Protective system:-

The combination of circuit breakers, trip circuits, C.T. and other Protective relaying equipments is called protective system.

Protective Scheme:-

The combination of various protective systems covering a particular protective zone for a particular equipment is called protective scheme.

Unit Protection:-

A protective system in which the protection zone is clearly define by the C.T. boundaries is called unit protection. such systems work for internal faults only.

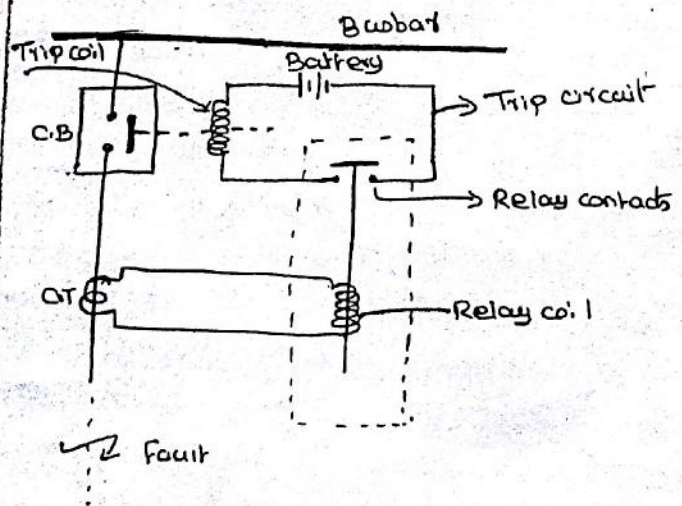
Reach:-

The limiting distance in which protective system responds to the faults is called reach of the protective system. The operation of distance relay beyond the set distance is called over-reach while failure of distance relay within set distance is called under-reach.

Burden:-

The power consumed by the relay circuitry at the rated current is known as its burden.

Basic Trip circuit:-



A circuit to be protected

Fig shows a single phase simplified circuit. Let part A is the circuit to be protected. The primary winding of C.T is connected in series to the line to be protected. The secondary of C.T is conned in series with the relay coil.

If a fault occurs as shown in Fig, current through the line in which CT is connected gets increased. This current energizes the relay coil & makes the relay contacts to close once the relay contacts gets closed, the Trip circuit gets short circuited. so a power supply from battery energizes the trip coil makes the contacts of C.B to open, thus the faulty circuit is disconnected.

Electromagnetic Relays:-

In an electromagnetic relay, the driving torque is created based on an electrical or electronic principle, while the restraining torque is generally provided with the help of springs. The two torques are mechanically compared and the relay operates when driving or operating torque is more than the restraining torque. Thus,

T_d – Driving torque or operating torque

T_r – Restraining torque

T_R – Resultant torque $= T_d - T_r$.

The relay operates when the resultant torque T_R is positive.

Operating force or torque:-

A force or torque which tends to close the contacts of the relay.

Restraining force or torque:-

A force or torque which opposes the operating force / torque.

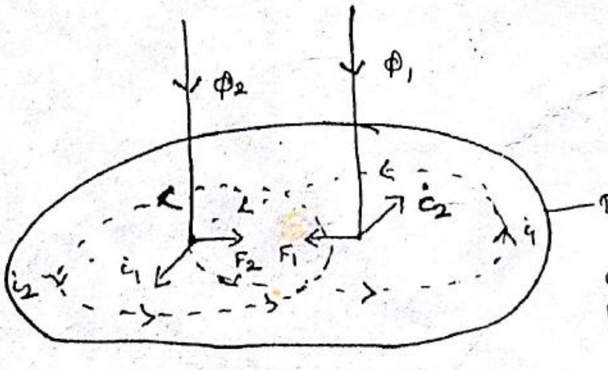
Induction type Relays:-

These relays are also called magnitude relays. These relays works on the principle of the induction motor or an energy meter. In these relays a metallic disc is allowed to rotate between two electromagnets. The coils of electromagnets are energized with the help of alternating currents. The torque is produced in these relays due to interaction of one alternating flux with eddy currents induced in the rotor by another alternating flux. These relays are used only for a.c quantities.

Based on construction, various types are

1. shaded pole type
2. watt hour meter type
3. Induction cup type.

Torque Equation for Induction type Relays:-



The alternating currents supplied to two electromagnets produce the two alternating fluxes ϕ_1 & ϕ_2. These two fluxes have same Frequency, but have a phase difference of α between them such that ϕ_2 leads ϕ_1.

$$\phi_1 = \phi_{1m} \sin \omega t$$
$$\phi_2 = \phi_{2m} \sin(\omega t + \alpha)$$

These alternating fluxes causes the induced emfs in the rotor. Due to the emf's, the eddy currents i_1 & i_2 are circulated in the disc. The interaction of one flux with other eddy currents generates a torque.

$$i_1 \propto \frac{d\phi_1}{dt} \propto \frac{d}{dt}(\phi_{1m}\sin\omega t) \propto \phi_{1m}\cos\omega t$$

$$i_2 \propto \frac{d\phi_2}{dt} \propto \frac{d}{dt}(\phi_{1m}\sin(\omega t+\alpha)) \propto \phi_{1m}\cos(\omega t+\alpha)$$

$$F_1 \propto \phi_1 i_2$$

$$F_2 \propto \phi_2 i_1$$

The directions of F_1 and F_2 can be obtained by Flemings left hand rule

$$F \propto F_2 - F_1$$

$$F \propto \phi_2 i_1 - \phi_1 i_1$$

$$F \propto [\phi_{2m}\sin(\omega t+\alpha)\,\phi_{1m}\cos\omega t - \phi_{1m}\sin\omega t\,\phi_{2m}\cos(\omega t+\alpha)]$$

$$\propto \phi_{1m}\phi_{2m}[\sin(\omega t+\alpha)\cos\omega t - \cos(\omega t+\alpha)\sin\omega t]$$

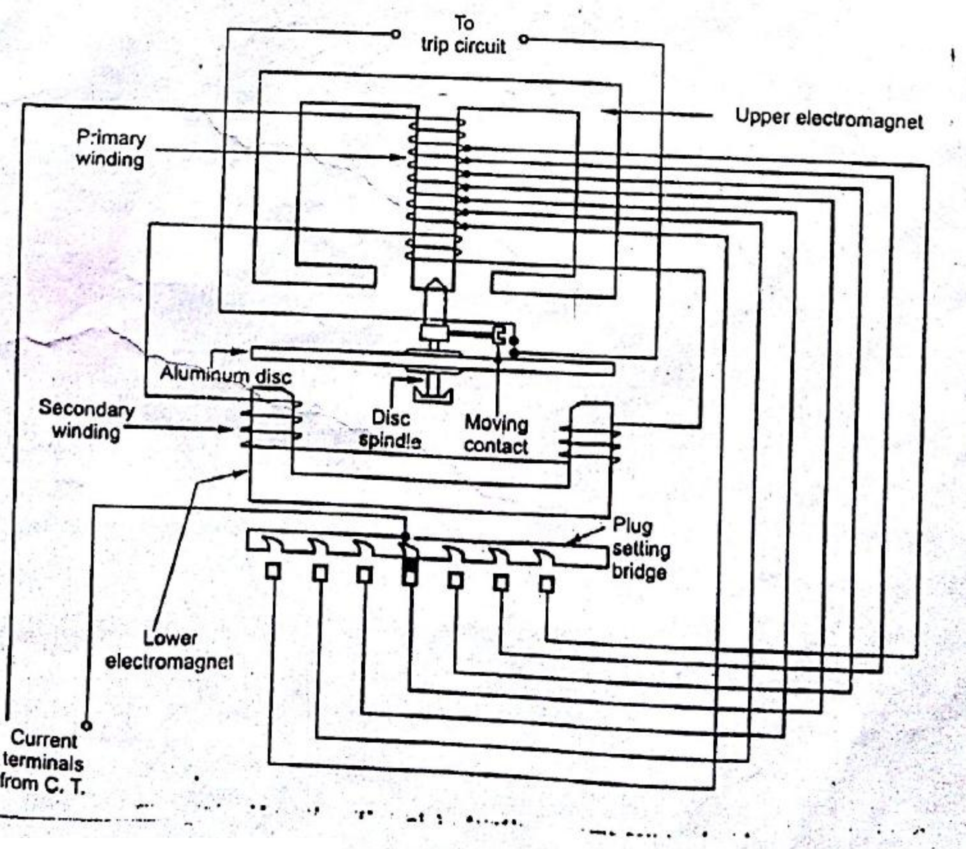
$$\propto \phi_{1m}\phi_{2m}[\sin[\omega t+\alpha-\omega t]]$$

$$F \propto \phi_{1m}\phi_{2m}\sin\alpha$$

$$F \propto \phi_1\phi_2\sin\alpha \quad [\phi_1, \phi_2 \rightarrow \text{rms values of Fluxes}].$$

if 'α' is zero, the net force is zero & disc cannot rotate. Hence there must exist a phase difference between the two fluxes. The torque is maximum when the phase difference α is 90°. The direction of the net force decides the direction of rotation of disc.

Non directional Induction type overcurrent Relay:-



This relay is also called earth leakage induction type relay. The overcurrent relay operates when the current in the circuit exceeds a certain preset value. The induction type nondirectional overcurrent relay has a construction similar to a watthour meter, with slight modification.

Construction:-

It consists of two electromagnets. The upper is E-shaped while the lower is U-shaped. The aluminium disc is free to rotate between the two magnets. The spindle of the disc carries moving contacts & when the disc rotates the moving contacts come in contact with fixed contacts which are the terminals of the trip circuit.

The upper magnet has two windings, primary and secondary. The primary is connected to the secondary of C.T whose primary is connected in series with the line to be protected. The windings is tapped at intervals & they are connected to plug setting bridge.

With the help of plug setting bridge, number of turns of primary winding can be adjusted, & desired current setting can be obtained. There are usually seven sections of tappings to have an overcurrent range from 50% to 200% in steps of 25% & these are percentages of the current rating of the relay. The adjustment of current setting is made by inserting a pin between spring loaded jaws of the bridge socket at the proper tap value required. When the pin is withdrawn for changing purpose, the relay adopts a higher current value, thus secondary of C.T is not open circuited. So relay remains operative even in changing the settings also.

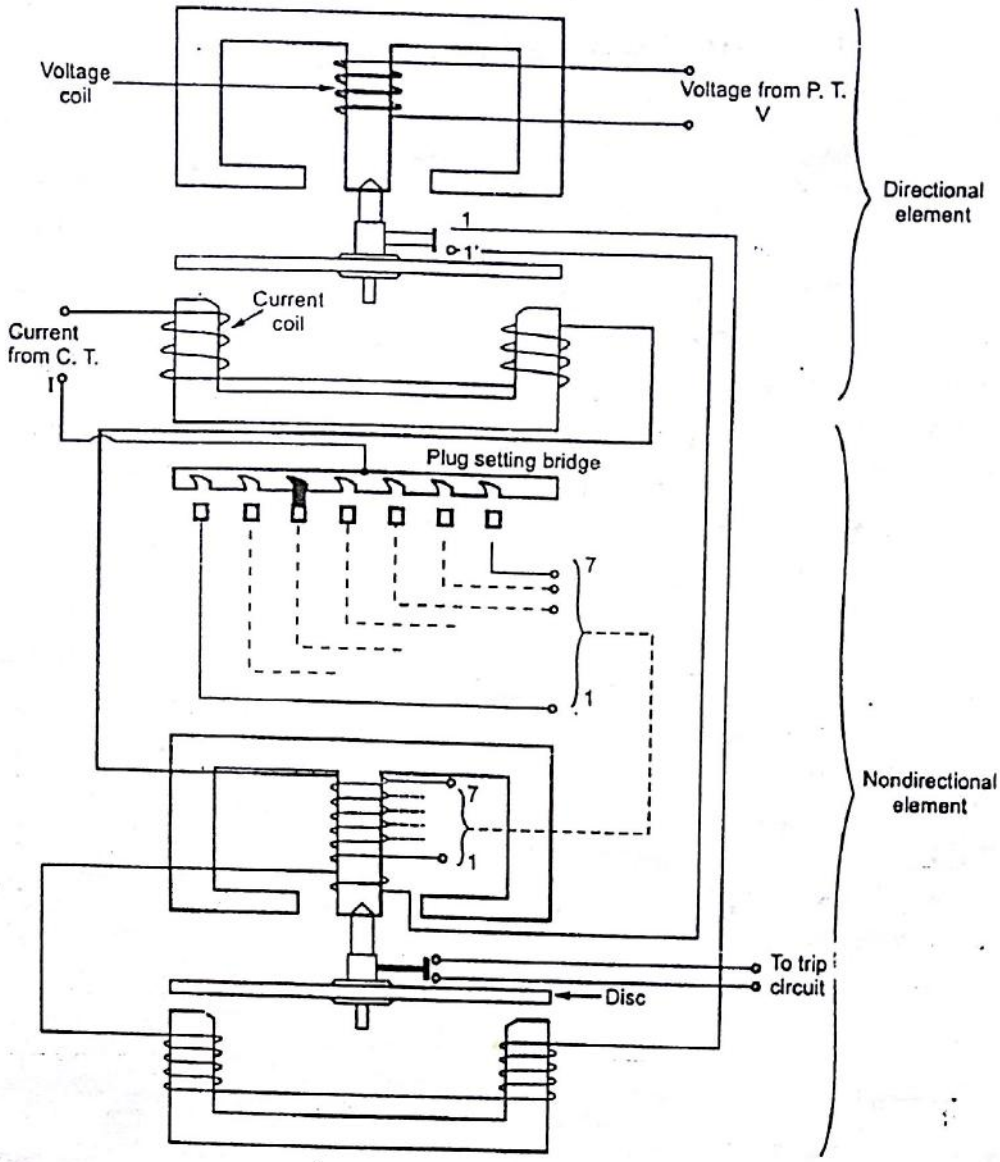
The secondary winding on the central limb of upper magnet is connected in series with windings on the lower magnet. This winding gets energized by the induction from primary. By arrangement, the primary and secondary fluxes are displaced in phase, & it produce a rotational torque on aluminium disc. The control torque is provided by the spiral spring.

