operation by providing shading rings on thier poles to split the air flux into two out of phase components.

These are normally employed as under current, short circuit, over voltage, under voltage relays in distribution circuits.

These relays are not suitable for continous operation on AC in the picked up position because there would be excessive vibration and noise.

Important types of electromagnetic attraction relays are

→ Attracted armature type relay
→ Balanced beam type relay
→ solenoid relay

Attracted armature type relay:-

The below figure shows an attracted armature type relay. This relay consists of a laminated electromagnet L and relay coil K and a pivoted laminated armature. The armature is balanced by a counter weight and carries a pair of spring contact fingers at its free end.

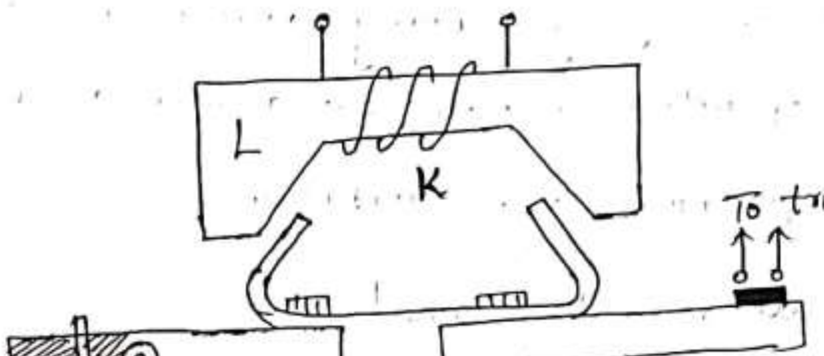


fig: attracted armature relay

Under normal operating condition, this current through the relay coil is such that the counter weight holds the armature in the position shown in above figure whenever a short circuit takes place then the current through the relay armature is attracted upwards hence the relay contacts comes in contact with the trip coil circuit to isolate the fault.

Operating principle :- The electromagnetic force exerted on the moving element (armature) is proportional to the square of the flux in airgap. If saturation is neglected, flux is proportional to square of operating current.

$$\therefore T = K_1 I^2 - K_2$$

where $K_1 I^2$ = operating force

K_2 = restraining force

The relay will operate when $k_1 I^2 - k_2 = 0$

(or) $I = \sqrt{\frac{K_2}{K_1}}$ = constant.

Balanced beam type relay:-

A balanced beam type relay is shown in below figure.

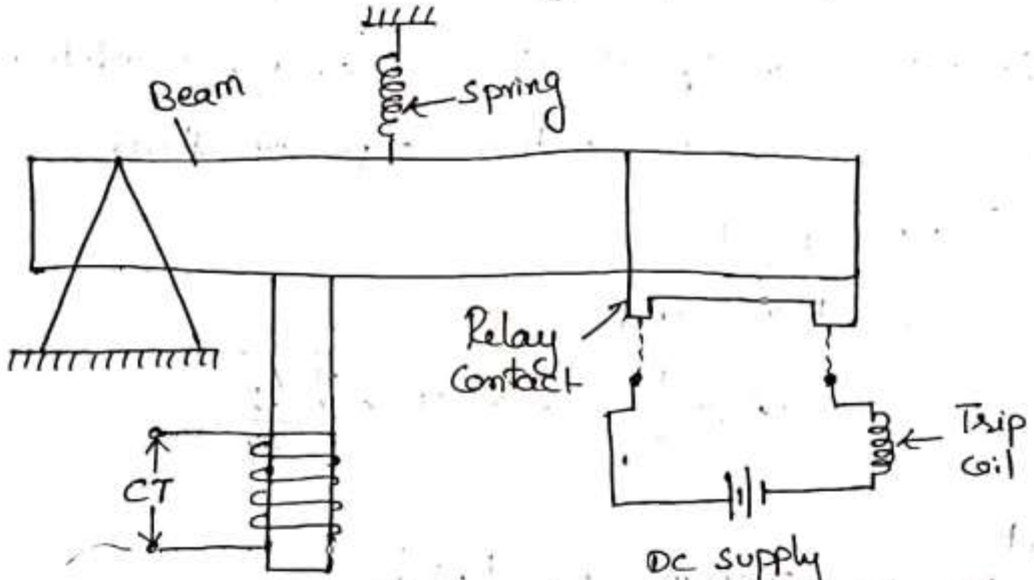


fig: Balanced beam type relay

It consists of an iron armature fastened to a balanced beam under normal operating conditions. the current through the relay coil is such that the beam is held in balanced (horizontal) position by the spring. whenever abnormal condition or fault exists in the system, the current through the relay coil becomes more than pick up value and the beam is attracted to close the trip circuit to isolate the fault.

Operating principle:-

In this relay the operating force is proportional to square of the operating quantity (current)

i.e, $F_1 \propto I^2$

And let the opposing force will be F_2 (including friction)

$\therefore$ operating force, $F_1 = K_1 I^2$

opposing force, $F_2 = K_2$

Net force, F = operating force − opposing force

$= F_1 - F_2 = K_1 I^2 - K_2$

For the relay to operate the necessary condition is the operating force in greater than opposing force.

i.e, $F_1 > F_2$

$K_1 I^2 > K_2$

$I^2 > \frac{K_2}{K_1} \Rightarrow I > \sqrt{\frac{K_2}{K_1}}$

$I > I_{set}$

For DC system, $F_1 = K_1 I_{dc}^2$

For AC system, $F_1 = K_1 I_m^2 \sin^2 \omega t$

$= K_1 I_m^2 \left(\frac{1 - \cos 2\omega t}{2} \right)$

$= \frac{K_1 I_m^2}{2} - \frac{K_1 I_m^2}{2} \cos 2\omega t$

In electromagnetic attraction type relays the operating force produced in a pulsating quantity at double the frequency when it is employed by the AC quantities since the restraining force or controlling force is constant, the net force is pulsating one which means that the relay armature vibrates at double the power supply frequency. These vibrations will lead to sparking between the contacts and the relay will be damaged.

To overcome this difficulty in AC, the two fluxes producing the force are displaced in time phase so that the resultant difficulty force is always positive and constant. This phase displacement can be achieved either by providing two windings on the electromagnet having a phase shifting network or by putting shading ring on the poles of the magnet.

i, Solenoid types relay:-

The below figure shows the schematic arrangement of a solenoid type relay. It consists of a solenoid and movable iron plunger arrangement as shown.

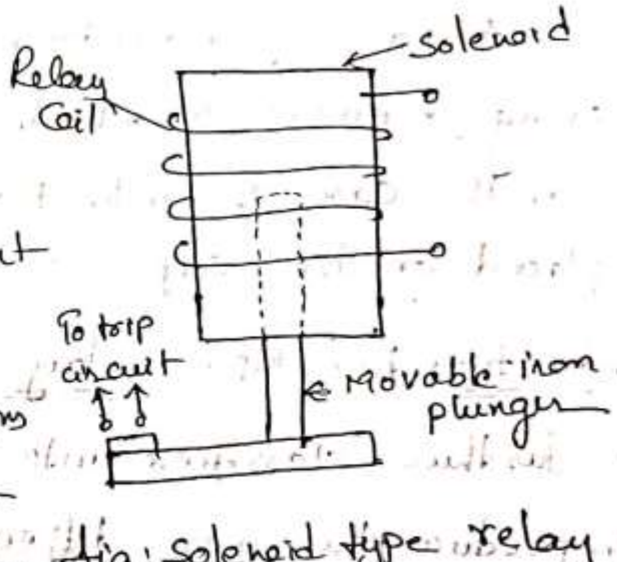


fig: Solenoid type relay

Under normal working conditions the current through coil is such that it holds the plunger by gravity or spring in the position shown. However, when a fault occurs, the current through the relay coil exceeds the pick-up value, causing the plunger to be attracted to the solenoid. The up-ward moment of the plunger closes the trip circuit, consequently CB opens and the faulty circuit is disconnected.

Electro Magnetic induction Relays:-

The electromagnetic induction relays operate based on the electromagnetic induction principle, therefore these relays can be used only on AC circuits and not on DC circuits. Based on the type of the rotor being used these relays are classified as

→ Induction disc type relay

→ Induction cup type relay.

In case of induction disc type relays the disc in the moving element on which the relay contact is placed where as in the case of induction cup type relays the relay contact is placed on the cup.

Induction disc type relay: The induction disc type relay is further classified into two types based on the construction to produce the phase difference between the fluxes to produce the necessary torque.

→ shaded pole structure

→ watt-hour meter structure.

Shaded pole (or) split phase structure:

The below figure represents the shaded pole structure. In this shaded pole structure the disc is placed in between shaded and unshaded poles of the relay. The relay consists of an operating coil which is fed by the current proportional to the system current. The air gap flux produced by this flux is split into two out of phase components by a shaded ring made up of copper that encircles the part of the poleface of each pole at the air gap. The two fluxes differing in phase will produce the necessary torque or force to rotate the disc from un-shaded poles to the shaded poles.

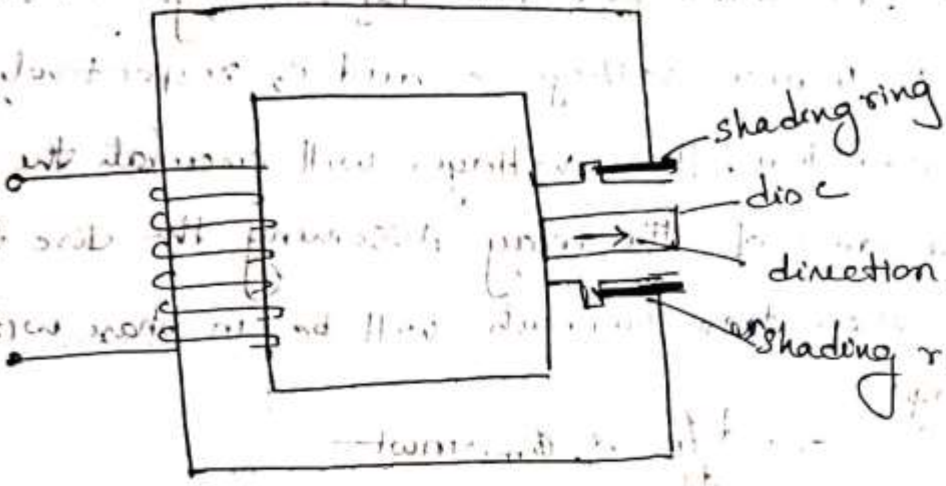


fig: shaded pole structure

The shape of the disc used in this relay is in spiral. The disc and cup in the induction type relays are made up of by aluminium to have low inertia so that the required operating force to move the system is less.

