LECTURE NOTES
ON
SWITCH GEAR AND PROTECTIVE DEVICES

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MODULE- I

1.1 Basic idea of Relay Protection

→ Protective relay and relaying system detect abnormal condition like faults in electrical circuits and operate automatic switchgear to isolate the faulty equipment from the system as quickly as possible.
[switch-gear must be capable of interrupting both normal currents as well as fault currents)

→ The most severe electrical failures in power system are shunt faults which are increase the system current, reduction in voltage, power factor and frequency.

There are two groups of relaying equipment for protecting any equipments.

1. Primary relaying equipment
2. Back-up relaying equipment

→ Primary relaying is the first defence for protecting the equipments where as back up protection relaying works only when the primary relaying equipment fails which means back-up relaying is inherently slow in action. (The cause of primary relay (fails: → Back up relay should not have anything common with primary relays.

(i) Protective relays (moving mechanism)
(ii) Circuit breaker
(iii) D.C tripping voltage supply.
(iv) Current or voltage supply to the relay.

Relay: A relay is an automatic device which senses an abnormal condition in an electric circuit and closes its contacts. These contacts in turn close the circuit breaker trip coil circuit, thereby it opens the circuit breaker ~~trip circuit~~. and the faulty part of. the electric circuit is disconnected for the rest of the healthy system.

Pick up level:- The value of actuating quantity which is on the threshold (border) above which relay operates.

operating time:- ~~The time which~~ The elapse between the instant when the actuating quantity exceeds the pick up value to the instant when the relay contact close.

Reset time:- The time which elapse between the instant when the actuating quantity becomes less the reset value to the instant when the relay contact returns to its normal position. Or The time which the operating relay to comes back to its initial position ~~as a result of a sudden~~ ~~specific~~ ~~close in~~

Reach:- A distance relay operates whenever the impedance seen by the relay is less than a prescribed value. The impedance or the corresponding distance is known as the reach of the relay.

underreach:- The tendency of the relay to restrain at the set value or the impedance or impedance lower than the set value is known as under reach.

over reach:- The tendency of the relay to operate at impedance larger than the setting is known as overreach.

Relay burden:- It is the value of power consumed by the relay circuit at rated current or voltage and expressed in VA for ac and watt for d.c

Functional characteristic of protective relay.

→ Reliability :- The relay should be reliable is the basic requirement.

→ Selectivity :- It is the basic requirement of the relay in which it should be possible to select which part of the system is faulty and which is not and should isolate the faulty part of the system from unhealthy part.

• Discrimination

Unit protection :- This type of protection means the one in which the protection responds only to fault within its own zone. and ~~does not make note~~

Non unit protection :- Non unit system protection is one which the selectivity is obtained by grading the time or current setting of the relay at different location,

Speed :- speed is desirable characteristic of relay. It should neither be too slow which may result the damage of equipment nor should be too fast which may result undesirable operation during transient faults.

Nature and cause of faults :—

① The nature of fault indicates any abnormal condition, between phase conductor & earth or between phase conductors.

② ~~A fault always~~ ~~exists~~ some effect on ~~the system~~

③ ⓐ Breakdown may occur at normal voltage on account ① the detoriation of insulation level (ii) ~~damage~~ perching of birds
(iii) accidental short circuiting by snakes.
(iv) kite strings

ⓑ Breakdown may occur due to switching surges (ii) Surge caused by lightning.

* pollution of insulator string which is commonly caused by deposited salt or cement dust which cause the insulation level will reduce.

* The insulation leve of sheathed cable and armoured cable will decrease because of ageing

* Void formation in the insulating compound of underground cable due to unequal

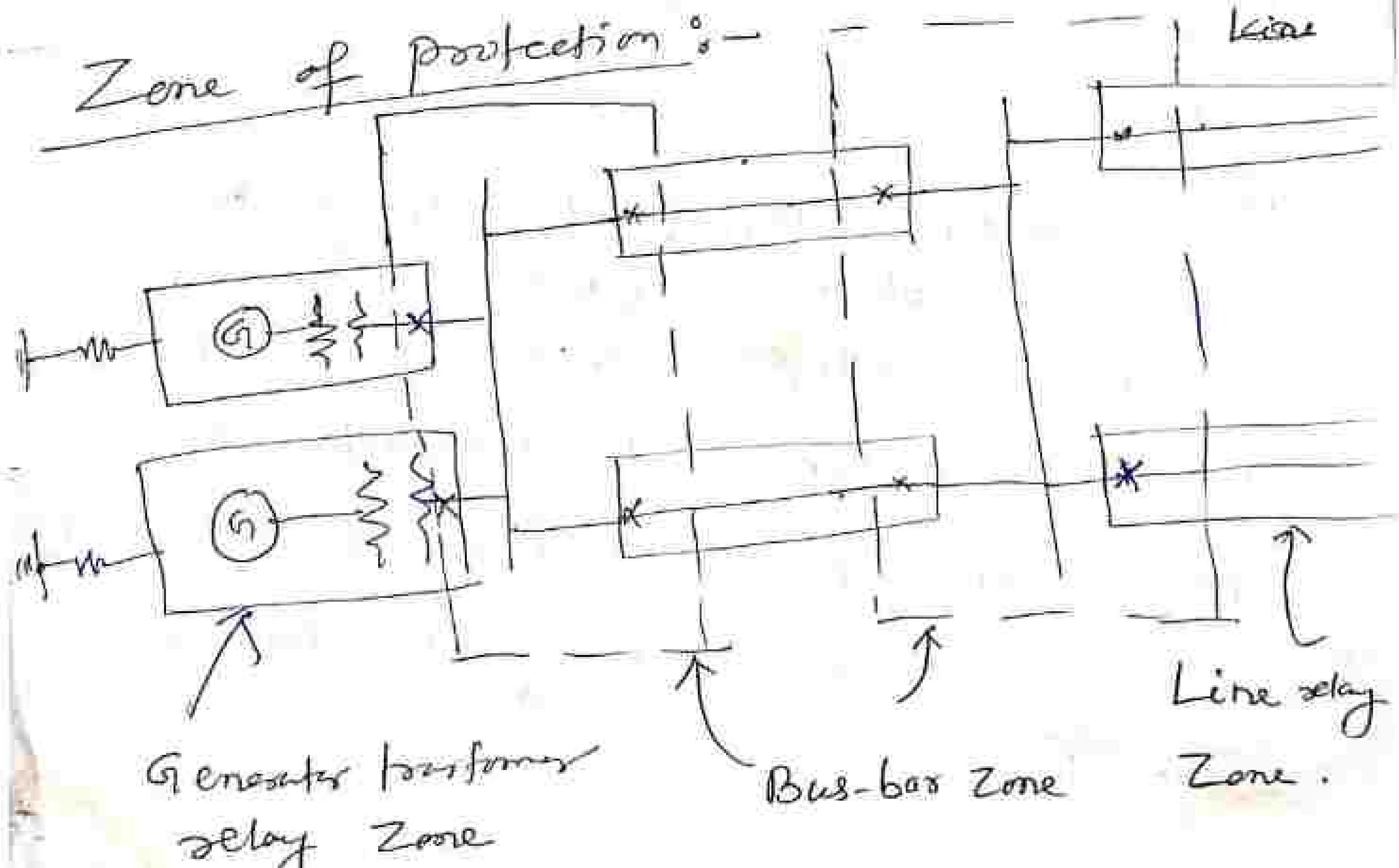
expansion and contraction caused by rise and fall of temperture is another cause of insulation failure.

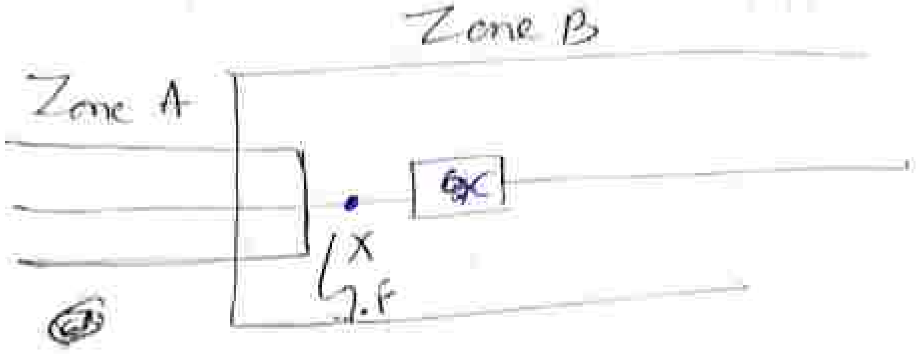
→ The line and apparatus insulation may be subjected to transient over-voltages because of the switching operation. The voltage level is very high, so requirement is high insulation level.

→ Lightning produce a very high voltage surges in power system of the order of millions of volts and thus it is not feasible to provide an insulation which can withstand this abnormality.

→ The surge level with the velocity of light in the power system is limited by surge impedance.

Zone of protection :-



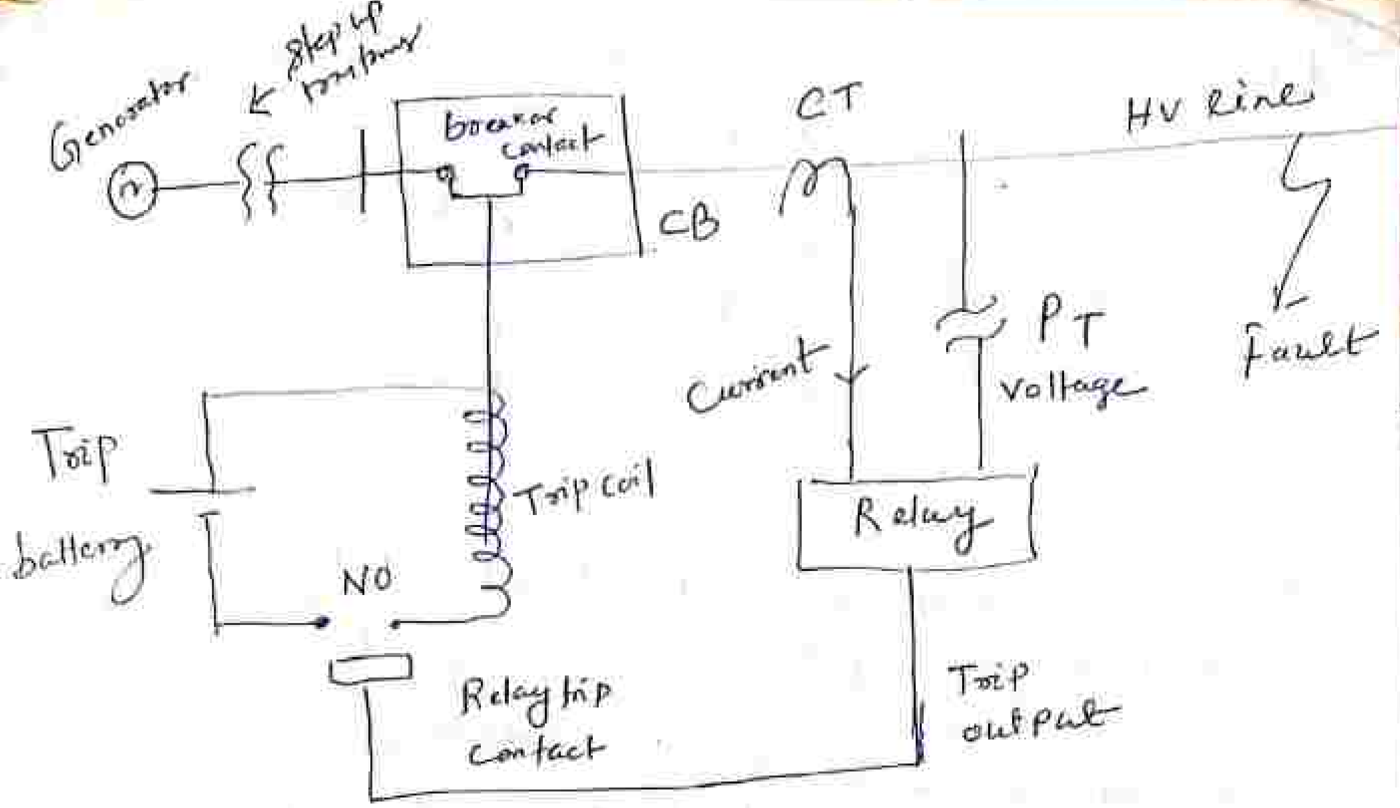


(1) Fault will occurs at X the CB of Zone B ~~and~~ including C will tripped, this does not interrupt the flow of fault current from Zone A. The relaying equipment of Zone B must trip certain breakers in Zone A. For faults in Zone B to the right of breaker C, the operation of breaker in Zone A is not useful.

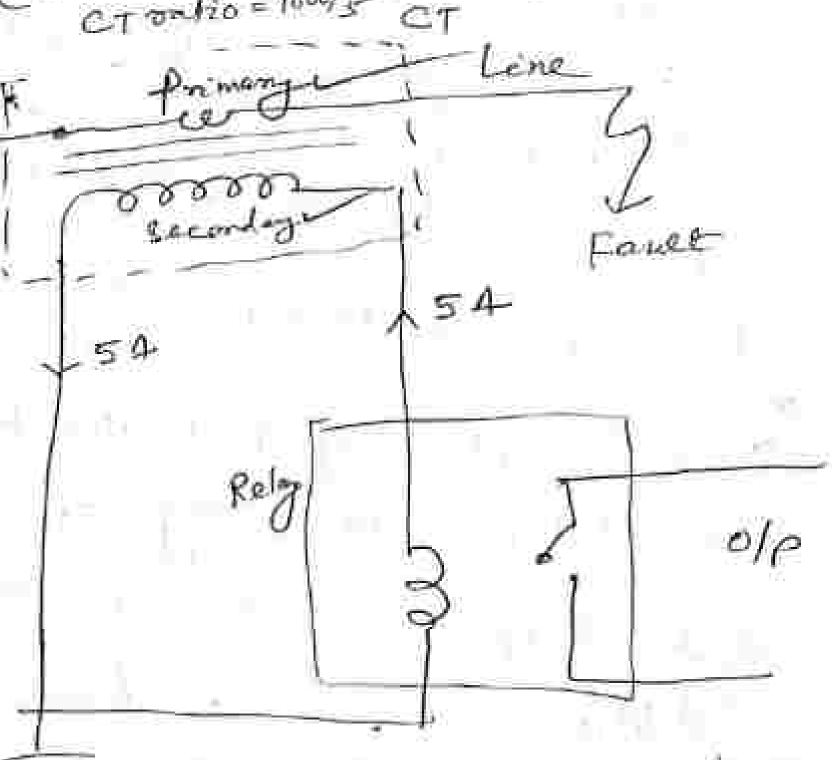
Basic principle of operation of protective system.

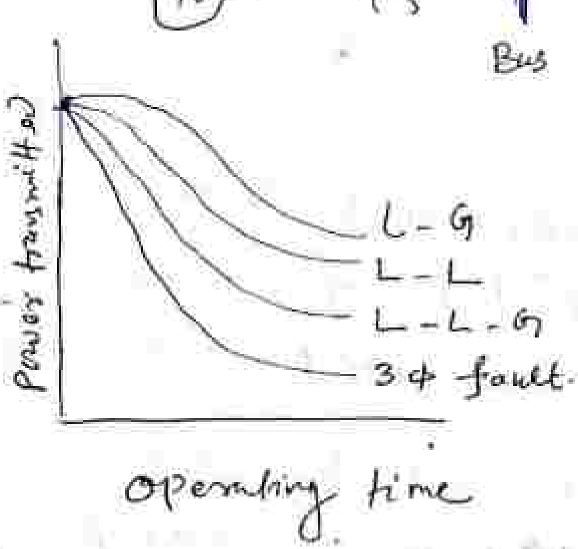
(1) This type relay operate when current increases above a certain magnitude. This is called over current relay.

(2) Another type relay operate when the ratio of V/I is less than a given value is known as under-impedance relay.

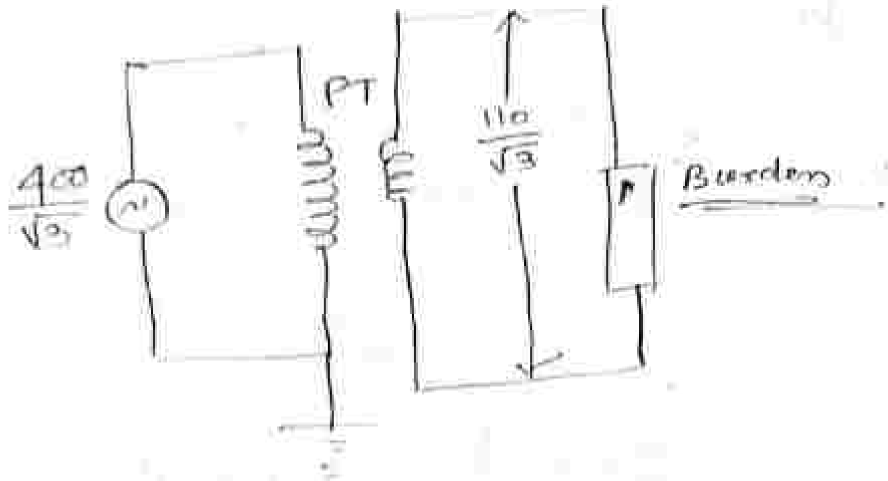


CT :- The standard secondary current ratings used in 5A and 1A. In practice, there is always some errors. This error is known as magnitude and phase angle (ratio error & phase angle error)





PT :-



→ The CB is an electrically operated switch which is making as well as breaking the short circuit current. When the trip coil is energised it releases a latch, the energy stored in spring to bring about quick opening operation.

→ The farthest point from the relay location ~~and the reach point is termed as reach of the relay~~ which is still inside the zone, is called reach point. The distance between the relay location and reach point is termed as the reach of the relay.

Primary and Backup protection:-

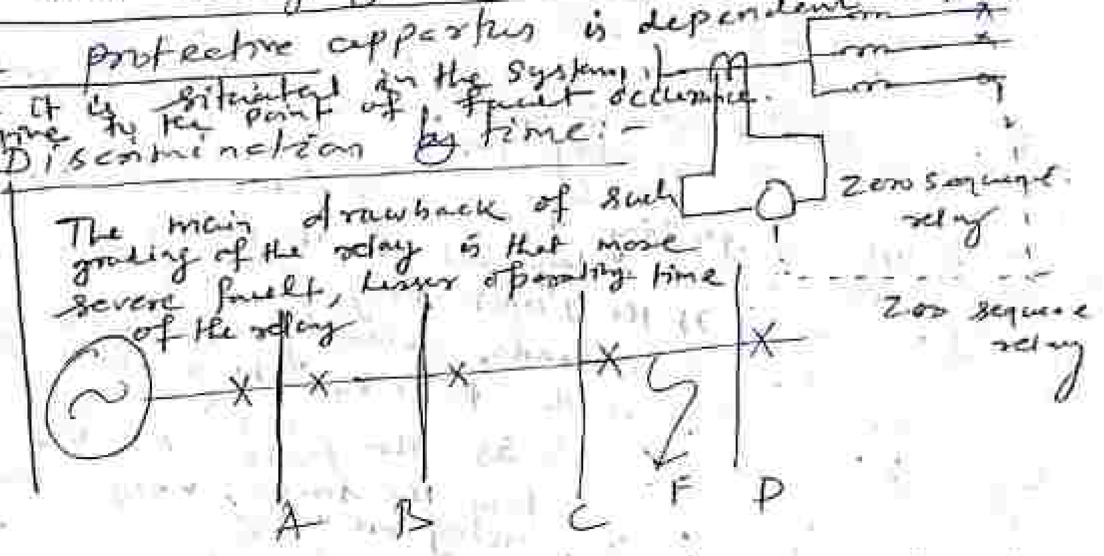
→ When primary protection fail, due to failure of CT/PT or relay or failure of CB or D.C tripping voltage or moving mechanism. Therefore, we must have to insorted second defence of back up protection. In case of primary protection fails, back up protection is required. Back up protection should not have anything common with primary protection.

Back up protection must wait for the primary protection to operate. The operating time of the back up protection must be ~~delayed by an~~ equal appropriate amount of ~~over that~~ primary protection a primary circuit breaker. plus operating time of the primary circuit breaker.

Methods of Discrimination:-

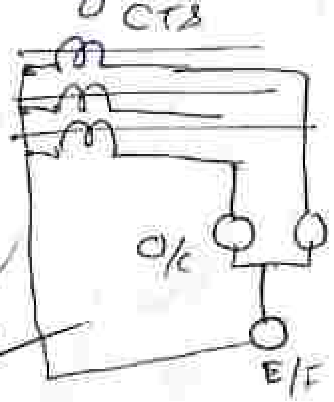
The objective to isolate the faulty system in a minimum time. These are various methods under this category are those in which the behaviour of the protective apparatus is dependent upon where it is situated in the system relative to the point of fault occurrence.

(a) Discrimination by time:-



The circuit breaker is to trip nearest the fault prior to those farther off the point of fault by using time lag features. suppose a fault in any section of CD, the whole breakers at A, B, C will trip, so the whole feeder beyond A becomes dead. So the requirement is that, time lag to the CB at A, B, ~~C and D~~

A = 1.2 sec
B — 0.8 sec
C — 0.4 sec
D — no time lag



Suppose fault occurs at CD section, the breaker at C will trip after a time of 0.4 sec. The feeder upto C will remain alive.

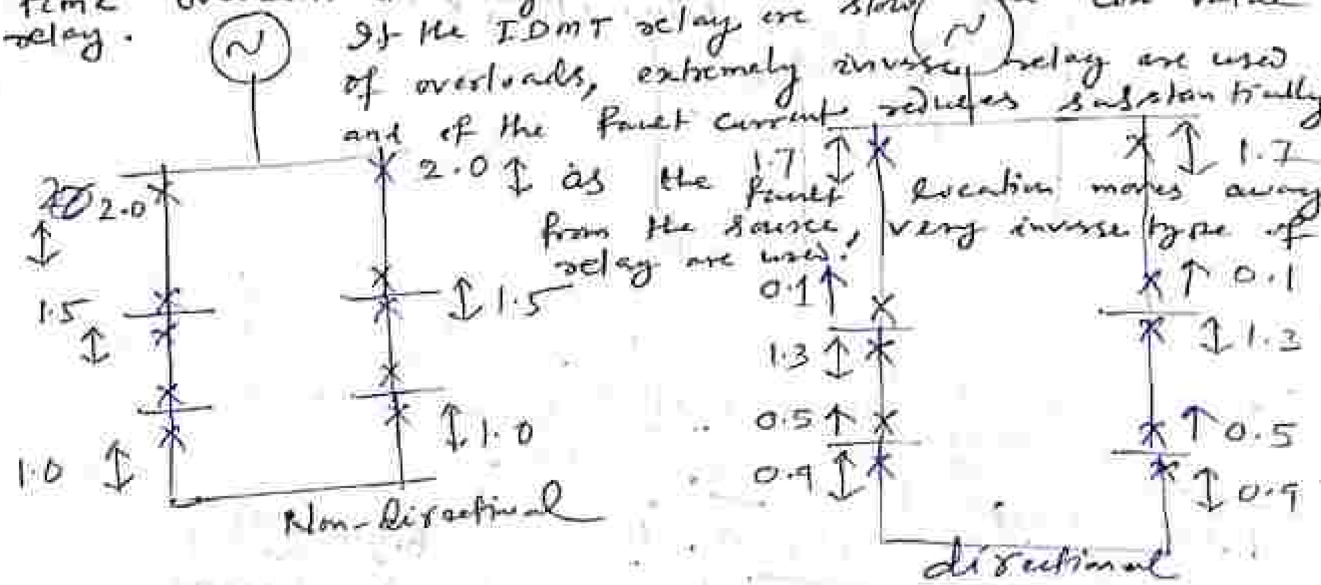
(b) Discrimination by current magnitude — Current grading

This type of grading is done on a system where the fault current varies with the location of the fault. The fault current increase as we go towards the source. The pick up value of relay are set at higher current towards the source then the system is ... In time graded system, long time delay is required, that is the disadvantage point. It is difficult to calculate the relay accuracy under transient cond^n.

~~If the relay pick up are set up to pick up at progressive higher current towards the source.~~

(c) Discrimination by time and direction:

This type of grading is achieved with the help of inverse time overcurrent relay and almost widely used is the IDMT relay. If the IDMT relay are slow at low value of overloads, extremely inverse relay are used and if the fault current reduces substantially as the fault location moves away from the source, very inverse type of relay are used.



→ If we set non directional relay with same current setting but different time lags, the proper discrimination can not obtained.

→ If we set directional features, the fault occurs at any section will be discriminated without loss of supply.

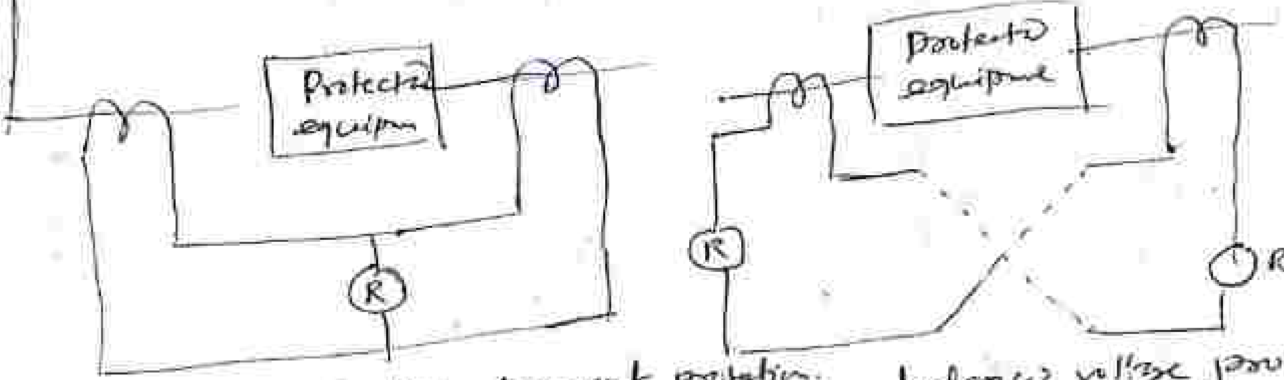
Discrimination by distance measurement :-

The faults nearer to the source have more severe takes larger time to clear if we have used time discrimination.

→ Combined time and distance protection gives the practical dimension of protection. unit protection is divide two parts.

(a) Circulating current principle

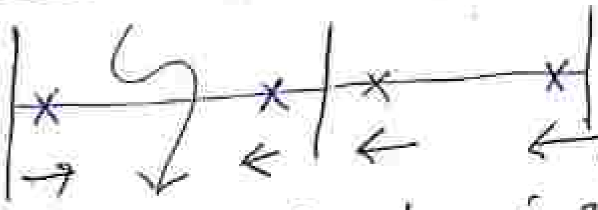
(b) opposed voltage principle or balanced voltage principle.



Circulating current protection.   balance voltage protection

→ In circulating current protection, the external fault does not distrub whereas, if the fault within the protective equipment, the relay trips. The CT secondary voltage will no longer balance and current will flow in the relay which will trip the CB at the two ends.

Power - direction Comparison discrimination



(1) Power flow out at the other end, which means either load condn or external fault condn and tripping should be prevented.
(2) power flow in, which means internal fault condn and the breaker trip.

In this case directional relay is used.

Phase Comparison discrimination :-

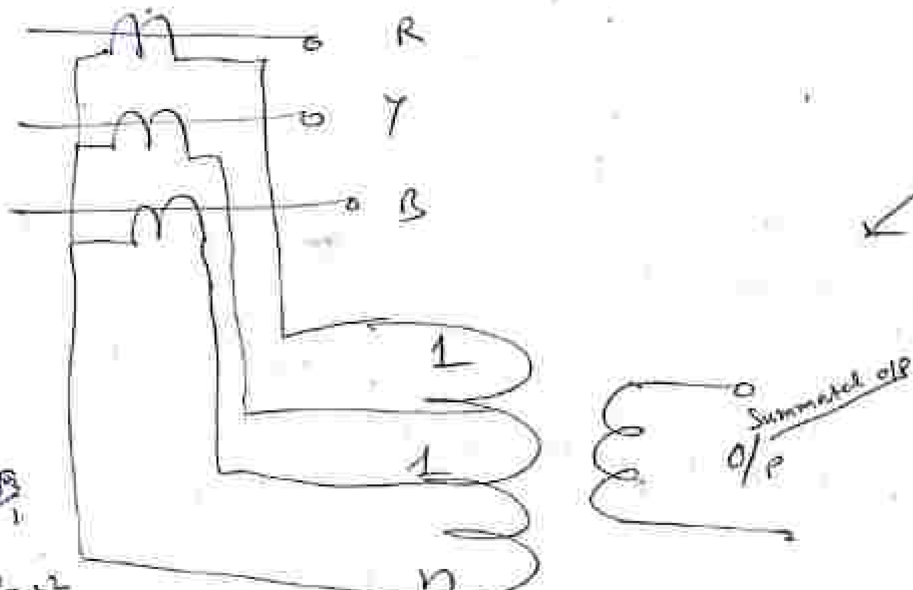
This is a power line carrier protection.
In this phase angle of current at both section will compared, whether the fault is internal or external. The phase angle information of primary current is transmitted by carrier line

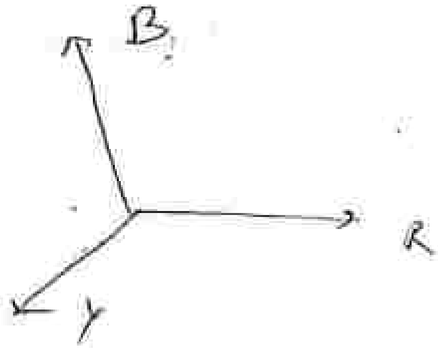
Derivation of a single phase quantity from three phase quantity. —

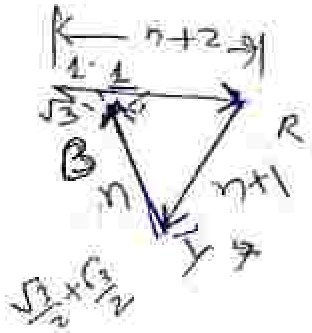
There are two commonly methods for deriving single phase quantity from a three phase system.

(a) Summation of transformer:—

→ The three CTs are connected to the primary winding of an auxiliary transformer. Each CT has different no. of turns.







$p^2+b^2=h^2$

$p^2=h^2-b^2$

$=\sqrt{2}-1$

$=\sqrt{2}-1$

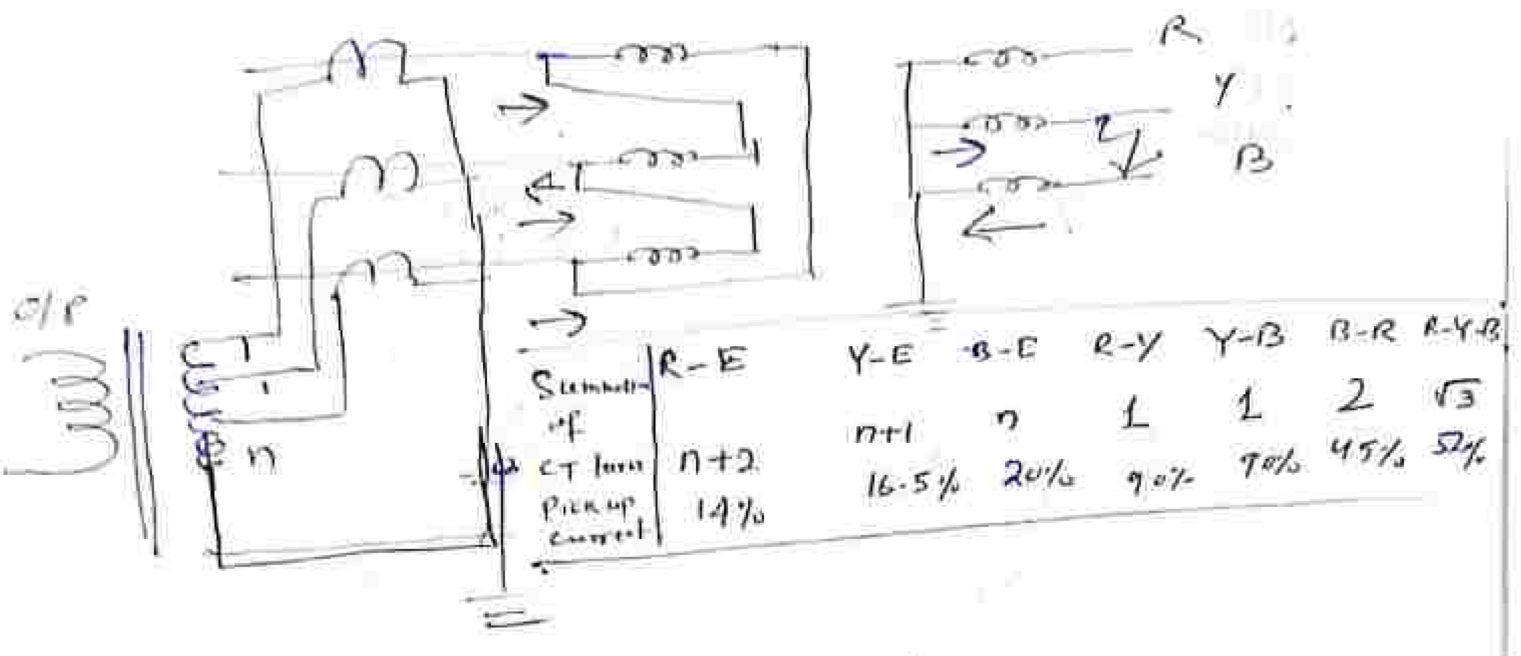
$=1.212-1$

$(n+2) I_R + (n+1) I_Y + n I_B$

→ By this also control independently the o/p for earth fault and phase fault.