When current exceeds the preset value, the disc rotates & moving contacts on spindle makes the contact with trip circuit terminals. Disc will rotate from 0° to 360°. The travel of moving contacts can be adjusted by adjusting the angle of rotation of disc & this gives the relay time setting which is calibrated from 0 to 1.

Operation:-

The operating torque is produced by induction principle & restraining torque is produced by spiral springs. Under normal conditions the restraining force is more than driving force & hence the disc remains stationary. Under fault conditions when current becomes high, the disc rotates through a preset angle & makes contact with the fixed contacts of trip circuit. The trip circuit opens the circuit breaker, isolating the faulty part from rest of the healthy system.

Directional Induction type overcurrent Relay:-



The directional induction type over current relay uses two relay elements mounted on a common case. They are

1. Directional element which is a directional power relay
2. Non directional element which is nondirectional overcurrent relay.

Directional element:-

It is nothing but a directional power relay which operates when power in the circuit flows in a particular direction. The voltage coil of this element is energized by a system voltage through a potential transformer. The current coil on the lower magnet is energized by the system current through a current transformer. The trip contacts of this relay (1-1') are connected in series with the secondary winding of nondirectional element.

Non-directional element:-

The current coil of the directional element is connected in series with the primary winding of nondirectional element. The plug setting bridge is provided in this element to adjust current setting as per the requirement. The trip contacts (1-1') are in series with winding on lower magnet of nondirectional element. unless & until trip contacts (1-1') are closed by the movement of the disc of directional element, the non-directional element cannot operate. Thus the movement of non-directional element is controlled by the directional element.

Operation:-

under normal conditions, Power flows in the proper direction and hence directional element of the relay is inoperative. Thus the secondary winding on lower magnet of nondirectional element is open & hence nondirectional element is also inoperative.

When the fault takes place, the current or power in the circuit flow in reverse direction. The current flows through current coil of directional element which produces the flux & current in the voltage coil produces another flux. The two fluxes interact to produce the torque which makes the disc to rotate. As disc rotates, the trip contacts (1-1') get closed. The directional element design is such that it is very sensitive and though voltage is less, the current in current coil is responsible to produce sufficient torque to have disc rotation. It is so sensitive that it can operate even at 2% of power flow in reverse direction.

The current also flows through the primary winding of the upper magnet of nondirectional element, & it get energizes to produce the flux. This flux induces the e.m.f in the secondary winding of the nondirectional element according to induction principle. As the contacts (1-1') are closed, the secondary winding has a closed path. Hence induced emf drives a current through it, producing another flux. These two fluxes interact to produce the driving torque which rotates the disc. Thus the contacts of trip circuit get closed and it opens the CB to isolate the faulty section.

So directional element must operate first to have the operation of the nondirectional element.

The conditions to be satisfied to operate the relay are

1. The direction of current in the circuit must reverse to operate directional element.
2. The current value must be greater than the current setting.
3. The high value of current must persist for a time period which is greater than the time setting of the relay.

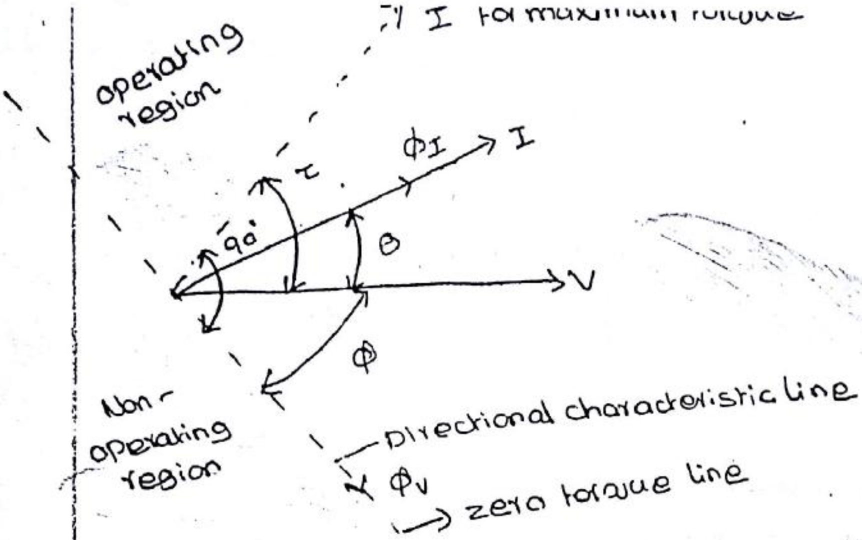
Directional characteristics:-

V = Relay voltage through P.T.

I = Relay coil current through C.T.

θ = Angle between V and I

The design is made such that I leads the voltage by angle θ.



ϕ_V – Flux produced by voltage V. It lags voltage by an angle ϕ.
ϕ_I – Flux produced by current I. It is in phase with current I.

$$T \propto \phi_V \phi_I \sin\alpha$$

$$T \propto \phi_V \phi_I \sin(\theta+\phi) \qquad \phi_V \propto V \ \& \ \phi_I \propto I$$

$$T = KVI\sin(\theta+\phi) \quad \text{where } K = \text{constant}$$

Maximum torque occurs when $\sin(\theta+\phi)$ is 1

$$\theta+\phi = 90°$$

Torque is zero when $\sin(\theta+\phi) = 0$

(ie) $\theta+\phi = 0°$ or $180°$

Zero torque line is at right angles to maximum torque condition line.

The directional element operates when the current phasor lies within ±90° of max torque line. If it is displaced more than 90°, then the element will restrain.

Maximum torque angle:- The angle by which the current supplied to the relay leads the voltage supplied to the relay so as to obtain the maximum torque is called maximum torque angle (M.T.A) (τ)

$$\phi = 90° - \tau$$

$$T = KVI\sin(\theta + 90° - \tau)$$

$$T = KVI\cos(\theta - \tau)$$

This is the torque equation interms of maximum torque angle τ.
The typical values of the maximum torque angle are 0°, 30°, 45° .....

Types of overcurrent Relay:-

1. Definite time overcurrent relay:-

The relay operates after a predetermined time when the current exceeds its pick up value. The operating time is constant, irrespective of the magnitude of the current above the pick-up value.

Instantaneous overcurrent Relay:-

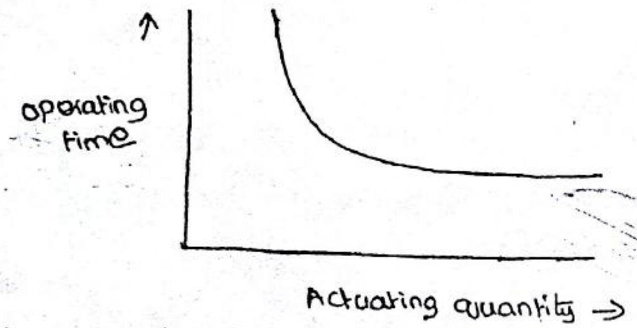
The relay operates in a definite time when the current exceed its pick-up value. The operating is constant, irrespective of the magnitude of the current. There is no intentional time delay. It operates in 0.1 sec or less.

Inverse-time overcurrent Relay:-

The relay operates when the current exceeds its pickup value. The operating time depends on the magnitude of the operating current. The operating time decreases as the current increases.

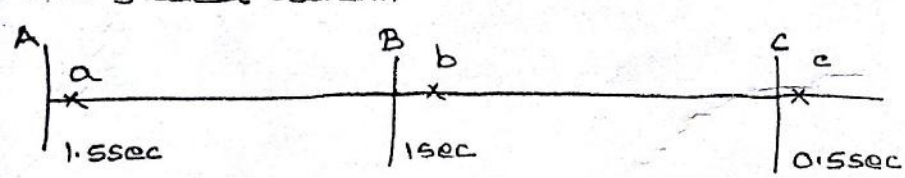
Inverse Definite Minimum Time overcurrent (I.D.M.T) Relay:-

This type of a relay gives an inverse-time current characteristics at lower values of fault current and definite time characteristic at higher values of fault current. These relays are widely used for the protection of distribution lines.



Selectivity of Relays:-

Time-graded system:-



In this scheme, definite time overcurrent relays are used. When a definite time relay operates for a fault current, it starts a timing unit which trips the circuit breaker after a preset time, which is independent of the fault current. The operating time of the relays is adjusted in increasing order from the far end of the feeder. The difference in the time setting of two adjacent relays is usually kept at 0.5sec. The difference is to cover the operating time of the C.B and errors in the relay & C.T.

When a fault occurs beyond C, all relays come into action as fault current flows through all of them. The least time setting is for the relay placed at C. So it operates after 0.5sec & the fault is cleared. Now the relays at A and B are reset. If C.B 'c' fails then C.B 'b' will trip. If C.B 'b' also fails, then only C.B 'a' will trip.

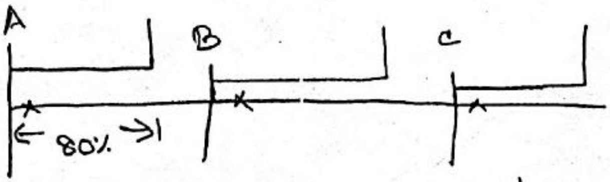
Drawbacks:-

The drawback of this scheme is that for faults near power source the operating time is more. If a fault occurs near the power source, it involves a large current and hence it should be cleared quickly, so this scheme is not suitable for a faults near power source.

It is suitable for a system where the impedance (distance) between substations is low. It means that the fault current is practically the same if a fault occurs on any section of the feeder.

Current graded system:-

In this scheme, the relays are set to pick-up at progressively higher values of current towards the source. The relays employed are high speed instantaneous overcurrent relays. The operating time is kept the same for all relays used to protect different sections of the feeder.



relay B should trip for faults anywhere between B & C, but it should not operate for faults beyond C. Similarly, the relay at A should trip for faults between A and B. The relay at C should trip for faults beyond C.

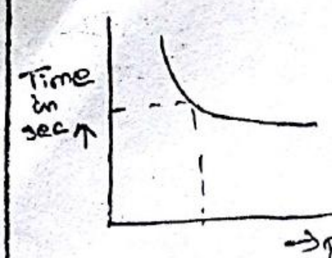
The ideal operation is not achieved due to

1. The relay at A is not able to differentiate between faults very close to B which may be on either side of B. This happens due to the fact that there is very little difference in fault currents if a fault occurs at the end of the section AB or in the beginning of the section BC.
2. During a fault, there is a transient condition & the performance of the relays is not accurate.