From above fig

ϕ_1 = flux produced by shaded pole = $\phi_{m1} \sin \omega t$.

ϕ_2 = flux produced by unshaded pole $\phi_2 = \phi_{m2} \sin(\omega t + \theta)$

$e_1 = \frac{d\phi_1}{dt}$ $\quad$ $i_1 = \frac{e_1}{R}$

$e_2 = \frac{d\phi_2}{dt}$ $\quad$ $i_2 = \frac{e_2}{R}$

Torque or force production in an induction relay

To produce torque or force, the two forces displace in space and time phase are required.

Let $\phi_1 = \phi_{m1} \sin \omega t$

$\phi_2 = \phi_{m2} \sin(\omega t + \theta)$

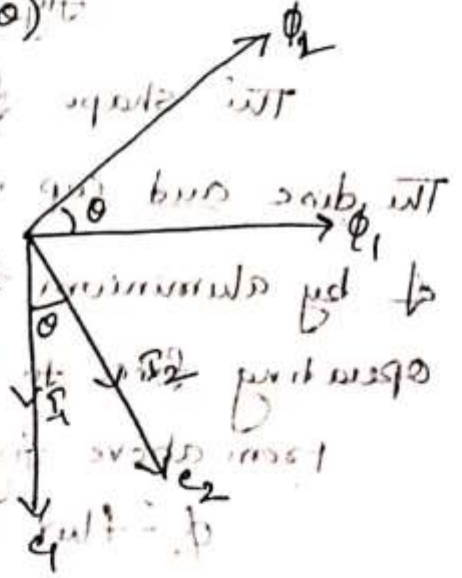
ϕ_1 is the flux produced by the shaded pole and ϕ_2 is the flux produced by the unshaded pole. The shaded pole flux ϕ_1 lags behind the unshaded pole flux by an angle θ. The two fluxes ϕ_1 and ϕ_2 induce voltages e_1 and e_2 respectively in the disc due to induction. These voltages will circulate the eddy currents in the disc of the relay. Assuming the disc to be non-inductive, then these currents will be in phase with their respected voltages.

$$e_1 \propto \frac{d\phi_1}{dt} \propto \phi_{m1} \sin \omega t$$

$$e_2 \propto \frac{d\phi_2}{dt} \propto \phi_{m2} \sin(\omega t + \theta)$$

$$i_1 \propto e_1 \propto \phi_{m1} \sin \omega t$$

$$i_2 \propto e_2 \propto \phi_{m2} \sin(\omega t + \theta)$$



In this the flux ϕ_1 will interact with ddy current i_2 and the flux ϕ_2 will interact sith eddy current i_1, since ϕ_2 is leading ϕ_1, he torque or force due to ϕ_2 and i_1 will be positive where as due to ϕ_1 and i_2 will be negative

fig: phasor representation

i.e, F or $T \propto (\phi_2 i_1 - \phi_1 i_2)$

$$\propto (\phi_{m2} \sin(\omega t + \theta)\, \phi_{m1} \cos \omega t - \phi_{m1} \sin \omega t \times \phi_{m2} \sin(\omega t + \theta)$$

$$\propto [\phi_{m1} \phi_{m2} [\sin(\omega t + \theta - \omega t)]]$$

$$\therefore F \text{ or } T \propto \phi_{m1} \phi_{m2} \sin \theta$$

Thus the torque or operating force is maximum when the two fluxes are displaced by 90° and since ϕ_2 leads ϕ_1 the rotation of the disc under the poles will be from unshaded pole to the shaded pole.

The operating time of the relay depends upon the distance between the moving contact and the fixed contact of the relay. The distance between the contacts is adjusted by the movement of the disc back stop which is controlled by rotating a curled moulded wheel at the base of the graduated time multiplier scale, This is known as time multiplier setting The higher the time multiplier setting greater is the operating time.

In the induction type relays, the control torque is obtained by the spring element and the damping torque is obtained by permanent magnet of high retentivity steel.

__Watt hour relay :-__

The below figure represents the schematic diagram of watt hour meter relay. The construction of this structure is exactly identical to watt hour meters.

The structure has two separate coils on two different magnetic circuits each of which produces one of the two necessary fluxes for driving the disc of the relay.

$F \text{ (or) } T \propto \phi_{m1}\phi_{m2} \sin\theta$

From the phasor diagram shown in below figure

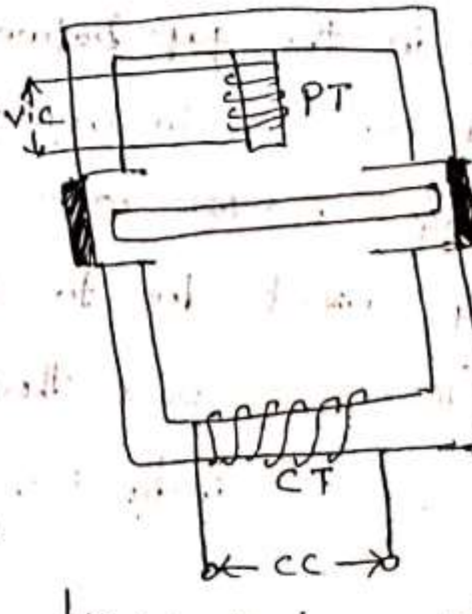


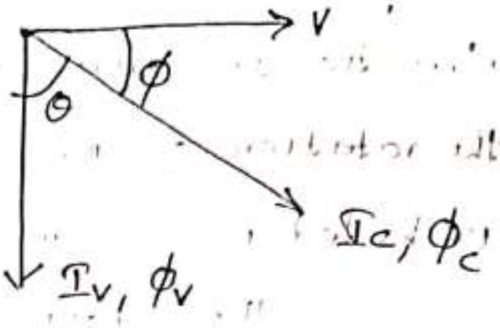
fig : watt hour relay

$\propto \phi_v \phi_c \sin\theta$

$\propto VI \sin\theta$

$\propto VI \sin(90 - \phi)$

$\propto VI \cos\phi$



Induction cup relays:- The induction cup relay will have four or more electromagnets and a stationary iron core is placed in between these electro magnets as shown in below figure.

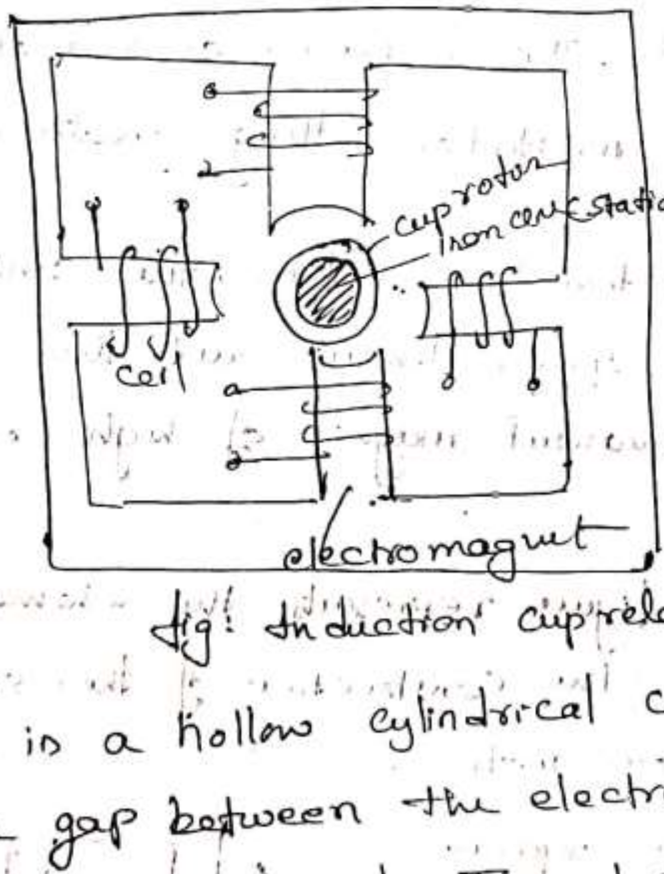


fig: Induction cup relay

The rotor is a hollow cylindrical cup which is free to rotate in the gap between the electromagnets and it is energized by the electromagnets. These electro magnets induced the voltages in the rotor cup and hence the eddy currents. The eddy currents due to one flux interact with the flux due to the other pole there by a torque is produced similar to the induction disc type relay.

The induction cup type of relays are more sensitive than the induction disc type relay and are used in high speed relay applications.

The ratio of reset to pick-up is inherently high in the case of induction relays as compared to attracted armature relays as their operation doesnot involve any change in the airgap of the magnetic circuit as it is in the case of later. Generally the ratio lies between 95% to 100%. This is not perfectly 100% because of the friction or imperfect compensation of the control spring torque.

Advantages of induction cup relays over induction disc relay.

The following are the advantages of using induction cup relays compared to induction disc relays.

- → In induction cup relays the inertia of cup is much lesser than that of disc in induction disc relays.
- → Induction cup structure have very high torque to weight ratio and therefore very sensitive measuring unit.
- → They are very fast in operation due to light rotor and are therefore suitable for high speed operation
- → The leakage in magnetic circuit is minimum in induction cup relays due to more efficient magnetic systems. This also reduces the resistance to the induced current path in rotor.
- → Because of efficient magnetic system and light weighted rotor, volt-ampere (VA) burden is greatly reduced in

induction cup relays. The torque per VA is about 3 times that of induction disc relays.

> They produce a steady non-vibrating torques

> The parasitic torque due to current or voltage alone is small in induction cup relay.

> They are inherently less sensitive to DC transients

> These relays are best suited for protection where the normal and abnormal conditions differ marginally.

Over Current / under Voltage Relay :-

A protective relay which operates when the load current exceeds a preset or pre specified value is called an over current relay. The value of the preset current above which the relay operates is known as its pick up value.

An over current relay is used for the protection of distribution lines, large motors and power equipment etc. Depending on the time of operation the relays are classified into the following types.