→ By this method pick up setting can be expressed in terms of n and 1.

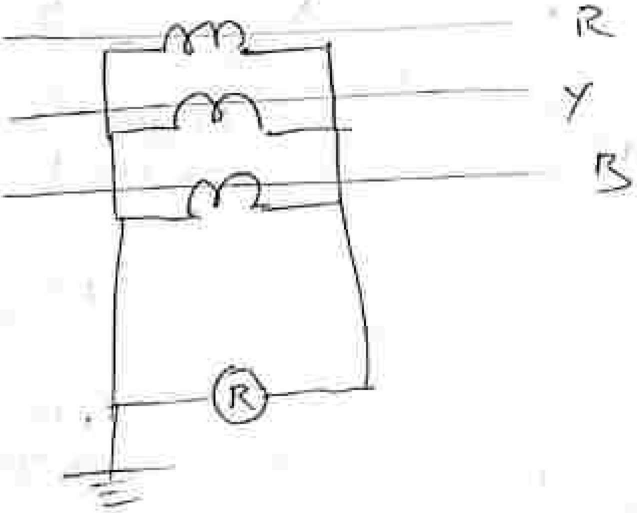
→ If there is phase to phase fault on the star side of delta/star transformer, zero o/p will occur under through fault condition



	R-E	Y-E	B-E	R-Y	Y-B	B-R	R-Y-B
Summation of CT turn	n+2	n+1	n	1	1	2	$\sqrt{3}$
Pick up current	14%	16.5%	20%	90%	70%	45%	57%

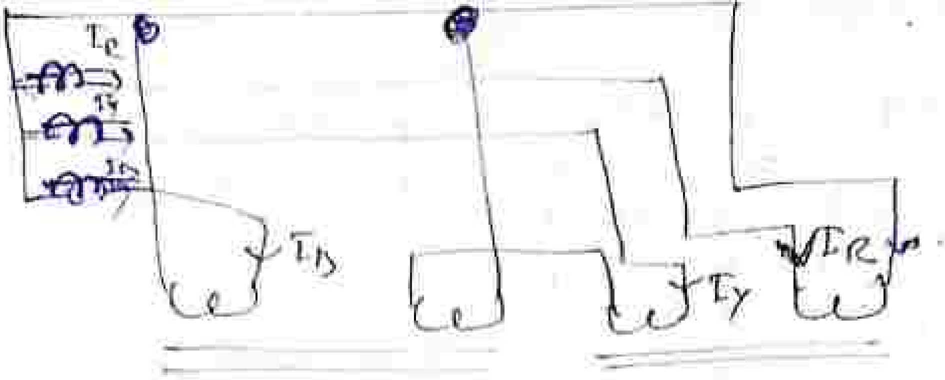
Sequence network :- Zero sequence and negative sequence network are always used in power system protection.

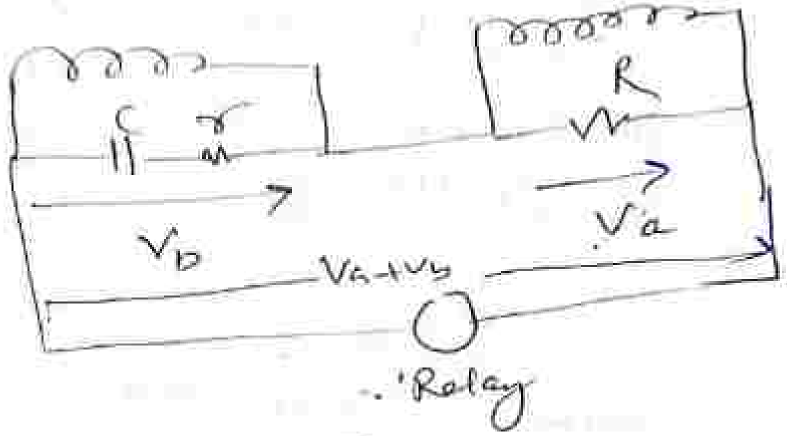
→ Zero sequence network are extensively used for earth fault protection.

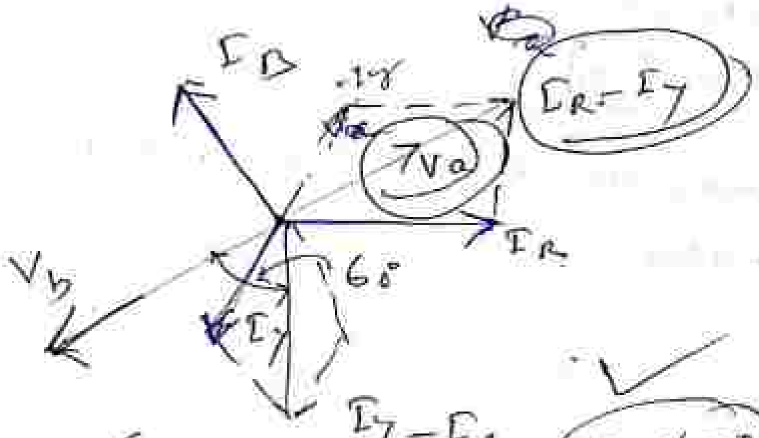


→ When single or double earth fault occurs, the sequence of current flows through the relay.

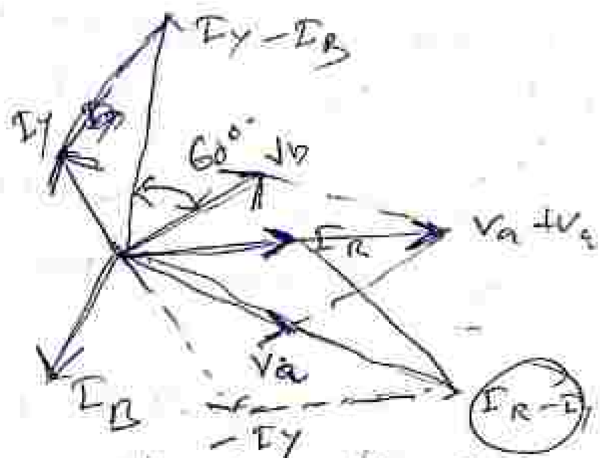
→ for unbalanced condition or unsymmetrical fault, negative phase sequence network are used.



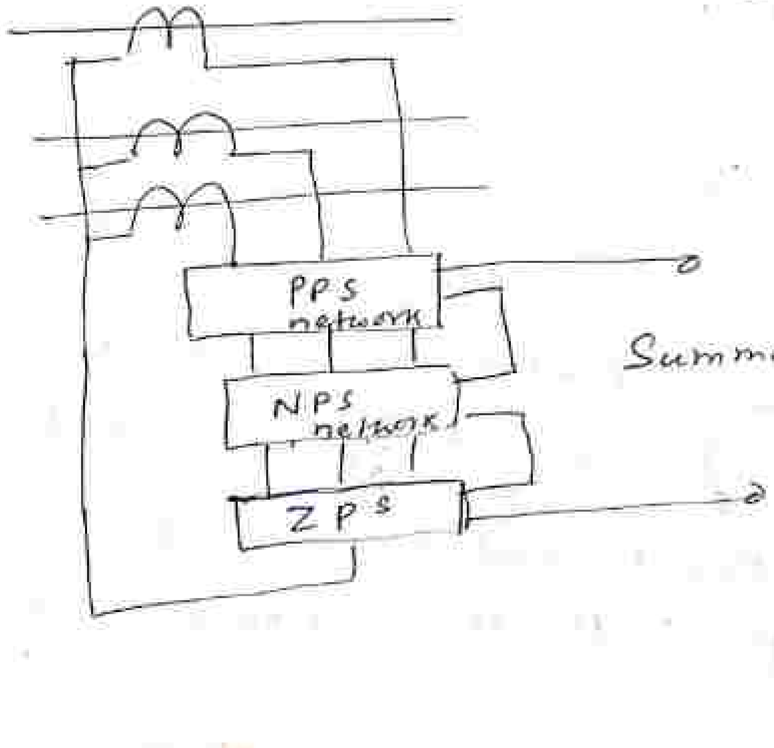




(positive Sequence current)



Negative Sequence current.



(Positive phase shifting PPS)

(NPS) Negative phase shifting

Summated output

Components of ~~Relay~~ protection

(1) Relay:— The main functions of a protective relay is to isolate a faulty section with the least interruption. The basic function of relay to design to detect and to measure abnormal conditions and close the contact in the tripping cut.

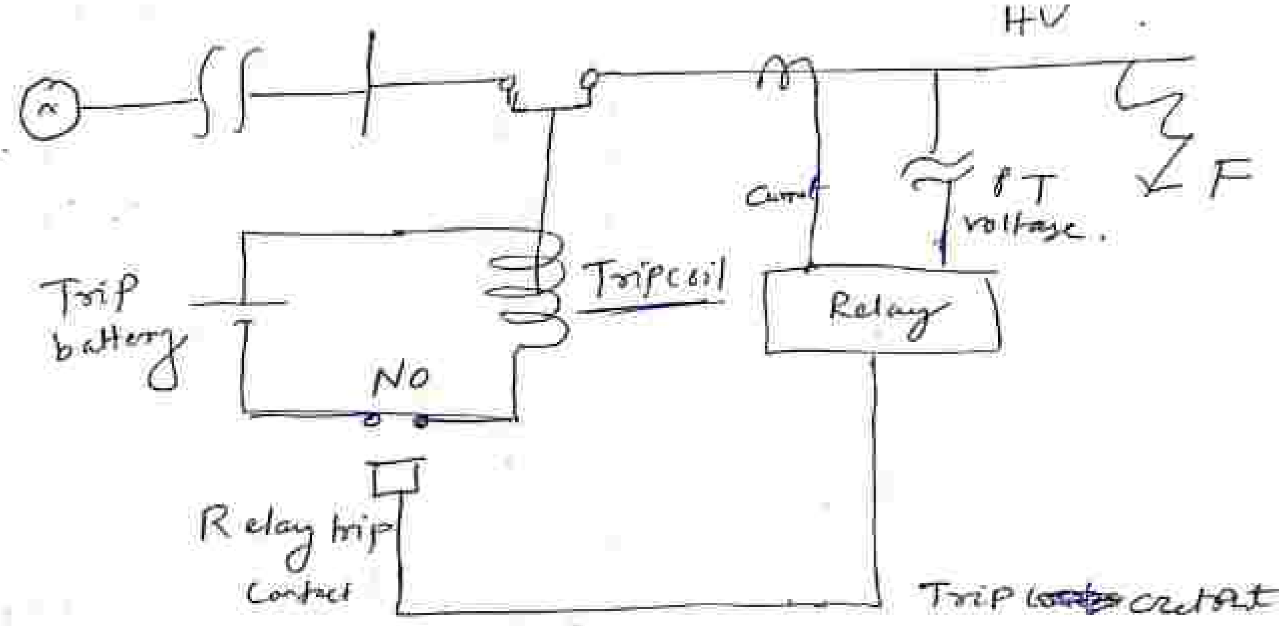
(2) Circuit breaker:—

→ Circuit breakers of various types are installed in all power circuit to ~~open and close them under normal load cond~~n. making as well as breaking short ckt currents.

→ CB are operated either manually or automatically

→ When tripping is required a trip coil is energized, which the energy will be released by trip coil. The trip battery supplies energy to the trip coil for this operation.

→ The relay usually it contact directly



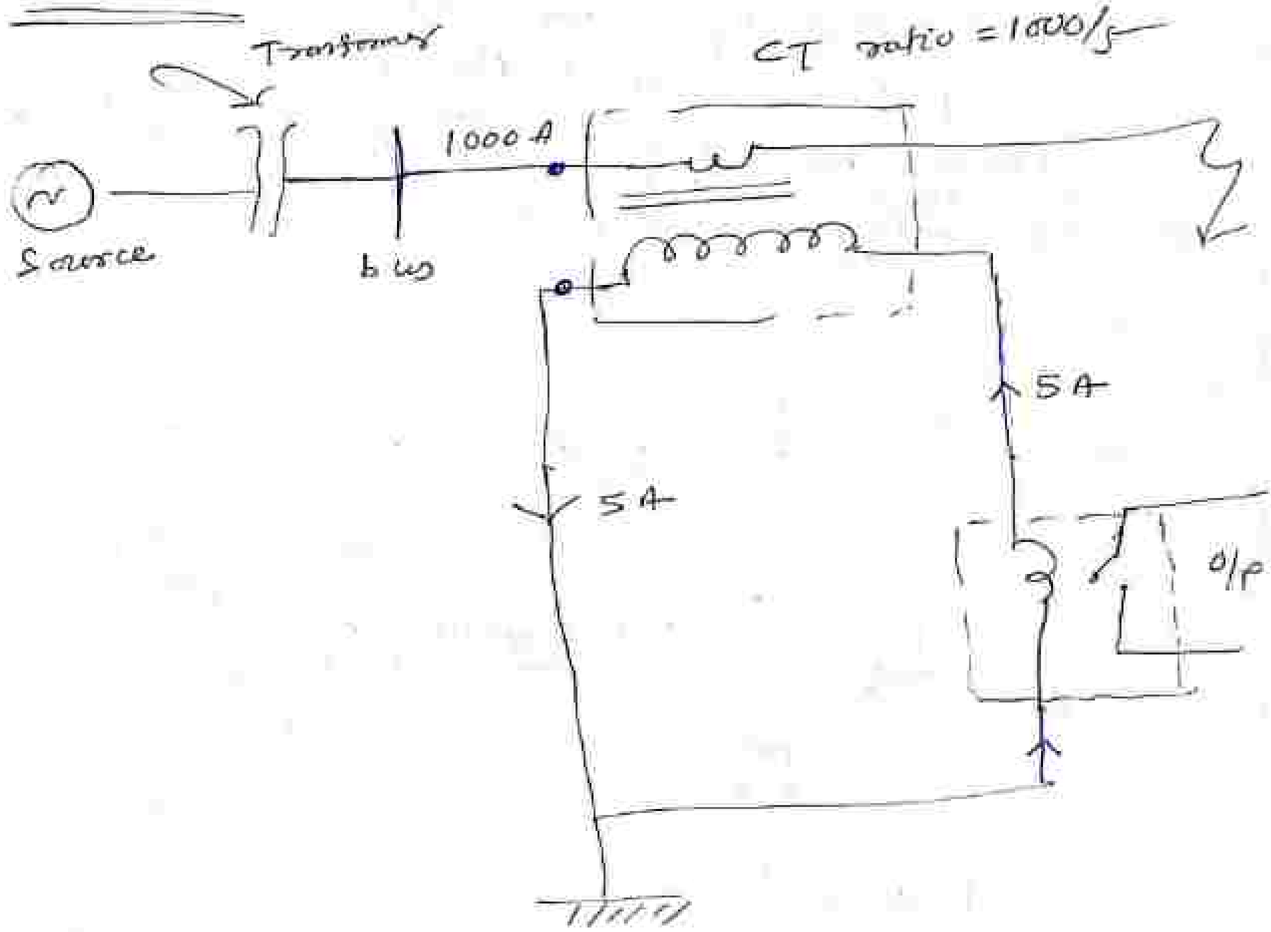
Tripping and other auxillary supply

→ In power system two kinds auxillary supply d.c or a.c.

→ All d.c auxillary supply circuit must have their insulation resistance maintained adequate level.

→ A.c auxillary supply for the protective relay scheme is mainly derived from CTs. under fault conditions, the amount of current passes through the CT will always be sufficiently to reliable trip the CB.

CT

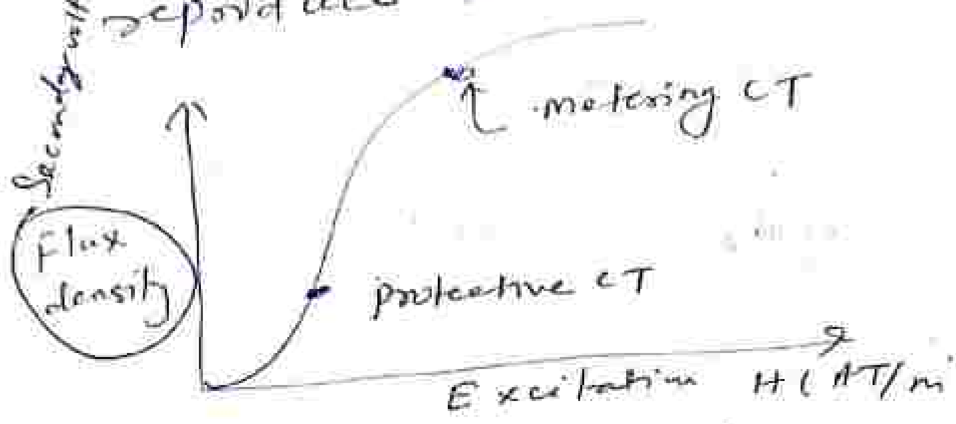


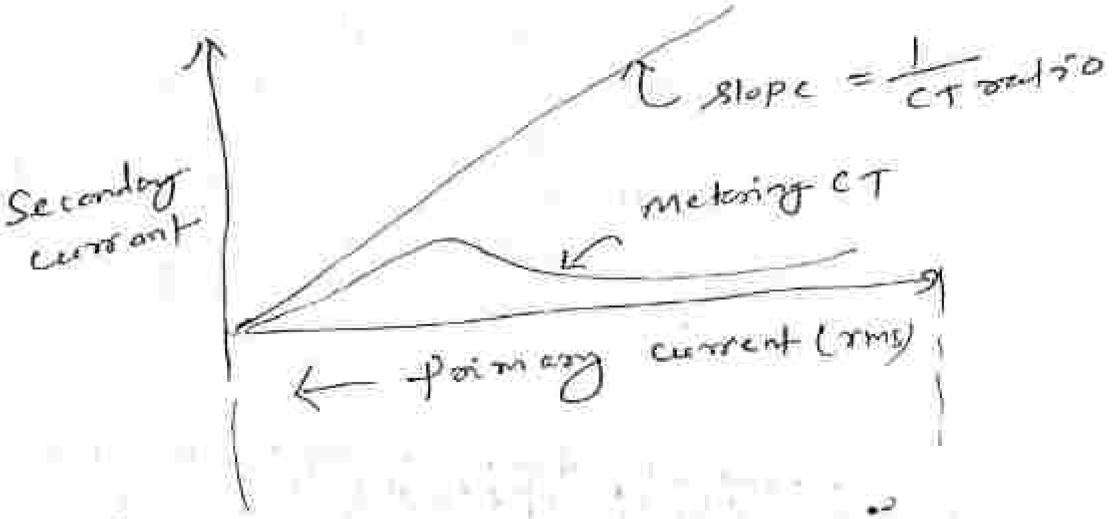
→ The standard secondary current rating of CT are 5A & 1A.

→ In pratice, there is always some errors. These errors are known as ratio errors and phase angle error.

→ A metering CT is so designed that it will saturate and it prevent from damage due to excessive current.

→ protective CT is designed to faithfully reproduce largest fault current





PT

Relay classification:— According to the protective scheme Relay may be divided main, auxillary and signal relays.

Main relay:— The main relay which responds to any change in actuating quantity, current voltage & power.

Auxillary relay:— To perform some auxillary function, the auxillary relay which are controlled by other relay to perform (a) time delay
(b) increasing no. of contact
(c) increase the making or breaking capacity of the contact.
(d) passing signal to other relay
(e) Tripping of ckt breaker
(f) energizing a signal or an alarm.

Signal relay:— signal relay function to register the operation of some relay by flag indication.
(a) It indicates flag indication.
(b) It can be actuate audible alarm ckt.

Over relay:— Relay which responds to the actuating quantity when it exceeds a pre-determined value are over relays ~~and if~~ ~~than~~

Under relay:— when the actuating quantity drops below a predetermined value, they known as under rely

MODULE- II

Basic principle of relay:-

The electromagnetic relay are two types
(a) electromagnetic attraction (b) electromagnetic ~~attraction~~ induction.

→ The armature is attracted to the pole of an electromagnet in electromagnetic attraction type relay.

→ The relay can be operated both d.c as well as a.c quantity.

→ With d.c supply, the torque is constant and if the force exceeds a predetermined value relay operates.

$$F \propto I^2$$

$$F = K' I^2$$

Let $I = I_m \sin\omega t$

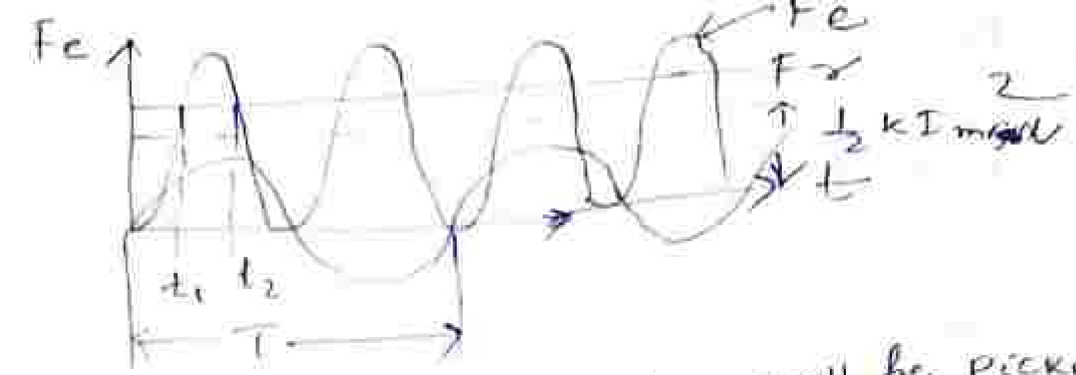
$$F_e = K'(I_m^2 \sin^2\omega t)$$

$$= K' I_m^2 \left(\frac{1-\cos 2\omega t}{2}\right)$$

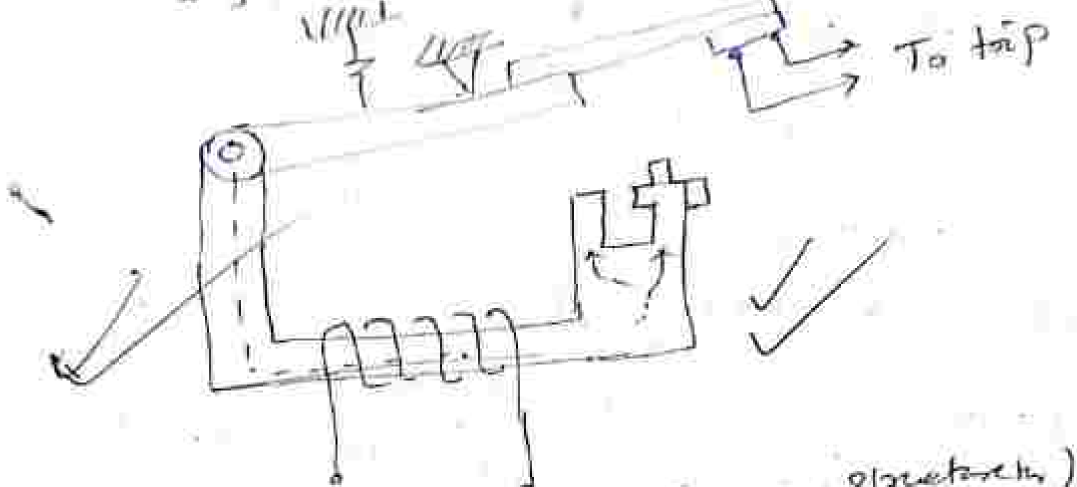
$$F_e = \frac{1}{2}K' I_m^2 - \frac{1}{2}K' \cos 2\omega t$$

The force has two component, one constant and other is function time i.e pulsating double frequency. The armature of the relay vibrates at double frequency. The will damage the relay contact.

→ To overcome these difficulties, the two fluxes producing the force are displaced in time phase or phase shifting network ~~connected~~ or connected Shading ring on the pole of the magnet.

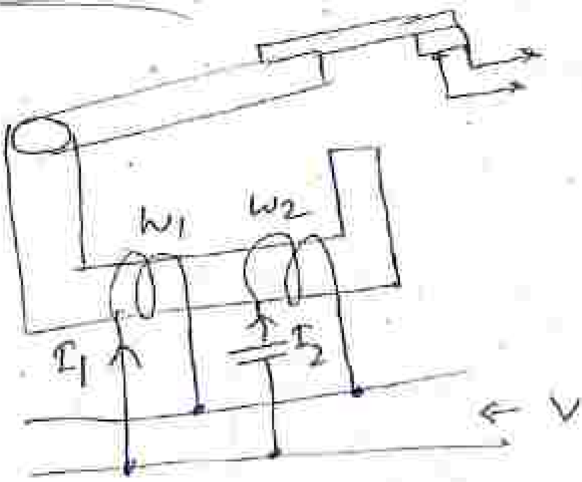


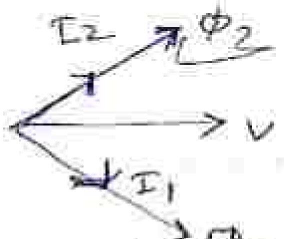
At time t_1, the relay armature will be picked up.
At " t_2, the armature drops off at t_2.



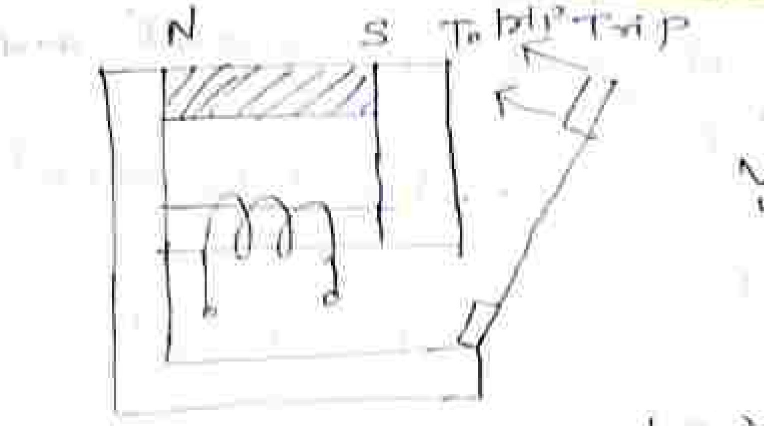
(hinged armature type structure)

The flux through the shading pole lags behind unshaded pole.

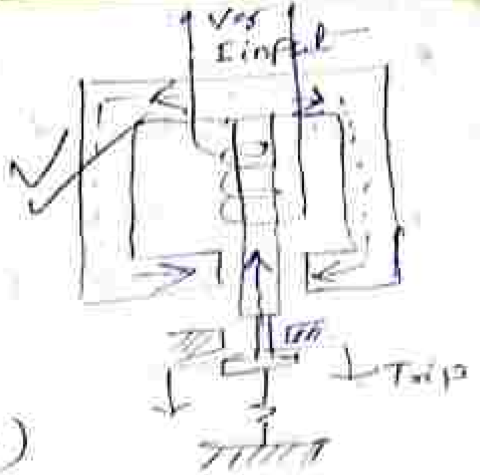




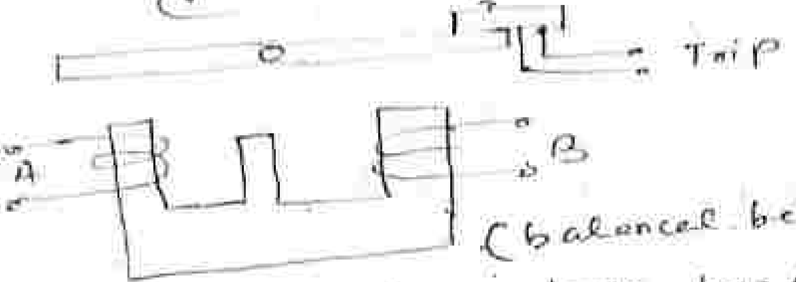
→ Hinged armature type relay are used auxiliary relay i.e tripping relay. The sensitivity of this relay can be increased for dc operation by addition of Permanent magnet. This is known as polarized moving iron relay.



(polarized moving iron type)



(Plunger type)



(balanced beam type)

→ In balanced beam type two quantity A and B are compared. Actually $|A|^2$ and $|B|^2$ are compared because electromagnetic force are proportional to $(\text{ampereturn})^2$. It has low ratio reset/operating current. If set for fast operation, there is a tendency to overreach on transient condn.

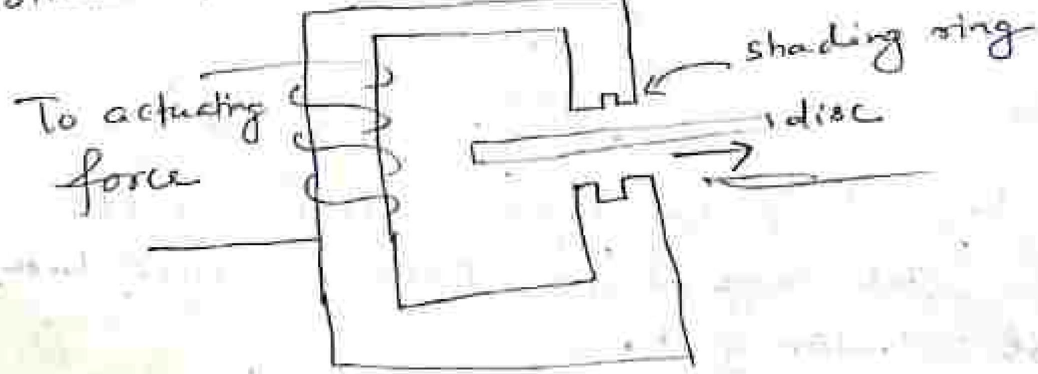
Induction relay:-

① This type of relay based on electromagnetic induction principle. These relay ~~can~~ can be used on a.c. Depending on rotor, it is divided two type

* (a) induction disc type
* (b) induction cup type

→ In induction disc type relay, disc is ~~fixed~~ movable but moving contact of relay is fixed

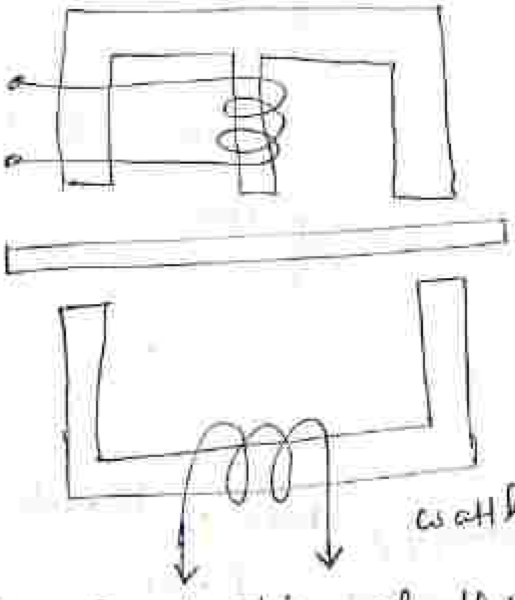
→ There are two type of structure is available (a) Shaded pole structure (b) the watthour meter structure.