So to obtain proper discrimination, relays are set to protect only a part of the feeder, usually about 80%. Since this scheme cannot protect the entire feeder, this system is not used alone.

The current graded scheme is used where the impedance between substations is sufficient to create a margin of difference in fault currents. The advantage of this system as compared to the time graded scheme is that the operating time is less near the power source.

Prob: The fig shows the part of a typical power system. For the discrimination, time grading margin between the relay is 0.5sec, calculate the time of operation of relay 1 & time setting multiplier for Relay 2. The time setting multiplier of relay 1 is 0.3.



The corresponding time for 6.4 PSM is 3 sec & the corresponding time for 5.33 PSM is 3.8 sec

Solu:-

For relay 1:- current setting = 125% = 1.25

Fault current = 4000A

C.T ratio = 500/5

∴ Fault current in relay coil = $4000 \times 5/500 = 40A$

$$P.S.M = \frac{40}{5 \times 1.25} = 6.4$$

The corresponding time for 6.4 P.S.M is 3 sec

∴ Actual time of operation = 3 × time setting multiplier

$= 3 \times 0.3 = 0.9$ sec

For relay 2:- current setting = 150% = 1.5

Actual time of operation = time of operation of relay 1 + time margin

$= 0.9 + 0.6 = 1.5$ sec

Fault current = $4000 \times 5/500 = 40A$

$$P.S.M = \frac{\text{Fault current}}{\text{C.T secondary rating} \times \text{current setting}}$$

$$= \frac{40}{5 \times 1.5} = 5.33$$

The corresponding time for 5.33 P.S.M is 3.8 sec

$$\therefore \text{Time setting multiplier} = \frac{\text{Actual time of operation}}{\text{Time for P.S.M obtained}}$$

$$= \frac{1.5}{3.8} = 0.395 \approx 0.4$$

This is the required time setting multiplier for the relay 2.

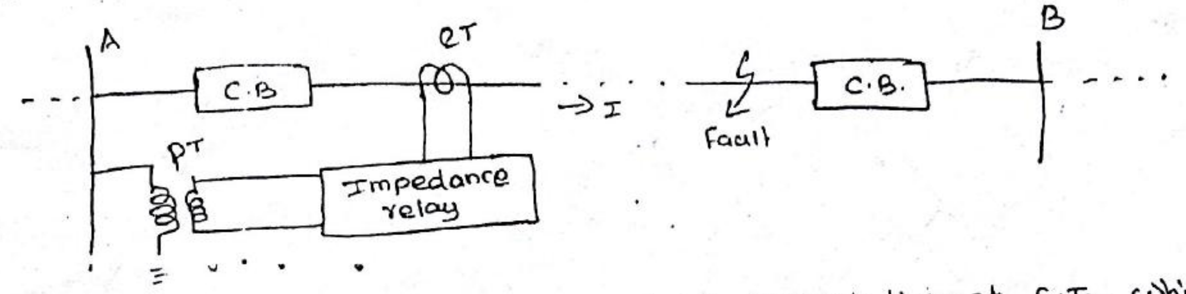
Distance Relays:-

In this Relays, the operation is dependent on the ratio of the voltage and current, which is expressed in terms of an impedance ($Z = V/I$). Hence these relays are generally called impedance relays or ratio relays. Dependent on the ratio of V and I, there are 3 types of distance relays which are

1. Impedance relay which is based on measurement of impedance Z.
2. Reactance relay which is based on measurement of reactance X.
3. Admittance or Mho relay which is based on measurement of component of admittance Y.

Impedance Relay :-

The impedance relay works corresponding to the ratio of Voltage V & Current I of the circuit to be protected. It consists of two elements. The current element produces operating torque which is said to be positive torque & voltage element produces restraining torque which is said to be negative torque. The torque produced by the current element is balanced against torque produced by the voltage element. This relay is also called as voltage restrained overcurrent relay.



The current element is energized by current through C.T, while Voltage element is energized by Voltage through P.T. The section AB of the line is the protected zone.

Under normal conditions, the ratio of V & I is denoted by Z_L - impedance of line. The relay is inoperative under this condition.

When the fault occurs at point F in the protected zone, the V drops & I increases. Thus $Z = V/I$ reduces drastically. So when impedance (Z) reduces than its predetermined value (Z_L), it trips & makes the C.B open.

Torque Equation :-

+ve torque produced by current element is $\propto I^2$ while

-ve torque produced by voltage element is $\propto V^2$

Let control spring effect produces a constant torque of $-K_3$. $K_3 \approx 0$ Spring Cont...

∴ Torque equation becomes

$$T = k_1 I^2 - k_2 V^2 - k_3 \qquad \text{where } k_1, k_2 \text{ are constants.}$$

At balance point, when the relay is on the verge of operating, $T = 0$

$$0 = k_1 I^2 - k_2 V^2 - k_3$$

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

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

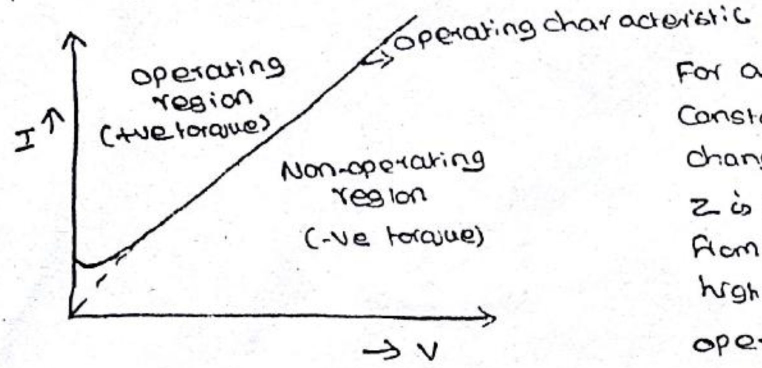
$$Z^2 = \frac{k_1}{k_2} - \frac{k_3}{k_2 I^2}$$

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

Generally the spring effect is neglected, as its effect is dominant at low currents which generally do not occur in practice. So with $k_3 = 0$

$$Z = \sqrt{k_1/k_2} = V/I = \text{constant}.$$

Operating characteristics :-



For a particular fault position, $V/I = Z$ is constant. It changes if the fault position changes. If fault is nearer to relay, Z is low & as fault position moves away from the relay (Relay) Z value becomes higher & higher. It can be installed to operate for a section to be protected & once installed it is inoperative beyond that section. As the effect of spring is dominating for lower values of currents, the curve shows a bend at lower currents.

The impedance Z which is predetermined set value is given by

$$Z = 1/\text{slope of characteristics}.$$

The relay will operate for any value of Z less than the constant value respented by the line. By adjustments, the slope of the characteristics can be changed.

Operating characteristics on R-X Diagram:-

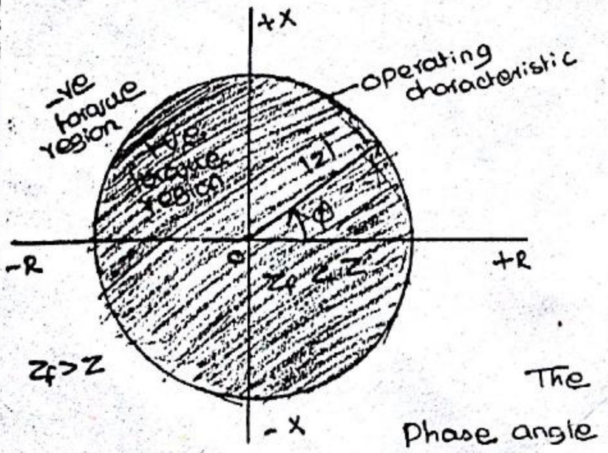
The operating charactoristis of an impedance relay can be more easily represented by a diagram called R-X Diagram. The plane is called R-X plane in which R is taken in X-axis & X is taken in Y-axis.

$$Z = R + jX$$

$$|Z| = \sqrt{R^2+X^2}, \quad \phi = \tan^{-1}(X/R)$$

$$Z^2 = R^2 + X^2$$

This equation looks like a circle equation where $|Z|$ is the radius of the circle having R in X-axis & X in Y-axis. The centre of the circle is at point where R and X axes intesect each other (ie) origin.



The numerial values of V & I determines the length of the radius vector Z & phase angle ϕ between V & I determines the exact position of vector Z.

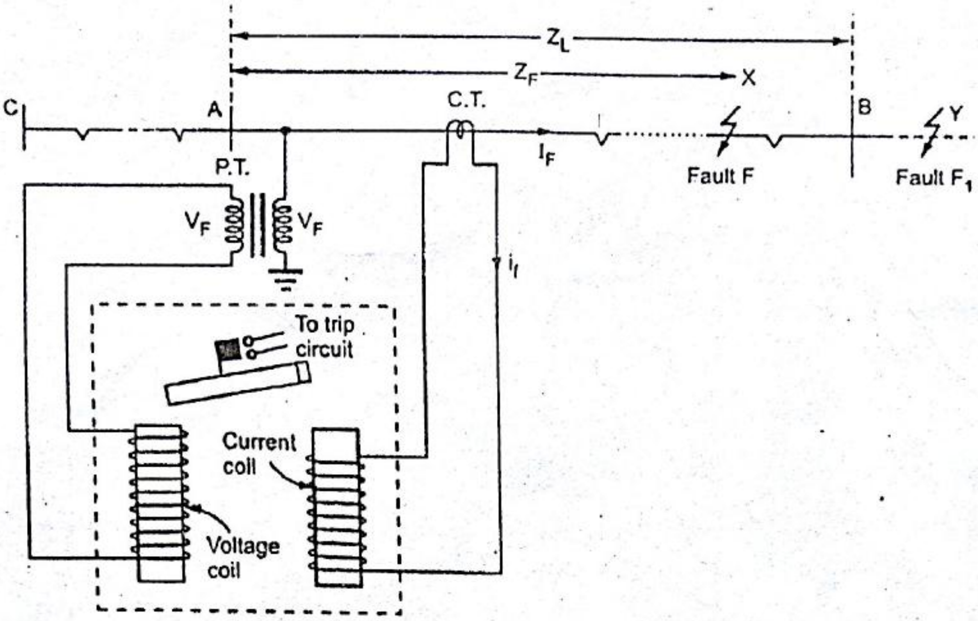
If I is in phase with V, Z vectors lies along the R-axis. If I lags V, then Z is negative while I leads V, Z is +ve.

The operation of the relay is independent of phase angle ϕ & hence the operating characteristic is a circle.

At any value of Z less than the radius of circle, the relay operates. Hence the entire portion inside the circle is +ve torque region. Such a relay is non-directional & can operate for faults on either side of a point where relay is installed. Z_f – faults impedance, Z = set impedance

$Z_f < Z$ → relay operates

Use of Impedance Relay for Transmission line protection:-



* This scheme is called distance protection for the transmission line.
* The voltage coil of the relay is fed from P.T while its current coil is fed from C.T.

I_F = Line current when fault occurs at point X.

V_F = supply voltage when fault occurs at point X.

i_F = current supplied to current coil when fault occurs

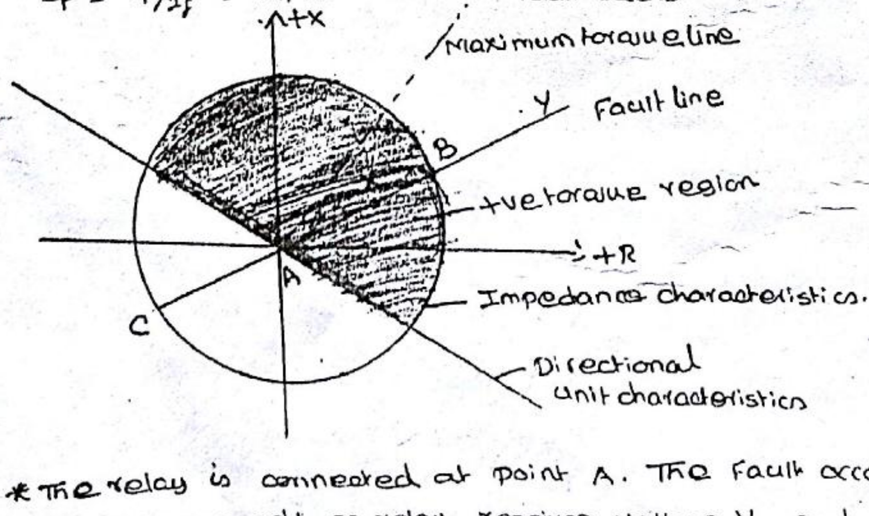
V_F = Voltage supplied to voltage coil when fault occurs

V = Normal supply voltage

I = Normal line current

$Z_L = V/I$ = Impedance of healthy section

$Z_F = V_F/I_F$ = impedance when fault occurs.