-> Instantaneous over current relay

-> Definite time over current relay

-> Inverse time over current relay

> Inverse definite minimum time over current relay

> very inverse over current relay

-> Extremely inverse over current relay:

Instantaneous over current Relay:

Instantaneous relays are the relays in which there is no intentional time delay to produce the operating force is the operating time is constant irrespective of the magnitude of the current. The time of operation of such relays is 0.001sec

→ They are used for fast relaying operations.
→ use for differential protection of transformers inrush currents
⇒ Backup protection for differential and distance type of relays.
→ They are used when impedance between source and relay is less w.r.to the impedance of the system to be protected

Definite time over Current Relay :-

These relays operate after a predetermined time when the current exceeds a pick up value. Here, the operating time of the relay doesnot depend on the magnitude of current above pick up value. Time delay mechanism is provided to get desired operating time.

They are used in applications where impedance (Z_s) between the source and the relay is small compared with the impedance (Z_L) of the section to be protected. They are also used to serve as a check against short time asymmetrical current

Inverse time Over Current Relay:

An inverse time over current relay operates when the current exceeds its pick up level.

This relay is one in which the operating time educes as the actuating quantity increases in magnitude. The time of operation of the relay is inversely proportional to he level of fault current and it is the one which is required to fulfill the property of speed of operation of relay.

This characteristic can be obtained with induction type of relays by using a suitable core which doesnot saturate for a large value of fault current. If the saturation occurs at a very early stage, the time of operation remains same, over the working range. The relay which does not have any magnet will come under inverse time over current relays. The characteristic for this type of relay is shown in below figure.

It is used where source impedance is much smaller than the line impedance.

Inverse Definite Minimum over-current (IDMT) Relays:-

These relays have the combining characteristics of minimum time and inverse time. It has inverse time current characteristics at lower values of the fault current and definite time characteristics at higher values of fault current.

The operating time of this relay is approximately inversely proportional to the fault current near pickup value and become almost constant just above the pick up value of he relay.

IDMT relays are widely used for over current protection because of the following reason.

→ IDMT relays have a provision for current and time settings due to this they are widely used for the protection of distribution lines.

→ In this types of relays, saturation occurs at large value of currents

→ By using IDMT relays in conjunction with directional relays the protection of ring main system can be achieved. once the system is set correctly, then discrimination is possible, so that the nearest relay to the a fault operates to isolate the smallest possible section in the shortest time.

Very inverse time over current relays:-

These relays gives more inverse characteristics than that of a plain inverse or IDMT relays. In this type of relay saturation occurs at the later stages. The time current characteristics is inverse over a greater range and after saturation in tend to definite time. These relays gives better selectively than IDMT. Their recommended standard time current characteristic is given by

$$t = \frac{13.5}{I-1}$$

where I → Current in relay coil
t → Relay time.

These are recommended for the case when there is a substantial reduction of fault current as the distance from the power source increase. They are more suitable for earth fault protection because of their steep characteristic.

Extremely Inverse over Current Relays

This relay gives a time-current characteristic more inverse than that of the very inverse and IDMT relays as shown in below figure. when IDMT and very inverse relays fail in selectivity extremely inverse relays are employed. Approximately mathematical form for these relays is given as

$$t = \frac{80}{I^2 - 1}$$

They are required for fuse co-ordination and thermal protection of transformers, induction motors, alternators and expensive cables etc.

These relays are used for reclosing distribution circuits after a long outage. Also used for load restoration purposes.

The time-current characteristics of different types of over-current relays are shown below figure.

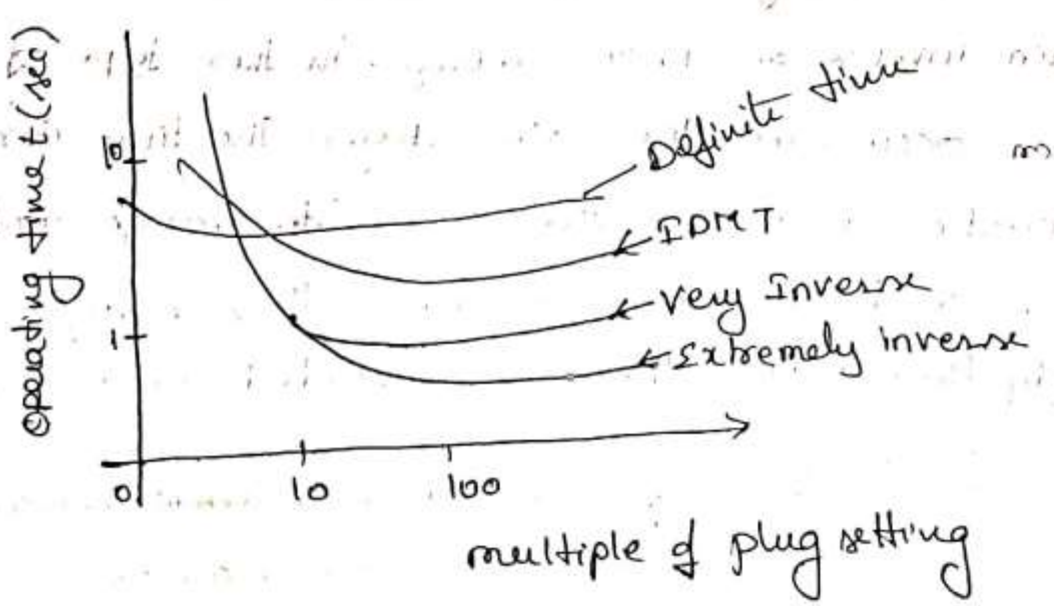


fig: characteristic of various over current relays.

Method of Defining shape of Time current characteristics :-

The general expression for time current characteristic of over current relay is given by

$$t = \frac{k}{I^n - 1}$$ where t = operating time, I = operating current

→ 'n' lies between 1.02 and 2 for very inverse relay.

The approximate expression, $t = \frac{k}{I^n}$

For definite time characteristics the value of $n = 0$

According to british standard, the following are the important characteristics of over current relays.

→ For inverse definite minimum time over current relay.

$$t = \frac{0.14}{I^{0.02} - 1}$$

→ For very inverse time over current relay

$$t = \frac{13.5}{I - 1}$$

→ For extremely inverse time over current relay

$$t = \frac{80}{I^2 - 1}$$

Plug Setting Multiplier (PSM)

If time current curves are drawn taking current in amps on X-axis, there will be one graph for each setting of the relay. To avoid this situation the plug setting multipliers are taken on the X-axis.

The actual rms current flowing in the relay coil may be expressed as a multiple of the setting current (pick-up current) and is known as plug setting multiplier. Any relay can b

Calibrated for the required set values, this is done by Keeping a tag at the required value of the set value as shown in below figure.

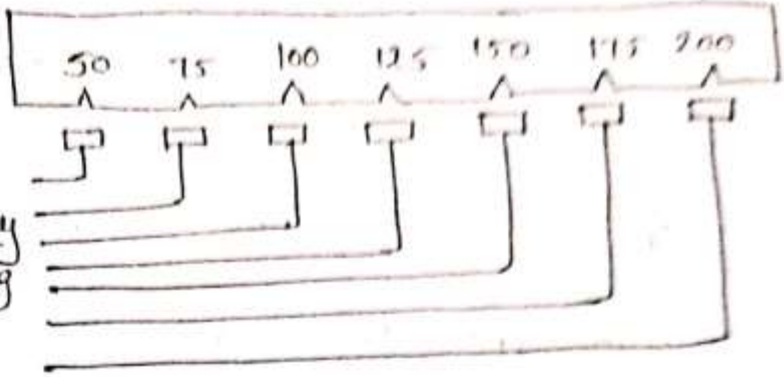


fig: PSM

The PSM may be given as

$$PSM = \frac{\text{secondary current}}{\text{relay current setting or set value of current}}$$

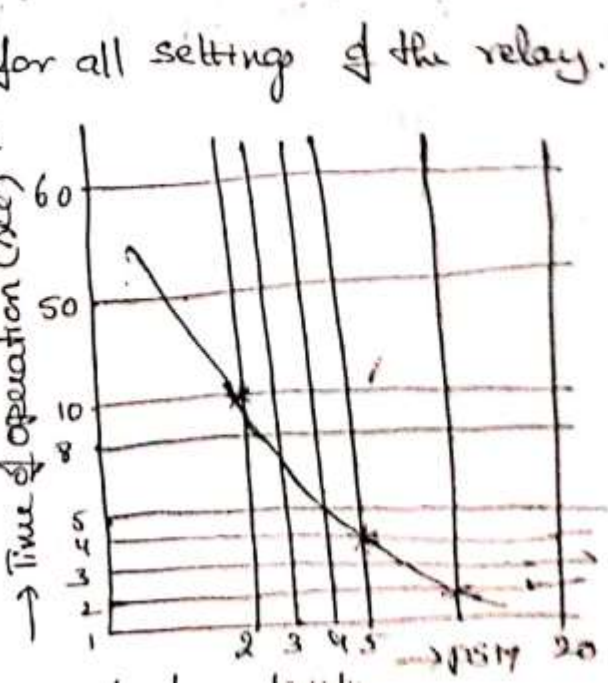
(or)

$$PSM = \frac{\text{Primary current during fault (fault current)}}{\text{relay current setting} \times \text{CT ratio}}$$

Relay current setting (or) set value of current, R = set value X Rated current of relay

While plotting the time current characteristic, if PSM is taken on X-axis there will be only one curve for all settings of the relay. The curve is generally plotted on log/log graph sheet. This curve will give the operating time for different settings of the relay.

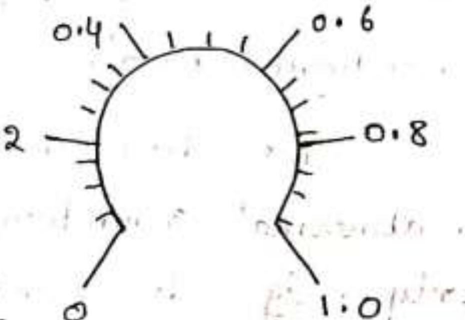
Let the relay is set at 6A the operating times for different currents are shown in figure.