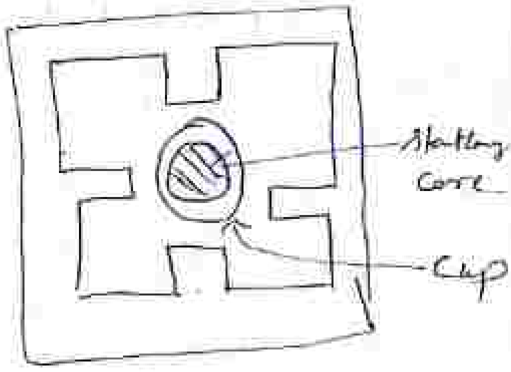
- The disc is placed between shaded and unshaded pole of the relay.
- The system current is fed to the operating coil of the relay.
- The air gap flux is split into two out of phase component
- The shading ring is made up of copper
- The disc is normally made off aluminium,
- because it have low inertia and less deflecting torque.

~~Torque equation of induction relay~~

watthour meter structure:



watthour meter struct



(induction cup struct)

→ The Construction of this Structure is exactly identical to watthour meter.

→ It has two coils on two different magnetic circuit.

→ induction Cup Relay

→ It has four or more electromagnets

→ A Stationary iron core is placed between these electromagnets.

→ The rotor is a hollow cylindrical cup which is free to rotate in gap.

→ When electromagnet is energized, they induce voltages in the rotor cup and eddy current will induced. This eddy current interact with other pole.

→ The induction cup type relay are more sensitive than induction disc type relay.

→ The ratio of reset to pick up is high in induction relay as compared to armature relay.

→ The ratio between 95% to 100%.

Theory of induction relay torque:-

Two fluxes displaced in space and time phase are required.

$$\phi_1 = \phi_m \sin \omega t$$
$$\phi_2 = \phi_m' \sin(\omega t + \theta)$$

ϕ_1 is produced by the shaded pole

ϕ_2 is the flux produced by unshaded pole

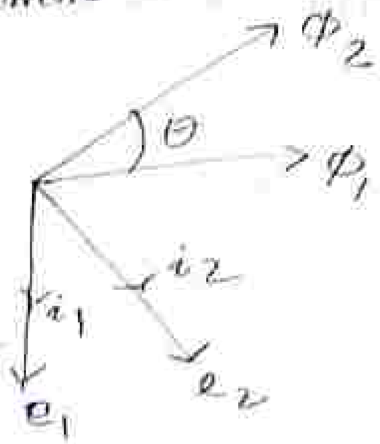
The shaded pole flux lags an angle θ by the unshaded pole. The flux ϕ_1 & ϕ_2 induced an emf e_1 and e_2.

$$e_1 \propto \frac{d\phi_1}{dt} \propto \phi_m \omega \cos \omega t$$
$$e_2 \propto \phi_m' \omega \cos(\omega t + \theta)$$

The voltage will circulate the eddy current in the disc of the relay.

$$e_1 \propto i_1 \qquad i_1 \propto \phi_m \omega \cos \omega t$$
$$i_2 = \phi_m' \cdot \omega \cos(\omega t + \theta)$$

Thus ϕ_1 will interact with eddy current i_2 and ϕ_2 will interact with i_1.



ϕ_2 leads ϕ_1, the torque due to ϕ_2 and i_1 will be act as positive & ϕ_1 & i_2 will be negative

$$T \propto \phi_2 i_1 - \phi_1 i_2$$

$$\propto \phi_m' \sin(\omega t + \theta) \cdot \phi_m \omega \cos\omega t - \phi_m \sin\omega t \cdot \phi_m' \omega \cos(\omega t + \theta)$$

$$\propto \phi_m \phi_m' \sin(\omega t + \theta) \cdot \omega \cos\omega t - \phi_m \phi_m' \omega \sin\omega t \cdot \cos(\omega t + \theta)$$

$$\propto \phi_m \phi_m' \omega \left(\sin(\omega t + \theta - \omega t)\right)$$

$$\propto \phi_m \phi_m' \omega \sin\theta.$$

→ The torque is maximum when $\underline{\theta = 90^\circ}$, if we maintained $\theta = 90^\circ$, no possibility of vibration

→ while we have doing different current setting, the no. of turns are changed

→ Higher the current setting required smaller of turns.

→ The higher the time multiplier setting greater the operating time.

→ The relay operating time depends upon between the moving contact & and fixed contact of the relay.

Relay design & construction

1 → (a) Selection of the operating characteristic

(b) Selection of proper construction

(c) ~~Selection of proper construction~~

(d) Design of the contact movement from the point of view of utmost reliability.

(a) → The operating characteristic of the relay must be same abnormal operating characteristic.

(b) The most important characteristic ~~of~~ ~~...~~ for construction are reliability, simple circuit design.

Construction :- (a) contact, (b) bearing (c) electromechanical design (d) terminations & housing.

Selection of contact material :-

1 → nature of current to be interrupted

2 → ~~voltage~~ breaking & making operation of voltage.

3 → The magnitude of current to be interrupted.

4 → Frequency of operation.

5 → The actual speed of contact to move or break.

6 → contact shape

7 — Contact closing force.

On the basis of practical experience the following are some of the rules recommended in the design of contact system of a relay.

(a) To avoid arcing

(b) To reduce contact resistance by increase pressure

(c) To maintain accuracy, so the relay permitted maximum torque/weight ratio.

(d)

Bearing

(i) Single ball bearing
(ii) Multi-ball bearing
(iii) Pivot & jewel bearing
(iv) Knife edge bearing.

Electromechanical design :- It relates the mechanical ~~fe~~ fixtures of core, yoke and the armature. The reluctance of the magnetic path is kept to a minimum. The relay coil usually limited to 5 A and the voltage to 220 V, but still the insulation ~~of~~ for the relay coil is designed to withstand 4 KV.

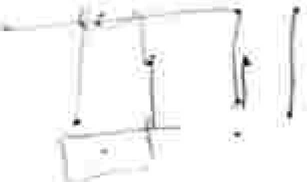
Termination & housing

(1) The base of armature is done with a spring. The spring is insulated by moulded blocks. These moulded block

Generation equation of comparators:—

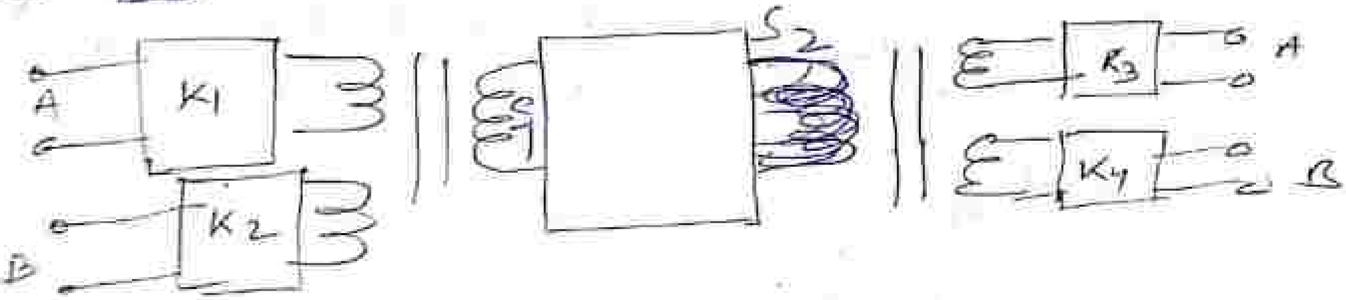
→ Amplitude & phase is two quantity require for sensing the fault. The comparator decides the operating characteristic of the relay.

Let S_1 & S_2 be two input signals such that when the phase relationship or magnitude relationship obeys predetermined condn, tripping is initiated.



→ The input signal has derived from voltage transformer and current transformer and some mixing circuit

→



$$\overline{S_1} = K_1\overline{A} + K_2\overline{B}$$

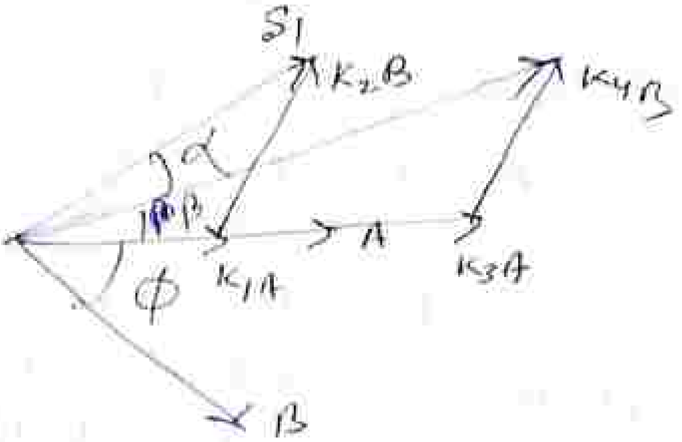
$$\overline{S_2} = K_3\overline{A} + K_4\overline{B}$$

A & B are primary system quantity, K_1 and K_3 are the scalar constant and $\overline{K_2}$ and $\overline{K_4}$ are the complex number with θ_2 and θ_4 as angles (vectors)

Let the vector A be the reference vector and B lags behind A by an angle ϕ. Then equation can be rewritten as:

$$S_1 = k_1|A| + k_2|B|\{\cos(\theta_2-\phi) + j\sin(\theta_2-\phi)\}$$

$$S_2 = k_3|A| + k_4|B|\{\cos(\theta_4-\phi) + j\sin(\theta_4-\phi)\}$$



If the operating criterion is such that $|S_1| \geq |S_2|$ then at the threshold operation $|S_1| = |S_2|$

$$\cancel{\{|K_1||A| + |K_2||B|\cos(\theta_2-\phi)\}^2 + \{B}$$

$$(K_1|A|)^2 + \{K_2 B\cos(\theta_2-\phi)\}^2 + \{K_2 B\sin(\theta_2-\phi)\}^2$$
$$= (|K_3 A|)^2 + \{K_4 B\cos(\theta_4-\phi)\}^2 + \{K_4 B\sin(\theta_4-\phi)\}^2$$

$$(K_1^2 - K_3^2)|A|^2 + K_2^2B^2\cos^2(\theta_2-\phi) + K_2^2B^2\sin^2(\theta_2-\phi)$$
$$- K_4^2B^2\cos^2(\theta_4-\phi) + K_4^2B^2\sin(\theta_4-\phi) = 0$$

$$\cancel{(K_1^2-K_3^2)|A|^2} +$$

$$(K_1-K_3)^2|A|^2 + \{K_2B(\cos\theta_2\cdot\cos\phi + \sin\theta_2\cdot\sin\phi)\}^2$$
$$+ \{K_2B\{\sin\theta_2\cdot\cos\phi - \cos\theta_2\cdot\sin\phi\}\}^2$$
$$- \{K_4B(\cos\theta_4\cdot\cos\phi + \sin\theta_4\cdot\sin\phi\}^2 - \{K_4B(\sin\theta_4\cdot\cos\phi - \cos\theta_4\cdot\sin\phi)\}^2$$

$$(K_1-K_3)^2|A|^2 + K_2^2B^2\cos^2\theta_2 \cdot \cos^2\phi + K_2^2B^2\sin^2\theta_2 \sin^2\phi$$
$$+ 2K_2B \cos\theta_2 \cdot \cos\phi \cdot \sin\theta_2 \cdot \sin\phi$$
$$+ K_2^2B^2 \sin^2\theta_2 \cdot \cos^2\phi - K_2^2B^2\cos^2\theta_2 \cdot \sin^2\phi$$
$$- 2K_2B \sin\theta_2 \cdot \cos\phi \cdot \cos\theta_2 \cdot \sin\phi$$
$$- K_4^2B^2\cos^2\theta_4 \cdot \cos^2\phi - K_4^2B^2\sin^2\theta_4 \cdot \sin^2\phi$$
$$- 2K_4B\cos\theta_4 \cdot \cos\phi \cdot \sin\theta_4 \cdot \sin\phi$$
$$- K_4^2B^2\sin^2\theta_4 \cdot \cos^2\phi + K_4^2B^2\cos^2\theta_4 \cdot \sin^2\phi$$
$$+ 2K_4B\sin\theta_4 \cdot \cos\phi \cdot \cos\theta_4 \cdot \sin\phi.$$

$$\Rightarrow (K_1-K_3)^2|A| + K_2^2|B|^2\cos^2(\theta_2-\phi) + K_2^2|B|^2\sin^2(\theta_2-\phi)$$
$$- K_4^2|B|^2\cos^2(\theta_4-\phi) - K_4^2B^2\sin^2(\theta_4-\phi)$$

Now

$$\{K_1|A| + K_2|B|\cos(\theta_2-\phi)\}^2 + \{K_2|B|\sin(\theta_2-\phi)\}^2$$
$$= \{K_3|A| + K_4|B|\cos(\theta_4-\phi)\}^2 + \{K_4|B|\sin(\theta_4-\phi)\}^2$$

$$(K_1^2 - K_3^2)|A|^2 + 2|A||B|\{K_1K_2\cos(\theta_2-\phi) - K_3K_4\cos(\theta_4-\phi)\}$$
$$+ K_2^2|B|^2\cos^2(\theta_2-\phi_4) - K_4^2|B|^2\cos^2(\theta_4-\phi$$
$$+ B^2\left(K_2^2\sin^2(\theta_2-\phi) - K_4^2\sin^2(\theta_4-\phi)\right) = 0$$

$$(K_1^2-K_3^2)|A|^2 + 2|A||B|\{K_1K_2\cos(\theta_2-\phi) - K_3K_4(\theta_4-\phi)\}$$
$$+ (K^2-K_4^2)|B|^2 = 0$$

Dividing by $(K_2^2 - K_4^2)|A|^2$

$$\frac{K_1^2 - K_3^2}{K_2^2 - K_4^2} + \left|\frac{B}{A}\right|^2 + 2\left|\frac{B}{A}\right| \left\{ \frac{K_1 K_2 \cos(\theta_2 - \phi) - K_3 K_4 \cos(\theta_4 - \phi)}{K_1^2 - K_4^2} \right\} = 0$$

$$\left|\frac{B}{A}\right|^2 + 2\left|\frac{B}{A}\right| \frac{\left\{ K_1 K_2 \cos\theta_2 \cdot \cos\phi + K_1 K_2 \sin\theta_2 \cdot \sin\phi - K_3 K_4 \cos\theta_4 \cdot \cos\phi - K_3 K_4 \sin\theta_4 \cdot \sin\phi \right\}}{K_1^2 - K_4^2} + \frac{K_1^2 - K_3^2}{K_2^2 - K_4^2}$$

$$\left|\frac{B}{A}\right|^2 + 2\left|\frac{B}{A}\right| \frac{\{ K_1 K_2 \cos\theta_2 - K_3 K_4 \cos\theta_4) \cos\phi + (K_1 K_2 \sin\theta_2 - K_3 K_4 \sin\theta_4) \sin\phi}{K_1^2 - K_4^2} + \frac{K_1^2 - K_3^2}{K_2^2 - K_4^2} = 0$$

$$\Rightarrow \left|\frac{B}{A}\right|^2 + 2\left|\frac{B}{A}\right| [a_0 \cos\phi + b_0 \sin\phi] + C_0 = 0$$

$$a_0 = \frac{K_1 K_2 \cos\theta_2 - K_3 K_4 \cos\theta_4}{K_2^2 - K_4^2}$$

$$b_0 = \frac{K_1 K_2 \sin\theta_2 - K_3 K_4 \cos\theta_2}{K_2^2 - K_4^2}$$

$$C_0 = \frac{K_1^2 - K_3^2}{K_2^2 - K_4^2}$$

$$r = |k_1 k_2|^2 \cos^2\theta_2 + k_3^2 k_4^2 \cos^2\theta_4 + 2 k_1 k_2 k_3 k_4 \cos\theta_2 \cdot \cos\theta_4$$

$$+ k_1^2 k_2^2 \sin^2\theta_2 + k_3^2 k_4^2 \sin^2\theta_4 + 2 k_1 k_2 \sin\theta_2 \cdot \sin\theta_4$$

$$\left|\frac{B}{A}\right|^2 + A(A_0\cos\phi + B_0\sin\phi) + C_0 = (A_0\cos\theta + B_0\sin\theta)^2$$

$$r = \sqrt{C_0^2 - a_0^2 - b_0^2}$$

$$\left|\frac{B}{A}\right|\cos\phi \qquad j\left|\frac{B}{A}\right|\sin\phi$$

$$k_1^2 - k_3^2$$

$$x = r\cos\omega$$
$$y = r\sin\omega$$

$$x^2 + y^2 = \left|\frac{B}{A}\right|^2$$

$$\left|\frac{B}{A}\right|^2$$

$$2\left|\frac{B}{A}\right|\cos\phi = 2x$$
$$2\left|\frac{B}{A}\right|\sin\phi = 2y$$

$$x^2 + y^2 + 2a_0 x + 2b_0 y + c_0 = 0$$

$$x^2 + y^2 + 2gx + 2fy + c = 0$$

$$(x-g)^2 + (y-f)^2 - g^2 - f^2 = 0$$

$$r = \sqrt{c_0 - g^2 - f^2}$$

$$r = \sqrt{c_0 - a_0^2 - b_0^2}$$

$$c = \sqrt{a_0^2 + b_0^2}$$

$$r = \sqrt{c_0^2 - a_0^2 - b_0^2}$$

$$= \left(\frac{k_1^2 - k_3^2}{k_2^2 - k_4^2}\right)^2 - \frac{\left(k_1^2 k_2^2 \cos^2\theta_2 + k_3^2 k_4^2 \cos^2\theta_4 - 2k_1k_2k_3k_4 \cos^2\theta_2 \cdot \cos^2\theta_4\right) - \left\{(k_1k_2\sin\theta_2)^2 + (k_3k_4\cos\theta_4)^2 + 2k_1k_2\sin\theta_2 \cdot k_3k_4\cos\theta_4\right\}}{(k_2^2 - k_4^2)^2}$$

$$= \left(\frac{k_1^2 - k_3^2}{k_2^2 - k_4^2}\right)^2 - \left\{k_1^2 k_2^2 \cos^2\theta_2 - k_3^2 k_4^2 \cos^2\theta_4 + 2k_1k_2k_3k_4 \cos^2\theta_2 \cdot \cos^2\theta_4\right\}$$

$$- k_1^2 k^2 \sin^2\theta_2 \; k_3^2 k_4^2 \cos^2\theta_4$$

$$- 2k_1k_2 \; k_3k_4 \sin^2\theta_2 \cdot \cos\theta_4$$

$$= \left(\frac{k_1^2 - k_3^2}{k_3^2 - k_4^2}\right)^2 - k_1^2 k_2^2 - k_3^2 k_4^2$$

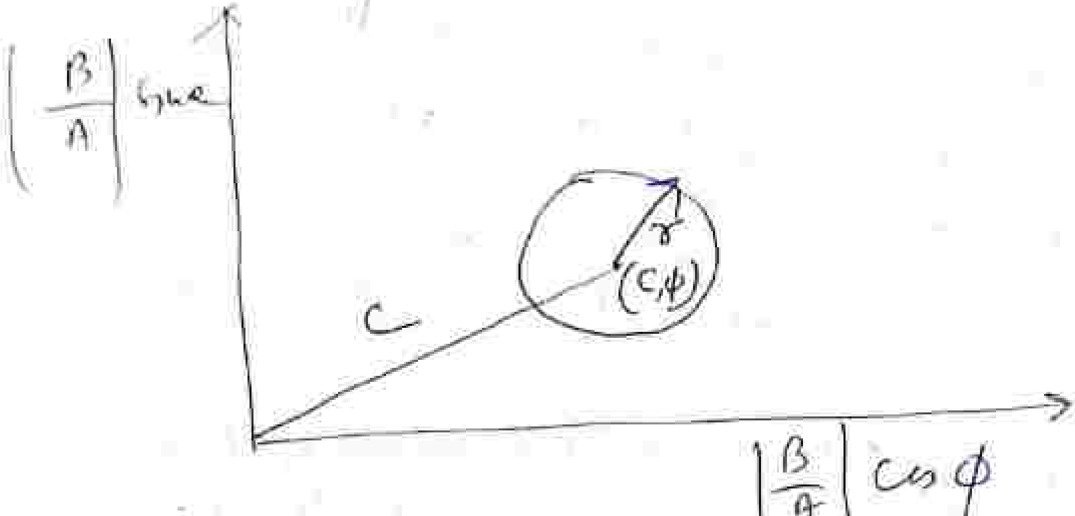
$$r = \sqrt{c_0 - a_0^2 - b_0^2}$$

$$= \sqrt{\frac{|k_1|^2 |k_4|^2 + |k_2|^2 |k_3|^2 - 2|k_1||k_2||k_3||k_4| \cos(\theta_2 - \theta_4)}{|k_1|^2 - |k_4|^2}}$$

$$C = \sqrt{a_0^2 + b_0^2}$$

$$= \sqrt{K_1^2 K_2^2 + K_3^2 K_4^2 - 2 K_1 K_2 K_3 K_4 \cos(\theta_2 - \theta_4)}$$

$$|K_2|^2 - |K_4|^2$$



(Thresold ch. of Amplitude comparator)

Analysis for phase comparator :—

~~Her~~. The inputs S_1 & S_2 sketal their phase relation $S_1 = |S_1| \angle \alpha$, $S_2 = |S_2| \angle \beta$ with respect to reference axis . The Scalar product of these two vector quantites is maximum when they are in phase and positive torque will be obtained when $\alpha - \beta = \pm \pi/2$

$\vec{A} \cdot \vec{B} = AB\cos\theta$

$$\boxed{\tan(\alpha - \beta) = \pm \infty}$$

$$\frac{\tan\alpha - \tan\beta}{1 + \tan\alpha \cdot \tan\beta} = \pm \infty$$

$S_1 = \tan(\theta_2 - \phi)$

$S_2 = \tan(\theta_4 - \phi)$

$1 + \tan\alpha \cdot \tan\beta = 0$

$$1 + \frac{|K_2||B|\sin(\theta_2-\phi)}{K_1|A| + |K_2||B|\cos(\theta_2-\phi)} \times \frac{|K_4||B|\sin(\theta_4-\phi)}{K_3|A| + K_4|B|\cos(\theta_4-\phi)} = 0$$

$$\Rightarrow \left\{K_1|A| + K_2|B|\cos(\theta_2-\phi)\right\}\left\{K_3|A| + K_4|B|\cos(\theta_4-\phi)\right\}$$
$$+ |K_2||B|\sin(\theta_2-\phi) \times |K_4||B|\sin(\theta_4-\phi) = 0$$

$$\Rightarrow K_1K_3|A|^2 + K_1|K_4||A||B|\cos(\theta_4-\phi) + |K_2||K_4||B|^2\cos(\theta_2-\phi)$$
$$+ |K_2||K_3||A||B|\cos(\theta_2-\phi)$$
$$\cos(\theta_4-\phi) + |K_2||K_4||B|^2\sin(\theta_2-\phi)\cdot\sin(\theta_4-\phi) = 0$$

Dividing the equations by $|K_2||K_4||A|^2\cos(\theta_2-\theta_4)$ we get

$$\left|\frac{B}{A}\right|^2 + \frac{\left|\frac{B}{A}\right|\left\{\left(K_1|K_4|\cos\theta_4 + |K_2||K_3|\cos\theta_2\right)\cos\phi + \left(K_1|K_4|\sin\theta_4 + |K_2||K_3|\sin\theta_2\right)\sin\phi\right\}}{|K_2||K_4|\cos(\theta_2-\theta_4)}$$
$$+ \frac{K_1K_3}{|K_2||K_4|\cos(\theta_2-\theta_4)} = 0$$

or $$\left|\frac{B}{A}\right|^2 + \left|\frac{B}{A}\right|\left\{A_0'\cos\phi + B_0'\sin\phi\right\} + C_0' = 0$$

$$A_0' = \frac{|K_1||K_4|\cos\theta_4 + |K_2||K_3|\cos\theta_2}{|K_2||K_4|\cos(\theta_2-\theta_4)}$$

$$B_0' = \frac{|K_1||K_4|\sin\theta_4 + |K_2||K_3|\sin\theta_2}{|K_2||K_4|\cos(\theta_2-\theta_4)}$$

$$C_0' = \frac{K_1K_3}{|K_2||K_4|\cos(\theta_2-\theta_4)}$$

Solved

$$\sin\theta \cdot \sin\phi = \frac{\cos(\theta-\phi) - \cos(\theta+\phi)}{2}$$

$$= \frac{\cos(\theta_2 - \cancel{\phi} - \phi_4 + \cancel{\phi}) - \cos(\theta_2 - \phi - \phi_4 + \phi)}{2}$$

$$= \frac{\cancel{2}\cos(\theta_2 - \phi_4)}{\cancel{2}}$$

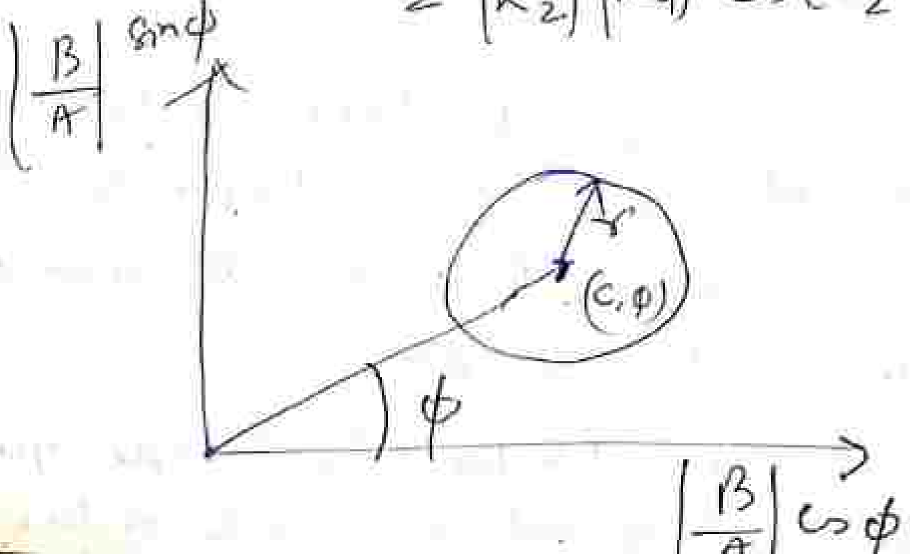
$$= \cos(\theta_2 - \phi_4)$$

The above equation represents a circle with radius.

$$r = \frac{\sqrt{|K_1|^2|K_4|^2 + |K_2|^2|K_3|^2 - 2|K_1||K_3||K_4|\cos(\theta_2 - \theta_4)}}{2|K_2||K_4|\cos(\theta_2-\theta_4)}$$

The co-ordinate of the centre (C, ϕ), where

$$C = \frac{|K_1|^2|K_4|^2 + |K_2|^2 K_3^2 + 2|K_1||K_2||K_3||K_4|\cos(\theta_2-\theta_4)}{2|K_2||K_4|\cos(\theta_2-\theta_4)}$$



General Equation for Electromagnetic Relay

The equation of the relay characteristic at the threshold condition of operation under steady-state condition, it will treated as circle on a complex plane.

The equation can be represent in general form

$$\underbrace{K|A|^2}_{\text{one constant}} - \underbrace{K'|B|^2}_{\text{ro constant}} + |A||B|\cos(\phi-\theta) - K'' = 0$$

$K_1K_2 \; K''$
$-2AB\cos(\phi-\theta)$
$+2AB\,K_3K_4\cos(\phi-\phi_2)$

positive quantity taken as torque

$|A|$ & $|B|$ — Two quantity being compared

ϕ = electrical angle between A & B

θ = Relay characteristic angle

K & K' — Scalar constant.

K'' — Mechanical Restraining torque constant.

A is the ~~voltage~~ current & B is the ~~current~~ voltage

$$K|I|^2 - K'|V|^2 + |V||I|\cos(\phi-\theta) - K'' = 0$$

Current winding produce a torque KI^2 and potential winding a torque $K'V^2$.

The interaction of voltage & current produce a torque $VI\cos(\phi-\theta)$

K'' is ~~[illegible]~~ finite only single quantity relay, where it is used as level

indicator, It is negligible small.
so $K'' = 0$

Divide by $K'|I|^2$ in equation.

$$\frac{K}{K'} - \left|\frac{V}{I}\right|^2 + \left|\frac{V}{I}\right| \frac{\cos(\phi-\theta)}{K'} = 0$$

$$\underbrace{\left|\frac{V}{I}\right|^2}_{x} - \left|\frac{V}{I}\right| \frac{\cos(\phi-\theta)}{K'} + \underbrace{\left|\frac{1}{2K'}\right|^2}_{y}$$

$$= \left|\frac{K}{K'}\right| + \left|\frac{1}{2K'}\right|^2$$

$$r = \sqrt{\frac{1}{2K'} + \left|\frac{V}{I}\right| \frac{\cos(\phi-\theta)}{K'}}$$

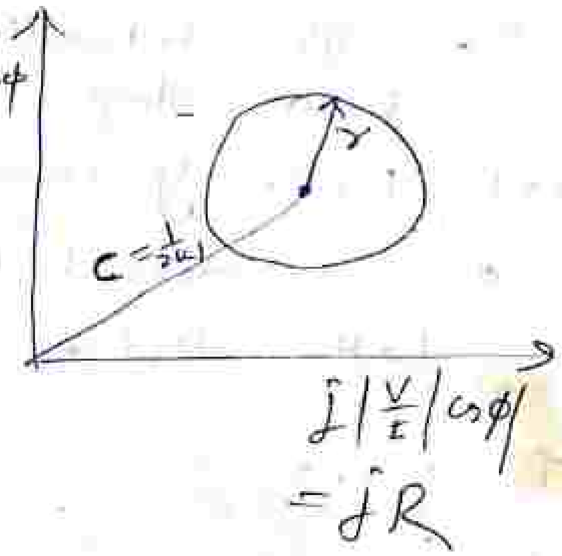
$$r^2 = \frac{K}{K'} + \left|\frac{1}{2K'}\right|^2$$

$$= \frac{K}{K'} + \frac{1}{4K'^2} = \frac{K \cdot 4K'^2 + 1}{4K'^2}$$

$c = \sqrt{a^2 + b^2}$

$$r = \frac{\sqrt{1 + 4KK'}}{2K'}$$

$$C = \frac{1}{2K'} = jX$$



Over current relay :-

(II) Depending the time of operation the relay are catagorized (i) Instaneous over current relay (ii) Inverse time overcurrent relay (iii) Inverse definite minimum time (iv) Very inverse relay (v) Extremely inverse.

(i) Instaneous over current relay

- It has no time delay operation.
- The time of operation is approximatly 0.1 sec.
- The characterstic is achieved by hinged type relay.

(ii) Inverse - time current relay:-

- operating time reduces as actuating quantity increases.
- This charectorstics can be obtained with induction type relay by using suitable core.

(iii) Inverse definite minimum type Current relay

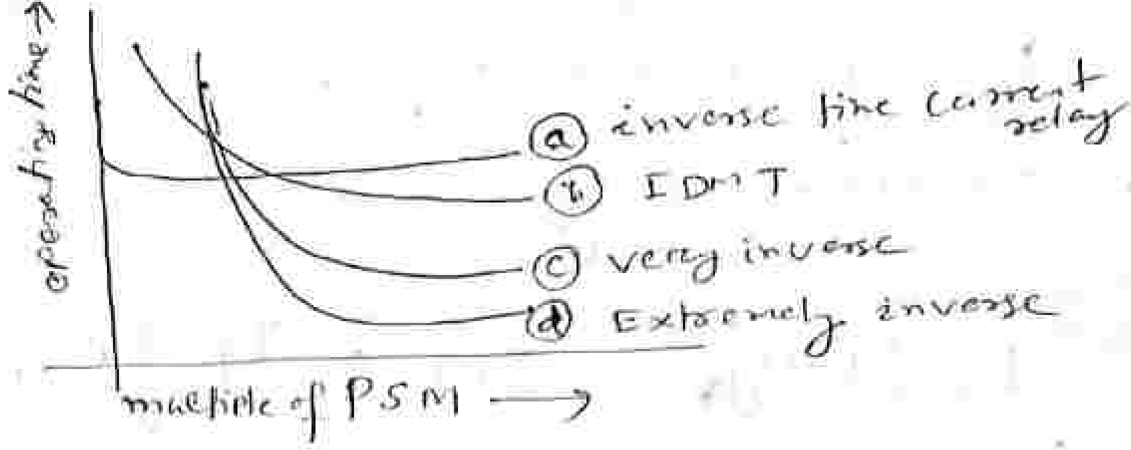
- The operating time is approximatly inversely proportional to the fault current.