* The relay is connected at point A. The fault occurs at point X.
* The voltage coil of relay receives voltage V_F and current coil receives current i_F, when fault occurs.
* The setting of the relay is selected such that it protects the transmission line upto point B. The protected zone is AB.
* In that zone if $Z_F < Z_L$, the relay operates.
* If it is a non-directional relay, th it will operate even for a fault occurs in AC region.

Adding capacitor, the torque angle is adjusted as 90°,

$$K_1 = K_2 Z \cos(\theta - 90^\circ)$$

$$K_1 = K_2 Z \sin\theta$$

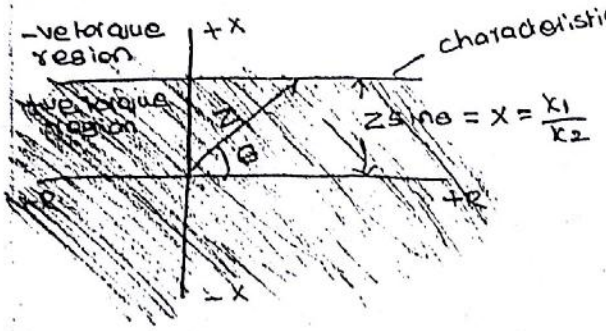
$$Z\sin\theta = \frac{K_1}{K_2}$$

$Z\sin\theta = X$ = reactance

$Z\cos\theta = R$ = resistance

$X = \frac{K_1}{K_2}$ = constant

Thus the relay operates on the reactance only. The constant X means a straight line parallel to X-axis on R-X diagram. For the operation of the relay, the reactance seen by the relay should be smaller than the reactance for which the relay is designed.

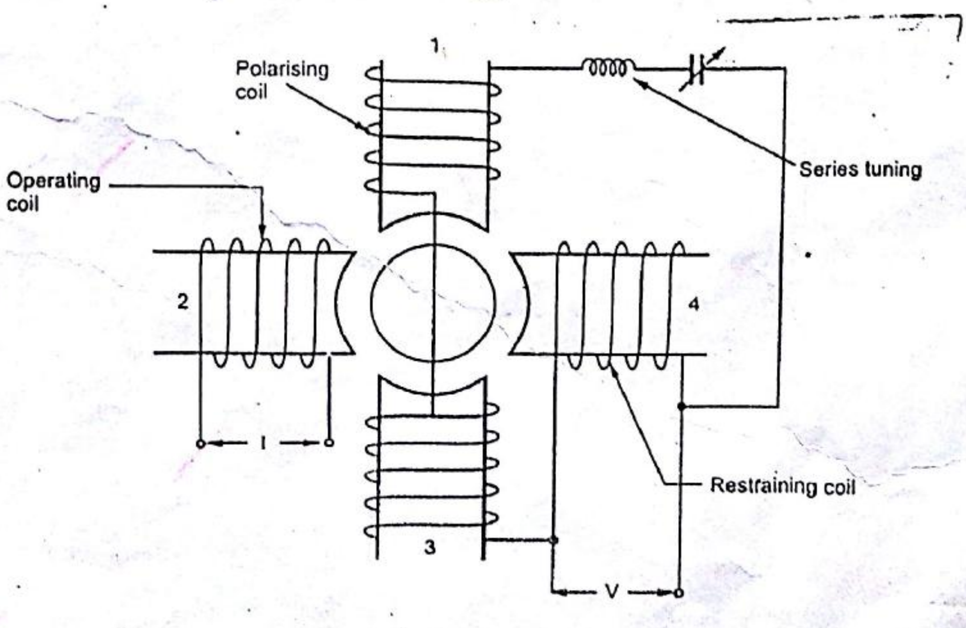


The resistance component of the impedance has no effect on the operation of the relay.

The relay will operate for all the impedances whose heads lie below the operating characteristics, whether below or above the R-axis.

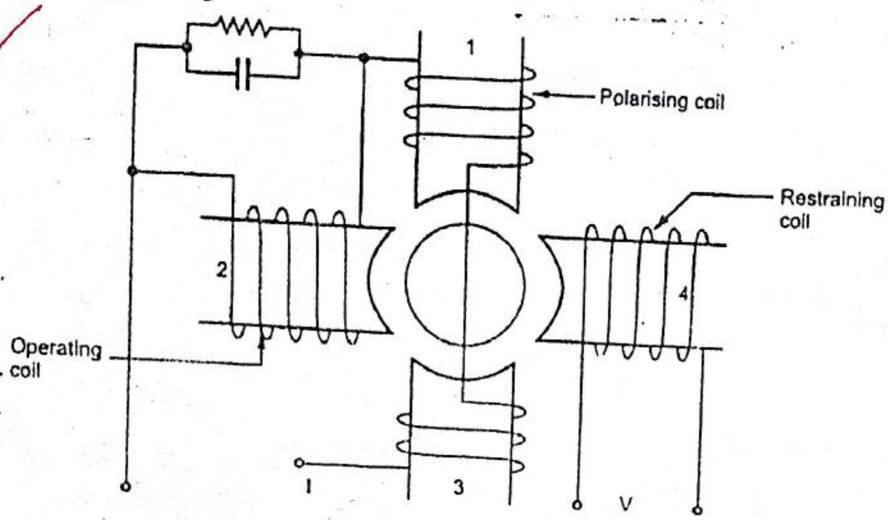
Disadvantage:- It is not possible to use a directional relay which is used with basic impedance relay because under normal conditions, with a load of high p.f, the reactance (X) measured by the reactance relay may be less than its setting. So reactance relay with directional element will have circular characteristic.

Mho Relay or Admittance Relay:-



* If the portion of line AB only is to be protected, then directional impedance relay can be used.
* So for any fault position along line AB, relay will trip as the entire section AB is in the protected zone.
* For fault at X, $Z_F < Z_L$, hence point X is in the operating region & relay will trip.
* For fault at Y, $Z_F > Z_L$, hence point Y lies outside the circle hence in the negative torque region & relay remains inoperative.

Reactance Relay:-



* In this relay the operating torque is obtained by current while the restraining torque is due to a current-voltage directional relay.
* The overcurrent element develops +ve torque and directional unit produces -ve torque.

* current produces polarising flux in the upper & lower poles. Also current is the operating quantity which produces flux in the right hand side pole.
* Flux in the right hand side pole is out of phase with the flux in the upper & lower poles because of the secondary winding which is closed through a phase shifting circuit & it is placed in the right hand side pole.
* The interaction of the polarising flux & the flux in the right hand side pole produces an operating torque $k_1 I^2$.
* The winding placed on the left hand side pole produces a flux which interacts with the polarising flux to produce a restraining torque.
* It is a non-directional relay as it operates for the negative values of x (ie:- fault behind the relay location)

Torque Equation:-

The driving torque is proportional to the square of the current while the restraining torque is proportional to the product of V & I.

Neglecting the spring effect, the net torque equation

$$T = k_1 I^2 - k_2 V I \cos(\theta - \tau)$$

At the balance point net torque is zero,

$$0 = k_1 I^2 - k_2 V I \cos(\theta - \tau)$$

$$k_1 I^2 = k_2 V I \cos(\theta - \tau)$$

$$k_1 = \frac{k_2 V I \cos(\theta - \tau)}{I^2} = k_2 \frac{V}{I} \cos(\theta - \tau) = k_2 Z \cos(\theta - \tau)$$

* The mho relay is made inherently directional by adding a voltage winding called polarizing winding. This relay works on the measurement of admittance $Y \angle \theta$. This relay is also called angle impedance relay.
* This relay also uses an induction cup type structure.
* The operating torque is obtained by V & I element while restraining torque is obtained by a voltage element. Thus an admittance relay is a voltage restrained directional relay.
* The operating torque is produced by the interaction of the fluxes due to the windings carried by the poles 1, 2 & 3.
* The restraining torque is produced by the interaction of the fluxes due to the windings carried by the poles 1, 3 & 4.

Torque equation:-

The operating torque is proportional to VI while restraining torque is proportional to V^2. Hence net torque is given by,

$$T = k_1 VI\cos(\theta-\tau) - k_2 V^2 - k_3$$; k_3 - control spring effect.

Generally k_3 is neglected.

At balance point, net torque is zero,

$$0 = k_1 VI\cos(\theta-\tau) - k_2 V^2$$

$$k_1 VI\cos(\theta-\tau) = k_2 V^2$$

$$k_1 \cos(\theta-\tau) = k_2 V^2/VI$$

$$k_1 \cos(\theta-\tau) = k_2 V/I$$

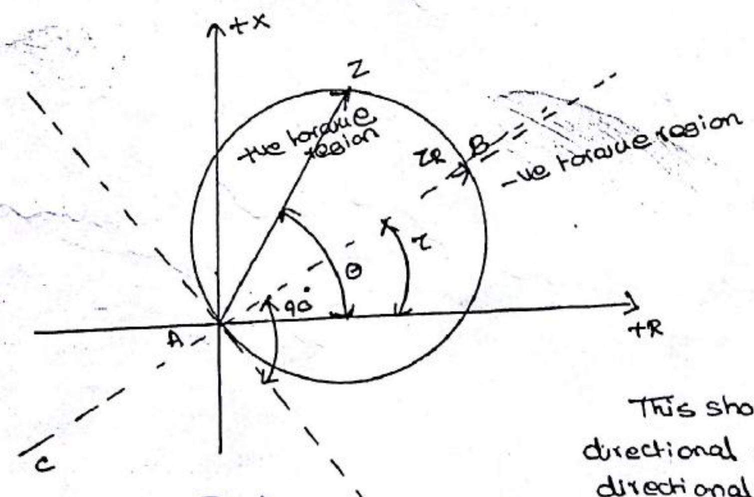
$$Z = \frac{k_1}{k_2}\cos(\theta-\tau)$$

$$1/Z \cos(\theta-\tau) = k_1/k_2$$

$$Y\cos(\theta-\tau) = k_1/k_2$$

— This is the equation of a circle having diameter k_1/k_2 passing through origin, & the constant k_1/k_2 is the ohmic setting of this relay.

Operating characteristics:-



This relay operates when Z seen by the relay falls within this circle. Consider two lines AB & AC with mho relay at point A. Relay will operate for the faults occuring in the section AB only & not in the section AC.

This shows that this relay is inherently directional without any additional directional unit.

Reactance Relay!

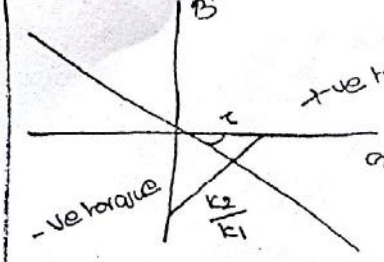
$$T = K_1 I^2 - K_2 VI\cos(90-\phi) - K_3 \qquad K_3 = 0$$

$$= K_1 I^2 - K_2 VI\sin\phi = 0$$

$$K_1 I^2 = K_2 VI\sin\phi$$

$$\frac{V}{I}\sin\phi < \frac{K_1}{K_2}$$

$$Z\sin\phi < K$$



The characteristics is a st.line when plotted on an admittance diagram (G-B axes)

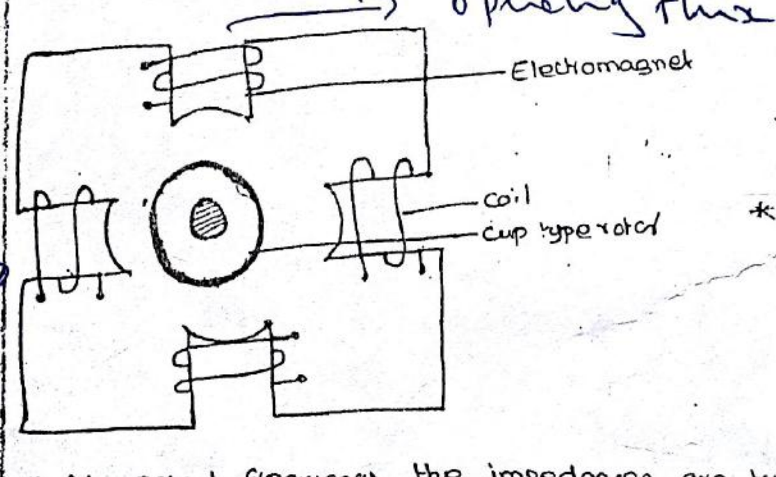
Frequency Relay:-

$$f = \frac{N_s P}{120}$$ where f - frequency

N_s - synchronous speed of generator

P - Number of poles.