PSM	operating time (sec)	Current (A)
1	NO operation	6
2	10	12
5	4	30
10	2	60

Time Setting Multiplier :-

A relay is generally having a control to adjust the time of operation. This adjustment is known as time setting multiplier. The time setting dial is calibrated from 0 to 1 in steps of 0.05 as shown in below figure. These figures are multipliers to be used to convert the time derived from time/PSM curve into the actual operating time.



If the time setting is 0.15 and time obtained from time/PSM curve is 2 seconds then the actual relay operating time is given as

$0.15 \times 2 = 0.3$ seconds.

Determination of Relay operating Time :-

For determination of actual operating time of a relay, the data required is i) Time - PSM curve ii) Current setting iii) Time setting iv) fault current v) CT ratio. The actual operating time of a relay determined by following steps

→ Time - PSM Curve :- Determination of relay current from fault current I_f and CT ratio $x : y$ from the expression.

$$\text{Relay current, } I_R = I_f \times \frac{y}{x}$$

→ Current setting :- Determination of relay current setting multiplier which is given as

$$PSM = \frac{\text{fault current in relay coil}}{\text{pick up value.}}$$

$$= \frac{I_R}{\text{Current setting} \times \text{rated secondary current of CT}}$$

$$= \frac{I_R}{\frac{I_p}{100} \times Y} = \frac{I_R \times 100}{I_p \times Y} = \frac{I_f \times 100 \times Y}{x \times I_p \times Y} = \frac{I_f \times 100}{x \times I_p}$$

Where I_p is the percent current setting of the relay.

→ Determination of operating time of relay corresponding to calculated PSM from Time-PSM Curve.

→ Determination of actual operating time of relay by multiplying the time in step (3) by the time setting multiplier in use.

Directional Relays:-

The directional relays are provided only when a fault or abnormal condition is taking place in the assigned direction only. Eg:- directional over current relay.

Directional over-current relay:

The directional over current relay is shown in below figure. This relay consists of two units.

→ Directional unit

→ Non directional (or) Inverse time current unit

The directional unit is a four pole induction cup unit. Two opposite poles are fed with voltage and other two poles are fed with current. The voltage is taken as the polarizing quantity which produces one of the two fluxes required for production of torque and this quantity is taken as the reference compared with the other quantity which is current here. This means that the phase angle of the polarizing quantity must remain more or less fixed when the other quantity suffers wide changes in phase angle.

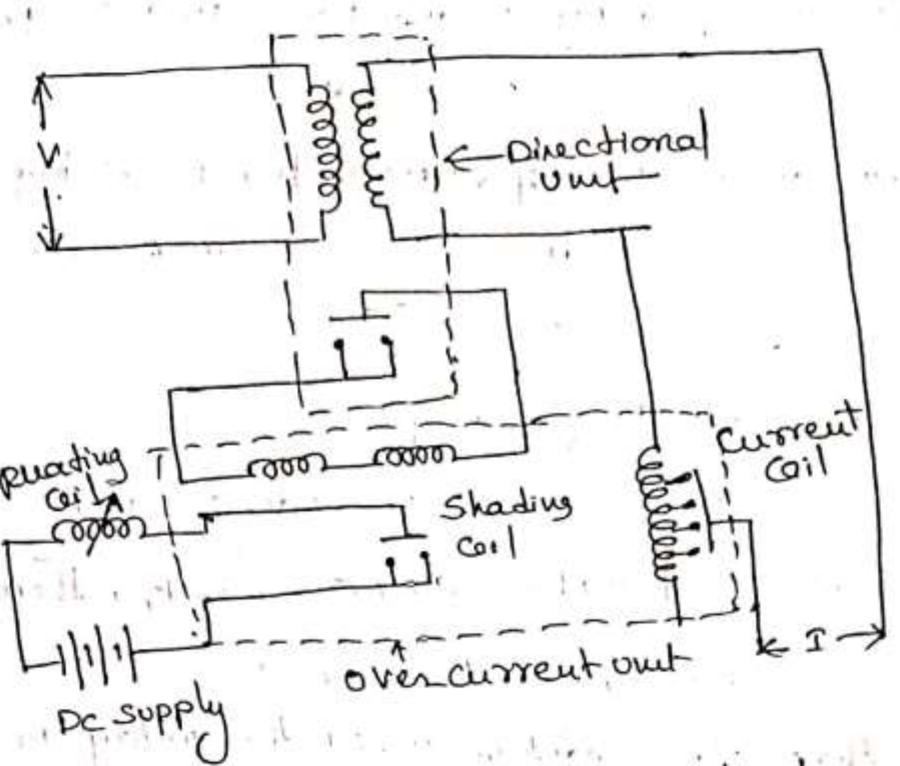


fig: Directional over current relay

In a circuit at a point the current can flow in on direction at a particular instant. let us say this is the norma direction of flow of current. under this condition the directio unit will develop negative torque and the relay will be restrained to operate whenever a fault occurs in the system then the current flows in the opposite direction. Hence the relay will develop positive torque and it will operate.

For a directional unit unless its contacts are closed the overcurrent unit is not energized because the operating coil of the overcurrent unit completes its circuit through the directional unit contacts or if the overcurrent unit has shading coil completes its circuit through the directional unit contacts.

The torque developed by a directional unit is given by

$$T = VI\cos(\theta - \tau) - k$$

$V \rightarrow$ rms magnitude of voltage fed to voltage coil circuit

$I \rightarrow$ rms magnitude of current in current coil

$\theta \rightarrow$ angle between V and I

$\tau \rightarrow$ the max torque angle

$k \rightarrow$ restraining torque including spring and friction

For a particular installation $\cos(\theta - \tau) = k_1$, then the torque becomes $T = k_1 VI - k$

under threshold condition, when the relay is about to start

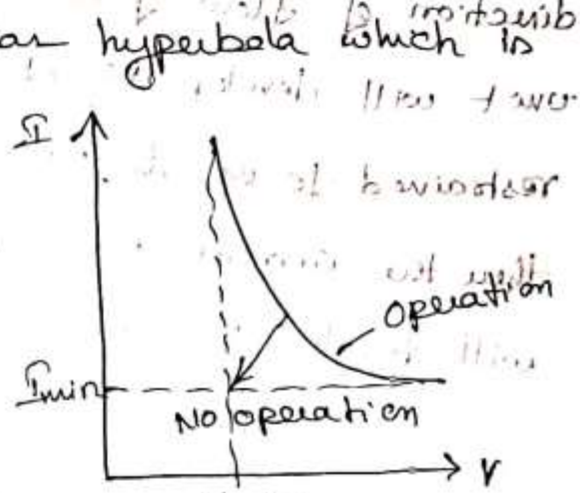
$$T = 0 = k_1 VI - k$$

(or) $VI = \frac{k}{k_1} = k'$

$$VI = \text{Constant}$$

This characteristic is known as constant product characteristic and is of the form of a rectangular hyperbola which is shown below.

For the operation of the relay the product of V and I should give a minimum torque which exceeds the friction and spring torque.



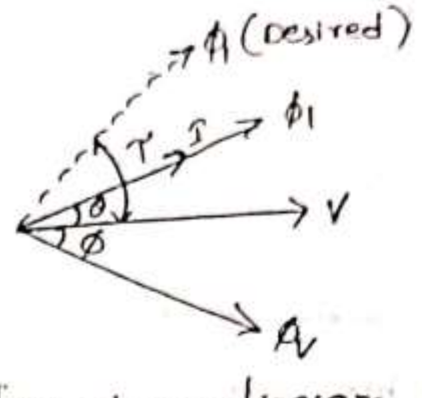
Consider the torque equation,

$$T = VI\cos(\theta - \tau) - k$$

let ϕ_v = flux due to voltage coil and lags behind the voltage by about 60° to 70°

ϕ_1 = flux due to Current Coil

The net torque is produced by the interaction of ϕ_1 and ϕ_2. The torque is maximum when the two fluxes are displaced by 90°. The below figure represents the phasor diagram. In this the dotted line represents the desired position of ϕ_1 for maximum torque.



From the figure in the max torque angle between reference V and dotted line. This means when the relay current leads the voltage by an angle τ maximum torque in K is negligible then

fig: phasor diagram

$$I\cos(\theta - \tau) = 0$$

∴ I cannot be zero for torque equation. hence

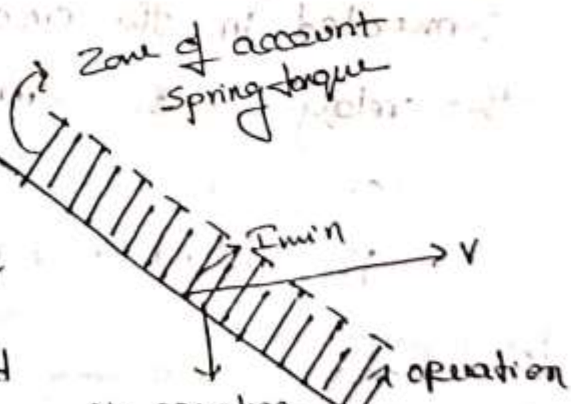
$$\cos(\theta - \tau) = 0$$

$$\theta - \tau = \pm \pi/2$$

$$\theta = \tau \pm \pi/2$$

This is the equation describing the polar characteristic of the directional relay.

The zone between the direct line and the line parallel to it corresponds to the spring torque. If the current vector lies within these lines the torque developed is less than the spring torque and hence the relay does not operate. If the current crosses the dotted line the spring torque is less than the operating torque and hence the relay operates.



Differential Relays :-

The differential relay is one that operates when the vector difference of two or more similar electrical quantities exceeds a preset or pre specified value.

Differential protection is a type of unit protection, which operates only when the fault occurs with in the protected zone. It will not respond to the fault outside the protected zone. The scheme of differential protection can be achieved by suitable connection of CT's on both sides of the apparatus to be protected.