(iv) very inverse relay:-

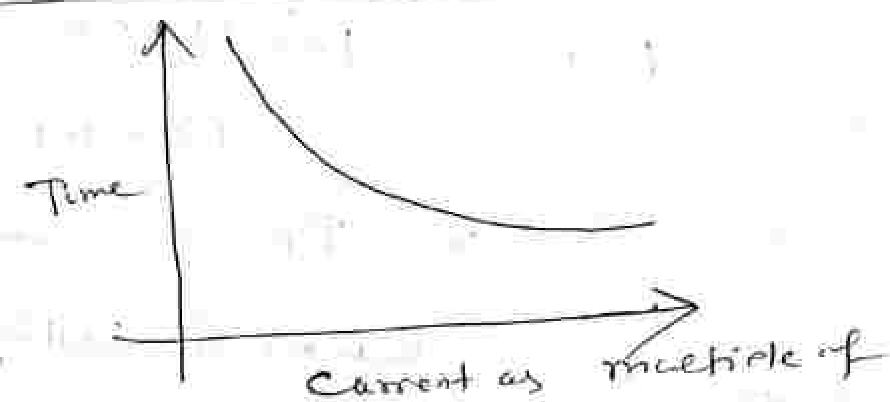
- The saturation of core occurs at a latter stage.

(v) Extremely inverse

- It is one in which the saturation occurs at a latter stage.



Time current characteristics



✓ Pick up adjustment is by coil (induction type relay)

✓ Ampere turns at pick up are same for each tap.

~~different gap.~~

✓ For a given multiple of pick up, the ampere turns and hence the torque are same.

✓ multiple of pick up should not less than 1.5.

✓ Inverse time current relay are non directional relay. The are use in feeder transmission line, transformer machine.

I_f = fault current

CT ratio = x/y

I_R (Relay current) = $\frac{I_f \times y}{x}$

(ii) Current setting multiplier (PSM)

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

$$= \frac{I_R}{\text{Current setting} \times \text{rated Secondary Current}}$$

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

I_p = per unit current setting of the relay

Problem :- An IDMT type overcurrent relay is used to protect feed through 500/1 CT. The relay has PS of 125% and TMS = 0.3. Find the time of operation of the said relay at a fault current of 5000 A flows through the feeder.

PSM	2	3	5	8	10	15
Time for unity TMS	10	6	4.5	3.2	3	2.5

(100% current = 1A)

Relay current $I_R = \frac{I_f}{CT\ ratio} = \frac{5000}{500} = 10A$

Pick up value of relay = current setting × rated secondary current of CT

$= \frac{125}{100} \times 1 = 1.25A$

Plug setting multiplier PSM = $\frac{\text{Fault current of relay}}{\text{Pickup value of relay}}$

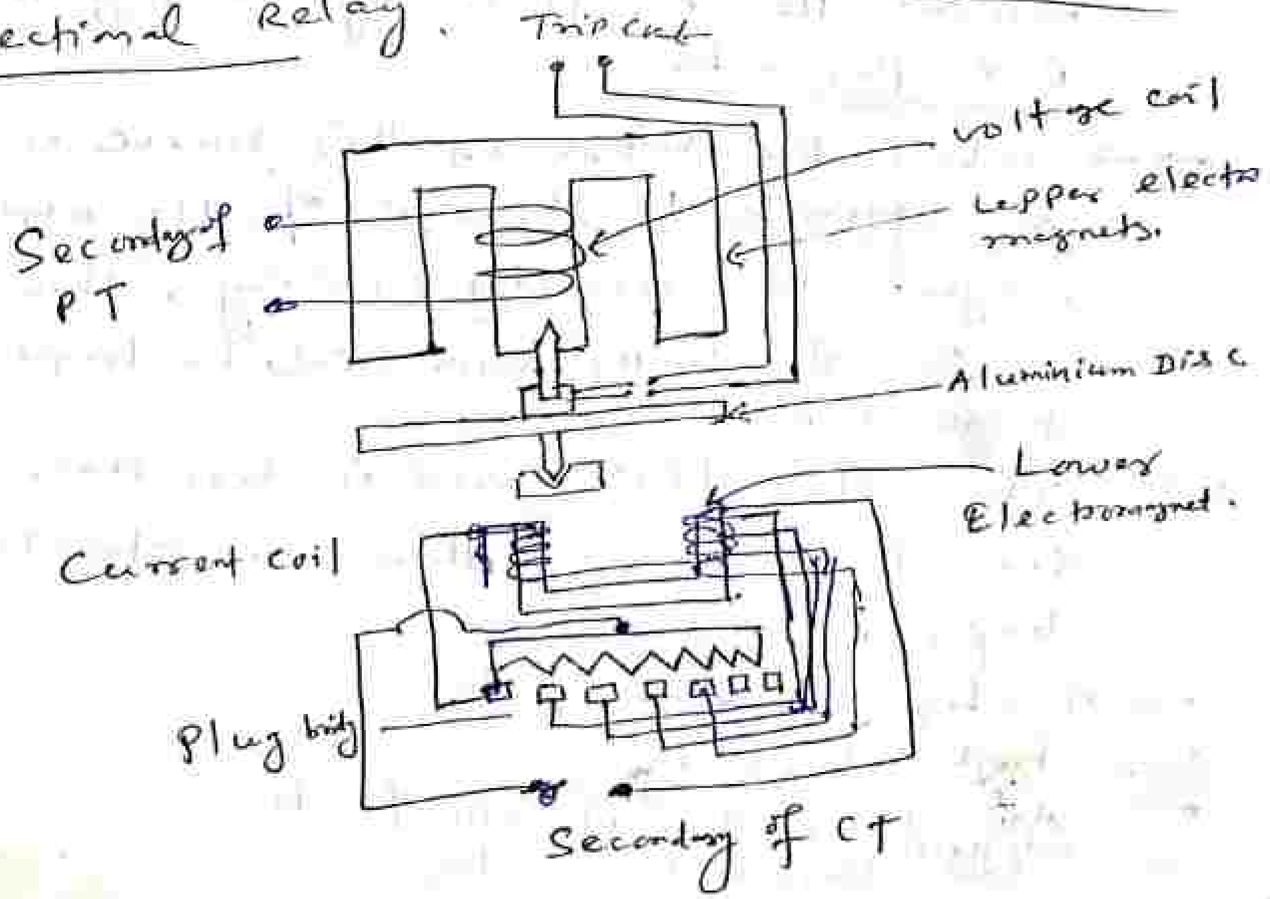
$= \frac{10}{1.25} = 8$

for given PSM = 8, time of 3.2 sec.

~~Time~~ or actual operating time = 3.2 × time multiplier setting

$= 3.2 \times 0.3 = 0.96$ sec.

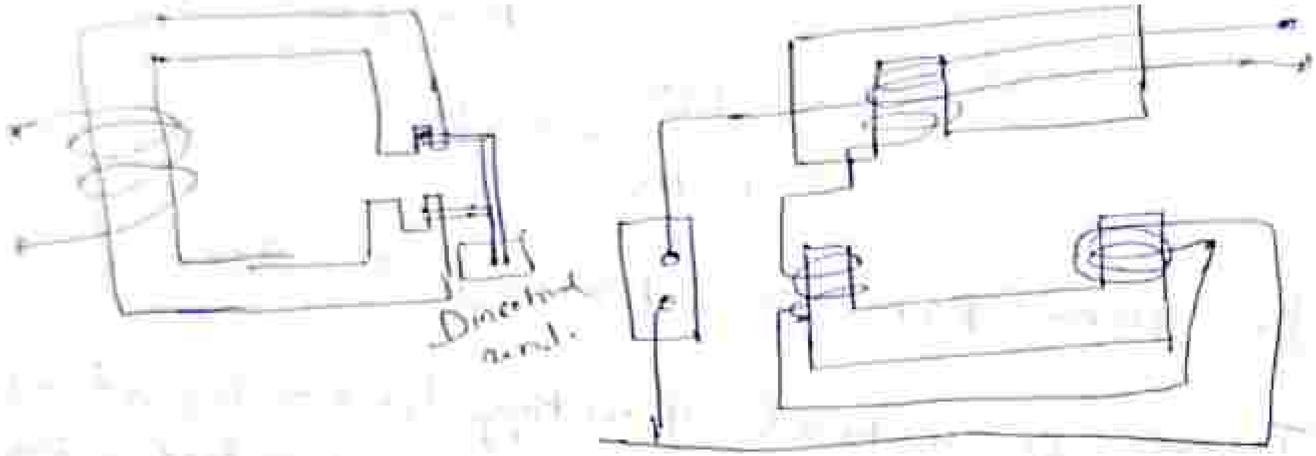
Directional Relay.



Direction Relay

→ In ring or loop system as well as ring main system time graded overcurrent protection cannot given proper protection

→ The directional features achieved by induction disc type overcurrent relay with split phase magnet in addition with directional unit. The directional unit consist of resistance & capacitance.



→ The directional unit control the angle between the two fluxes by varying the R-X parameter.

→ when the voltage of this source is equal & opposite to the o/p of the upper magnet of secondary winding, there is no current in the lower coil, no torque is produced.

→ If it opposes and is less than the secondary output, there is an operating torque.

- → It has high speed operation
- high sensitivity
- At low voltage it will operate
- adequate low thermal time rating.

Single Phase directional Relay

The modification of general equation $K|A|^2$ & $K'|B|^2$ is eliminated. considering voltage current directional relay

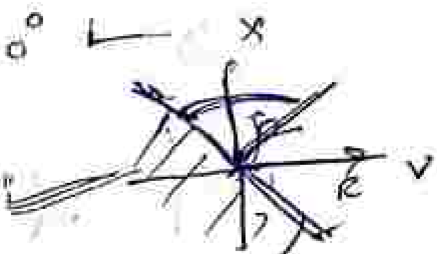
$$VI\cos(\phi-\theta) - K'' = 0$$

The spring constant K'' has no function.

$$VI\cos(\phi-\theta) = 0$$

$T \propto \phi_V \phi_I \sin(\phi+\theta)$

$$\phi - \theta = \pm 90^\circ$$

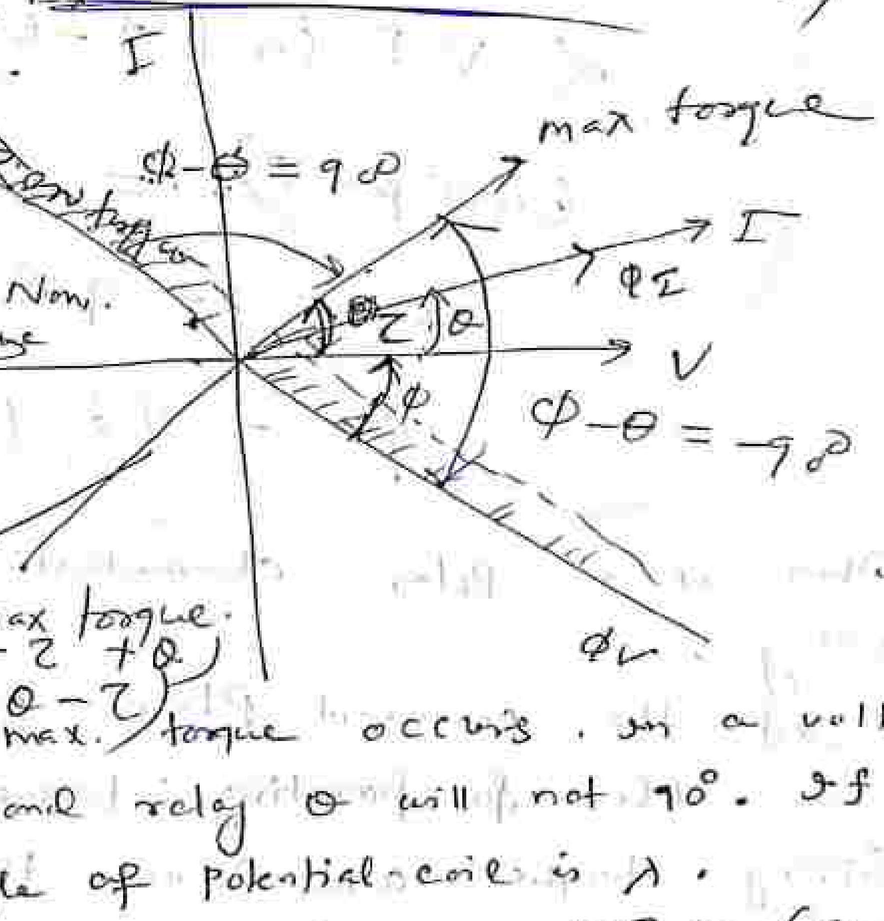


$T = KVI\sin(\phi+\theta)$

$\phi+\theta = 90^\circ$

$$\phi = \theta \pm 90^\circ$$

Zero torque $\sin(\phi+\theta) = 0$
or $\phi+\theta = 0^\circ$ or 180°
0 torque.



ϕ = ~~angle~~ angle between ~~V & I~~ Now.

θ = ~~the maximum torque~~ angle.

$\tau = 90^\circ - \phi$

$\phi = 90^\circ - \tau$

$T = KVI\sin(\underbrace{90 - \tau + \theta}_{\text{max torque}})$

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

when $\theta = \phi$ max. torque occurs. in a voltage current directional relay θ will not 90°. If the impedance angle of potential coil is λ.

$$\boxed{\begin{aligned}\theta &= 90 - \lambda \\ \theta + \lambda &= 90^\circ\end{aligned}}$$

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

$\theta - \tau = 90^\circ$

$\theta = \tau + 90^\circ$

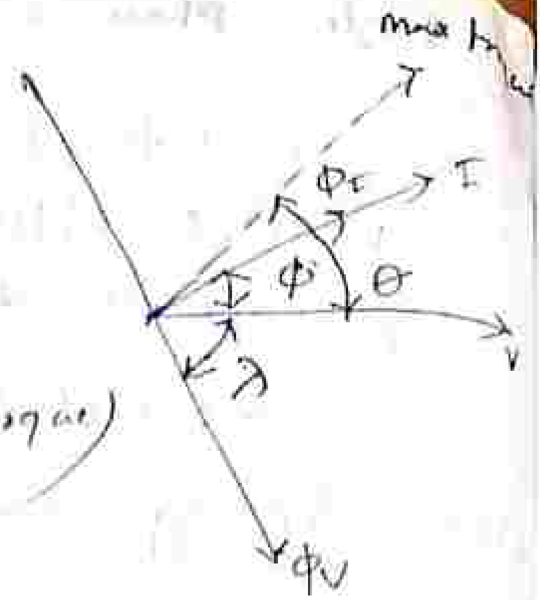
ϕ_V = main flux due to voltage coil

ϕ_I = flux due to current coil

$\underline{\text{Torque}}$ $\propto \phi_V \phi_I \sin(\lambda + \phi)$

$$T \propto K V I \sin(\lambda + \phi)$$

when $\lambda + \phi = 90^\circ$ (max. torque)



$$\theta = 90^\circ - \lambda$$

$$\lambda = 90^\circ - \theta$$

$$T \propto V I \sin(\phi + 90^\circ - \theta)$$

$$\propto V I \cos(\phi - \theta)$$

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

$$\phi - \theta = 90^\circ$$

$$\phi = 90^\circ + \theta$$

This is a polar characteristic of directional relay.

* If the current phasor crosses the dotted line the operating torque exceeds the spring torque and hence the relay operates.

Distance relay

The distance relay has classified (i) Impedance relays (ii) reactance relays (iii) mho relays.

Impedance relay:-

This is a device which measures distance by comparing the fault current I with the voltage V across the fault loop. The amplitude comparator and balanced beam structure is most common.

The equation of amplitude comparator

$$\underbrace{(K_1^2 - K_3^2)}_{K_1}|A|^2 + 2|A||B|\{K_1K_3\cos(\theta_2-\phi) - K_3K_4\cos(\theta_4-\phi)\} + \underbrace{(K_2^2-K_4^2)}_{K_2}|B|^2 = 0$$

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

operating torque is produced by current coil and restraining torque produced by voltage coil. So impedance relay is <u>voltage restrained over current relay</u>. For proper operation of the relay, the operating torque should be greater than the restraining torque.

$$K_1 I^2 > K_2 V^2$$

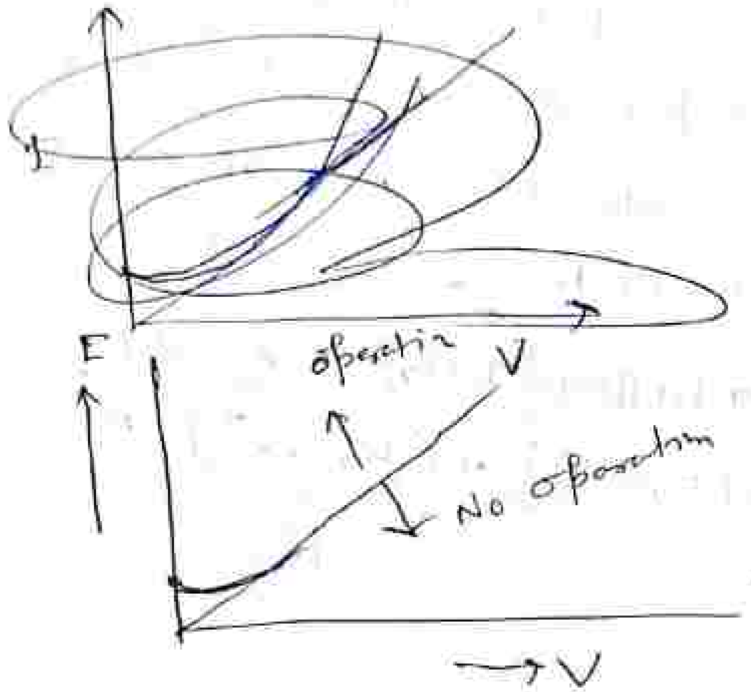
$$\frac{V^2}{I^2} < \frac{K_1}{K_2}$$

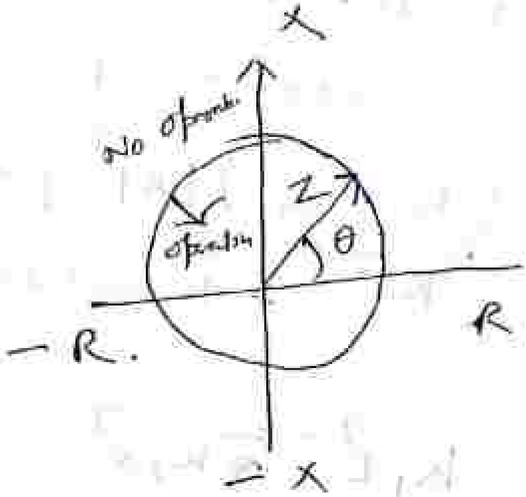
$$Z < \sqrt{\frac{K_1}{K_2}}$$

$$Z < \text{constant (design impedance)}$$

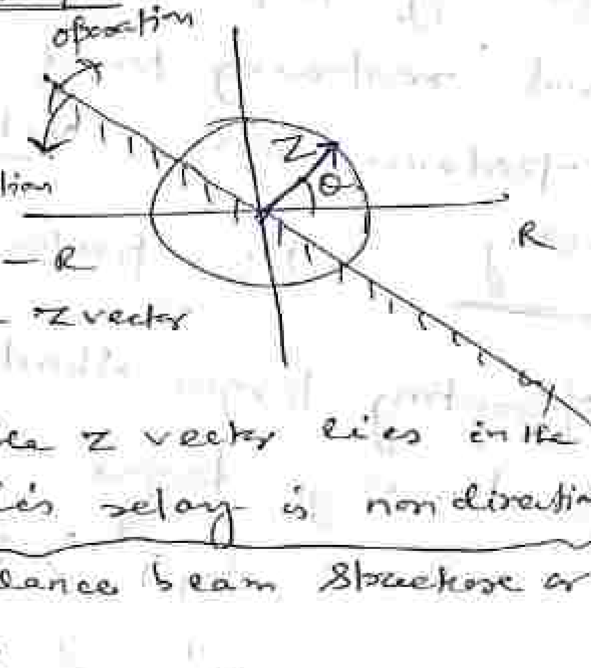
This means that the impedance relay will operate only if the impedance seen by the relay is less than a prescribed value. At threshold cond^n

$$Z = \sqrt{\frac{K1}{K2}}$$





The initial bend in the characteristics is due to the presence of spring torque.



In case two were in phase, the Z vector coincided with +R axis. when current lagging the voltage by 180°, the Z vector coincides with −R axis

when I lags behind V, the Z vector lies in the upper semicircle. So this relay is non directional.

These relays may use balance beam structure or induction cup structure.

Reactance relay:— In this relay the operating torque is obtained by current and restraining torque due to current-voltage directional element, so, a reactance relay is an overcurrent with directional restraint. The directional element is so designed that its maximum torque angle is 90° i.e. $\theta = 90^\circ$

$$T = K_1 I^2 - K_3 V I \cos(\phi - \theta)$$

$$= K_1 I^2 - K_3 V I \cos(\phi - 90^\circ)$$

$$= K_1 I^2 - K_3 V I \sin\theta$$

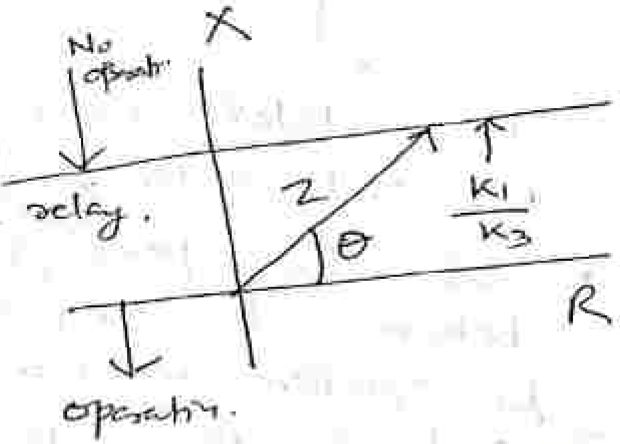
For the operation of the relay

$$K_1 I^2 > K_3 V I \sin\theta$$

$$\frac{VI}{I^2} \sin\theta < \frac{K_1}{K_3}$$

$$Z \sin\theta < \frac{K_1}{K_3}$$

$$X < \frac{K_1}{K_3}$$



It is a non-directional relay.

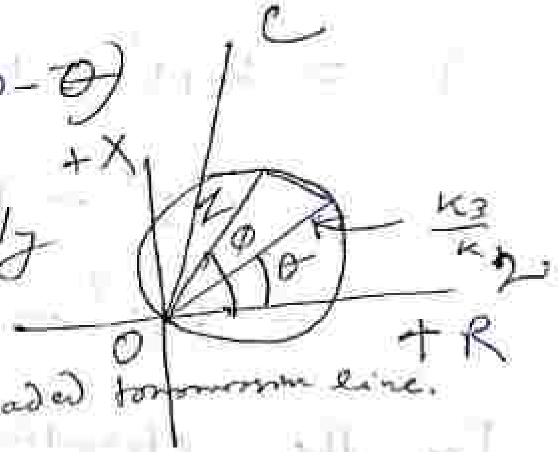
Mho relay:— In this relay the operating torque is obtained by the V-I element and restraining torque due to the voltage element. This means a mho relay is a voltage restrained directional relay. Mho relay is high speed relay & known as admittance relay.

$$T = K_3 V I \cos(\phi - \theta) - K_2 V^2$$

For the relay operates $K_3 V I \cos(\phi-\theta) > K_2 V^2$

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

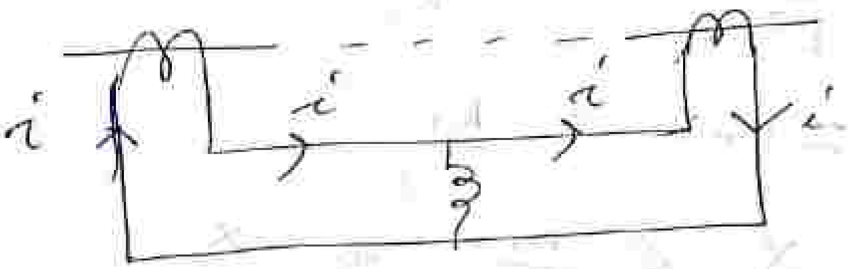
$$Z < \frac{K_3}{K_2} \cos(\phi-\theta)$$



* This relay is inherently directional.
* Mho relay is suitable for long EHV/UHV heavily loaded transmission line.

Differential relay:—

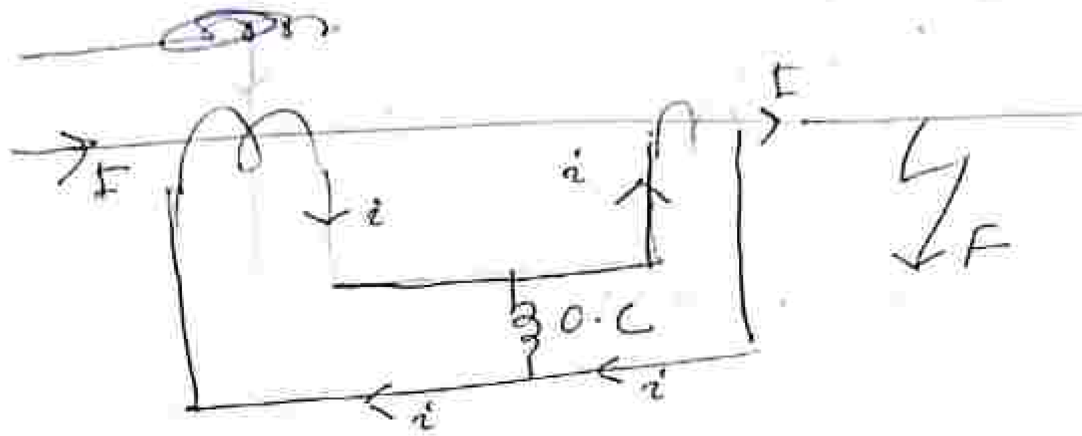
- The vector difference of two similar quantity when exceeds a predetermined value, relay operates
-



The dotted line represents (a) transformer, an alternator, bus.

- If the operating coil is not connected between the equipotential point, there will be difference current through the operating coil of the relay and this may result in maloperation of the relay.

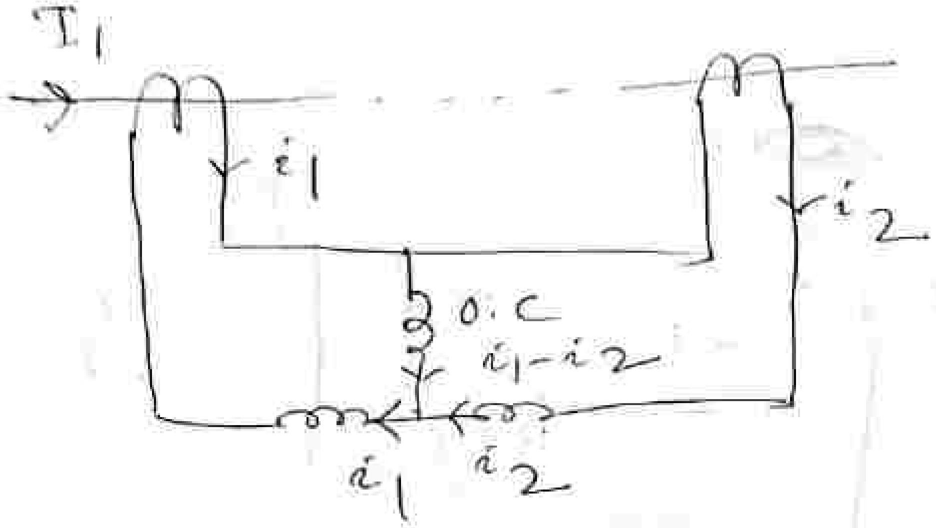
If the burden of the two CT is unequal, the heavily loaded CT will saturate during through fault. Causing different characteristic of the two CT. So that, there is dissimilarity in the characteristics of the two CT's which results in maloperation of the relay.



The desirable feature of this relay is that when there is a fault in the outside, relay does not operate. If the two CT are identical and obeying the same secondary current, For interfault situation, the relay coil operate. The form of protection is known as merz - price protection.

Under transient condition, the CT do not transform their current accurately. Two CT under normal condition differ their magnetic properties slightly in terms of different their residual magnetism or unequal burden on the two CTs. In the result, one CT will saturate earlier or during short circuit.

This case is validated with transformer. The ~~mer~~ Merz-Price protection is modified by biasing the relay. This is known as biased differential protection or percentage differential protection is used.



The relay consist of operating coil and restoring coil. The operating coil is connected to mid point of restoring coil. ~~Due to~~ but owing to the dissimilarities in CTs, the differential current through the operating coil is $(i_1 - i_2)$ and equivalent current in the restoring coil is $(i_1+i_2)/2$

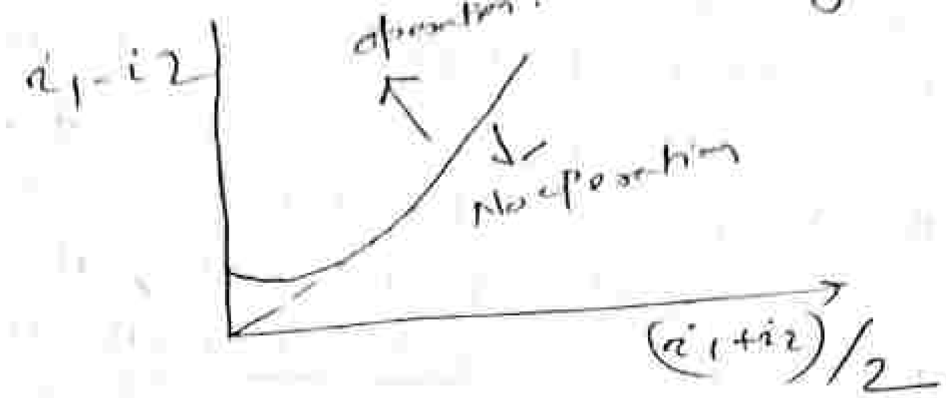
Operating coil torque $T_o \propto (i_1 - i_2) n_o$

Restoring coil torque $T \propto \frac{(i_1+i_2)}{2} n_T$

At balance $\frac{(i_1+i_2)}{2} n_T = (i_1 - i_2) n_o$

$$\frac{n_T}{n_o} = \frac{i_1 - i_2}{(i_1+i_2)/2}$$

The ratio of differential operating current to the average restraining current is a fixed percentage. This is why it is known as percentage differential relay.



Feeder protection

Non-unit type

① overcurrent protection ⟶ back up
② Distance protection ⟶ primary
③ pilot relaying protection

In a distribution circuit ~~relay~~ nondirectional relay is used,

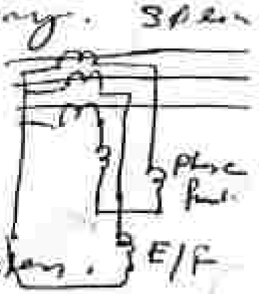
Two phase and one earth fault relay are required for complete protection of ~~the system~~ three phase circuit

overcurrent protection is used for phase and ground fault on station serving distribution ckts

over current protection used as back up protection

The discrimination using overcurrent protection is used in the following way.

① Time graded system
② Current graded system
③ Time current graded system.



Time graded System :—

This is a radial feeder line is being fed from one source. The time of the relay is so adjusted that the relay farthest from the source will have minimum time of operation. Near the source, the operating time increases.

The main disadvantage point is that the fault current does not vary much with the location of fault and inverse characteristics does not apply. Time graded system is normally employed for back up protection in large transmission system.

Current graded System :— This type of grading is done on a system where the fault current varies appreciable with the location of the fault. The current nearer to the source is highest. ~~More relay can~~ The set up value of the relay is highest, so that long time required for operation of the relay. In this system it is very difficult to determine the magnitude of current under transient condⁿ.

Time & current grading System

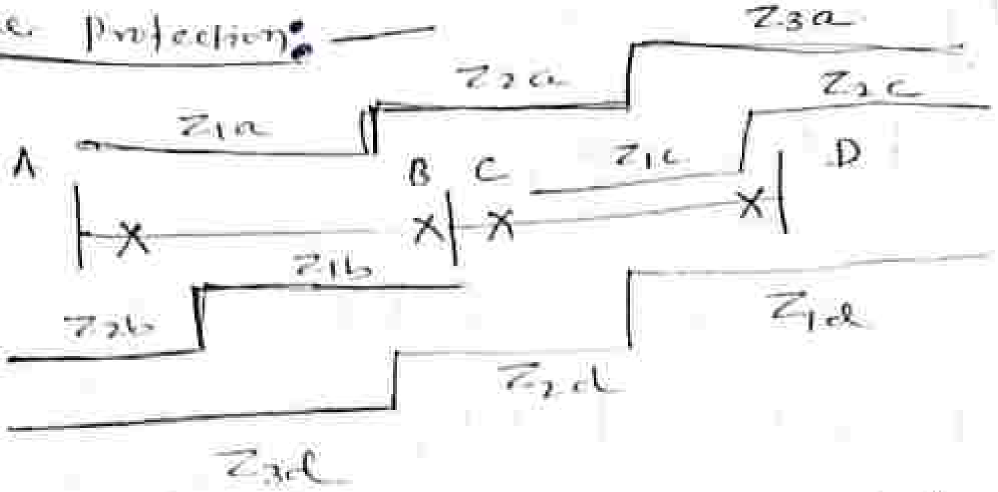
→ This type of grading is achieved with the help of inverse time over current relay and the most widely used. If IDMT relays are ~~too~~ slow at low values of overload extremely inverse relay are used.