* If the load is reduced, the speed of the synchronous generator increases & frequency increases.
* If load increases, the speed decreases and the frequency decreases.
* Hence frequency relays are required if frequency changes from its normal value & are used in the generator protection & for load frequency control.
* They can be under frequency or over frequency relays.



* It consists of two pairs of coils & a cup type rotor.
* These relays are connected to the secondary of voltage transformer
* The two pairs of coils are connected in parallel to the supply voltage through the impedances, which are the functions of the frequency.

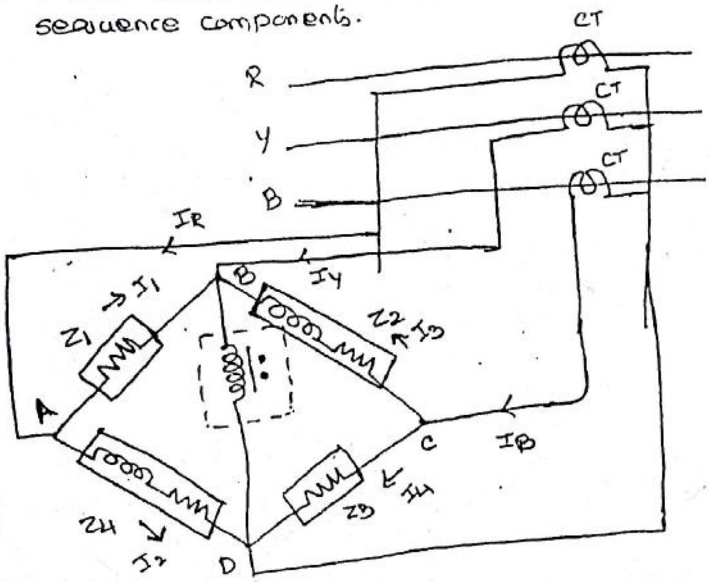
* At normal frequency the impedances are tuned balancing each other & no torque is experienced by the cup type rotor at normal rated frequency.
* If frequency increases, then there is unbalance in the impedances and clockwise torque is exerted on the rotor. If frequency increases beyond the setting, the relay operates & it is called over frequency relay.
* If frequency decreases, then there is unbalance in the impedances, but the torque exerted is anticlockwise. If frequency decreases beyond the setting, the relay operates & it is called under frequency relay.
* By varying the position of sliding resistor the frequency setting can be adjusted.
* The pickup sensitivity can be controlled by adjusting the restraining spring.

Negative Sequence Relays:-

* These relays are also called phase unbalance relays because these relays provide protection against negative sequence component of unbalanced currents existing due to unbalanced loads or phase-phase faults.

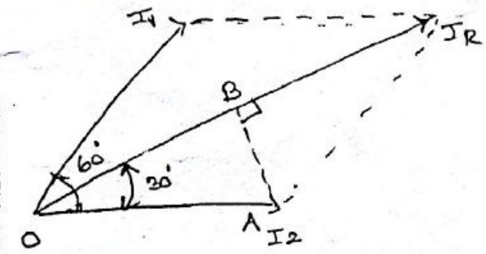
* The unbalanced currents are dangerous from generators & motors point of view as these currents can cause overheating.

* These relays have a filter circuit which is operative only for negative sequence components.



* It consists of a resistance bridge network.
* $|Z|$'s of all branches are equal.
* impedances Z_1 & Z_3 are purely resistive while the impedances Z_2 & Z_4 are the combinations of resistance & reactance.
* I's in the branches Z_2 & Z_4 lag by 60° from the I's in the branches Z_1 & Z_3.

* The vertical branch B-D consists of inverse time characteristics relay. The relay has negligible impedance.



I_R gets divided into two equal parts I_1 & I_2 at point A. I_2 lags I_1 by 60°

$$\bar{I_1} + \bar{I_2} = \bar{I_R}$$

Let $I_1 = I_2 = I$

The perpendicular drawn from A to B bisects the diagonal.

$$OB = I_R/2$$

In Δ^{le} OAB, $\cos 30° = \frac{OB}{OA}$

$$\sqrt{3}/2 = \frac{I_R/2}{I}$$

$$I = \frac{I_R}{2} \times 2/\sqrt{3} = I_R/\sqrt{3} = I_1 = I_2$$

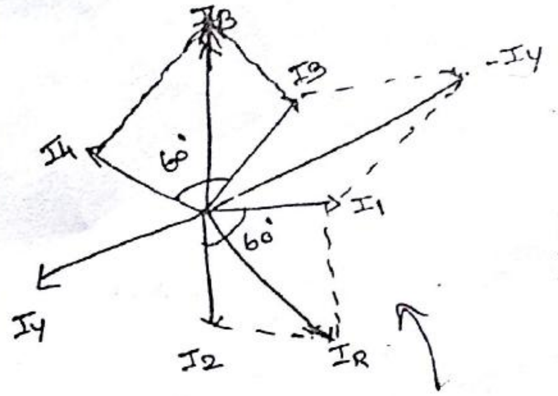
Now I_1 leads I_R by 30° while I_2 lags I_R by 30°

$|||^{ly}$ I_B gets divided into two equal parts I_3 & I_4, I_3 lags I_4 by 60°.

$$\frac{I_B}{\sqrt{3}} = I_3 = I_4$$

I_4 leads I_B by 30° while I_3 lags I_B by 30°

$$I_{relay} = \bar{I_1} + \bar{I_3} + \bar{I_Y}$$
$$= I_Y + I_R/\sqrt{3} \text{ (leads } I_R \text{ by } 30°) + I_B/\sqrt{3} \text{ (lags } I_B \text{ by } 30°)$$



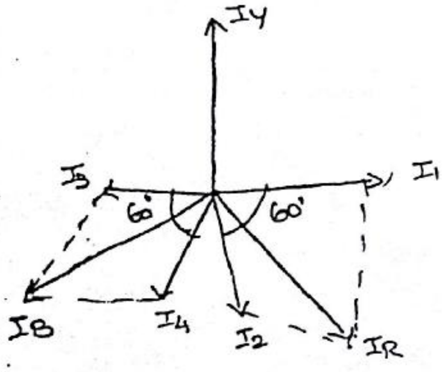
$\bar{I}_1 + \bar{I}_3 = -\bar{I}_y$

$\bar{I}_1 + \bar{I}_3 + \bar{I}_y = 0$

Thus the current entering the relay at point B is zero. |||ly the resultant current at junction D is also zero, & thus the relay is inoperative for a balanced system.

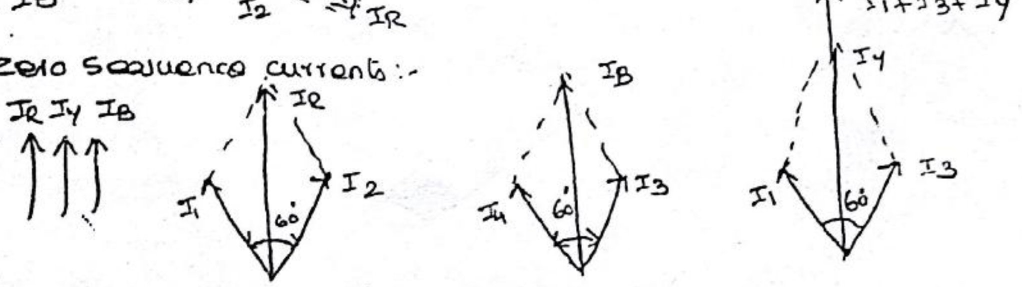
Balanced condition vector sum

Now consider, there is unbalanced load on generator or mot due to which negative sequence currents exist.



Here I_1 & I_3 are equal and opposite to each other at junction point B. Hence I_1 & I_3 cancel each other. Now the relay coil carries the current I_y & when this current is more than a predetermined value, the relay trips closing the contacts of trip circuit which opens the C.B.

Zero sequence currents :-



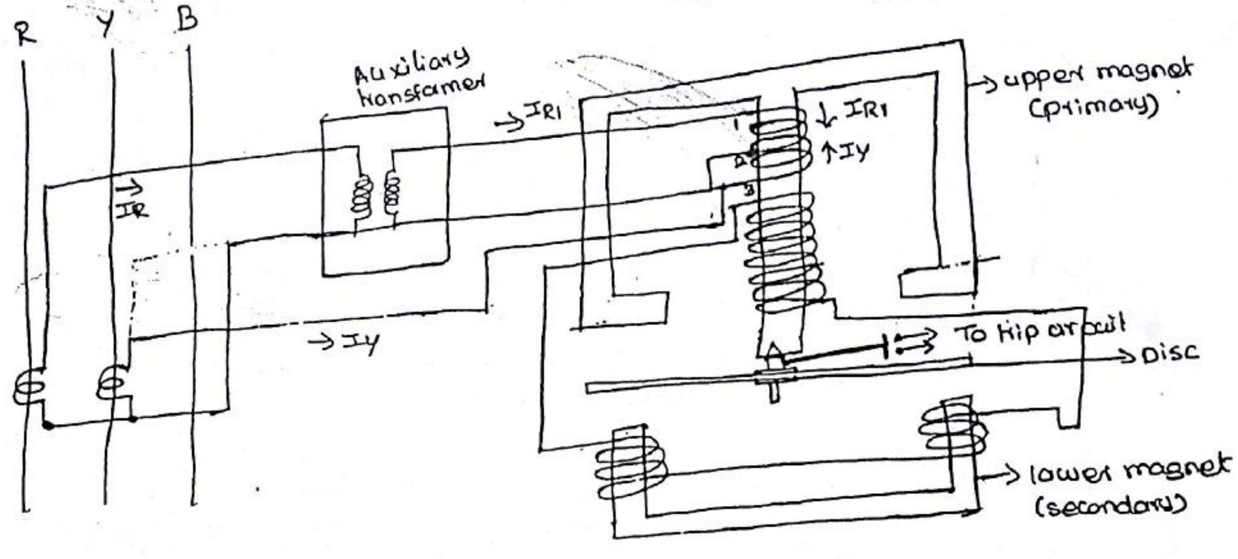
$\bar{I}_R = \bar{I}_1 + \bar{I}_2$

$\bar{I}_B = \bar{I}_3 + \bar{I}_4$

$\bar{I}_1 + \bar{I}_3 = \bar{I}_y$ in phase with I_y

The total current through the relay is $\bar{I}_1 + \bar{I}_3 + \bar{I}_y$. Thus under zero sequence currents condition, twice the value of currents flows through the relay. So the relay operates to open the C.B. To make the relay sensitive to operate only for Negative sequence currents, the CT's can be connected in delta such that zero sequence current will not flow in the network.

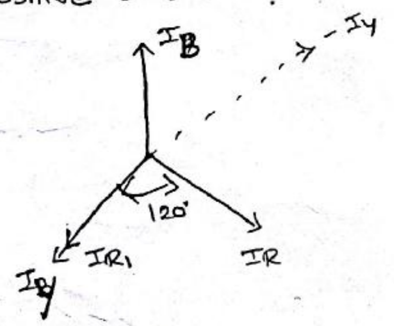
Induction type Negative sequence Relay:-



* The central limb of upper magnet carries the primary which has a centre tap. Due to this, the primary winding has three terminal 1, 2 & 3.
* The section 1-2 is energized from the secondary of an auxiliary transformer to R-phase.
* The section 2-3 is directly energized from the y-phase current.
* The auxiliary transformer is a special device having an air gap in its magnetic circuit. With help of this, the phase angle between primary and secondary is adjusted such that output current lags the input current by 120°.