The basic requirements of differential relay are

→ Two or more similar electrical quantities, and

→ These quantities should have phase displacement (normally approximate value of 180°), for the operation of the relay

The name is not due to particular construction of the relay but is due to the way in which the relay is connected in the circuit. The most common application of this relay is the current differential type. The simple connection for this type of construction is shown below

The dotted line represents the equipment to be protected which may be a transformer, an alternator or a bus etc. In this two suitable CTs are connected in series as shown in figure with the help of pilot wires

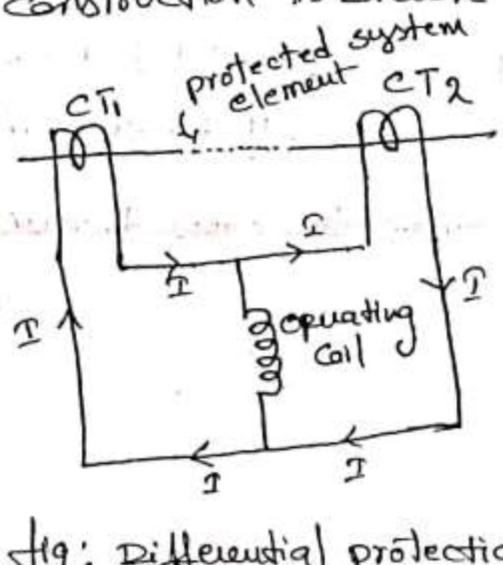
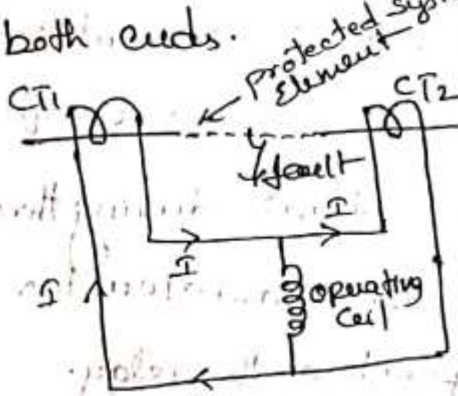
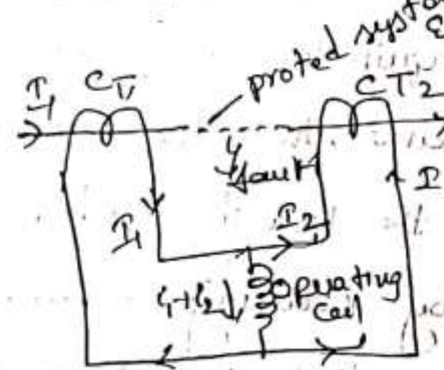


fig: Differential protection scheme

For all fault current the secondary currents are of the same magnitude and phase. The difference current therefore being zero through the operating coil, hence the relay doesnot operate and is shown in above figure. This is a desirable feature of the relay.

Now consider the case of an internal fault. The below figure represents when the circuit is fed from one end. The below another figure represents when the circuit is fed from both ends.





It can be seen that in both the cases, a current will flow through the operating coil of the relay and it will operate. This form of protection is known as Merz-price protection. The above form of protection was assumed on the fact that the two CT's used were identical, but in practice this is not true.

CT's of the type normally used do not transform their currents so accurately under transients conditions especially. This is true because the short circuit current is offset. i.e., it contains DC components. let the two CT's under normal condition differ in their magnetic properties slightly in terms of different amounts of residual magnetism or in terms of unequal burden on the two CT's.

The relay operating coil is connected between the equi potential (mid) points of the pilot wire. The voltage induced in the secondary of the CT's will circulate a current through the combined impedance of the pilot wires and CT's.

In case the operating coil is not connected in between the equipotential points, there will be difference current through the operating coil of the relay and this may result in mal operation of the relay.

When the operating coil of the relay is not connected between the equipotential points, even though the current through each CT is same, then the burden on the two CT's is unequal. This causes the heavily loaded CT's to saturate during through fault, there by causing dissimilarity in the characteristics of the two CT's which results in mal operation the relay.

For a fault in the system in between the two CT's the relay must operate and in case the fault outside this zone the relay should not operate such protection is known as unit protection. When the fault is outside the zone of protection it is known as external or through fault and is shown in below figure

For a through fault, the current flowing through the primaries of the two CT's is same. If the two CT's behave identically

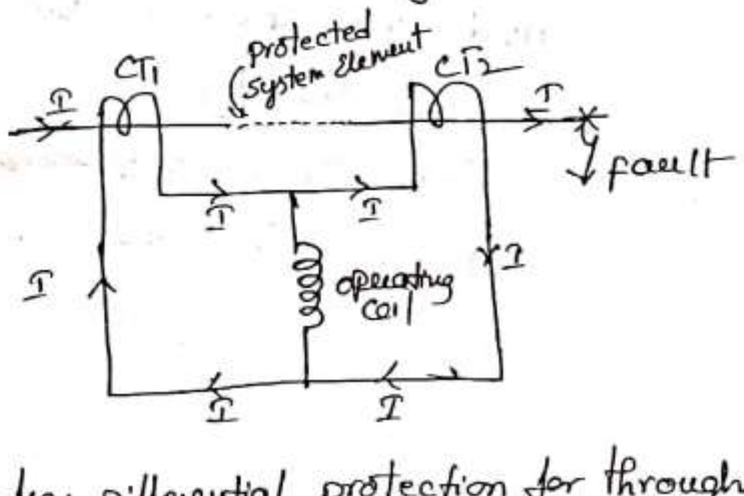


fig: Differential protection for through fault one of the CT will saturate earlier during shortcircuit current and thus the two CT's will transform their primary current differently even for a through or external fault condition. This effect is increased especially when the scheme is used for the protection of power transformer. To accomodate these features, Merz-price protection is modified by biasing the relay. This is commonly known as biased differential protection or percentage differential protection.

Applications

The various applications of differential protection are listed as

- This type of protection scheme can be used for the protection of generators, transformers and generator, transformer unit and transmission lines.
- By using pilot wires differential protection, protection of transmission lines can be done.
- Buy zone protection
- protection of large motors
- protection of large transmission line by phase comparision carrier current protection
- protection against inter turn faults.

Percentage Differential protection

The percentage differential scheme is shown in below figure

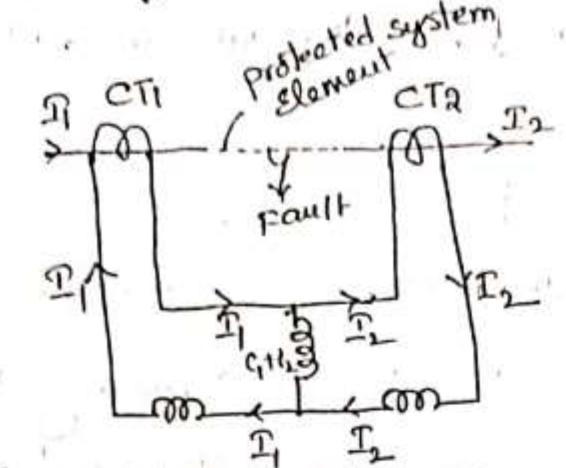


fig: percentage differential protection.

The percentage differential relay consists of an operating coil and restraining coil. The operating coil is connected to the mid-point of the restraining coil. The operating current is a variable quantity because of the restraing coil. No current flows through the operating coil under through fault condition, but owing to the dissimilarities in CT's, the differential current through the operating coil is (i_1-i_2) and the equivalent current in the restraining coil is $\frac{(i_1+i_2)}{2}$. the torque developed by the operating coil is proportional to the ampere turns and is given as

$$T_o \propto n_o (i_1 - i_2)$$

where $T_o \rightarrow$ operating torque

$n_o \rightarrow$ Number of turn's in operating coil

The torque due to the restraining coil is given as

$$T \propto \frac{(i_1+i_2)}{2} n$$

n_r – number of turns in restraining coil

at threshold condition $T_o = T$

$$n_o (i_1 - i_2) = n_r (i_1 + i_2)/2$$

$$\frac{i_1 - i_2}{(i_1+i_2)/2} = \frac{n_2}{n_0}$$

The operating characteristic is shown in below figure

It is clear from the characteristic that except for the effect of the control spring at low currents, the ratio of the differential operating current to the average restraining current is a fixed percentage. Hence it is known as percentage differential relay.

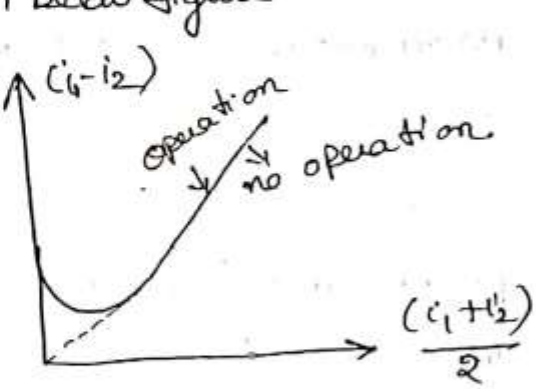


fig: operating characteristics

The electromagnetic representation of the relay is shown below.

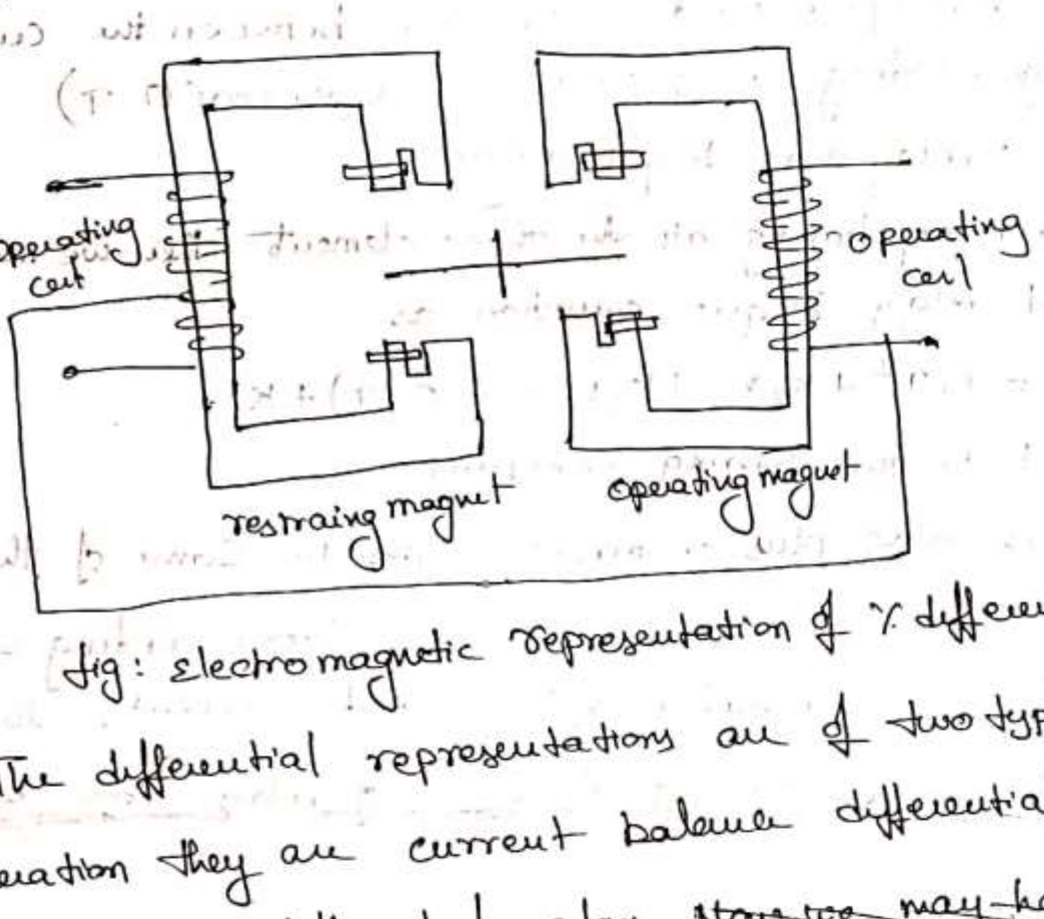


fig: electromagnetic representation of % differential relay.