Selection of Time Setting

In case of radial distribution line, the pick up value of relay so adjust that, it will trip for all value of short circuit and it also provide for back up protection for CO for adjoining line. The set up value of relay is equal to the current at the farthest end. Suppose 3 ϕ fault, under ~~minimum~~ maximum generation gives the ~~minimum~~ maximum fault current and line to line fault under minimum generation gives minimum fault current. The relay must ~~be~~ respond between these two extreme limits. The current setting of the relay farthest from the source should be minimum. According to Indian standard specification, the operating value should exceed 1.3 times the setting

Min short circuit current $\geq$ 1.3 setting.

Distance Protection:



This protection scheme is divided into 3 zones. AB & CD are the two line section. The three zones are Z_{1a}, Z_{2a}, Z_{3a}. Z_{1a} covers 80% of the line AB and it is a high speed zone. No intentional time lag is provided for this zone. Second zone Z_{2a} for relay at A covers remaining 20% length of the line AB and 20% of line CD. If fault will occur in this section relay at A will operate when the time elapsed corresponds to the ordinate Z_{2a}. The main idea of the second zone is to provide protection for the remaining 20% section of the line AB. In case of an arcing fault in section AB which adds to the impedance of the line as seen by the relay at A, the relay A will see the 2nd zone and will operate. The operating time of 2nd ~~protection~~ zone is normally about 0.2 to 0.5 sec.

The third zone at A provide back up protection for faults in the line CD, In some reason the relay at C fails to operate than the relay A will provide back up protection.

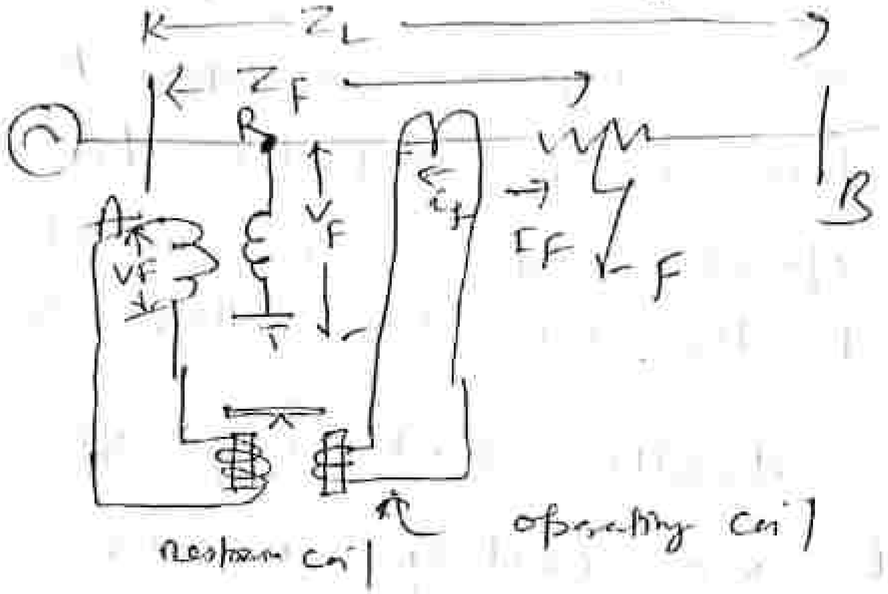
Distance protection : —

The action depends ~~on~~ upon the distance of the feeding point to the fault. The time of operation of such protection is a function of the ratio of voltage & current.

It is a double actuating quantity relay with one coil is energised by voltage and other coil by current. The current element produce positive value torque and ~~negative~~ voltage element produce negative value of torque. The relay operates only $\frac{V}{I}$ ratio falls below a predetermined value. The V/I ratio measured the location of CT & PT. Near the fault nearer to PT, voltage decreases and fault farthest from the CT, voltage increase. So, we maintained constant V/I ratio ~~for~~ measured from the relay location. Distance protection is a non-unit type protection.

Distance protection is a primary and back up protection. For faster clearing fault, distance relay used.

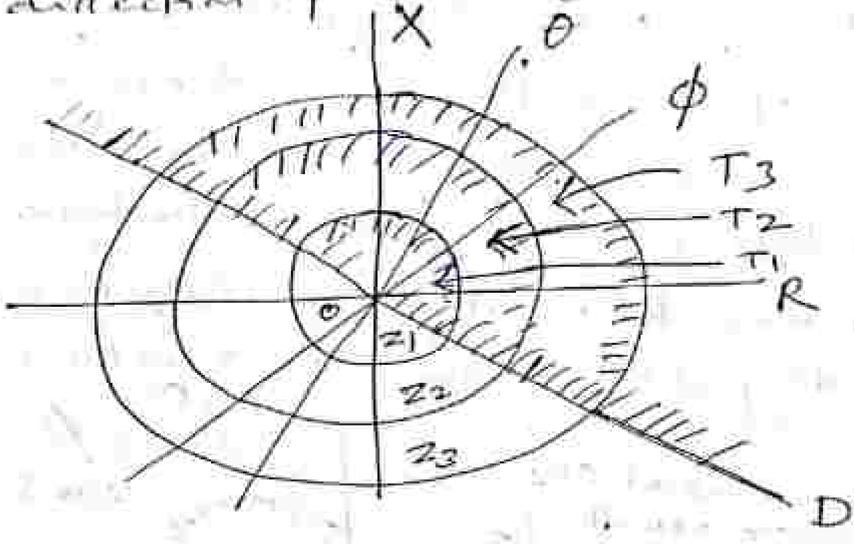
Principle of distance relay operates



The analysis of distance relay is governed by the ratio of voltage to current at the relay location. R is the point where relay connected and the two coils of the relay operating and restraining coils receive current i_F and V_F proportional to the fault current I_F. Below a particular value of $Z = V/I$ the relay operates.

istance Protection by impedance relay :-

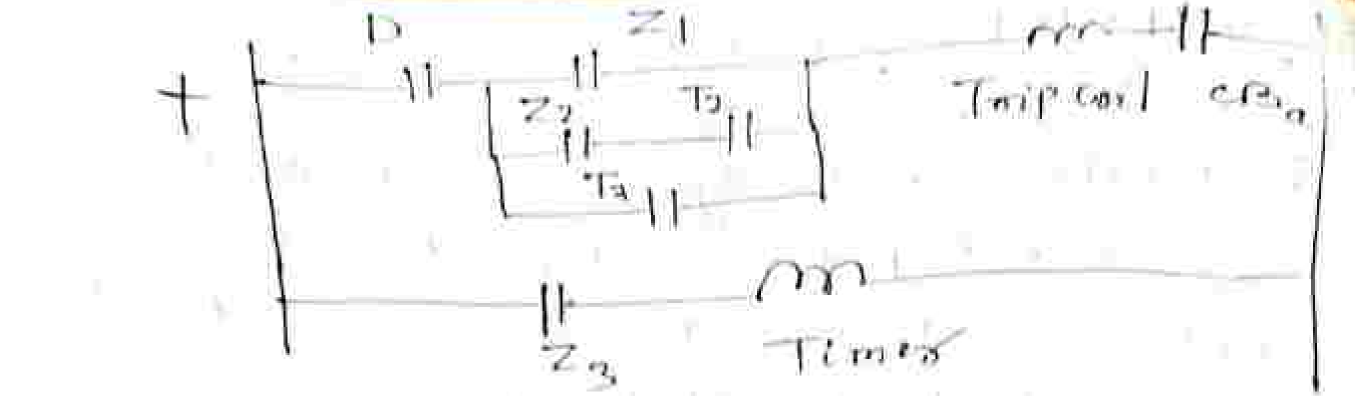
1.) impedance is directly proportional to the length of line. Impedance relay which measures impedance can be used to recognize a fault condition and operate. It has no directional features and it will operate irrespective of the direction of current.



The characteristic for a 3 zone impedance relay with directional unit D. The ~~distance~~ impedance corresponding distance is known as reach of the relay. The torque angle φ is less than the impedance angle θ. This is done in order to reduce the effect of arc resistance of the relay.

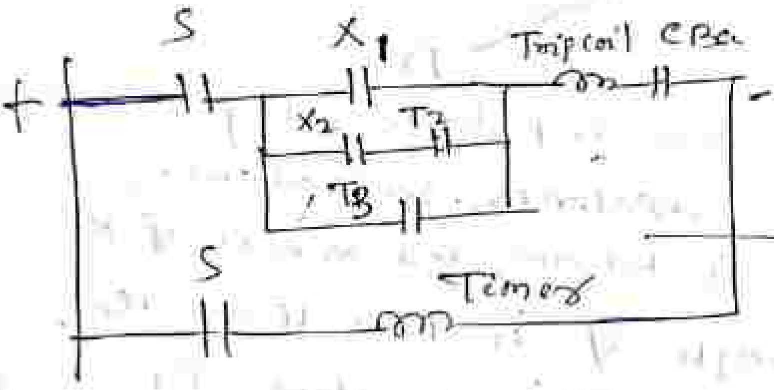
→ The element Z_3 of zone 3 controls the timer.

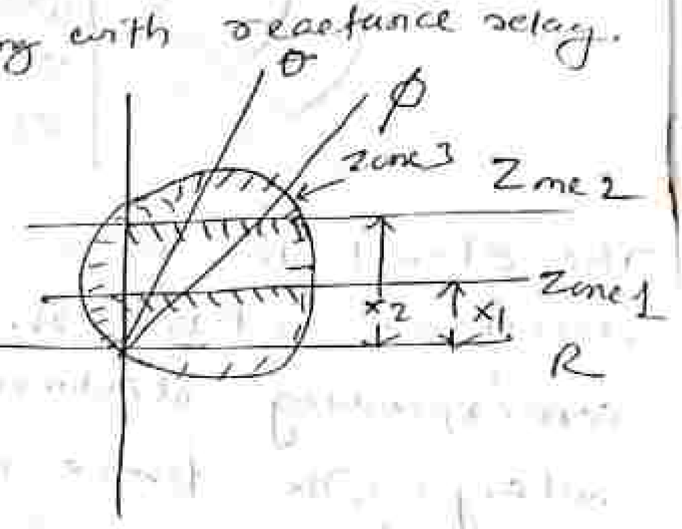
→ The zone 1 element operates without any intentional time delay, but still it has some finite time of operation T_1, whereas Z_2 & Z_3 operates with a time delay of T_2 and T_3 respectively.



Distance protection by reactance relays

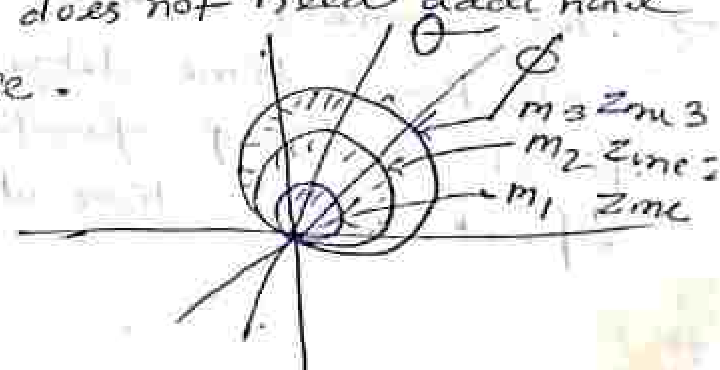
This type of relay responds only to the reactance component of the impedance. A reactance relay is a non-directional relay ~~and the directional unit of the type used along the impedance relay can not be used for~~. A mho relay is used as the starting relay along with reactance relay.



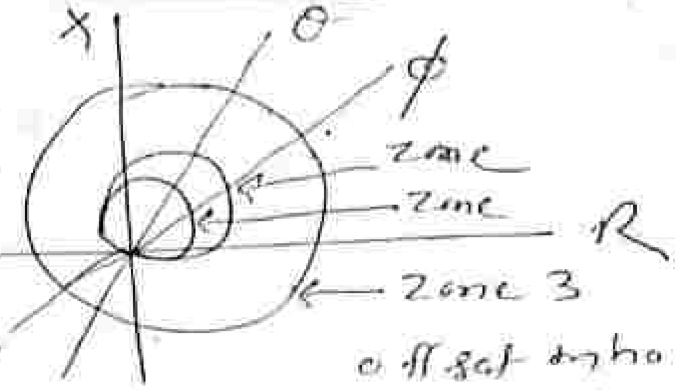


In case fault takes place 1st zone, all the three unit X_1, X_2 and S starts. The operation of X_1 takes less time, the contact X_1 is closed.

Mho relay :- Mho relay, inherently being a direction relay, does not need additional unit for the purpose.



Zone 3 mho unit which act as starting relay or for controlling the timer can also be replaced by an off-set mho unit which has advantages under closed loop fault condition.



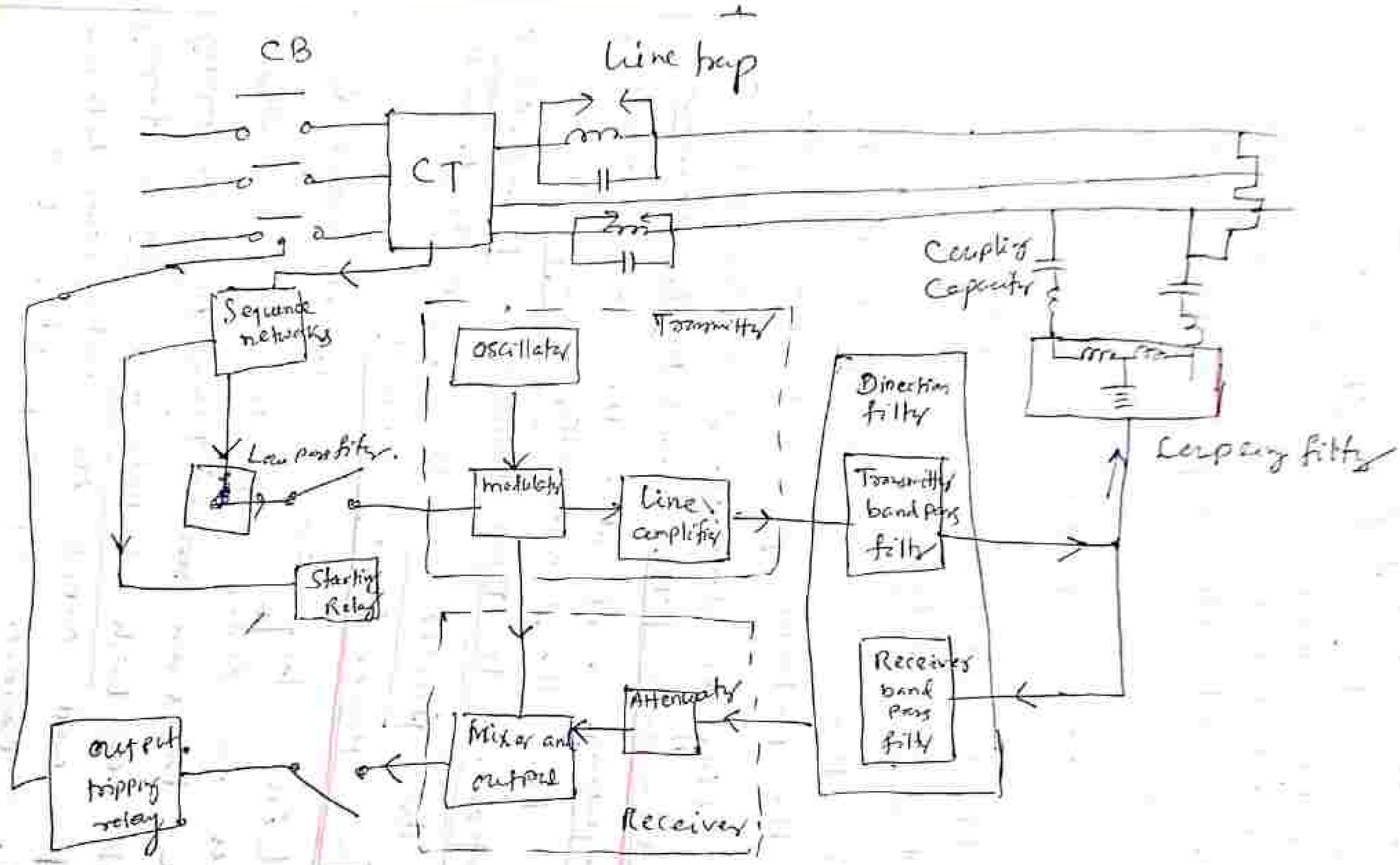
Pilot wire protection

1→ Pilot wire protection is usually limited to 10 to 10 miles

2. The prime consideration is the coupling of the protective gear to the power line.

3. Coupling is done through a series L-C wide-band filter tunned to the carrier frequency. It allows the carrier frequency to pass through and offer a very high impedance to power frequency. Parallel L-C filter provide a drainage path to earth for power frequency current.

4. Line trap are provided at overhead lines in series with the phases. The line traps are ~~provided~~ tuned to power frequency offer a high impedance to carrier frequency. It will avoid the interference between the carrier signals of adjacent line.

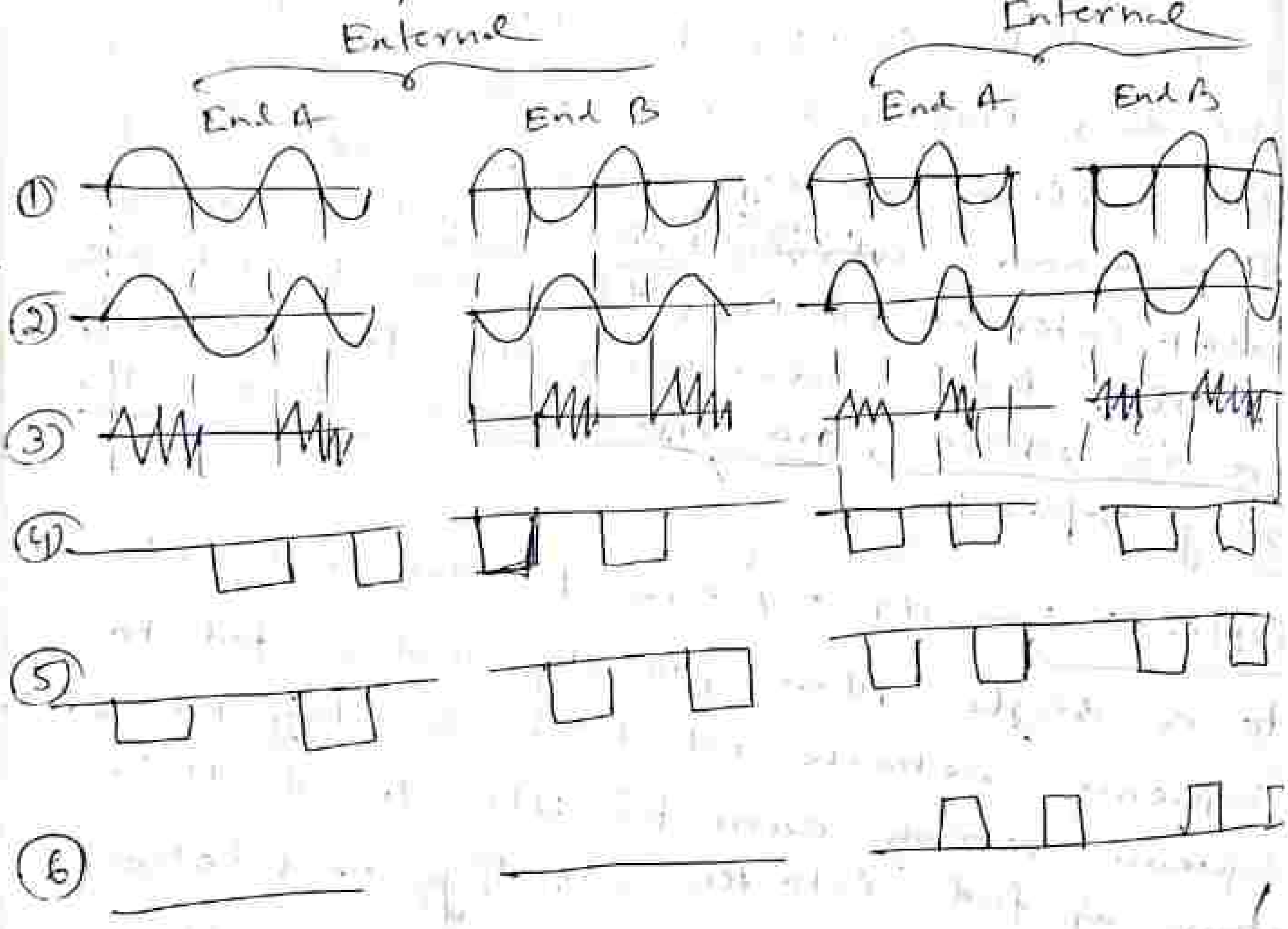

CB
Line trap
CT
Coupling Capacitor
Coupling filter
Sequence networks
Low pass filter
Starting Relay
Transmitter
Oscillator
Modulator
Line amplifier
Direction filter
Transmitter band pass filter
Receiver band pass filter
Attenuator
Mixer and output
Receiver
Output tripping relay

The signal is generated by transmitter consist of oscillator and amplifier with frequency 50 to 500 kHz.

Phase comparison scheme:—

The phase comparison scheme block will operate ~~the relay~~ whenever the carrier current signals are displaced in time. under relay operation no signal is transmitted at both ends. For phase comparison scheme, the line CTs are so connected that their secondary current are 180° out of phase under normal / External fault. Under internal fault, the current at one of the end reverses, the two currents are in phase, no signal received and the relay operates.

Explanation:— (1) 3 ϕ currents are reduced to a single phase quantity and is fed to network which is sensitive to negative sequence current. The o/p of this sequence ~~network~~ network is fed into the ~~starting modulator~~ transmitter through a low pass filter. This 50 Hz modulator fed into the transmitter modulator ~~through a low pass filter~~. The o/p of the modulator is partly fed to the mixer and partly amplified by amplifier and fed to the line through band pass filter and coupling equipment. The transmitted signal enters the receiver circuit through receiver band pass filter. It is then attenuated and passed into the mixer circuit. These mixture circuit receives two signals one from the local circuit and another from the end circuit. The phase relation of these signals is so arranged that it is 180° for normal operation of the system or external fault. 0° for internal fault.



1:- Primary current
2:- Secondary current
3. Transmitted signal
4. Received "
5. Locally derived signal
6. O/P.

MODULE- III

Generator protection

Stator fault :- (1) Phase to phase fault

(2) phase to ground fault

(3) inter-turn fault

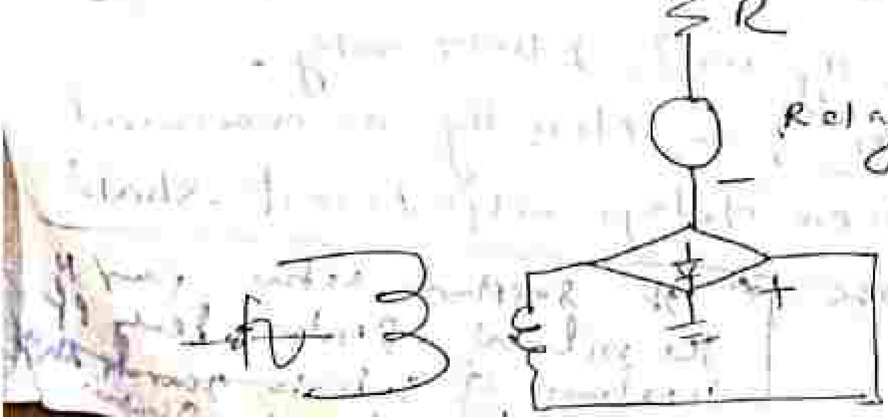
The phase to phase and interturn fault are less common are compared to the phase to ground fault.

Rotor fault (1) ground fault or short cut between the turn of the field winding g cause severe mechanical and thermal stresses acting upon the winding insulation

Abnormal running cond?

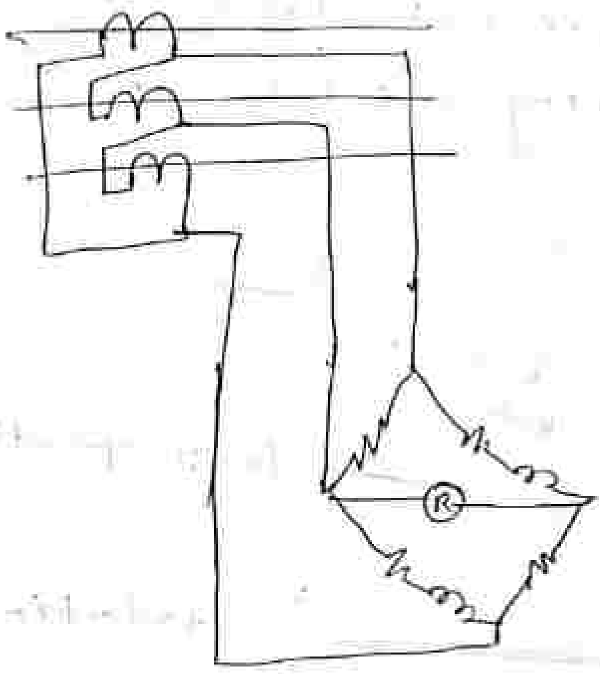
(1) unbalanced loading
(2) overloading
(3) overspeed
(4) overvoltage — faulty operation of the voltage regulator.
(5) failure of prime mover :-
(6) Loss of excitation induction generator.

Rotor protection :-



Small power supply is connected to the positive pole of the field circuit. A fault detecting relay and a high resistance to limit the current are connected in series with this circuit. A fault occurs at any point on the field circuit will pass a current through the relay to cause relay operation. The earth fault relay are instaneous and are connected to alarm circuit for indication.

<u>Unbalance Loading</u>



Negative sequence relay

Unbalance loading creates negative phase sequence current. The negative sequence current is ~~proportional~~ to fed to the relay with inverse square law characteristic i.e $I^2 t = K$ or $t = 1/I^2$

The relay normally used IDMT relay.

<u>Overload Protection</u> :— Normally an overcurrent relay with time delay adjustment should serve the purpose

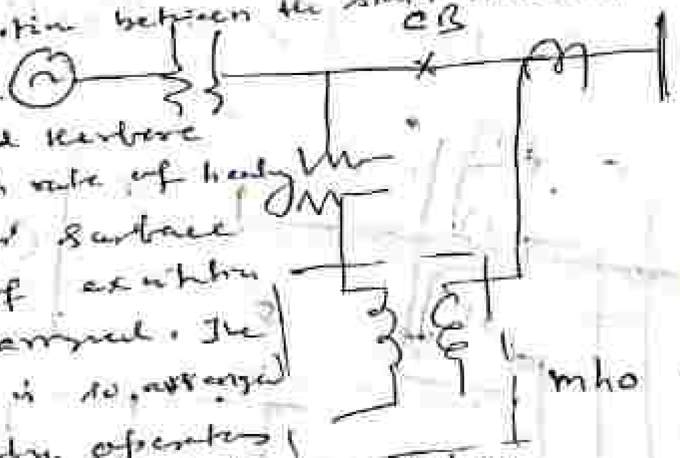
It supplies active power to the grid and operates leading p.f. [illegible] impedance of ~~Inductive generator~~ into [illegible] [illegible]

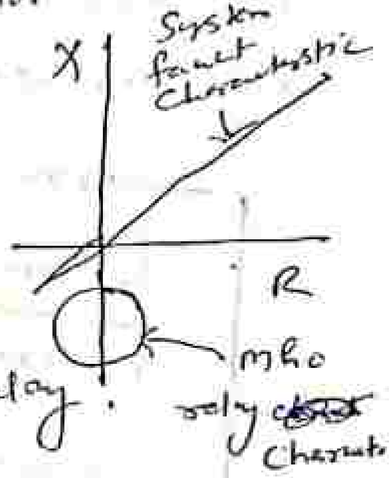
Overspeed protection :— wattmetric relay is used. The speed goes up whenever there is sudden loss of load.

Overvoltage protection :— a.c overvoltage relay is used which pick up value 110% of the normal value. The operation of the relay introduce resistance in the generator or exciter field circuit and if overvoltage persists

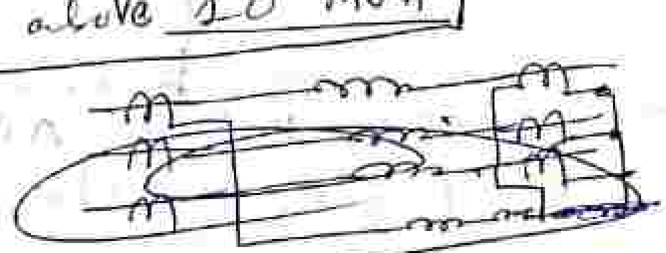
Failure of prime mover :— The wattmetric relay with directional characteristic is used.

Loss of excitation :— offset mho relay is used for this case. very large alternators can not be allowed to run asynchronously for long as the relative motion between the stator field and rotor induces large current on the rotor body and therefore there is high rate of heating of the rotor surface and loss of excitation scheme is arranged. The relay setting is so arranged that the relay operates whenever the excitation goes below a certain value and machine starts running asynchronously.



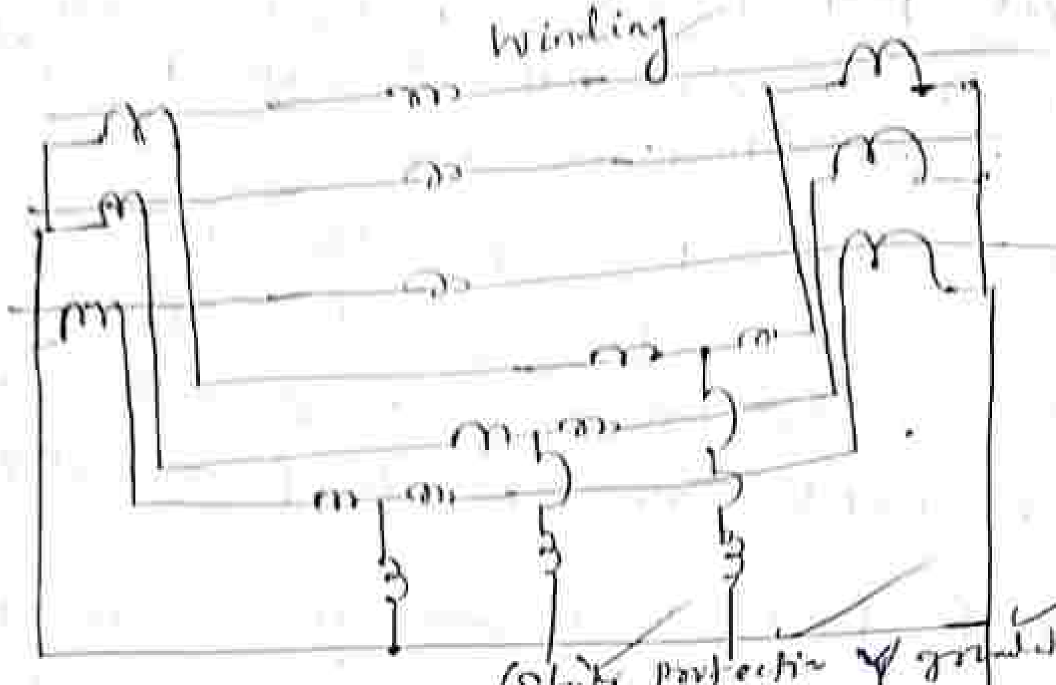


Stator protection :— It is required differential protection above 10 MVA



* Due to failure of excitation, the synchronous alternator now works as an induction generator and draws lagging reactive power from the grid, off course

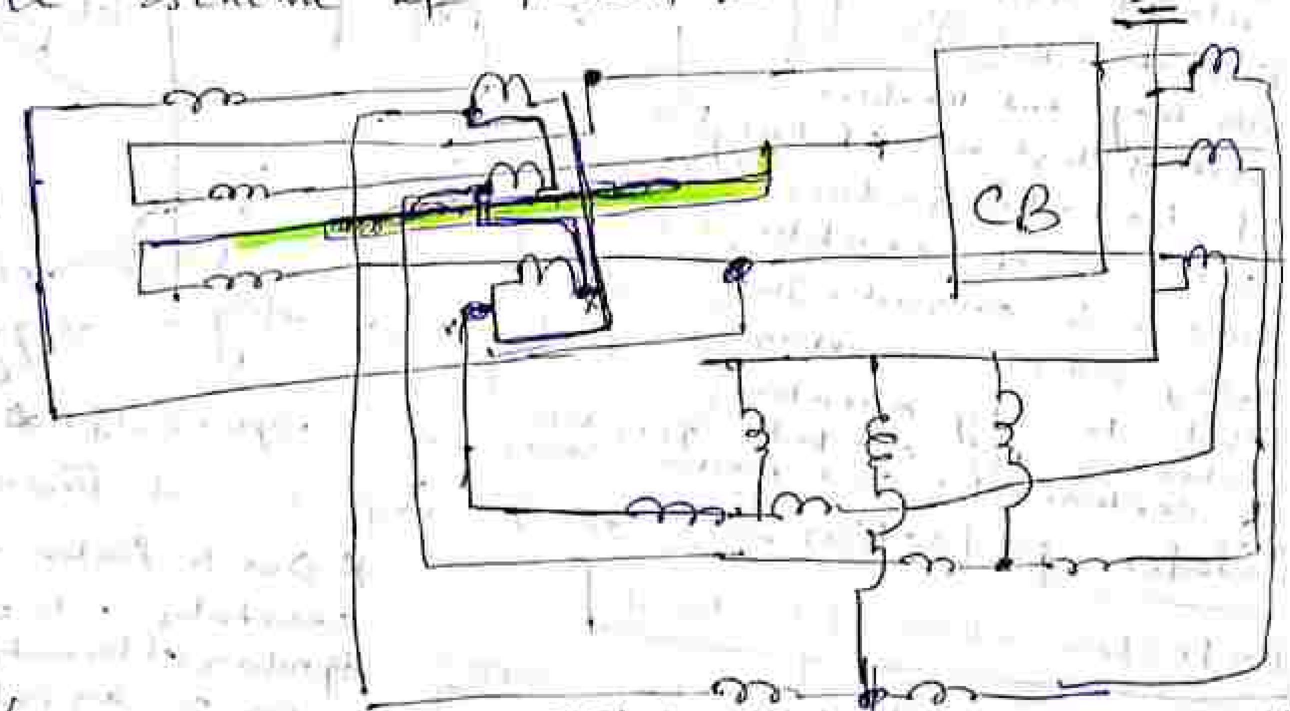
* under normal operating condition when a asynchronous alternator is connected to the grid it supplies reactive power to the system in addition to power and pf is lagging and impedance of ... relay first quadrant.