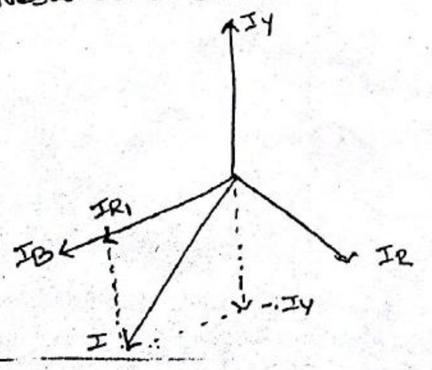
I_R - i/p current of auxiliary transformer
I_{R1} - o/p current of auxiliary transformer

Positive sequence currents:-



The phase difference between I_R & I_y is 120°. ||ly the phase difference between I_R & I_{R1} is 120°. The phase difference of I_{R1} & I_y is the vector sum of I_{R1} & $-I_y$ & thus resultant is zero. Thus the relay primary current is zero & relay is inoperative for +ve sequence currents.

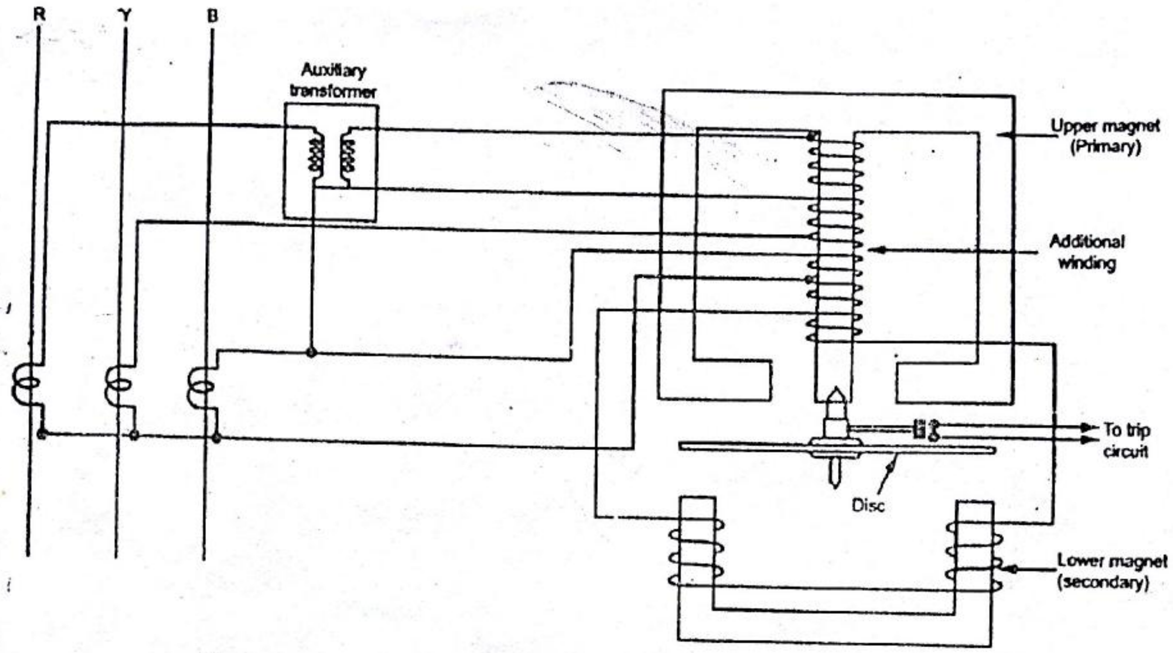
Negative sequence currents:-



Under negative sequence currents, the vector difference of I_{R1} & I_y results in a current I & this flows in the primary coil of the relay, so the relay operates.

* The relay is inoperative for zero phase sequence currents. But it can be made operative for the flow of zero sequence currents by providing an additional winding on the central limb of the upper magnet of the relay.

* This winding is connected in the residual circuit of the three line C.T's.
* This relay is called induction type negative & zero sequence relay.



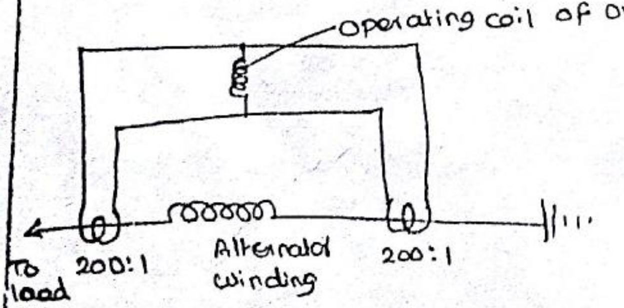
Differential Relays:-

The relay operates when the vector difference of two or more similar electrical quantities exceeds the predetermined value.

Various types:-

1. current differential relay
2. Biased beam relay or percentage differential relay.
3. Voltage balance differential relay.

Current Differential relay:-



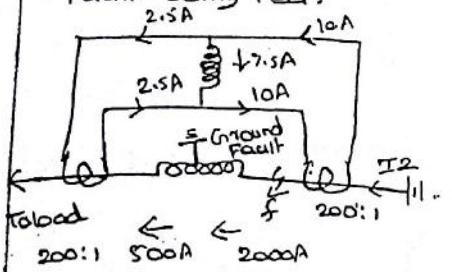
* A pair of identical current transformers are fitted on either end of the section to be protected.

* The secondaries of CTs are connected in series in such a way that they carry the induced currents in same direction. The operating coil of the overcurrent relay is connected across the CT secondary circuit.

* The differential relay compares the current at two ends of alternator winding. under normal operating conditions, suppose the alternator winding carries a normal current of 1000A, the currents in two secondaries of CT's are equal. These currents will merely circulate between 2 CTs and no current will flow through differential relay. ∴ relay is inoperative.

* If ground fault occurs in alternator winding, the two secondary currents will not be equal & current flows through operating coil of relay causes the relay to operate.

* Amount of current flow through relay will depend upon the way the fault being fed.

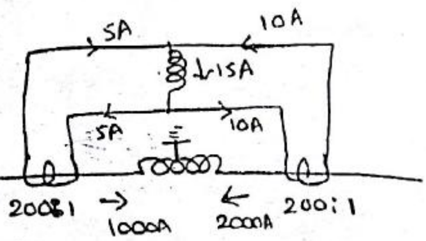


CT ratio : 200:1

$500 \times 1/200 = 2.5A$

$2000 \times 1/200 = 10A$

If some current (500A) flows out of one side, while larger current (2000A) enters the other side, then the difference of CT secondary current is $10-2.5 = 7.5A$ will flow through the relay.



If the current flows through the fault from both sides, the sum of CT secondary currents will flow through the relay.

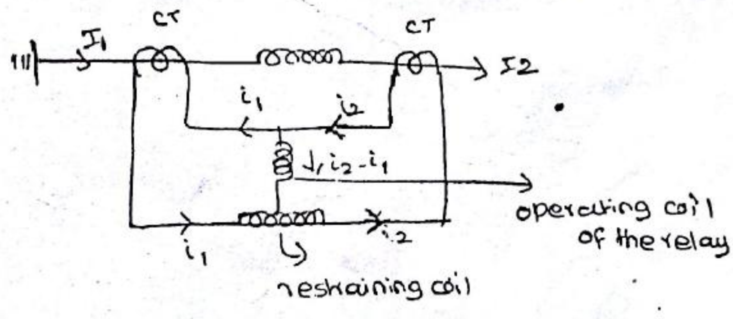
Disadvantage:-

1. The circuit operates inaccurately with heavy external faults.
2. The CT's may saturate & cause unequal secondary currents & the differences of secondary currents may approach the pickup value to operate the relay unnecessarily.

Percentage differential relay (Biased Beam relay)

* The percentage differential relay responds to the differential current in terms of fractional relation of the current flowing through the protected section.

* It is essentially current balanced beam relay type with additional restraining coil which produces bias force in the opposite direction to the operating force.



operating coil current is $i_2 - i_1$

restraining coil current is $\frac{i_1+i_2}{2}$ since operating coil is connected to mid of the restraining coil.

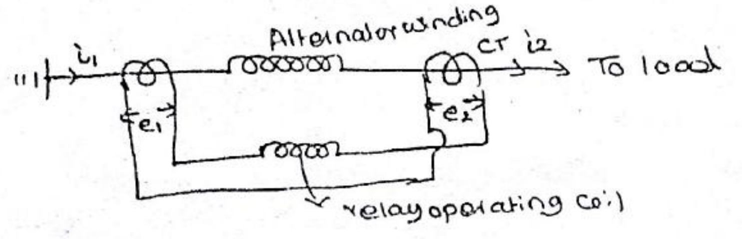
If N is the number of turns in the restraining coil, then

$$I = \frac{Ni_1+Ni_2}{2} = \frac{N(i_1+i_2)}{2}$$

under heavy load, greater differential current flows through relay operating coil. The operating current required to trip can be expressed as % of load current.

Bias force can be adjusted by varying the number of turns in the restraining coil.

Voltage Balance Differential Relay:-



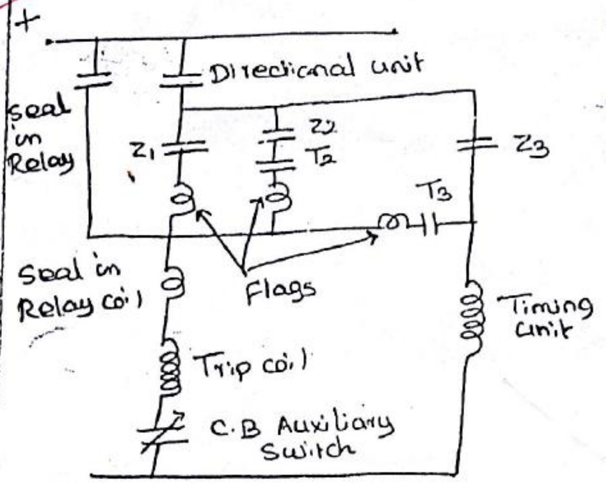
* The two similliar current transformers are connected at either end of the element to be protected by means of pilot wires.
* The secondaries of CT are connected in series with relay such that under normal conditions, their induced emfs are in opposition.
* under healthy conditions, equal current ($I_1 = I_2$) flows in both primary windings. Therefore secondary voltages of two transformers are balanced against each other & no current will flow through relay operating coil.
* when fault occurs in protected zone, the currents in two primaries will differ from one another (ie: $I_1 \neq I_2$) & secondary voltages will no longer in balance, causes large voltage drop across the relay.
* This large voltage difference will cause a current to flow through the operating coil of relay which closes the trip circuit.

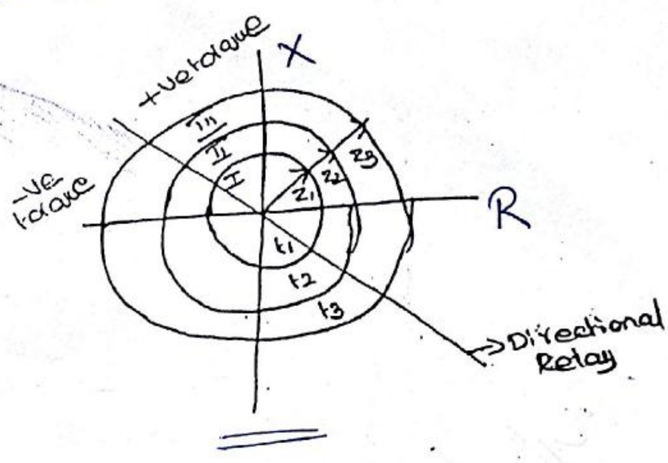
Disadvantages:-

* Multigap transformer construction is required for accurate balance between CT pairs.
* On long cables, the charging currents may be sufficient to operate the relay even if a perfect balance of CT is attained.

Connections of Impedance Relays:-

R-X diagram





Z_1, Z_2, Z_3 → impedance relays

T_2, T_3 → Timing contacts for Z_2 & Z_3 impedance relays

t_1, t_2, t_3 → operating time of the impedance relays.