The differential representations are of two types. Based on the operation they are current balance differential relay and voltage balance differential relay. ~~Now we may have a look on the voltage balance differential relay.~~

Universal Torque Equation:-

Most of the protective relays consist of some arrangements of electromagnets with an armature and induction motor carrying the relay contact. The electromagnets have current windings, voltage windings or both currents through the winding produce magnetic fluxes and the torque is developed by the interaction between the fluxes of the same winding or between the fluxes of both windings.

The torque developed by the current windings, $T = K_1 I^2$

The torque developed by the voltage winding, $T = K_2 V^2$

The torque developed by the interaction between the current and voltage windings is given as $T = K_3 VI \cos(\theta - \tau)$

when $\tau \rightarrow$ relay max torque angle

Consider a relay having all the three elements then we may write the universal relay torque equation as

$$T = K_1 I^2 + K_2 V^2 + K_3 VI \cos(\theta - \tau) + K$$

where K is the spring constant

By assuming plus or minus signs to same of the terms and letting others be zero and some times adding some terms having a combination voltage and current, the operating characteristics of all types of relays can be obtained.

Distance protection:-

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

Distance relay group is perhaps the most interesting and versatile family of relays. principal types of distance relays are → Impedance Relays
→ Reactance Relays
→ admittance or mho Relays.

Application of Distance protection:-

Distance protection schemes are widely employed for the protection of high voltage ac transmission lines and distribution lines. They have replaced the over-current protection of the transmission lines. The reasons are faster protection, simpler co-ordination, simpler application, permanent setting without need for readjustments less effect of amount of generation and fault levels, fault current magnitude, permits the high line loading.

Distance protection schemes are commonly employed for providing the primary or main protection and back-up protection for ac transmission and distribution lines against 3-phase faults, phase-to-phase faults and phase-to-ground faults.

In some schemes for short lines, the phase-to-ground fault protection sensing may be by distance relay and measurement by over-current relays because distance protection for shorter lines are susceptible to errors due to arc fault resistance. In general, the choice of type of distance protection depends on length of line, tripping time required and co-ordination requirements.

Impedance type Distance Relay:-

In protective relaying terminology, however, an impedance relay has a characteristic that is different from that of a relay responding to any component of impedance and therefore, the "impedance relay" is very specific

An impedance relay is a voltage restrained over-current relay. The relay measures impedance upto the point of fault and gives tripping command if this impedance is less than the relay setting Z. Relay setting Z is known as replica impedance and it is proportional to the set impedance i.e, impedance upto the reach of the relay. The relay monitors continuously the line current I through CT and the bus voltage V through PT and operates when the V/I ratio falls the set value.

Principle of Operation :

The principle of operation of an impedance relay is illustrated in the below figure. The voltage element of the relay is excited through a potential transformer (PT) from the line under protection and current element of the relay is excited from a CT in series with the line. The portion AB of the line is the protected zone.

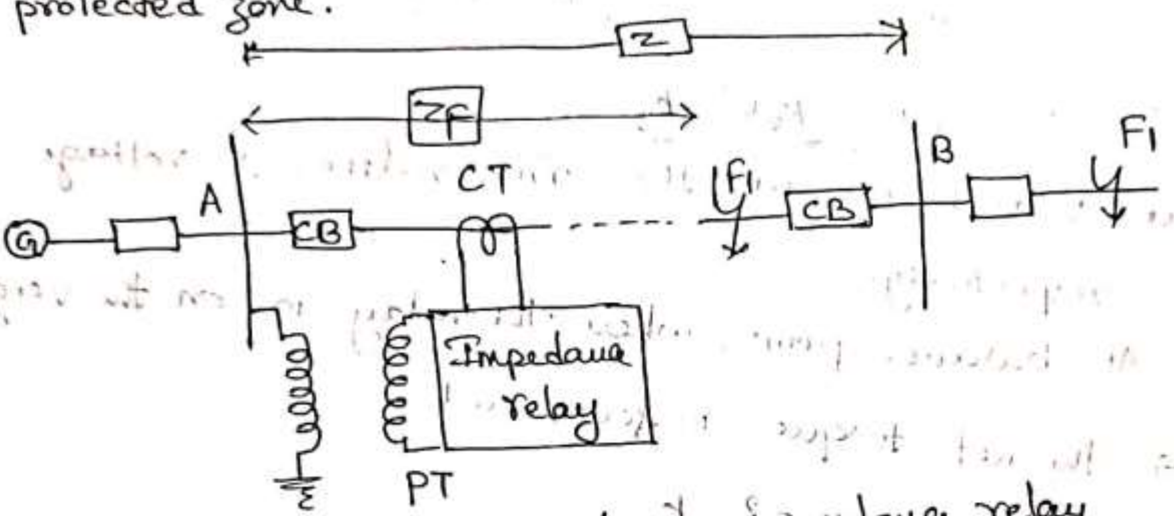


fig: principle of operation of an impedance relay

Under normal operating conditions, the impedance of the protected line is Z. This relay is so designed it closes its contacts whenever impedance of the protected section falls below the set value i.e, Z in this case.

Now assume that a fault occurs at point F_1 in the protected zone. The impedance, the ratio of the bus voltage and fault current (V/I), between the point where the relay is located and the point of fault will become less than Z and hence the relay operates. If the fault occur beyond the protected zone the impedance will be more than Z and the relay contacts do not close.

Operating characteristic of an impedance Relay:

The impedance relay is a double actuating quantity relay and essentially consists of two elements - current operated element and voltage - operated element. The current element produces a positive or pick up torque while the voltage element develops a negative or reset torque. Taking the spring control effect as $-k_3$, 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 values of voltage and current respectively.

At balance point, when the relay is on the verge of operating, the net torque is zero, and

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

$$(\text{or}) \quad \frac{V}{I} = Z = \sqrt{\frac{k_1}{k_2} - \frac{k_3}{k_2 I^2}}$$

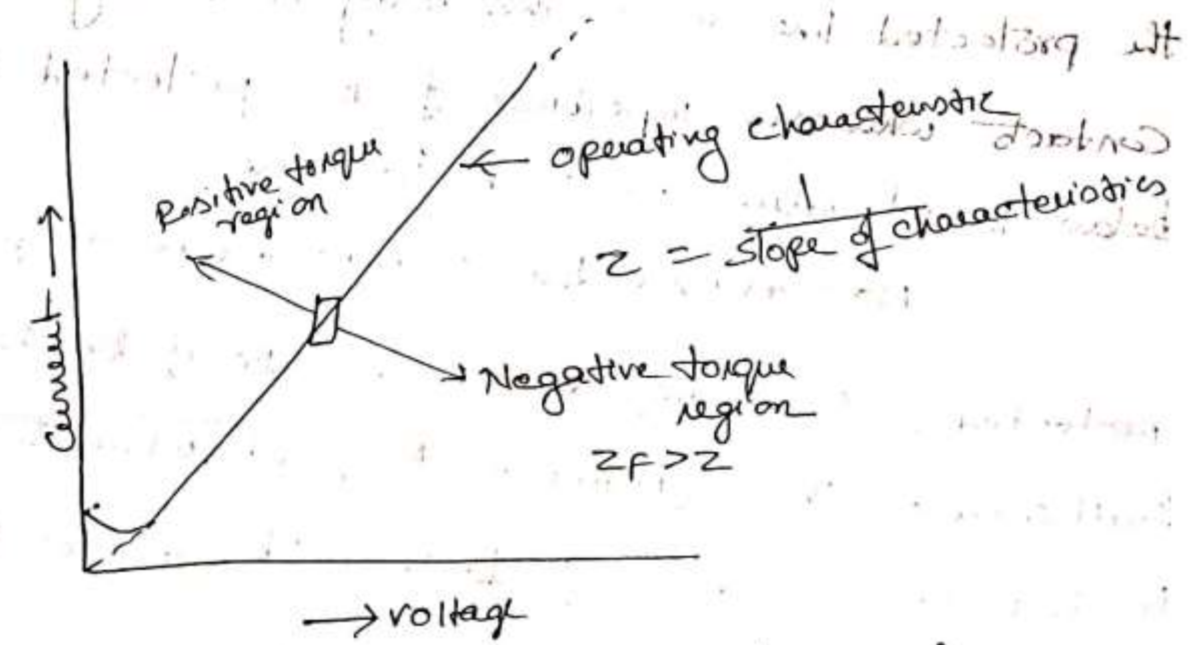


fig: operating characteristic of an impedance relay.

It is customary to neglect the effect of control spring since its effect is noticeable only at current magnitudes well below those normally encountered. Hence taking $k_3 = 0$, the relay torque equation becomes-

$$Z = \sqrt{\frac{K_1}{K_2}} = \text{Constant}$$

The operating characteristic in terms of voltage V and current I is shown in above figure, where the effect of control spring is shown as causing a noticeable bend in the characteristic only at the low-current end. For all practical purposes, the dast line, which represents a constant value of Z, may be considered the operating characteristics. The relay will pick-up for any combination of V and I represented by a point above the characteristic in the positive torque region, or, in other words for any value of impedance less than constant value represented by the operating characteristic. By adjustment, the slope of the operating characteristic can be changed so that the relay will respond to all values of impedance less than any desired upper limit.