(Stator protection Y grounded alternator)

The percentage differential relay. It can be seen that for an external fault, the relay does not operate and for internal fault it does operate.

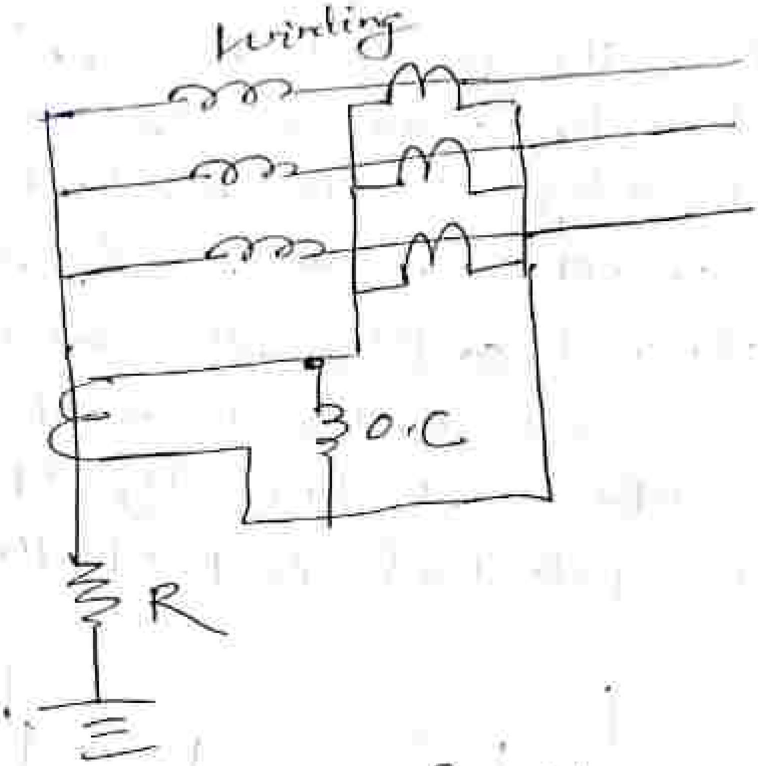
In case the generator Δ connected, gives the scheme of percentage differential protection



(Stator protection Δ connected alternator)

Restricted Earth fault protection :-

If the star point is not available because it is made inside the generator and if it is grounded through some low impedance, Percentage differential relaying for ground faults only can be provided. This is known as restricted earth fault protection is used.

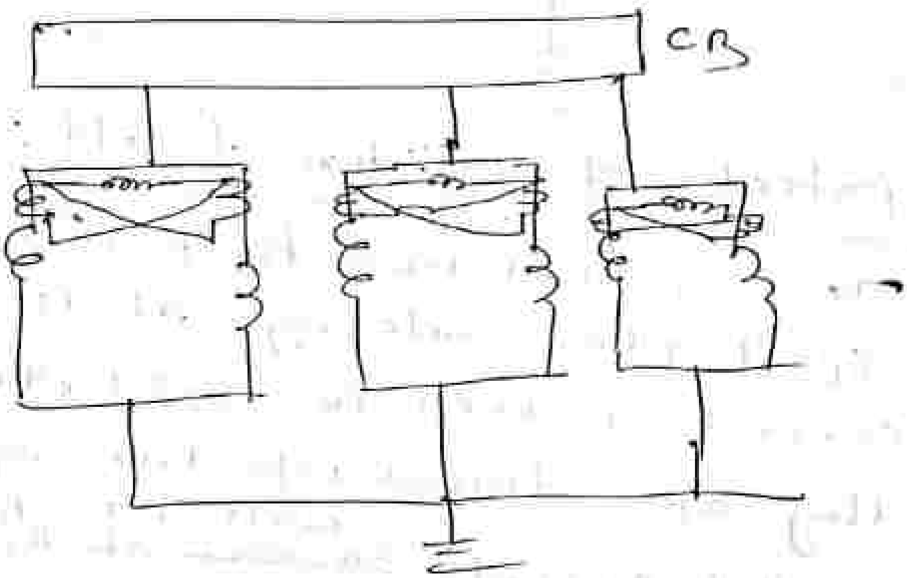


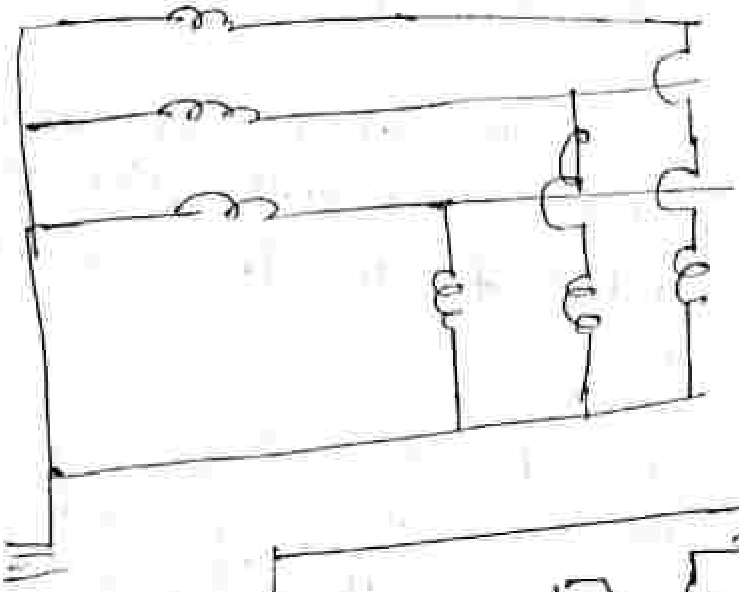
protection of inter turn fault:—

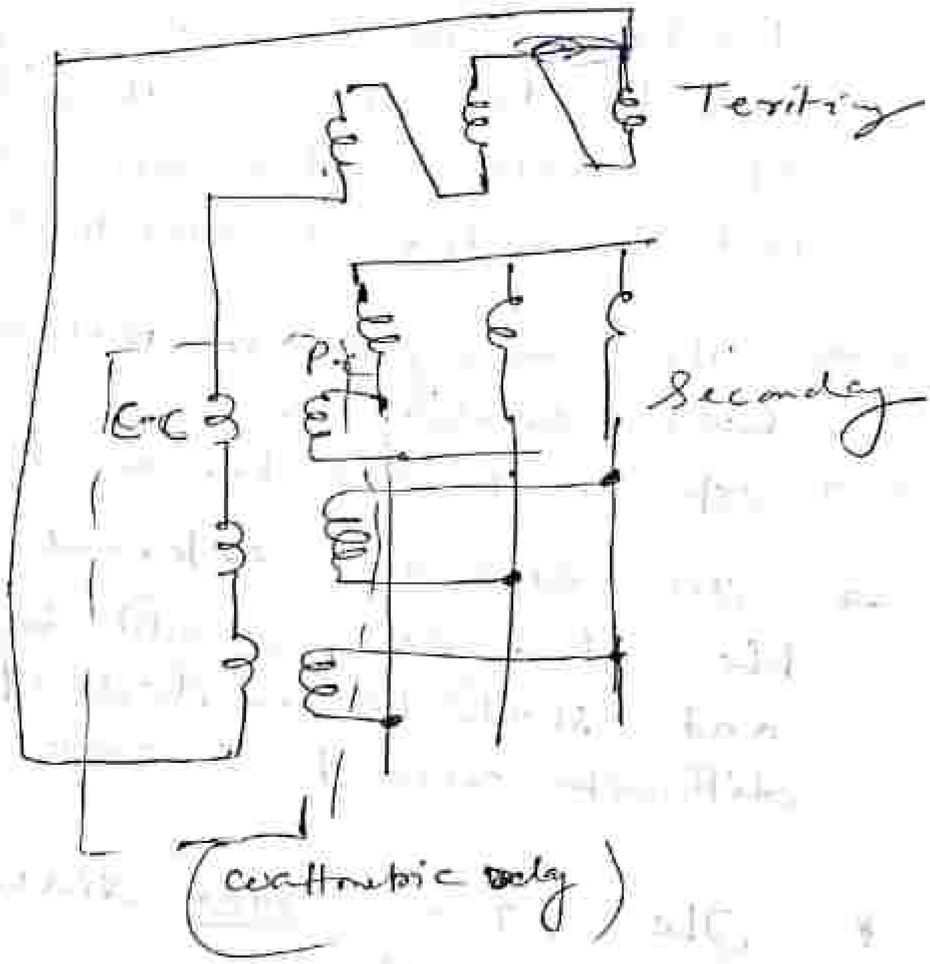
The method used for protection is known as split phase relaying. If the number of circuit is even for split phase protection, they are divided into two equal groups of parallel circuits ~~in each of the two groups~~ with CT for each group.
If the no. of is odd, the no. of ckts in each of the two groups will not be equal and the CT must have different primary current ratings so that under normal cond^n their secondary current will be equal.

For protection of inter-turn fault

winding having one ckt per phase, one of the method suggested uses a five limb V.T with tertiary winding. The tertiary winding along with secondary winding wattmetric relay is used. The H.V winding is connected between the neutral and line terminal of the alternator. The voltage across the tertiary winding is the residual voltage which in normal condition is zero and some voltage under abnormal condn. The residual voltage circulating current in the current coil of the relay and secondary of the transformer feeds the potential coil of the relay element.







Teritiry
P.C
C.C
Secondry
(wattmetric relay)

Protection of Transformer :-

→ For protection of transformer under short ckt and overheating, percentage differential protection is recommended for transformer rated for more than 1 MVA.

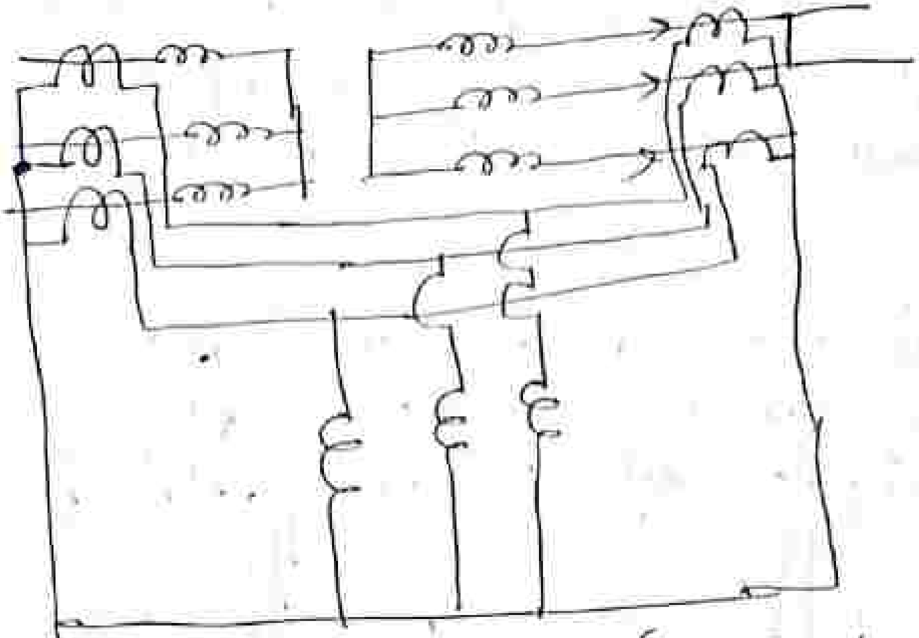
→ The primary and secondary current of a transformer are normally different. These currents from each other by 30°. In case of winding star-delta connected, differential protection scheme is considered.

→ The relay must not operate under normal load condition.

→ It must operate on internal fault condn.

→ In case of external fault condition, the two CTs should be equal in magnitude and should be in phase opposition so that different current is zero.

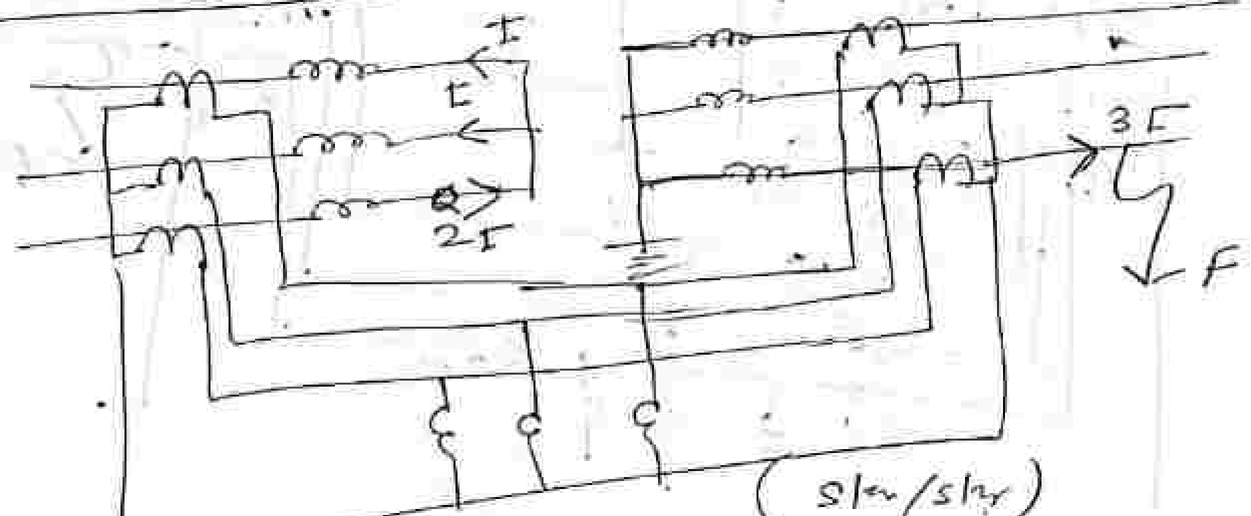
* The CT on star side of power transformer are in delta and on the delta side they are connected in star. The line current of star-delta power transfn will be displaced by 30°. In order to reduce the phase displacement, required is that to be connected by such fashion



(Star-Star) transformer

→ In this case star point of both transformer is ungrounded. When line to ground fault occurs, no fault current can flow. For external fault there will be no current through the operating coil. The relay will not operate.

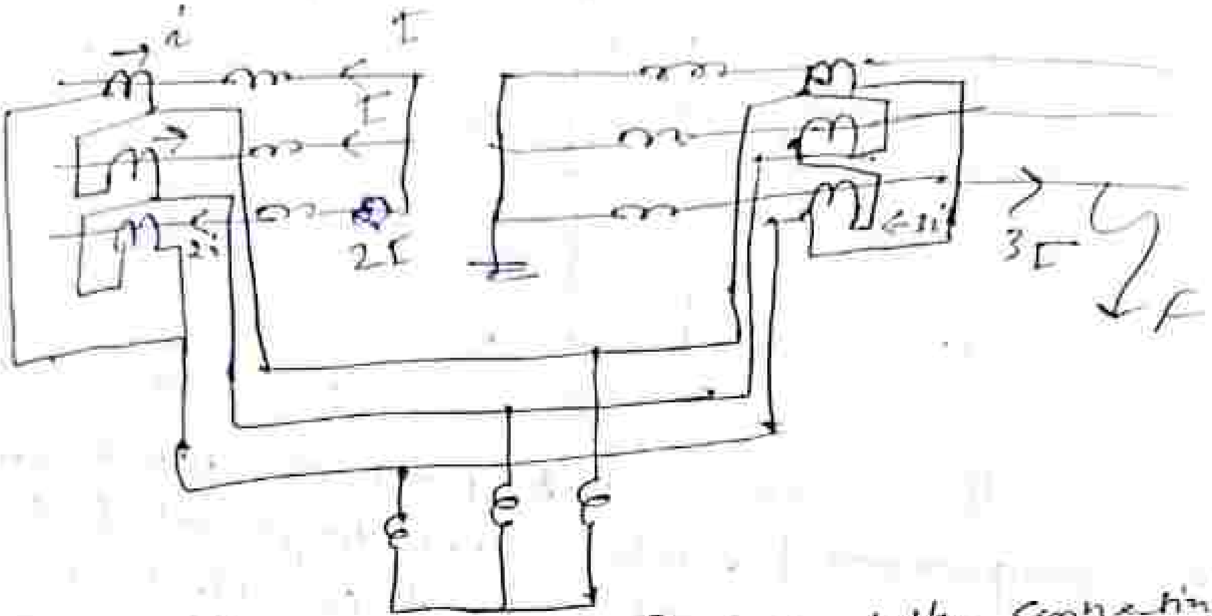
Star point is grounded :—



(star/star)

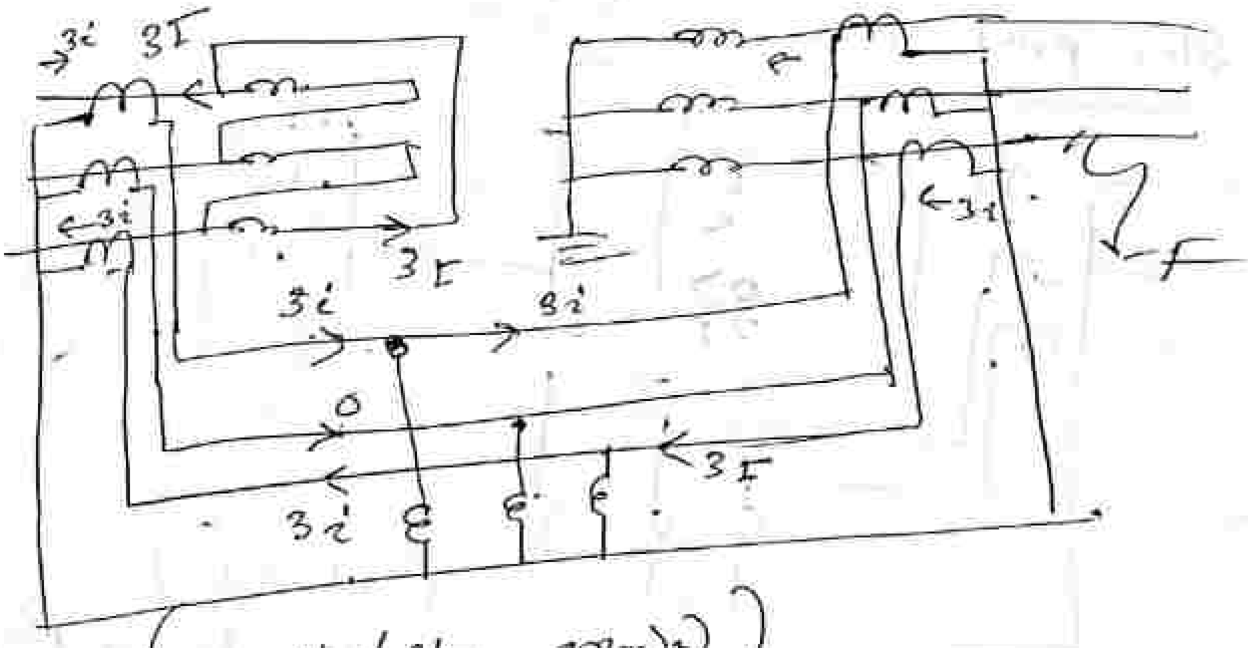
Assume that unity transformation ratio, If the fault current on the secondary side is 3I, only 2I current will be supplied by the primary. This type of connection is known as Zero sequence current generator.

In case of through fault, the current circulate through the operating coil of the relay and relay will operate which is not desirable.



(Star/Star grounded CT, delta connection)

In the case of external fault, the relay do not operate.



(Delta/Star grounded)

Problem :-

A 3 phase transformer rated 33 kV/6.6 kV is connected star/delta and the protecting current transformer on the low voltage side have a ratio of 400/5. Determine the ratio of current transformer on HV side.

Soln :- Low voltage side is delta, the CT on that side will be star.

A Y Δ (33/6.6 kV) 400 Y ~~[illegible]~~ 5

The line current on the star side of the power transformer

$$\frac{I_1}{I_2} = K \quad \therefore I_1 = I_2 \times K$$
$$= 400 \times \frac{6.6}{33}$$
$$= 80 \text{ Amp.}$$

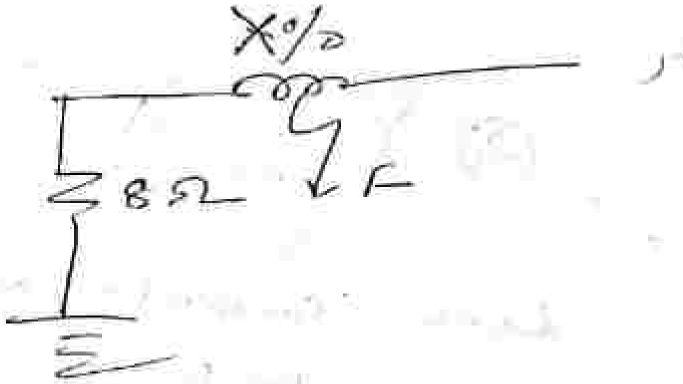
The CT on the star side are delta connected and the current required on relay side of CT is 5 Amp. The current in the CT secondary is $5/\sqrt{3}$.

The CT ratio on the HT side is

$$\left(80 : 5/\sqrt{3}\right)$$

A 6.6 kV, 5 MVA star connected alternator has a reactance 1.5 ohm/phase and negligible resistance. Mertz price protection scheme is used which operates when the out of balance current exceeds 25% of the full load current. The neutral of the generator through a resistance of 8 ohms. Determine the proportion of the winding which remains unprotected against earth fault. Show that alternator reactance can be ignored.

[illegible]



reactance of the winding ∝ square of the current. $x_g \propto n^2$

The number of turns will be $\frac{xN}{100}$

The reactance of the unprotection winding will be $\frac{1.5x^2N^2}{100^2}$

The voltage of the unprotected portion $= 3810\frac{x}{100}$

The fault current $= 3810 \times \frac{x}{100} \times \frac{1}{8}$ amps full load current $= \frac{5000}{\sqrt{3} \times 6.6} = 437.37$ amp

(c) out of balance current required for the operation of the relay

$437.37 \times 0.25 = 109.34$ A

$$\frac{3810x}{8 \omega} = 109.34$$

$x = 22.95\%$

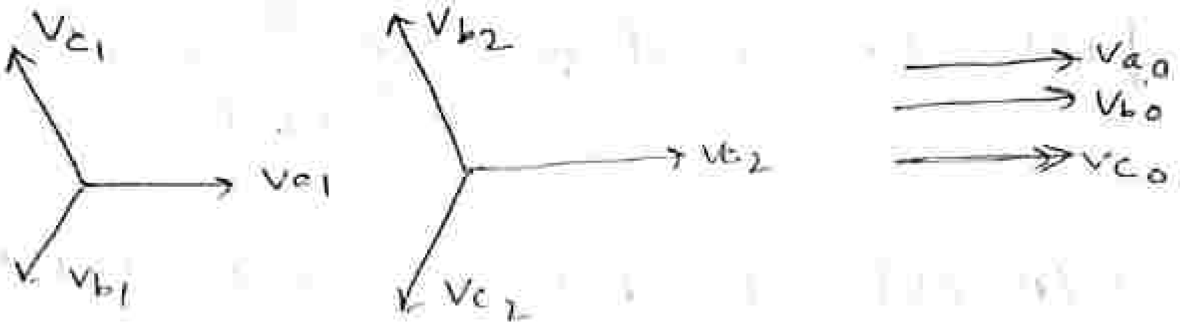
Symmetrical component and System

According to Fortescue's theorem, the three unbalanced vector V_a, V_b and V_c can be replaced by three unbalanced vectors.

positive sequence component :— It has three vectors equals in magnitude but displaced to in phase each other by 120° and has the phase sequence as the original vectors.

Negative sequence component :— Negative sequence component has three vectors equal in magnitude but at displaced from each other by 120° and phase sequence opposite to the original vectors.

(3) Zero sequence component :— Zero sequence component which has three vectors of equal magnitude and also are in phase with each other



$$V_a = V_{a1} + V_{a2} + V_{a0}$$
$$V_b = V_{b1} + V_{b2} + V_{b0}$$
$$V_c = V_{c1} + V_{c2} + V_{c0}$$

$$\lambda = 1\angle 120^\circ$$
$$\lambda^2 = 1\angle -120^\circ$$
$$\lambda^3 = 1\angle 0^\circ$$
$$\lambda^4 = \lambda \qquad \lambda^2 + \lambda + 1 = 0$$

$$\left.\begin{aligned} V_a &= V_{a1} + V_{a2} + V_{a0} \\ V_b &= \lambda^2 V_{a1} + \lambda V_{a2} + V_{a0} \\ V_c &= \lambda V_{a1} + \lambda^2 V_{a2} + V_{a0} \end{aligned}\right\}$$

$$I_a = I_{a1} + I_{a2} + I_{a0}$$
$$I_b = \lambda^2 I_{a1} + \lambda I_{a2} + I_{a0}$$
$$I_c = \lambda I_{a1} + \lambda^2 I_{a2} + I_{a0}$$

$$V_a + \lambda V_b + \lambda^2 V_c = V_{a1}(1 + \lambda^3 + \lambda^3) + V_{a2}(1 + \lambda^2 + \lambda^4) + V_{a0}(1 + \lambda + \lambda^2)$$
$$= 3V_{a1} + V_{a2}(1 + \lambda^2 + \lambda) + 0$$
$$= 3V_{a1}$$

$$\therefore V_{a1} = \frac{1}{3}(V_a + \lambda V_b + \lambda^2 V_c)$$

$$V_a + \lambda^2 V_b + \lambda V_c = V_{a_1}(1+\lambda^4+\lambda^2)$$
$$+ V_{a_0}(1+\lambda^3+\lambda^3) + V_{a_0}(1+\lambda^2+\lambda) = 3V_{a_0}$$

$$V_{a_2} = \frac{1}{3}(V_a + \lambda^2 V_b + \lambda V_c)$$

$$V_a + V_b + V_c = V_{a_1}(1+\lambda^2+\lambda) + V_{a_2}(1+\lambda+\lambda^2)$$
$$+ 3V_{a_0}$$

$$V_{a_0} = \frac{1}{3}(V_a + V_b + C)$$

$$V_{a_1} = \frac{1}{3}(V_a + \lambda V_b + \lambda^2 V_c)$$
$$V_{a_2} = \frac{1}{3}(V_a + \lambda^2 V_b + \lambda V_c)$$
$$V_{a_0} = \frac{1}{3}(V_a + V_b + V_c)$$
$$I_{a_1} = \frac{1}{3}(I_a + \lambda I_b + \lambda^2 I_c)$$
$$I_{a_2} = \frac{1}{3}(I_a + \lambda^2 I_b + \lambda . I_c)$$
$$I_{a_0} = \frac{1}{3}(I_a + \cancel{I_b + I_c})$$

Average 3 phase power in terms of symmetrical component

$$P = V_a I_a \cos\phi_a + V_b I_b \cos\phi_b + V_c I_c \cos\phi_c$$
$$= V_a . I_a + V_b I_b + V_c I_c$$

$$(V_{a_1} + V_{a_2} + V_{a_0})(I_{a_1} + I_{a_2} + I_{a_0})$$
$$+ (\lambda^2 V_{a_1} + \lambda V_{a_2} + V_{a_0})(\lambda^2 I_{a_1} + \lambda I_{a_2} + I_{a_0})$$
$$+ (\lambda V_{a_1} + \lambda^2 V_{a_2} + V_{a_0})(\lambda I_{a_1} + \lambda^2 I_{a_2} + I_{a_0})$$

$\Rightarrow V_{a1}I_{a1} + V_{a1}I_{a2} + V_{a1}I_{a0} + V_{a2}I_{a1} + V_{a2}I_{a2} + V_{a2}I_{a0}$

$+ V_{a0}I_{a1} + V_{a0}I_{a2} + V_{a0}I_{a0}$

$\cancel{+ \lambda^4 V_{a1}I_{a1} + \lambda^3 V_{a1}I_{a2} + \lambda^2 V_{a1}I_{a0} + \lambda V_{a1}I_{a1} + \lambda V_{a1}I_{a2}}$

$\cancel{+ \lambda V_{a1}I_{a0} + V_{a0}I_{a0}}$

$+ \lambda^4 V_{a1}I_{a} + \cancel{\lambda^3 V_{a1}I_{a2} + V_{a0}}$

$\lambda^4 V_{a1}I_{a1} + \lambda^3 V_{a1}I_{a2} + \lambda^2 V_{a1}I_{a0}$

$+ \lambda^3 V_{a2}I_{a1} + \lambda^2 V_{a2}I_{a2} +$

Taking first terms on the R.H.S

$(V_{a1} + V_{a2} + V_{a0})(I_{a1} + I_{a2} + I_{a0})$

$= V_{a1}I_{a1} + V_{a2}I_{a2} + V_{a0}I_{a0} + V_{a1}I_{a2} + V_{a1}I_{a0}$

$+ V_{a2}I_{a1} + V_{a2}I_{a0} + V_{a0}I_{a1} + V_{a0}I_{a2}$

2nd term

$(\lambda^2 V_{a1} + \lambda V_{a2} + V_{a0})(\lambda^2 I_{a1} + \lambda I_{a2} + I_{a0})$

$= \lambda^2 V_{a1} \cdot \lambda^2 I_{a2} + \lambda^2 V_{a1} \cdot \lambda I_{a2} + \lambda^2 V_{a1} \cdot I_{a0} + \lambda V_{a2} \cdot \lambda^2 I$

$+ \lambda V_{a2} \cdot \lambda I_{a2} + \lambda V_{a2} \cdot I_{a}$

$+ V_{a0} \cdot \lambda^2 I_{a1} + V_{a0} \cdot \lambda I_{a2} + V_{a0} I_{a}$

$$\left[\begin{array}{l} \lambda^2 V_{a1} \cdot \lambda^2 I_{a1} = V_{a1} \cdot I_{a1} \\ \lambda^2 V_{a1} \cdot \lambda I_{a2} = \lambda V_{a1} \cdot I_{a2} \end{array}\right]$$