I zone protection:-

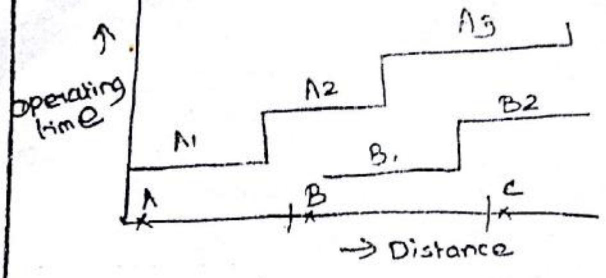
* The characteristic circle for Z_1 is the smallest.
* If any fault point lies within the circle Z_1 & it is in forward direction, the directional relay & all the three impedance relays operate.
* The relay in circle Z_1 is a high speed instantaneous relay & it will trip out at time t_1.
* It covers upto 80 to 90% of the protected line distance. It doesn't cover 100% because of unnecessary tripping due to overreach.
* If the relay operates for a fault beyond the protected line, this phenomenon is called overreach.
* It is the primary protection of the protected line.

II zone protection:-

* The main purpose of the second unit is to protect the rest of the protected line which is beyond the reach of the first unit & will also take care of underreach which is caused due to arc resistance, errors in C.T, P.T & measurements performed by the relay.
* It covers the 20 to 10% of the remaining line to be protected & 50% of the adjoining line.
* The II zone unit (Z_2) operates after a certain time delay (T_2) & it's operating time is 0.25 to 0.5sec.

III zone protection:-

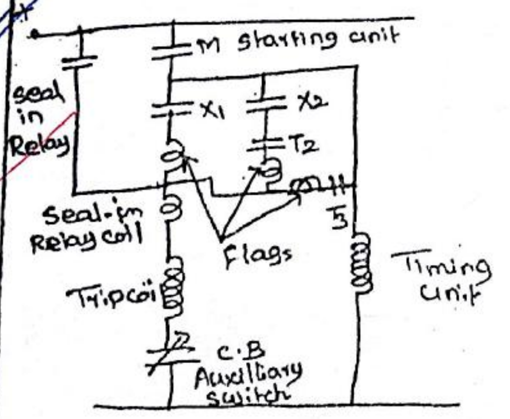
* It is provided as a backup protection of the adjoining lines.
* It covers the first line plus the longest second line plus 25% of the third line.
* The time delay for the third unit is 0.4s to 1sec.

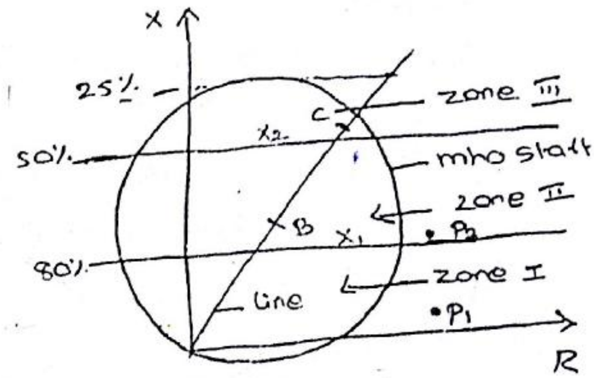


A_1, A_2 & A_3 → operating times for I, II & III zone relays.

III^ly B_1, B_2 & B_3 → operating times for I, II, III zone relays.

Connections of reactance relays:-



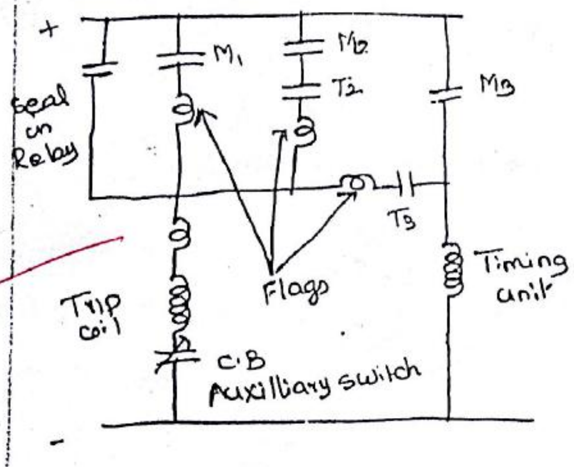


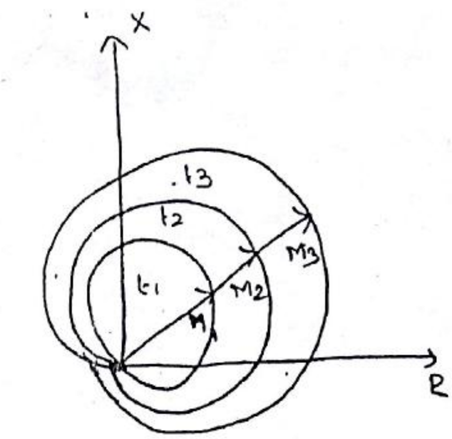
X_1, X_2 → reactance relays

T_2, T_3 → timing contacts

* unit I is a high speed unit to protect 80% to 90% of protected line.
* Unit II protects up to 50% of adjacent line.
* unit III is a backup unit protection for the adjacent line.
* It is a non-directional relay & it will operate for all values of x less than the predetermined x value.
* If a directional unit which is used in impedance relay is used here also, the false tripping occurs because for a normal health conditions for a load with high p.f, the reactance value is less than the preset value.
* To overcome this (i.e) to limit the area to be operated, a starting unit or fault detecting unit is connected which will give a circular characteristics.
* The starting unit detects the faults & also serves the function of the III zone unit.
* The flag indicates which relay is operating.
* The seal-in relay is a auxilliary relay which is used to bypass the contacts of main relay to save their costly & delicate contacts. Once the contact of main relay is closed & current passes through trip coil, the coil of seal-in relay is energized & its contacts are closed.
* The auxilliary C.B switch is normally closed one & once the C.B contacts gets opened, this switch is opened to prevent unnecessary drainage of the battery.

Connections of Mho relay:-



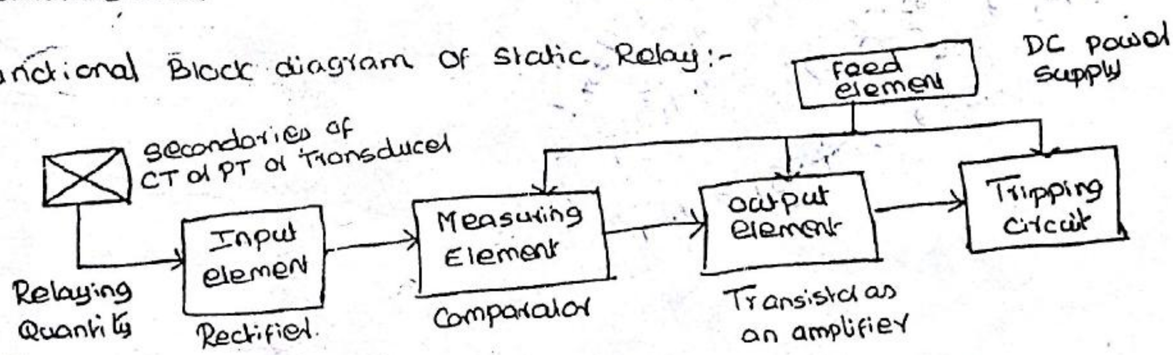


* unit protection remains the same as reactance & impedance relays.
* It is inherently directional, so no need of additional directional or starting unit.

Static Relays:-

The relays which do not use moving parts & use the solid state components like diodes, transistors, thyristors, logic gates etc are called static relays. The static relay response circuit does not have moving parts and made up of electronic components, but its tripping circuit may be electronic or electromagnetic.

Functional Block diagram of Static Relay:-



ac-dc

Input Element:-

The relaying quantity can be the output of C.T or P.T or it may be the output of a transducer or it may be combination of various signals. Thus an electronic circuit such as rectifier is required as an input element to get the input signal in a convenient form before applying it to a measuring element.

Measuring Element:-

This is the heart of the static relay. It compares the output of an ~~output~~ input element with a set value and decides the signal to be applied to the output element which ultimately drives the tripping circuit. Thus measuring element is a deciding signal generator.

Output Element:-

The signals obtained from the measuring element are required to be amplified before applying to the tripping circuit. Thus output element is an amplifier. sometimes the element not only amplifies the signals but multiplies them or combines them with other signal to delay them.

Feed element:-

The measuring element uses electronic circuits like transistors, diodes etc. The output element uses transistor as an amplifier. All these components, circuits along with the tripping circuit require dc supply for the proper functioning. The feed element provides the dc voltage required by the various elements.

The output unit device is usually an electromagnetic one. The output unit energizes the trip coil only when the relay operates.

In static relay the measurement is carried out by static circuits consisting of comparators, level detectors, filters etc.

Comparision of Static and Electromagnetic Relays:-

Disadvantages of Electromagnetic Relays:-

* Conventional electromagnetic relays use the moving parts such as armature, disc etc. They are bulky in size.
* These relays are robust & highly reliable but require different forces to operate under fault conditions results in several measuring problems.
* Lot of manufacturing difficulties & problems are related to mechanical stability of the relays.
* The current and potential transformers are subjected to high speed burdens in case of electromagnetic relays.

Advantages of Static Relays:-

* Moving parts are absent. The moving parts are present only in the actual tripping circuit and not in the control circuit.
* Static Relays can be designed for repeated operations, because of absence of moving parts in the measuring circuits.
* The risk of unwanted tripping is less with static relays.

* The burden on CT gets considerably reduced, thus smaller CT's be used.
* The power consumption is very low as most of the circuits are electronic.
* The response is very quick.
* As moving parts absent, the minimum maintenance is required. No bearing friction or contact troubles exist.
* The use of printed circuits eliminates the wiring errors & mass production is possible.
* The low energy levels required in measuring circuits make the relays smaller and compact in size.
* The testing and servicing is simplified.

Limitations of Static Relays:-

* The characteristics of electronic components such as transistors, diodes etc. are temperature dependent. Hence relay characteristics vary with temperature and ageing.
* The reliability is unpredictable as it depends on a large number of small components & their electrical connections.
* These relays have low short time overload capacity compared to electromagnetic relays.
* Additional dc supply is required for various transistor circuits.
* Susceptable to the voltage fluctuations & transients.
* Less robust compared to electromagnetic relays.

Comparators:-

* When faults occur on a system, the magnitude of voltage and current & phase angle between voltage & current may change.

* These quantities during faulty conditions are different from healthy conditions.

* Static relay circuitry is designed to recognize the changes & to distinguish between healthy & faulty conditions.

* Either magnitudes of voltage / current are compared or phase angle between voltage and current are compared & a signal is sent to C.B.

* The part of static relay circuitry which compares the two actuating quantities either in amplitude or phase is known as comparator.

Amplitude comparator:-

Amplitude comparator compares the magnitudes of two input quantities, irrespective of the angle between them. one of the input quantity is an operating quantity & other a restraining quantity. when the amplitude of the operating quantity exceeds the amplitude of the restraining quantity, the relay sends a tripping signal.

Types of Amplitude comparators:-

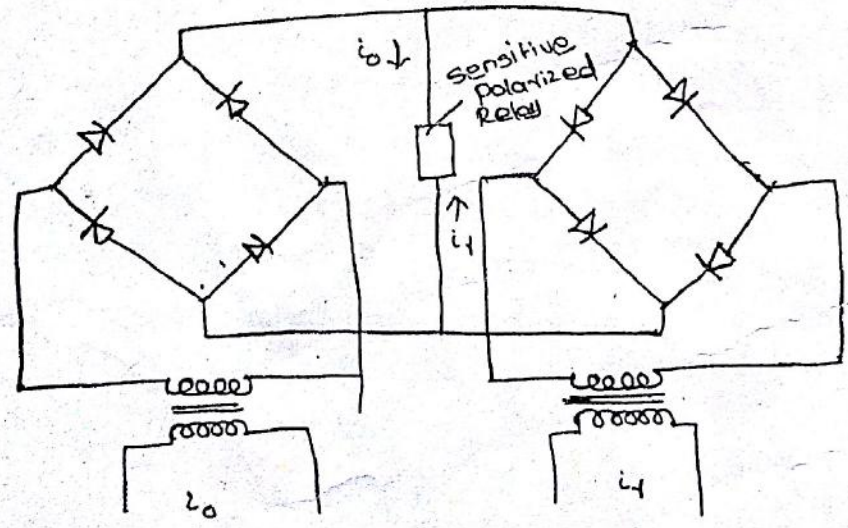
As the ratio of the instantaneous values of sinusodial inputs varies during the cycle, Instantaneous comparison of two inputs is not possible. There are various techniques to achieve instantaneous comparison. In some techniques both inputs are rectified, while in some methods, only one input is rectified & other value is compared with this rectified input at a particular moment of the cycle. Another technique is integrating technique.

i) circulating current type rectifier bridge comparators
ii) Phase splitting type comparators
iii) sampling comparators.