The more convenient way of describing the operating characteristic of a distance relay is by means of impedance diagram or R-X daigram, as shown in the below figure. The numerical value of the ratio of V to I is shown as the length of the radius vector such as Z, and the phase angle θ between V and I determines the position of vector, as shown since the operation of the impedance relay is practically or actually independent of the phase angle θ, the operating characteristic is a circle with its centre at the origin. Any value of impedance less than the radius of the circle will result in positive torque and any value of impedance greater than this radius will result in negative torque.

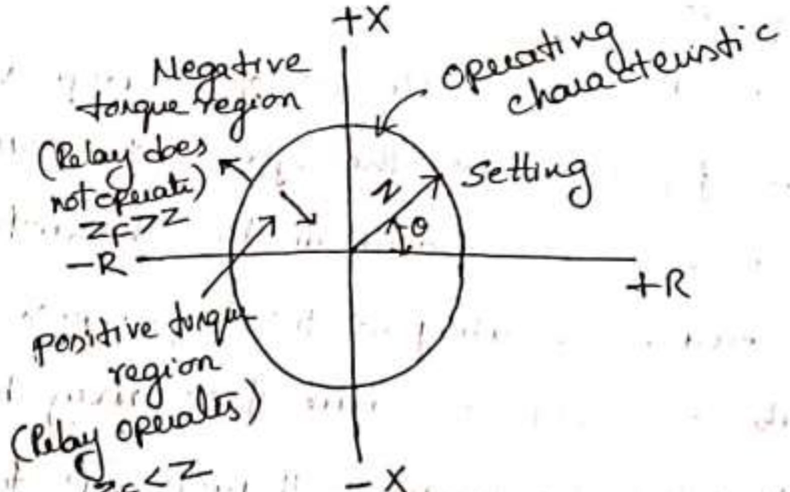


Fig: operating characteristic of an impedance relay on an R-X diagram

The impedance relays normally used are high speed relays. These relays may be of electro-magnetic or induction type described in the following sections.

Directional impedance Relays

The directional feature to the impedance relay can be provided by employing the impedance relay along with a directional unit as is done in the case of a simple over-current relay to operate as a directional over-current relay. This means the impedance unit will operate only when the directional unit has operated.

Directional feature senses the direction in which fault power flows with respect to the location of CT and PT.

Directional impedance relays operate for the following conditions.

→ impedance between the fault point and relay location is less than the relay setting Z.

→ The fault power flows in a particular direction from relay location. The direction power flow is sensed by measuring phase angle between voltage and current.

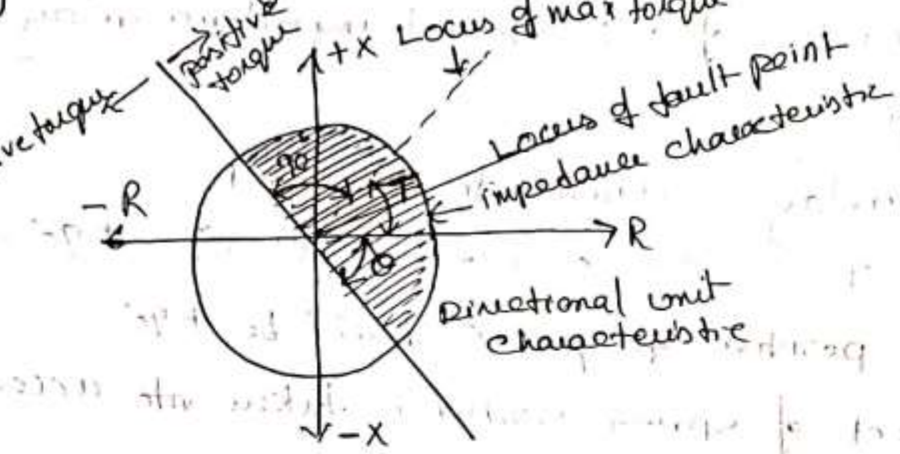


fig: operating characteristic of an impedance relay with directional unit

The operating characteristic of an impedance relay with directional unit as shown in above figure. since the directional unit permits tripping only in the positive torque region the active portions of the impedance unit characteristic is shown shaded. The net result is that the relay will operate only for fault points that are both within the circle and above directional unit characteristic.

Torque equation for direction Impedance relay:

Torque equation for directional element is given as

$$T = K_1 V I \cos(\theta - \tau)$$

where θ is the phase angle between V and I and τ is the impedance angle of the relay values of angles are taken as positive in clockwise direction.

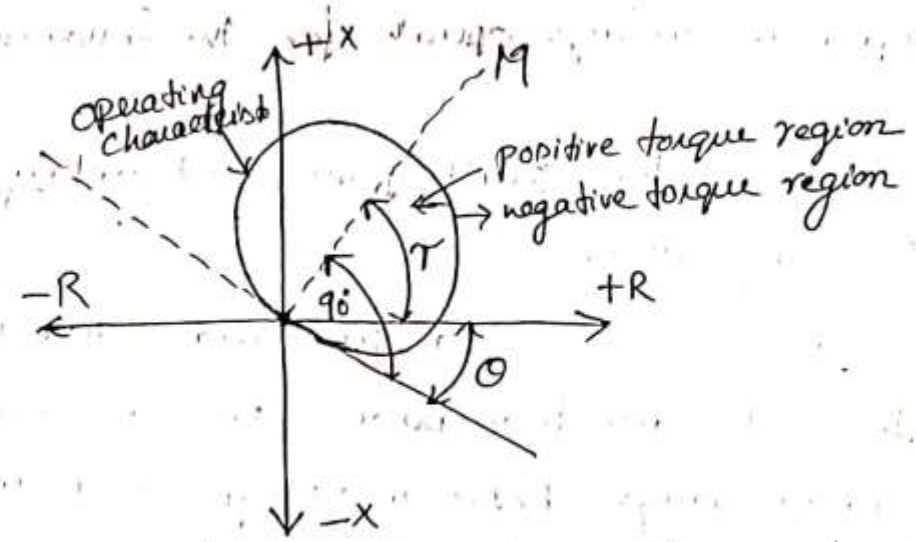


fig: characteristics of a directional impedance relay for one value of voltage.

when the relay is about to pick up

The torque $T = 0$, $\cos(\theta - \tau) = 0$ or $(\theta - \tau) = \pm 90°$ or $\theta = \tau \pm 90°$

Hence for positive torque, θ should be $\pm 90°$

If the effect of spring control is taken into account, the torque equation becomes

$$T = K_1 V I \cos(\theta - \tau) - K_2$$

At balance point i.e, when the relay is about to pick-up

$$T = 0$$

$$K_1 V I \cos(\theta - \tau) = K_2$$

substituting $I = \frac{V}{Z}$ in above equation, we have

$$K_1 \times V \times \frac{V}{Z} \cos(\theta - \tau) = K_2$$

(or) $$Z = \frac{K_1}{K_2} V^2 \cos(\theta - \tau) \quad \text{—} ①$$

The eq ① describes an infinite number of circles and for each value of V there will be a corresponding circle. The characteristics of directional impedance relay for one value of V can be represented on the R-X diagram as shown ~~below~~ above

The fact that for some values of θ, impedance z will be negative which should be ignored. Negative z has no significance and cannot be shown on R-x diagram.

when $\cos(\theta - \tau) = 1$ impedance z will have maximum value and will lie on the line of max torque OM. when $\cos(\theta - \tau) = 0$, $z = 0$ and $\theta = 90^\circ \pm \tau$.

The characteristic will therefore be a circle with z as diameter and the centre of the circle will lie on the line OM.

Modified Impedance Relay:

The characteristic of the modified impedance relay is shown in below figure. The characteristic of this impedance relay is a circle on the R-X plane. It is similar to that of an basic impedance relay but has a shifted characteristic. The basic impedance characteristic is shifted outwards along the R-axis by a current bias for realizing this relay characteristic. This is achieved by introducing an additional voltage into the voltage supply circuit of the relay. The torque equation of the relay is

$$T = K_1 I^2 - K_2 (V + IR)^2$$

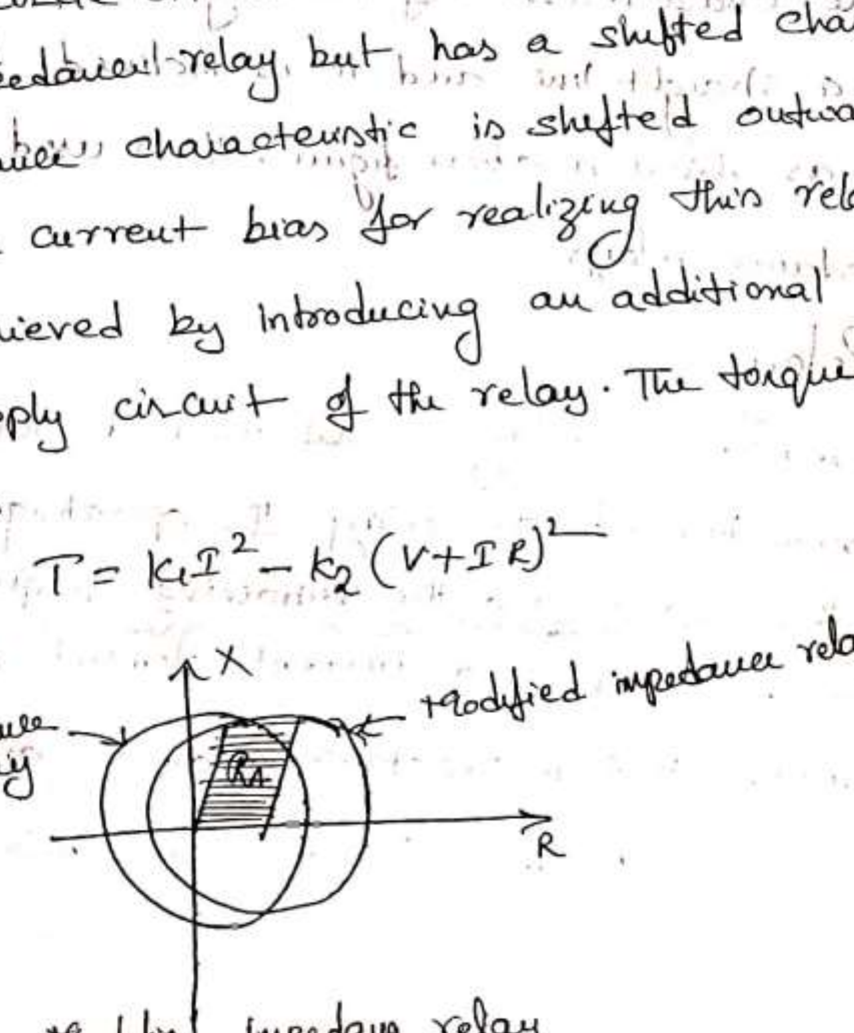


Fig: Modified impedance relay

Angle impedance (OHM) Relay

It is also called an mho relay. It measures a component of the impedance of the line at the relay location. The torque equation of this relay is given as