$P_{over} = 3 V_0 I_{a0} + 3 V_{a2} I_{a2} + 3 V_{a1} I_{a1} +$

$+ V_{a1} I_{a2} (1 + \lambda + \lambda^2) + V_{a1} I_{a0} (1 + \lambda + \lambda^2)$

$$+V_{a_2} I_{a_1} (1+\lambda+\lambda^2)$$

$$+V_{a_2} I_{a_0} (1+\lambda+\lambda^2) + V_{a_0} I_{a_1} (1+\lambda+\lambda^2)$$

$$+V_{a_0} I_{a_0} (1+\lambda+\lambda^2)$$

$$= 3 (V_{a_1} I_{a_1} + V_{a_2} I_{a_2} + V_{a_0} I_{a_0})$$

$$= 3 [|V_{a_1}| I_{a_1} \cos\theta_1 + |V_{a_2}| |I_{a_2}| \cos\theta_2 + V_{a_0} I_{a_0} \cos\theta_0$$

$$P + jQ = V_a I_a^* + V_b I_b^* + V_c I_c^*$$

$$= \begin{bmatrix} V_a & V_b & V_c \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

$$= \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}^T \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \underset{A}{\begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda^2 & \lambda \\ 1 & \lambda & \lambda^2 \end{bmatrix}} \underset{V}{\begin{bmatrix} V_{a_0} \\ V_{a_1} \\ V_{a_2} \end{bmatrix}} = AV$$

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}^T = [AV]^T = V^T A^T$$

$$(P+jQ) = \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}^T \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

$$= \begin{bmatrix} V_{a_0} & V_{a_1} & V_{a_2} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda^2 & \lambda \\ 1 & \lambda & \lambda^2 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^*$$

$$\begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix}^* = \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda^2 & \lambda \\ 1 & \lambda & \lambda^2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}^*$$

$$= \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}^*$$

$(3+j4)(3-j4)$

$$(P+jQ) = \begin{bmatrix} V_{a0} & V_{a1} & V_{a2} \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda^2 & \lambda \\ 1 & \lambda & \lambda^2 \end{bmatrix} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \lambda & \lambda^2 \\ 1 & \lambda^2 & \lambda \end{bmatrix} \begin{bmatrix} I \\ I \\ I \end{bmatrix}$$

$$= \begin{bmatrix} V_{a0} & V_{a1} & V_{a2} \end{bmatrix} \begin{bmatrix} 3 & 0 & 0 \\ 0 & 3 & 0 \\ 0 & 0 & 3 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

$$= 3 \begin{bmatrix} V_{a0} & V_{a1} & V_{a2} \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}^*$$

$$= 3 \left[V_{a0} I_{a0}^* + V_{a1} I_{a1}^* + V_{a2} I_{a2}^* \right]$$

$$P = 3 \left[V_{a0} I_{a0} \cos\theta_0 + V_{a1} I_{a1} \cos\theta_1 + V_{a2} I_{a2} \cos\theta_2 \right]$$

The potential of the neutral $V_n = -I_n Z_n$ where Z_n is the neutral grounding impedances and I_n is the neutral current. The negative sign is used as the current flow from the ground to the neutral and potential of the neutral is lower than the ground

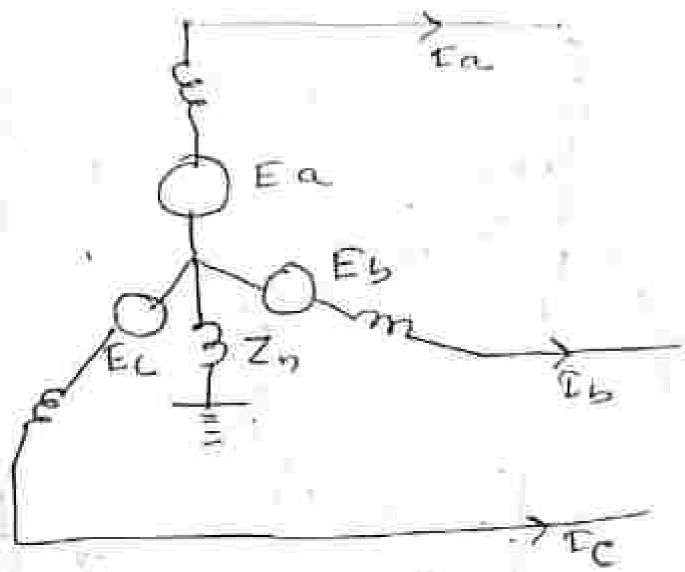
$$I_n = I_a + I_b + I_c$$
$$= (I_{a1} + I_{a2} + I_{a0}) + (\lambda^2 I_{a1} + \lambda I_{a2} + \lambda I_{a1})$$

$+ (\lambda I_{a_1} + \lambda^2 I_{a_2} + I_{a_0})$

$\Rightarrow I_a (1+\lambda+\lambda^2) + I_{a_2}(1+\lambda+\lambda^2) + 3I_{a_0}$

$= 3I_{a_0}$ $\quad V_n = -3I_{a_0}Z_n$.

Sequence Network equation



→ These equations will be derived for an unloaded alternator with neutral solidly grounded, assuming that the system is balanced. The positive sequence component of voltage at the fault point is the positive sequence generated voltage minus the drop due to positive sequence current

$$V_{a_1} = E_a - I_a Z_1$$

The negative sequence component of voltage at the fault point is the generated sequence voltage minus the drop due to negative sequence current.

$$V_{a_2} = E_{a_2} - I_{a_2} Z_2$$

$$E_{a_2} = 0$$

$$V_{a_2} = -I_{a_2} Z_2$$

for zero sequence voltage $E_{a_0} = 0$

$$V_{a_0} = V_n - I_{a_0} Z_{g0}$$

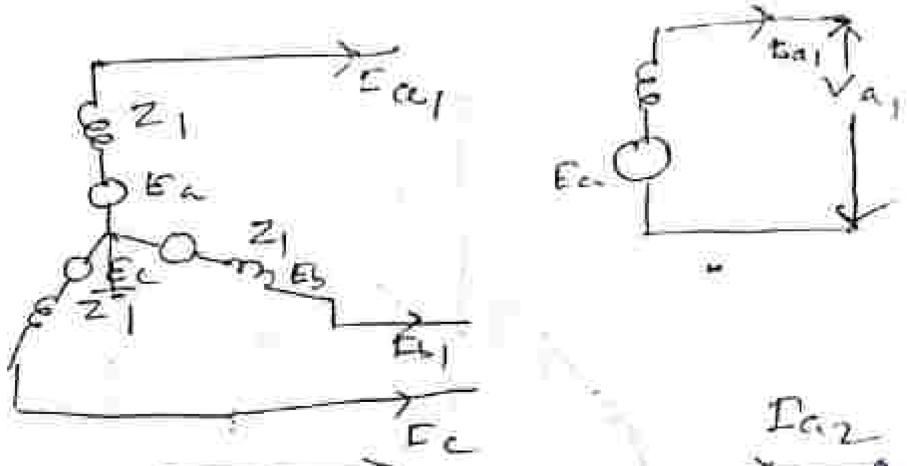
$$= -3I_{a_0}Z_n - I_{a_0}Z_{g0}$$

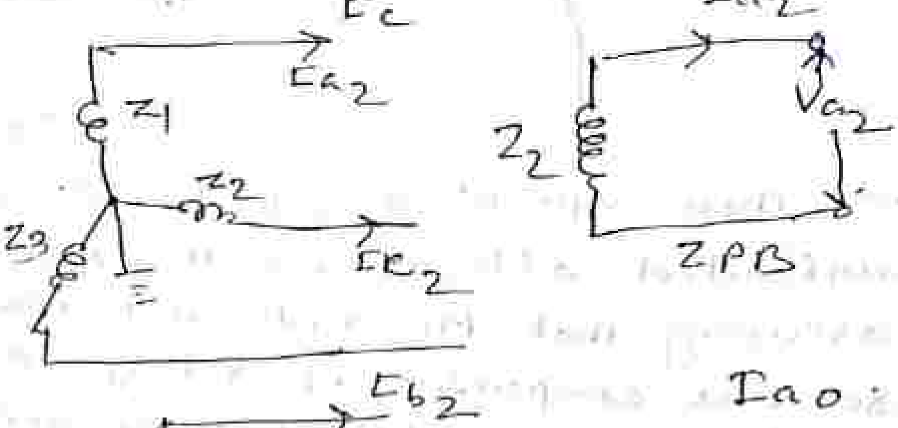
$$= -I_{a_0}(3Z_n + Z_{g0})$$

Z_{g0} is the zero sequence impedance.
Z_n is the neutral impedance.

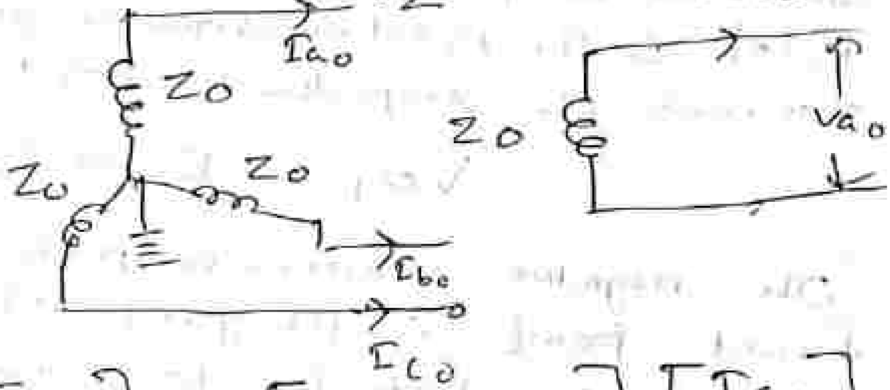
$$V_{a1} = E_a - I_{a1} Z_1$$
$$V_{a2} = -I_{a2} Z_2$$
$$V_{a0} = -I_{a0} Z_0$$

$$Z_0 = Z_{g0} + 3Z_n$$





I_{a0}:



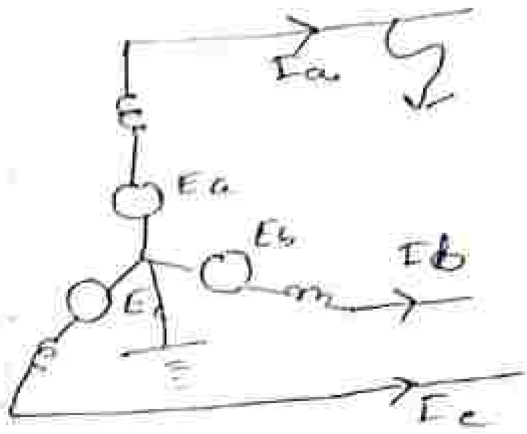
$$\begin{bmatrix} V_{a0} \\ V_{a1} \\ V_{a2} \end{bmatrix} = \begin{bmatrix} 0 \\ E_a \\ 0 \end{bmatrix} - \begin{bmatrix} Z_0 & 0 & 0 \\ 0 & Z_1 & 0 \\ 0 & 0 & Z_2 \end{bmatrix} \begin{bmatrix} I_{a0} \\ I_{a1} \\ I_{a2} \end{bmatrix}$$

Single line to ground fault:—

The boundary conditions are

$$V_a = 0$$
$$I_b = 0$$
$$I_c = 0$$

$$V_{a0} = -I_{a0}Z_0$$



$$V_{a1} = E_a - I_{a1}Z_1$$

$$V_{a2} = -I_{a2}Z_2$$

$$I_{a1} = \frac{1}{3}\left(I_a + \lambda I_b + \lambda^2 I_c\right)$$

$$I_{a2} = \frac{1}{3}\left(I_a + \lambda^2 I_b + \lambda I_c\right)$$

$$I_{a0} = \frac{1}{3}\left(I_a + I_b + I_c\right)$$

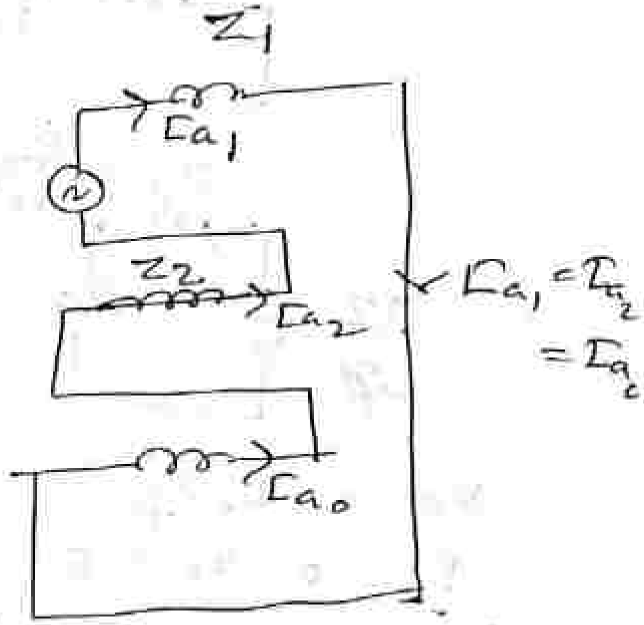
$$I_{a1} = I_{a2} = I_{a0} = I_a/3$$

$$V_a = 0 = V_{a1} + V_{a2} + V_{a0}$$

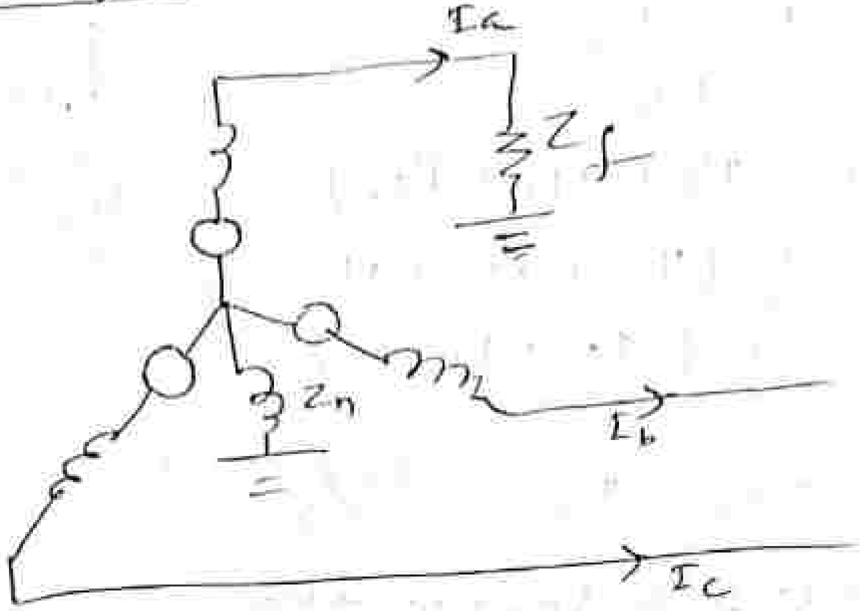
$$E_a - I_{a1}Z_1 - I_{a2}Z_2 - I_{a0}Z_0 = 0$$

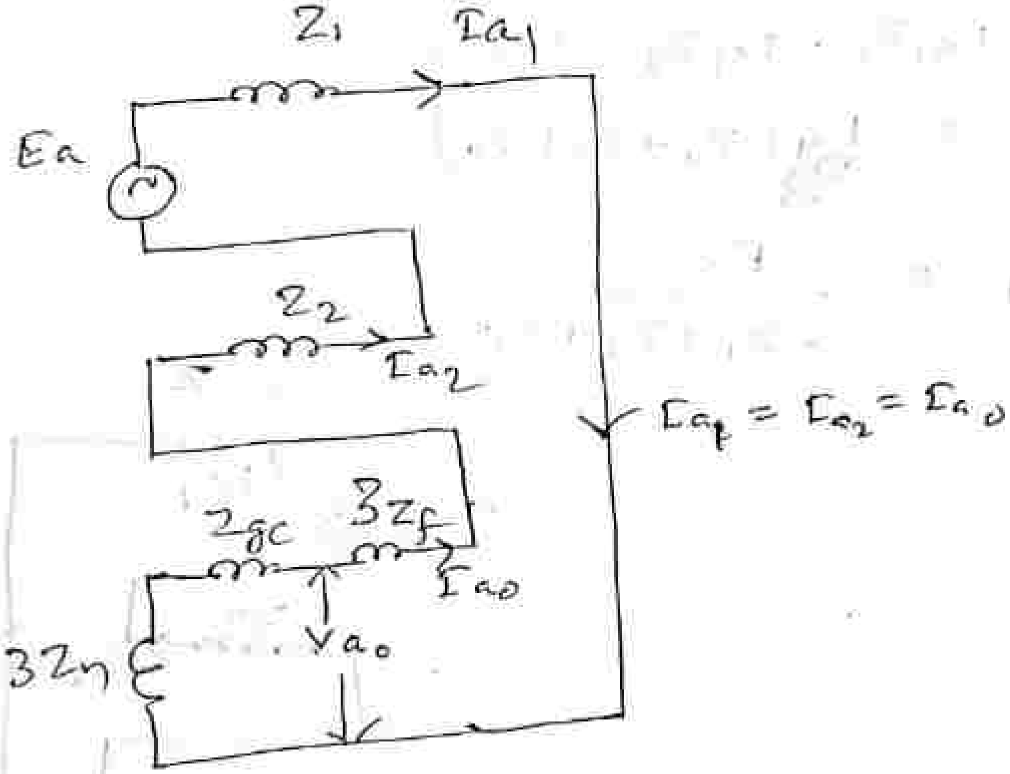
$$E_a = I_{a1}(Z_1 + Z_2 + Z_0)$$

$$I_{a1} = \frac{E_a}{Z_1 + Z_2 + Z_0}$$



Line to ground fault with Z_f





$V_a = I_a Z_f$

$I_b = 0 \quad I_c = 0$

$V_{a0} = -I_{a0}(Z_{g0} + 3Z_n)$

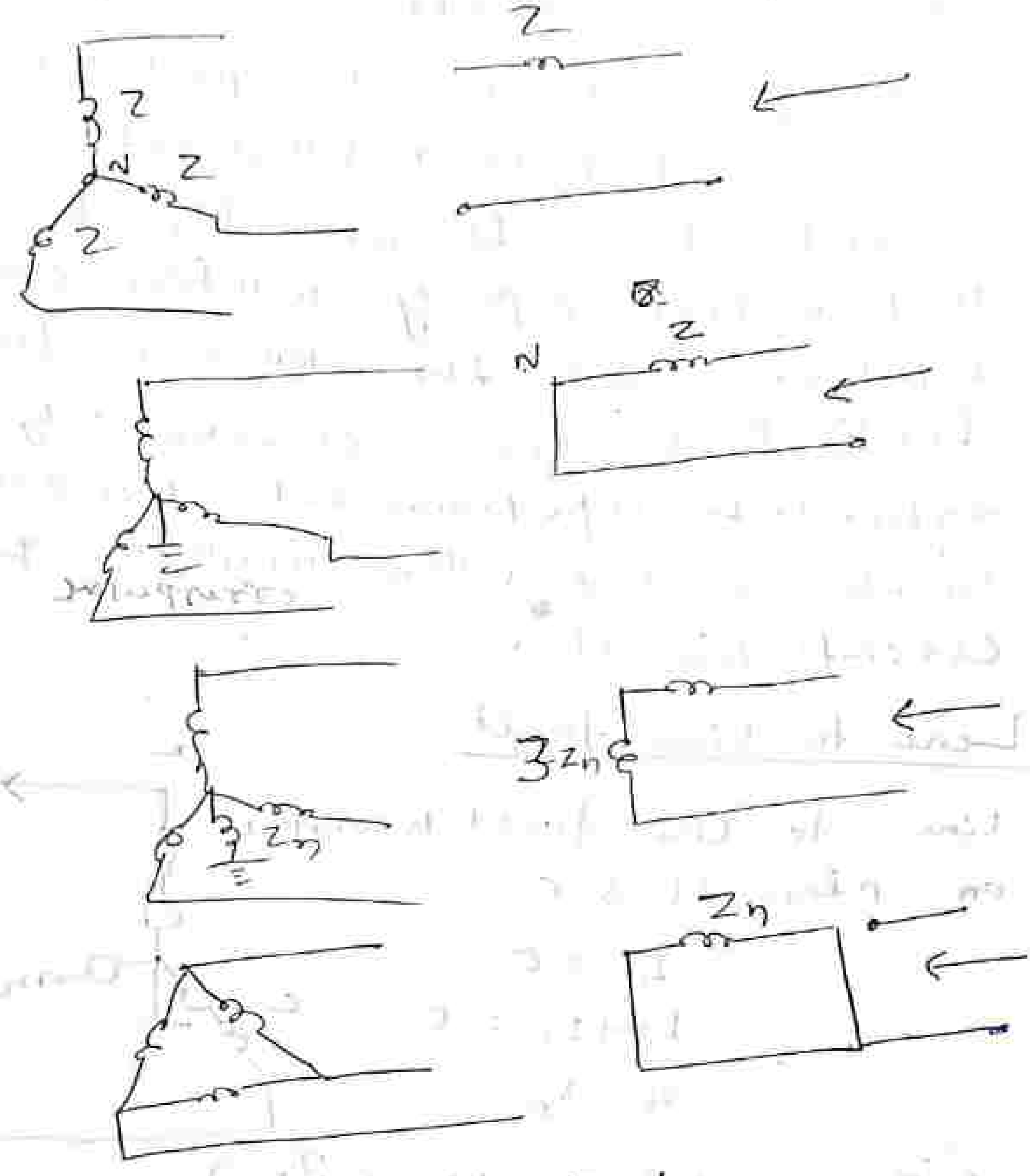
$V_{a1} = E_a - I_{a1} Z_1 \, , \; V_{a2} = -I_{a2} Z_2$

$$I_{a1} = I_{a2} = I_{a0} = I_a/3$$

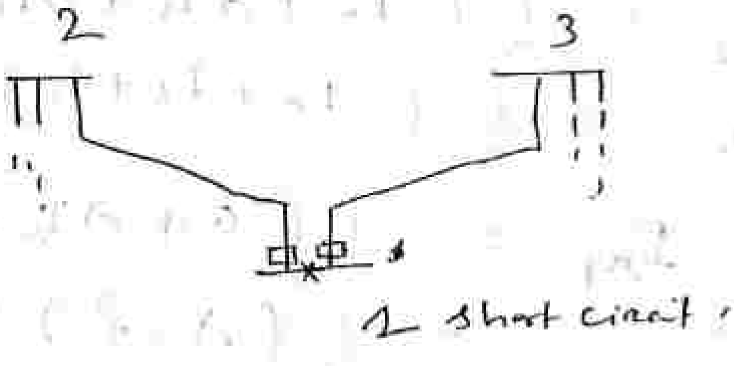
$$V_{a1} + V_{a2} + V_{a0} = V_a = 3 I_{a1} (Z_f)$$

$$E_a - I_{a1}Z_1 - I_{a2}Z_2 - I_{a1}(Z_0+3Z_n) = 3I_{a1}Z_f$$

$$\therefore \quad I_{a1} = \frac{E_a}{Z_1+Z_2+(Z_0+3Z_n)+3Z_f}$$



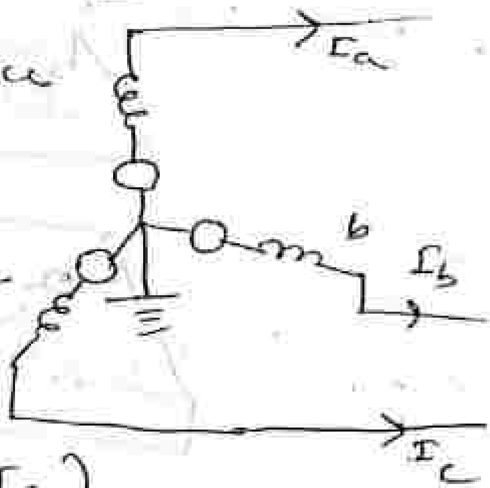
Short circuit capacity of a bus



→ Let us consider symmetrical fault occurs at bus 1. The prefault voltage of bus is 1 p.u. When fault occurs the voltage is zero. The voltage of the other buses will be during short circuit. The short-circuit capacity is defined as the product of the magnitude of prefault voltage and post fault current. For a bus which has infinite short circuit capacity will have zero equivalent impedance. This bus is known as infinite bus. Such a bus is characterized by a zero equivalent impedance and it is able to maintain constant voltage irrespective of short circuit takes place.

Line to Line fault

Line to line fault takes place on phase - b & c



$$I_a = 0$$
$$I_b + I_c = 0$$
$$V_b = V_c$$

$$I_{a_1} = \frac{1}{3}\left(I_a + \lambda I_b + \lambda^2 I_c\right)$$
$$I_{a_2} = \frac{1}{3}\left(I_a + \lambda^2 I_b + \lambda I_c\right)$$
$$I_{a_0} = \frac{1}{3}\left(I_a + I_b + I_c\right)$$

$$I_{a_1} = \frac{1}{3}\left(0 + \lambda I_b - \lambda^2 I_b\right)$$
$$= \frac{1}{3}\left(\lambda - \lambda^2\right) I_b$$

$$I_{a_2} = \frac{1}{3}\left(0 + \lambda^2 I_b - \lambda I_b\right)$$

$$= \frac{I_b}{3}\left(\lambda^2 - \lambda\right)$$

$$I_{a_0} = \frac{1}{3}(0+0) = 0$$

In a line to line fault zero sequence component is absent. The positive sequence component of current is equal in magnitude but opposite in phase to negative sequence component of current.

$$\boxed{I_{a_1} = -I_{a_2}}$$

$$V_b = V_{a_0} + \lambda^2 V_{a_1} + \lambda V_{a_2}$$

$$V_c = V_{a_0} + \lambda V_{a_1} + \lambda^2 V_{a_2}$$

$$V_{a_0} + \lambda^2 V_{a_1} + \lambda V_{a_2} = V_{a_0} + \lambda V_{a_1} + \lambda^2 V_{a_2}$$

$$(\lambda^2 - \lambda) V_{a_1} = (\lambda^2 - \lambda) V_{a_2}$$

$$V_{a_1} = V_{a_2}$$

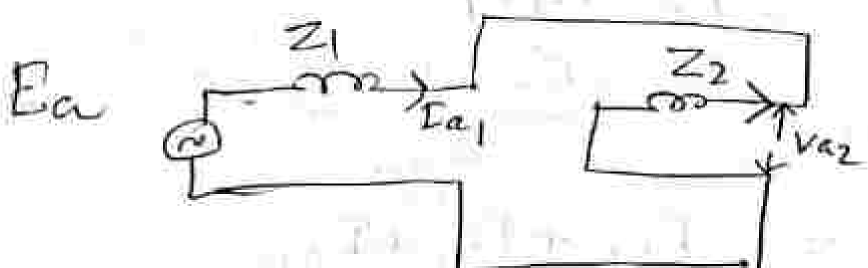
$$E_a - I_{a_1} Z_1 = -I_{a_2} Z_2$$

$$E_a - I_{a_1} Z_1 = I_{a_1} Z_1$$

$$E_a = I_{a_1} Z_1 + I_{a_1} Z_2$$

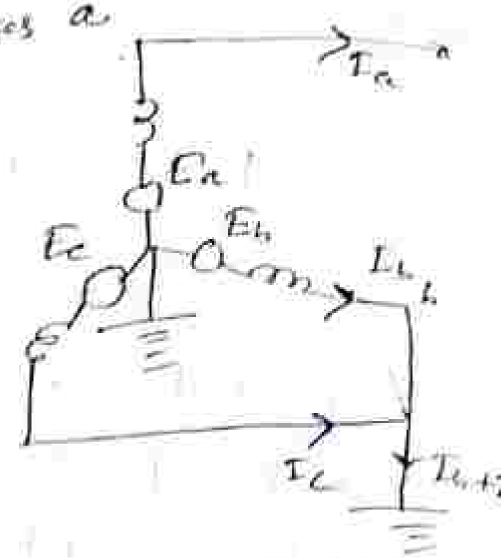
$$= I_{a_1}(Z_1 + Z_2)$$

$$\boxed{I_{a_1} = \frac{E_a}{Z_1 + Z_2}}$$



Double Line to ground fault

Double line to ground fault takes a place on phase b and c.



$$\left.\begin{array}{l} I_a = 0 \\ V_b = 0 \\ V_c = 0 \end{array}\right\} C$$

$$V_{a0} = \frac{1}{3}(V_a + V_b + V_c)$$

$$= \frac{V_a}{3}$$

$$V_{a1} = \frac{1}{3}(V_a + \lambda V_b + \lambda^2 V_c)$$

$$= \frac{V_a}{3}$$

$$V_{a2} = \frac{1}{3}(V_a + \lambda^2 V_b + \lambda V_c)$$

$$= \frac{V_a}{3}$$

$$V_{a0} = V_{a1} = V_{a2} \quad (1)$$

$$V_{a0} = V_{a1}$$

$$-I_{a0}Z_0 = E - I_{a1}Z_1$$

$$I_{a0} = -\frac{E - I_{a1}Z_1}{Z_0}$$

$$V_{a2} = V_{a1} \quad (2^{nd}\ cond^n)$$

$$-I_{a2}Z_2 = E_a - I_{a1}Z_1$$

$$\therefore I_{a2} = -\frac{E_a - I_{a1}Z_1}{Z_2}$$

$$I_a = I_{a1} + I_{a2} + I_{a0}$$

$$0 = I_{a1} + I_{a2} + I_{a0}$$

$$I_{a_1} - \frac{E_a - I_{a_1}Z_1}{Z_2} - \frac{E_a - I_{a_1}Z_1}{Z_0} = 0$$

$$I_{a_1}\left[1 - \frac{E_a - I_{a_1}Z_1}{Z_2} -\right.$$

$$I_{a_1} = \frac{E_a - I_{a_1}Z_1}{Z_2} + \frac{E_a - I_{a_1}Z_1}{Z_0}$$

$$= \left(E_a - I_{a_1}Z_1\right)\left(\frac{1}{Z_2} + \frac{1}{Z_0}\right)$$

$$= \left(E_a - I_{a_1}Z_1\right)\left(\frac{Z_0 + Z_2}{Z_2 Z_0}\right)$$

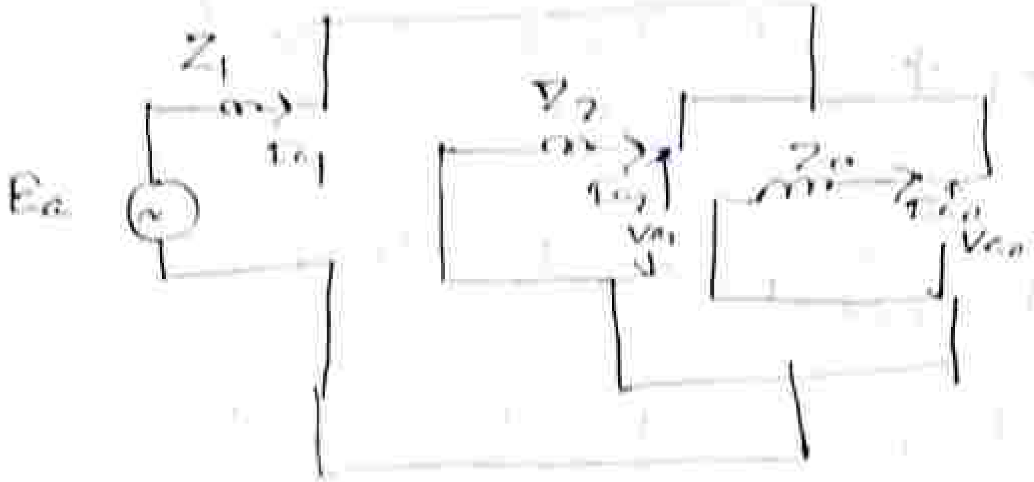
$$= \frac{E_a(Z_0+Z_2)}{Z_2 Z_0} - \frac{I_{a_1}(Z_0+Z_2)Z_1}{Z_2 Z_0}$$

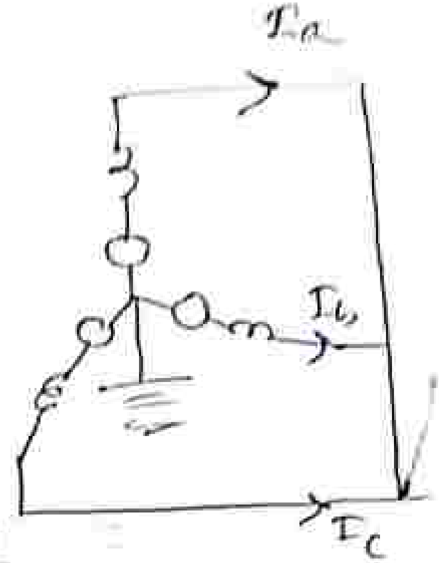
$$I_{a_1}\left(1 + \frac{Z_1(Z_0+Z_2)}{Z_2 Z_0}\right) = \frac{E_a(Z_0+Z_2)}{Z_2 Z_0}$$

$$I_{a_1} = \frac{\dfrac{E_a(Z_0+Z_2)}{Z_2 Z_0}}{1 + \dfrac{Z_1(Z_0+Z_2)}{Z_2 Z_0}}$$

$$= \frac{E_a(Z_0+Z_2)}{Z_2 Z_0 + Z_1(Z_0+Z_2)}$$

$$= \frac{E_a}{Z_1 + \dfrac{Z_0 Z_2}{Z_0 + Z_2}}$$





3 φ fault

$$\left.\begin{array}{l} I_a + I_b + I_c = 0 \\ V_a = V_b = V_c \end{array}\right\}$$

Since $|I_a| = |I_b| = |I_c|$ and if I_a taken as reference

$$I_b = \lambda^2 I_a \qquad I_c = \lambda I_a$$

$$I_{a1} = \frac{1}{3}\left(I_a + \lambda I_b + \lambda^2 I_c\right)$$

$$= \frac{1}{3}\left(I_a + \lambda^3 I_a + \lambda^3 I_a\right)$$

$$= I_a$$

$$I_{a2} = \frac{1}{3}\left(I_a + \lambda^2 I_b + \lambda I_c\right)$$

$$= \frac{1}{3}\left(I_a + \lambda^4 I_a + \lambda^2 I_a\right)$$

$$= \frac{1}{3}\left(I_a + \lambda I_a + \lambda^2 I_a\right)$$

$$= \frac{1}{3} I_a\left(1 + \lambda + \lambda^2\right)$$

$$= 0$$

$$I_{a0} = \frac{1}{3}\left(I_a + I_b + I_c\right) = 0$$

In a 3 ϕ fault zero as well as negative sequence component of current are absent and positive sequence component current is equal to the phase current.

$$V_{a1} = \frac{1}{3}\left(V_a + \lambda V_b + \lambda^2 V_c\right)$$

$$= \frac{1}{3}\left(V_a + \lambda V_a + \lambda^2 V_a\right)$$

$$= \frac{1}{3} V_a \left(1 + \lambda + \lambda^2\right)$$

$$= 0$$

$$V_{a2} = \frac{1}{3}\left(V_a + \lambda^2 V_b + \lambda V_c\right)$$

$$= 0$$

$$V_{a0} = 0 \qquad \frac{1}{3}\left(V_a + V_b + V_c\right)$$

$$V_{a1} = 0 = E_a - I_{a1} Z_1$$

$$\boxed{I_{a1} = \frac{E_a}{Z_1}}$$

Static Relays :—

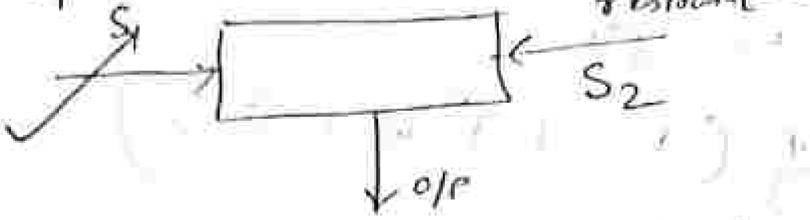
Amplitude comparator

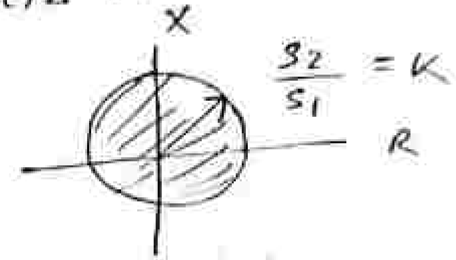
If two input signals are S_1 and S_2 the amplitude comparator gives the o/p of $\boxed{\frac{S_2}{S_1} \leq K}$

S_1 = operating quantity

S_2 = restraining quantity

The function is represented by circle in a complex plane.