Rectifier bridge type amplitude comparator:-

* These are widely used for the realisation of overcurrent & distance relay characteristics.

* The operating and restraining quantities are rectified & then applied to a slave relay or thyristor circuit.



* There are two full wave rectifiers, one for the operating quantity & the other for the restraining quantity.

* when operating quantity exceeds the restraining quantity the relay operates.

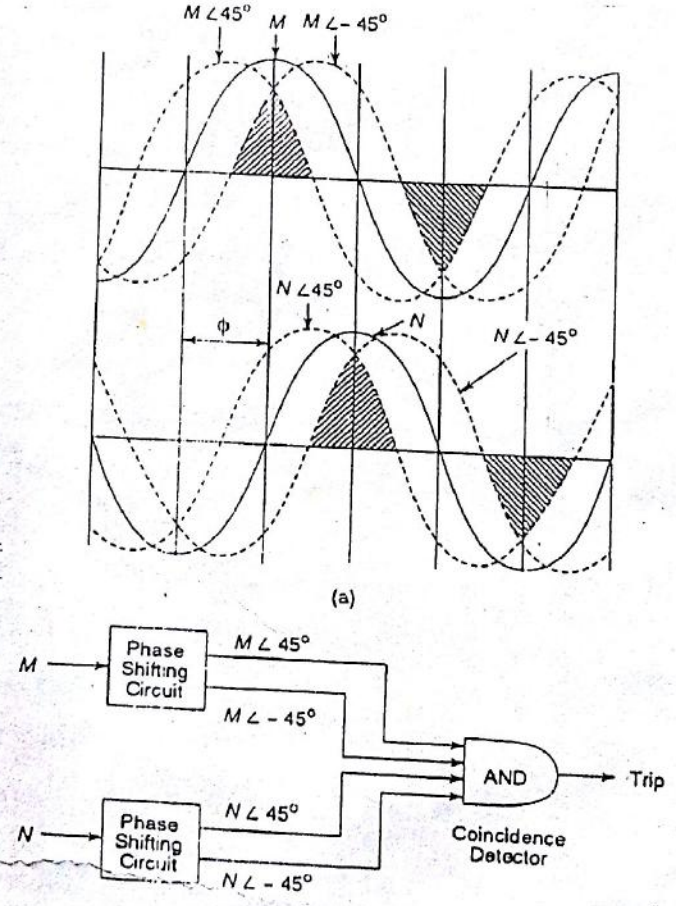
* To get more accurate results, the bridge rectifier can be replaced by a precision rectifier employing an operational amplifier.

Phase-splitting type phase comparator:-

* In this technique, both inputs are split into two components shifted ±45° from the original wave. All the four components are now fed into an AND gate.
* The tripping occurs when all the four signals become simultaneously positive at any time during the cycle.
* An AND gate is used as a coincidence detector.
* The coincidence of all the four signals occurs only when ϕ is less than 90°. The full range of operation is

$$-90° < \phi < 90°$$

* It is a technique of direct comparison.



Duality between Amplitude and Phase comparators

An amplitude comparator can be converted to a phase comparator and vice versa if the input quantities to the comparator are modified.

The actual inputs are M & N. The modified inputs are M+N & M-N.

Phase comparators:-

A phase comparator compares two input quantities in phase angle, irrespective of their magnitudes & operates if the phase angle between them is $\leq 90°$.

Types of phase comparators:-

i) vector product phase comparators

*. In these comparators, the output is proportional to the vector product of the ac input signals.

1. Hall effect phase comparator
2. Magneto-resistivity

Hall effect phase comparator:-

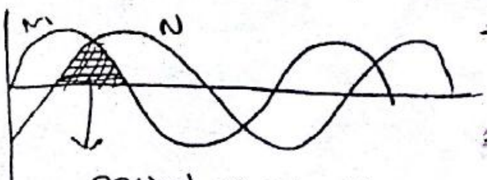
Hall effect:-

When a conductor is kept perpendicular to the magnetic field and a direct current is passed through it, it results in an electric field perpendicu to the directions of both the magnetic field and current. This phenomenon is known as Hall effect.

Hall effect is utilised to realise the phase comparator. Indium antimon (InSb) & indium arsenide (InAs) are the suitable semiconductors. These devices have low output, high cost & they can cause errors due to rising temperatures.

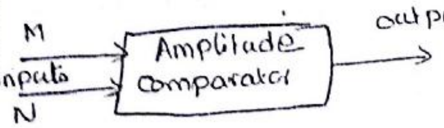
ii) Coincidence circuit type phase comparators:-

* In this type, the period of coincidence of positive polarity of two input signals is measured & compared with a predetermined angle, usually 90°. The period of coincidence is represented by an angle φ.
* If the two input signals have a phase difference of ϕ, the period of coincidence $\varphi = 180 - \phi$.
* If ϕ is less than 90° ($\phi < 90°$), then $\varphi > 90°$
* The relay is required to trip when $\phi < 90°$ i.e. $\varphi > 90°$.
* The phase comparator circuit is designed to send a trip signal when $\varphi > 90°$.



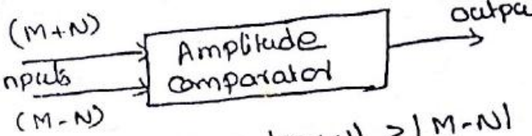
Period of coincidence

1. phase-splitting type phase comparator
2. Integrator type phase comparator
3. Rectifier bridge type phase comparator
4. Time-bias type phase comparator.



operates when $|M| > |N|$

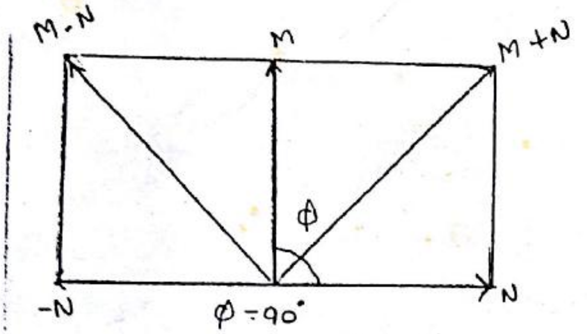
Amplitude comparator



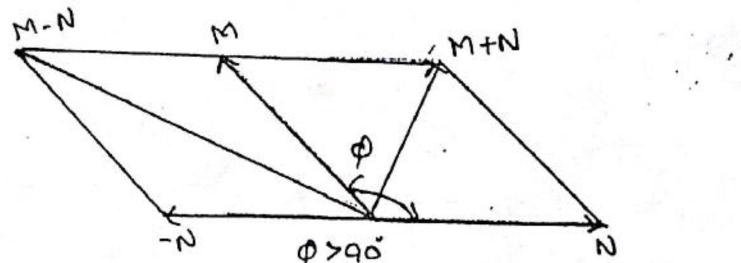
operates when $|M+N| > |M-N|$.
This condition is satisfied when $\phi < 90°$.

Amplitude comparator used for phase comparison

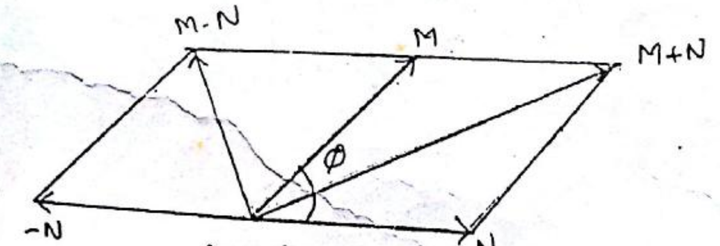
* Consider the operation of an amplitude comparator which has two input signals M & N.
* It operates when $|M| > |N|$.
* Now change the input quantities to $(M+N)$ & $(M-N)$.
* As the circuit is designed for amplitude comparison, now with the changed input, it will operate when $|M+N| > |M-N|$.
* This condition will be satisfied only when the phase angle between M and N is less than $90°$.
* It means that the comparator with the modified inputs has now become a phase comparator for the original input signals M and N.



Comparison $|M+N| = |M-N|$

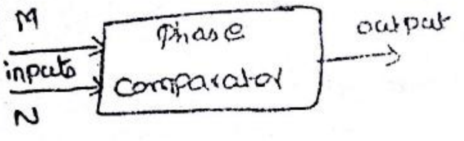


Comparison $|M+N| < |M-N|$



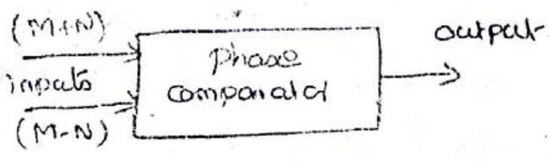
Comparison: $|M+N| > |M-N|$

* The vector diagram shows that $|M+N|$ becomes greater than $|M-N|$ only when ϕ is less than $90°$.
* It will be true irrespective of the magnitude of M & N.
* The above vector diagrams are drawn for $|M| = |N|$. The concept is same for $|M| > |N|$ & $|M| < |N|$.



operates when $\phi < 90°$

phase comparator

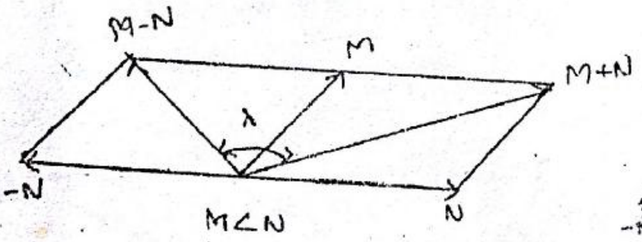


operates when $\lambda < 90°$.

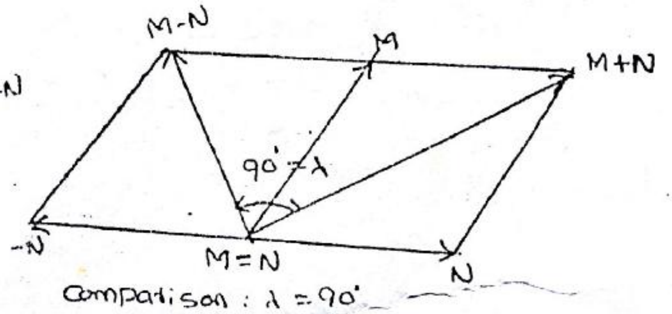
This condition is satisfied when $|M| > |N|$

phase comparator used for amplitude comparison.

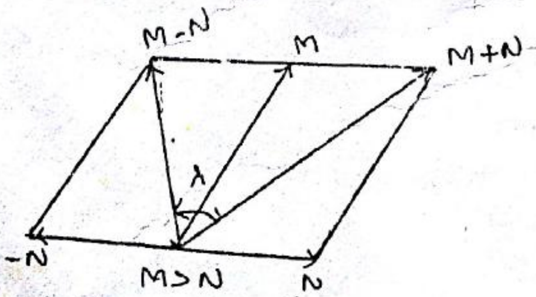
* Consider a phase comparator which compares the phases of input signals M and N.
* If the phase angle between M and N (ϕ) is less than 90°, the comparator operates.
* with the changed inputs (M+N) & (M-N), this comparator will operate for $\lambda < 90°$, & this condition will be satisfied only when $|M| > |N|$.
* In other words, the phase comparator with changed inputs has now become an amplitude comparator for the original input signals M & N.



comparison : $\lambda > 90°$



comparison : $\lambda = 90°$



comparison : $\lambda < 90°$

* The vector diagram shows that $\lambda < 90°$ only when $|M| > |N|$.
* The vector diagrams are drawn for $\phi < 90°$. This concept will be true for $\phi = 90°$ & $\phi > 90°$ also.