$$T = K_1 I^2 - K_2 VI \cos(\phi - \alpha) - K_3$$

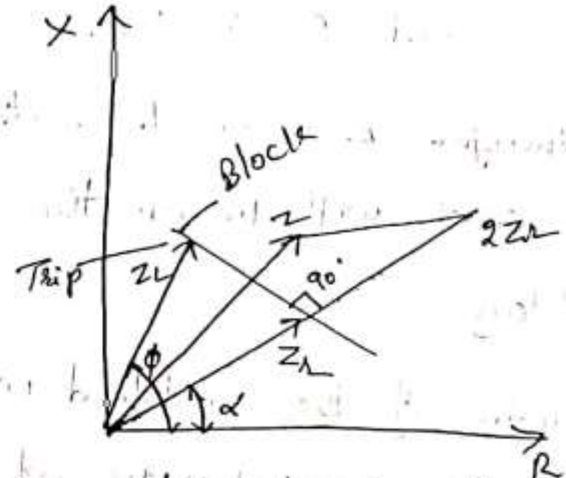


fig: characteristic of angle impedance relay

The characteristic of an angle impedance relay on R-x plane is a straight line and it is inclined to the R axis at any angle as shown in above figure. It is used in conjunction with other distance relays.

Reactance Relay:

The reactance relay is used for the protection of short transmission lines. In this relay the operating torque is obtained by the current and the restraining torque is due to the interaction of voltage and current element or a directional element. This means that a reactance relay is an over current relay with directional restraint. The directional relay is so designed that its maximum torque angle is 90° i.e, $\tau = 90°$ in the universal torque equation.

$$T = K_1 I^2 - K_3 VI \cos(\theta - \tau)$$
$$= K_1 I^2 - K_3 VI \cos(\theta - 90^\circ)$$
$$= K_1 I^2 - K_3 VI \sin\theta$$

For the operation of the relay, $T > 0$

$$K_1 I^2 - K_3 VI \sin\theta > 0$$
$$K_1 I^2 > K_3 VI \sin\theta$$
$$\frac{VI}{I^2} \sin\theta < \frac{K_1}{K_3}$$
$$Z \sin\theta < \frac{K_1}{K_3}$$
$$X < \frac{K_1}{K_3}$$

This means for the operation of the relay the reactance seen by the relay should be smaller than the pre specified reactance. The characteristic is shown below.

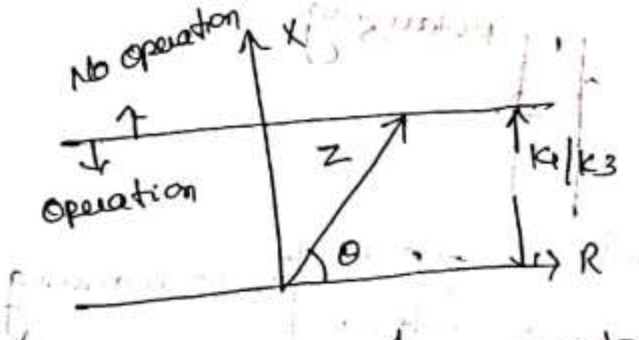


fig: Characteristic of a reactance relay

This means that the impedance vector lead lies on the paralle lines this will have a constant X-component.

The resistance component of the impedance has no effect on the operation of the relay. It responds only to the reactance component of the impedance. The relay will operate for all impedance whose leads lie below the operating characteristic whether below or above the R-axis.

The structures used for the reactance relay are induction cup and double induction cup structure. A typical reactance relay using induction cup structure is shown above.

It consists of a four pole structure. This has operating, polarizing and restraining coils. The operating torque is produced by the interaction of fluxes due to the windings carrying the current coils i.e, interaction of of fluxes of poles 1, 2 and 3 and the restraining torque is developed due to the interaction of fluxes of the poles 1, 3 and 4. The operating torque will be proportional to I^2 and the restraining torque is proportional to $VI\cos(\theta-90^\circ)$. The desired maximum torque angle is obtained with the help of R-C circuits as shown below.

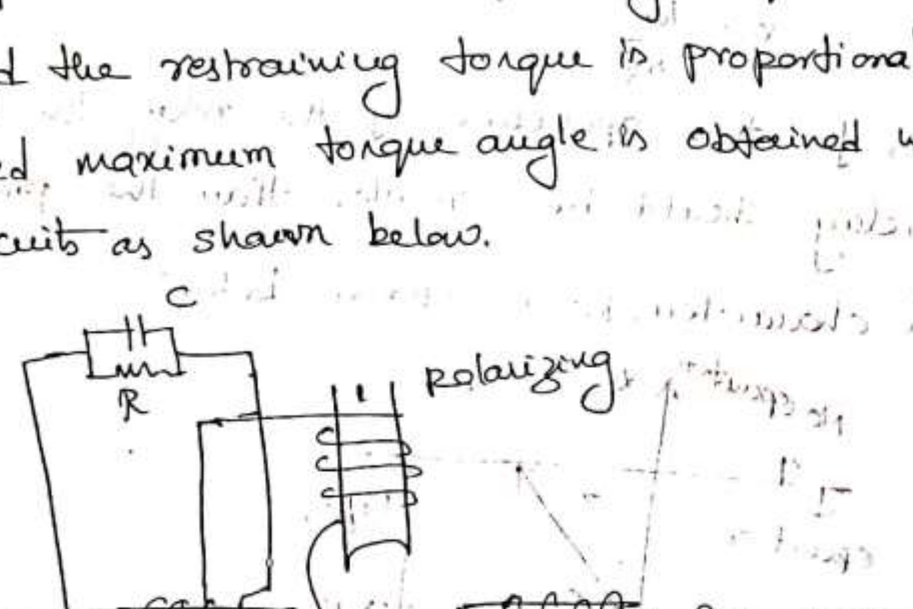


fig: Reactance relay structure

Advantages

> Reactance relay is not affected by the resistance
> These types of relays are used for the protection of short lines having fault current then 20kA.

Disadvantages

→ Reactance relay is not used seperately. It is used in conjunction with mho relay or offset mho relay

→ when used on transmission lines discrimination can not be obtained as it is a non-directional relay

→ under the condition of high p.f or leading p.f, the impedance seen by the relay is very low (or) even negative reactance.

MHO Relay or Admittance Relay :-

A mho relay measures a component of admittance $|Y|\angle\theta$. But its characteristic, when plotted on the impedance diagram (R-x diagram) is a circle, passing through the origin. It is inherently a directional relay as it detects the fault only in the forward direction. It is obvious from its circular characteristic passing through the origin as shown in the above figure. It is also called as admittance or angle admittance relay. It is called a mho relay because its characteristic is stright line when plotted on an admittance diagram (G-B axes). The impedance angle of the protected line is normally 60° to 70° which is shown by the line AB in below figure

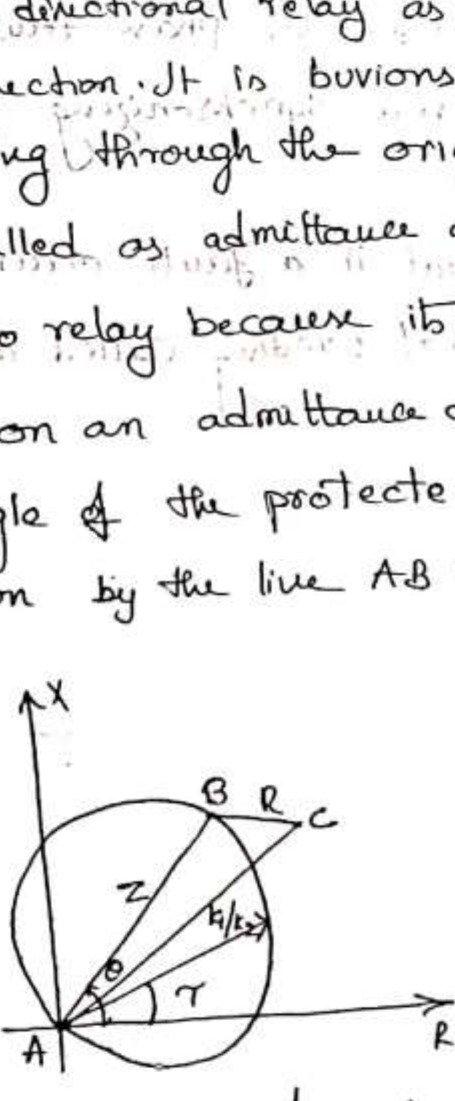


fig: characteristic of a mho relay

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

For the relay to operate, $T > 0$

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

$$K_3 VI \cos(\theta - \tau) > K_2 V^2$$

$$\frac{V^2}{V_1} < \frac{K_3}{K_2} \cos(\theta - \tau)$$

$$Z < \frac{K_3}{K_2} \cos(\theta - T)$$

Advantages

→ Mho relay is heterently directional., No seperate directional unit is required

> Due to its fast tripping for fault clearance it reduces the VA burden on the CT's.

> Mho relays can be used for phase fault relaying on long line particularly when severe synchronizing power surges can occur

Disadvantages

> Mho relay fault to operate, it a fault occurs due to arc resistance

> It requires an additional winding called as polarizing winding for polarized voltage.