Static amplitude comparator ~~mo~~ is calassified

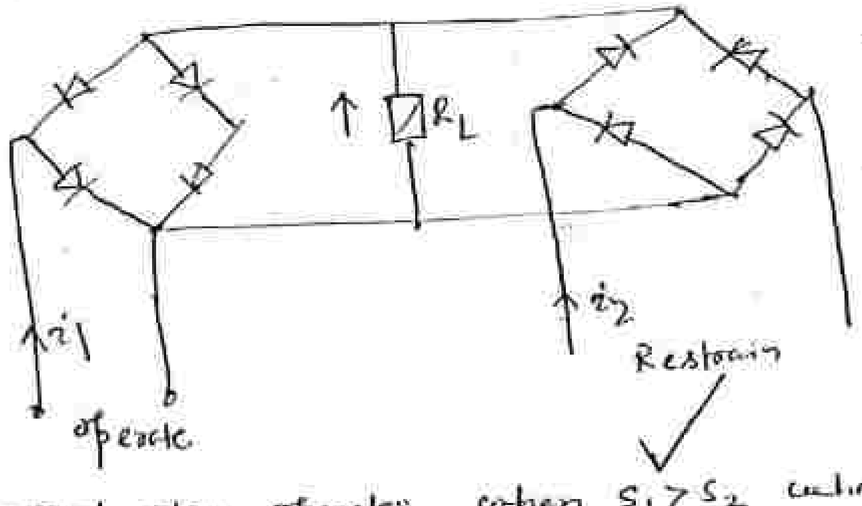
ⓐ integrating comparator

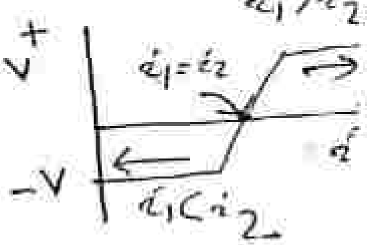
ⓑ Instaneous comparator

ⓒ Sampling comparator.

Integrating comparator :—

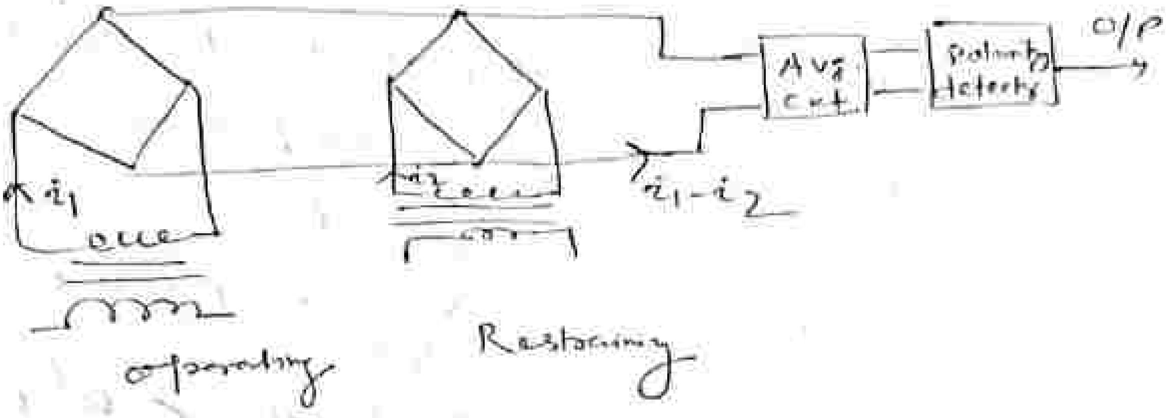
Rectifier bridge comparator can be either be circulating type or opposal voltage type.



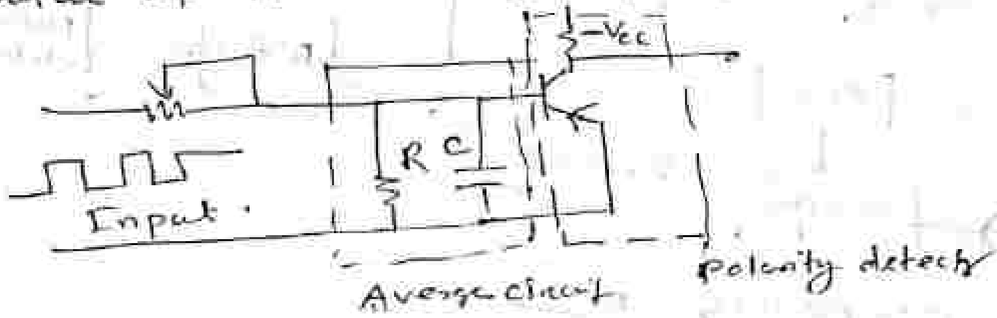


The polarized relay operates when $S_1 > S_2$ where $S_1 = K_1 i_1$ $S_2 = K_2 i_2$. The voltage across the relay never exceeds twice the forward voltage drop of one of the rectifier.

A static integrator can be used instead of polarized relay which consist of averaging circuit and polarity detector. The two current i_1 & i_2 rectified and their difference $(\bar{i_1} - \bar{i_2})$ is averaged. When average is positive the o/p is active.

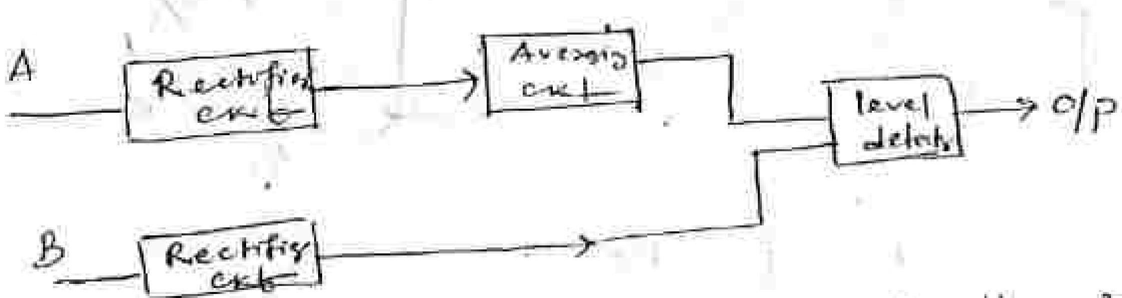


A integrator circuit consisting capacity. The tripping occurs when the capacitor voltage reaches the setting value of the level detector.



Instaneous comparator

Instaneous or direct comparator can be two types.
(a) averaging ~~type~~ type (b) phase splitting type



The restraining signal is rectifier and ~~~~ then smothing to obtain level constraints. This ~~~~ is compared with operating signal. The tripping signal occurs when operating signal exceeds the level constraints.

Sampling comparator

Reactance characteristics is obtained by comparing the rectifier and smooth value of current. If I lags behind voltage V by an angle ϕ the value of voltage at current zero is $V_m \sin\phi$.

The reactance relay operates for $X < K$

$X < K$

$Z\sin\phi < K$

$\frac{V}{I}\sin\phi < K$

$\frac{V_m}{\sqrt{2}}\sin\phi < K\frac{I_m}{\sqrt{2}}\frac{\sin\alpha}{\sin\phi}$

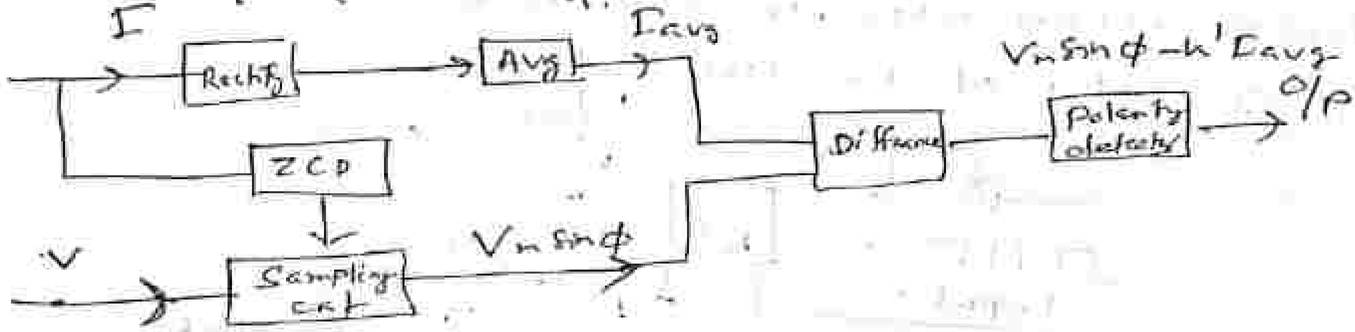
$V_m\sin\phi < K' I_m \sin\alpha$.

$Z\sin\phi < K$

$\frac{V}{I}\sin\phi < K$

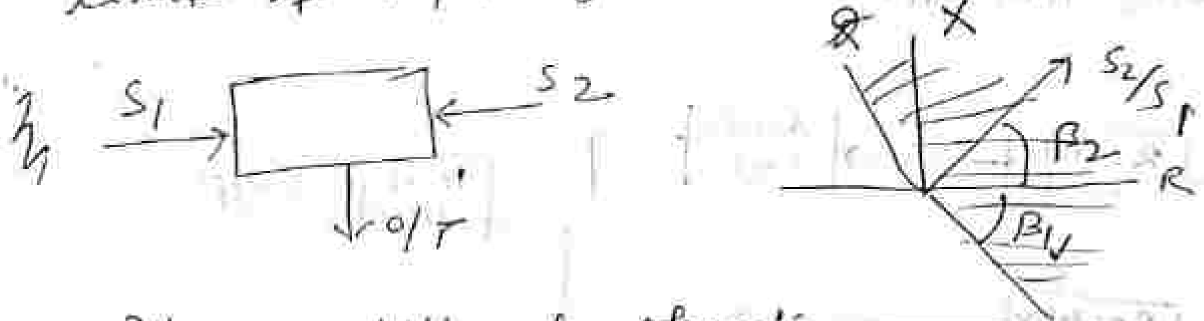
$\frac{V_m}{\sqrt{2}}\sin\phi < K I_{av} \times 1.11$

$V_m\sin\phi < K' I_{av}$



Phase comparator :-

→ It is most useful in differential and carrier relays. The phase relationship laying within specific limit of input signal S_1 & S_2.



The condition of operation

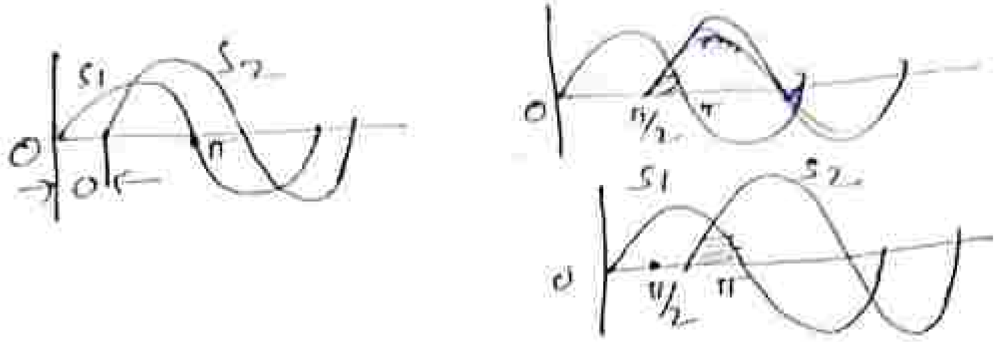
$$-\beta_1 \leq \theta \leq +\beta_2$$

θ = angle by which S_2 leads S_1, If $\beta_1 = \beta_2 = 90°$ the comparator is known Cosine comparator.

If $\beta_1 = 0$ $\beta_2 = 180°$ Sine comparator

1 coincidence comparator :-

The two input signals S_1 & S_2, the period of coincidence of S_1 and S_2 will depend the phase difference between S_1 and S_2



* period of coincidence is equal to the period of non coincidence for a phase difference of $\pm 90°$
* The period of coincidence is less than the period of non-coincidence and vice versa when the phase difference is less than $\pm 90°$.

Basic Element of Static Relay

(1) input element :-

1→ mixing circuit are required
→ summing junction are required
→ using OP-Amp as a summer or mixer

Measuring Element :-
(1) single input device
(2) two-input device
(3) multi-input device.

single input device are comparator.

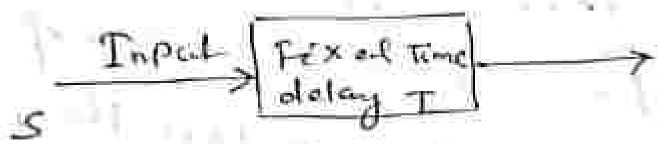
for obtaining ~~critical to~~ fast response with the robust contact pressure S is either zero or great then marginal operation level.

(1) To provision of tripping signal to the CB and give some possible additional functions of intertripping, alarm and indication.

(ii) For operation $S \geq A$ (critical)

for reset $S \leq KA$ ∴ $K \leq 1$.

Fixed time delay :- (fixed definite time function)

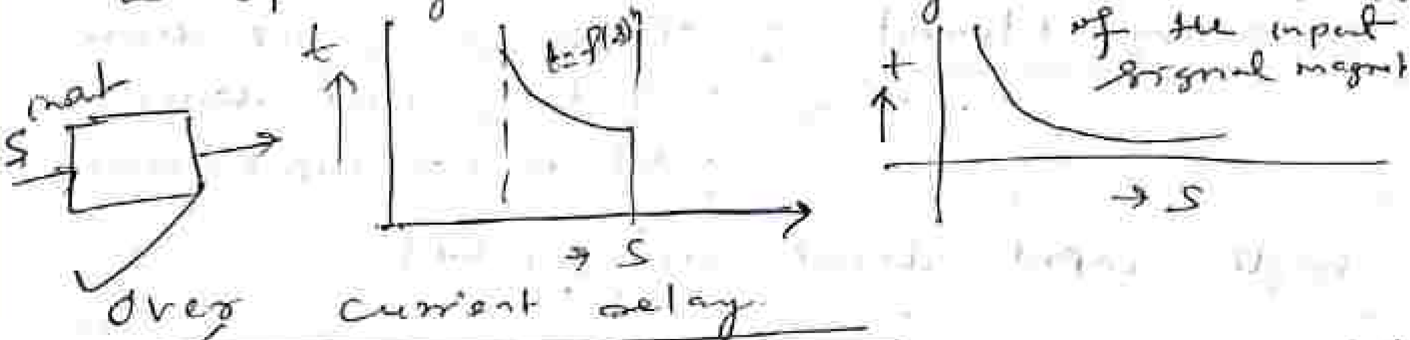


There must be fixed time delay between input and o/p. The time delay between the application of input and occurance of o/p.

Time function dependent input.

$$t = f(S^n)$$

when n is negative. The relay for this category are inverse definit minimum time lag. The essential features of such relay is that the operating time is inversely related to power of the input signal magnitude.



Over current relay

(1) Low burden CT, so that smaller CT is required
(2) compactness of the unit and space reduction
(3) Instaneous reset possible
(4) Low maintenance and long life
(5) No overreaching tendency.

$\rightarrow$ [Rectifier unit] $\rightarrow$ [over load detector] $\rightarrow$ [Timing ckt] $\rightarrow$ [level detector] $\rightarrow$ [tripping ckt] $\rightarrow$

Principle — The static overcurrent relay consist of a rectifier unit which converts the a.c signals to d.c signal followed by overload detector timing circuit, level detector and tripping ckt.

Time current characteristic

A general expression for the operating time of a time-current relay is

$$t = \frac{KM}{I^n - I_p^n}$$

t = time of operation in second.

K = design constant

M = time multiplier setting

I = multiple tap ~~setting~~ current

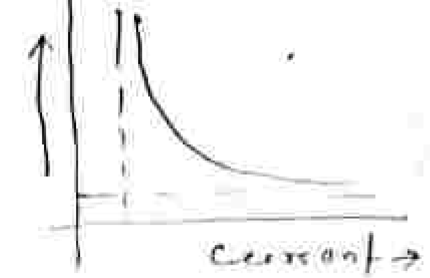
I_p = multiple of tap current at which pick up occurs.

n = index number, which is empirical.

IDMT ⇒ $t = \dfrac{0.17}{I^{0.02} - I}$

Very inverse $t = \dfrac{13.5}{I - 1}$

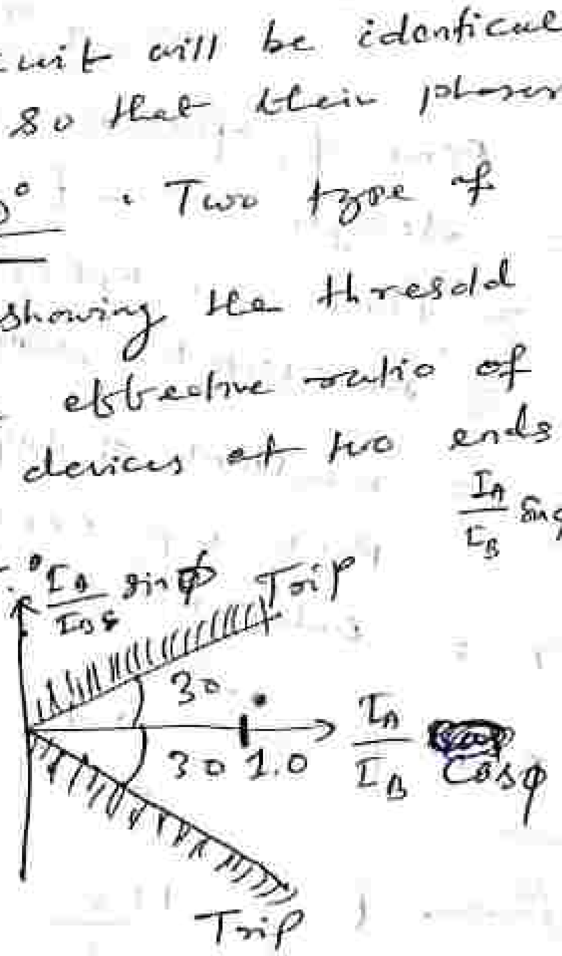
extremely inverse $t = \dfrac{80}{I^2 - 1}$



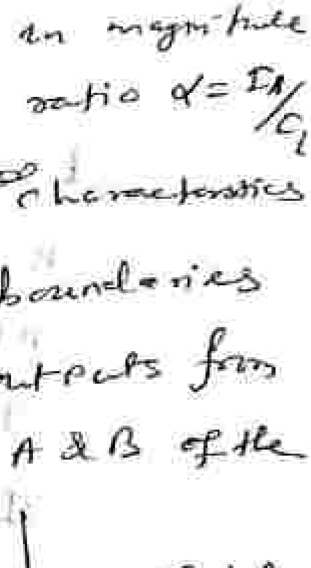
Differential protection:—

A differential protection scheme compares quantity derived from the input and output currents of the protected circuit in such a manner that, for all healthy system and through fault conditions the quantities balance and protection is inoperatives, while the internal fault condition the balance is distributed and the protection operates.

The relaying quantities at both ends of the transmission circuit will be identical in magnitude and phase, so that their phasor ratio $\alpha = I_A/I_B$ $= 1+j0 = 1\angle 0^\circ$. Two type of α characteristics are plotted showing the threshold boundaries in terms of the effective ratio of outputs from the the summation devices at two ends A & B of the protected line.



Phase comparison



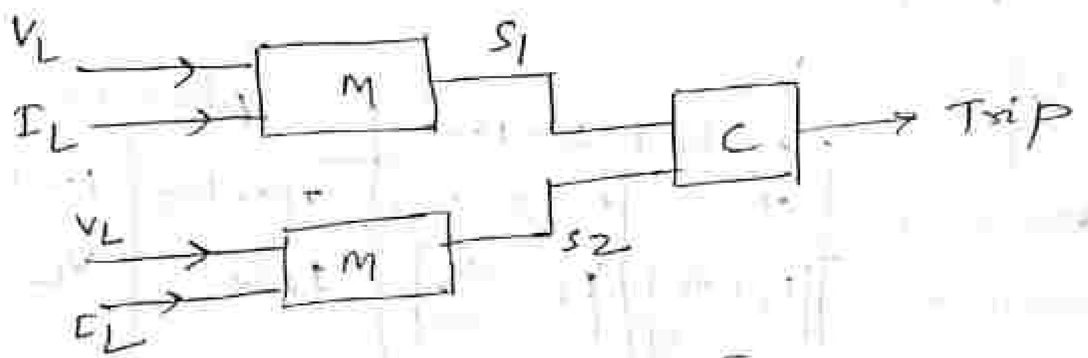
Phase and amplitude comparison

In practice, the pilot wire protection system characteristic tend to be variable because a relay having closed - threshold characteristic under

Pilot wire system may employ either the above characteristics while current of system employ pure phase comparison

Static distance protection :—

→ Distance relays are characterized by having two input quantities respectively proportional to the voltage and current at a particular point in the power system.

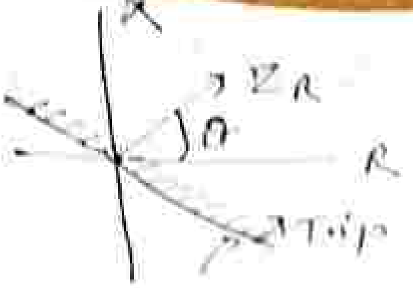


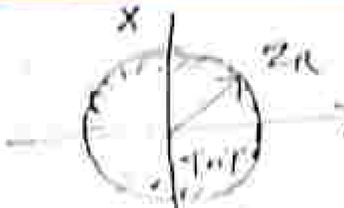
$$S_1 = K_1 V_L + K_2 I_L$$
$$S_2 = K_3 V_L + K_4 I_L$$

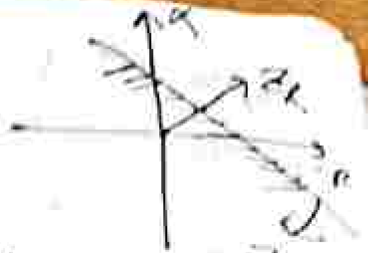
Voltage V_L and current I_L are fed into measuring circuit M which produce voltages

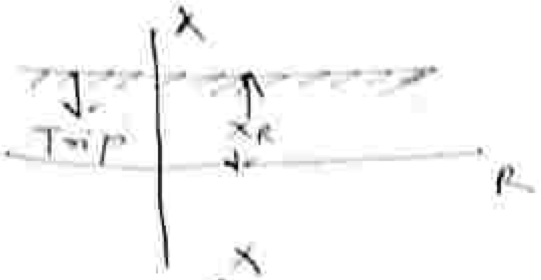
$$S_1 = K_1 V_L + K_2 I_L$$
$$S_2 = K_3 V_L + K_4 I_L$$

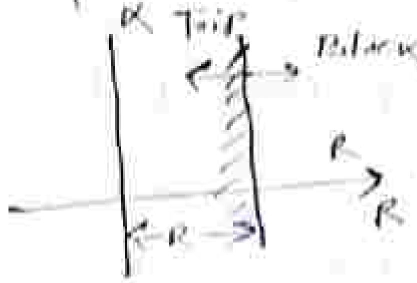
These voltage is fed to the comparator C so as to produce a desired pickup characteristics, the constant of K_1 through K_4 are being selected accordingly. The polar characteristics of a distance relay defines the range of impedance values of the protected primary circuit for which the relay gives circuit breaker tripping. In this way polar characteristic of the relay provides its main characteristics of the relay provides its main discriminative features.

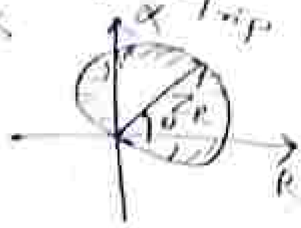


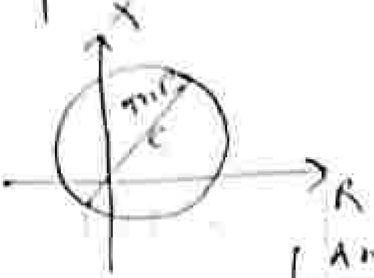












	Amplitude comparator		Phase comparator	
(1) ~~Directional~~	operating	Restraining	operating	Restraining
Directional	$\left\lvert I_L + \frac{V_L}{Z_R} \right\rvert$	$\left\lvert I_L - \frac{V_L}{Z_R} \right\rvert$	$I_L Z_R$	V_L
Plain impedance	$\lvert I_L \rvert$	$\left\lvert \frac{V_L}{Z_R} \right\rvert$	$I_L Z_R - V_L$	$I_L Z_R + V_L$
Angle-impedance	$\left\lvert I_L - \frac{V_L}{Z_R} \right\rvert$	$\frac{V_L}{Z_R}$	$(I_L Z_R - V_L)$	$I_L Z_R$
Reactance	$\left\lvert I_L - \frac{V_L}{X_R} \right\rvert$	$\left\lvert \frac{V_L}{X_R} \right\rvert$	$(I_L Z_R - V_L \sin\theta)$	$I_L Z_R$
Conductance	$\left\lvert I_L - \frac{V_L}{R} \right\rvert$	$\left\lvert \frac{V_L}{R} \right\rvert$	$I_L Z_R - V_L \cos\theta$	$I_L Z_R$
Mho	$\lvert I_L \rvert$	$\left\lvert I_L - \frac{V_L}{Z_R} \right\rvert$	$I_L Z_R - V_L$	V_L
Offset mho	$\lvert I_L \rvert$	$\left\lvert \frac{V_L}{Z_R} - n I_L \right\rvert$	$(I_L Z_R - V_L) \cos(\phi - \theta)$	$V_L + n I_L Z_R$

MODULE- IV

7.1 Autoreclosing

The trasient faults are more frequent in nature, but they have not doing any damage of the device. For a certain time, the line disconnected from the system momentarily. After the arc is deionized, the line can be reclosed to restore the normal value. In present day power system, automatic reclosing finds wide application. It therefore that to effect fault clearance and subsequent reclosure.

Definition & available features:—

(a) Operating time of protective relay:— Time from the inception of the fault to the closing of the tripping contact.

(b) Operating time of circuit breaker:— Time from the energizing of the trip coil untill the fault arc is extinguished.

(c) Dead time of the circuit breaker or system:—

(1) Depending upon the time, fault existing on the system. (a) Transient fault (b) Semipermanent fault (c) permanent fault. It is found that 80% are permanent fault, 12% of semi-permanent and 8% are permanent fault. Reclosing could be resort some delay so that cause of fault could be burnt away during the time del

Auto reclosing could be single phase or three phase. Single phase autoreclosing is restarted when a line to ground fault takes place and reclosed after a predetermined time.

Circuit breaker

→ The basic requirement of any circuit breaker requires the separation of contact in an insulating fluid which serves two function:

(a) It extinguishes the arc.

(b) It provides adequate insulation between the contact.

Basic fluid requirement

1. Air at atmospheric Pressure
2. compressed air
3. Oil which produce hydrogen for arc extinction
4. ultra high vaccum.
5. sulphur hexafloride.

properties of CB :-

1. High dielectric Strength.
2. Thermal and chemical Stability
3. Non - inflammability
4. High thermal conductivity.

Initiation of arc

→ The separation of CB contact which are carrying gives rise to an arc without changing the current waveform. At the separation, magnitude of current is very high and resistance is

→ The distance of separation is very small, large voltage gradient is set up which cause ionization the particles. When current is high the discharge attains the form of an arc having a temperature high enough so for thermal ionization.

→ The arc is initiated due to field effect and then maintained due to thermal ionization.

Deionization :- The process of deionization is possible in the following ways.
(i) high pressure (ii) forced convention and turbulence
(iii) arc splitting.

There are two methods by which arc interruption is done (i) High resistance method (ii) Low resistance or current zero interruption method.

High resistance method :-
(i) In this method, arc resistance is increased in time to such a high value that the current to zero without restrike thereafter. There will be induced harmful voltage. This is the disadvantage because large energy received by CB.

Low resistance or Current Zero interruption,
This method is used only in ac circuit interruption because there is natural zero of current present in such system. In case of a 50 HZ supply there are 100 zeros per second.

This property of ac circuit is exploited for interruption purpose and the current is not allowed to rise again after a zero occurs.

The arc extinction is explained by two theories.

(i) Energy balance theory

(ii) voltage race theories.

Energy balance theory

If the rate at which the heat generated between the contact is lower than the rate at which heat between the contact dissipated the arc will be extinguished, otherwise it will restrike.

1. Initially when the contact are open, the restriking voltage is zero, heat generated is zero.

2. When the contact is fully opened, the resistance or is infinite, heat generated zero.

Voltage race theory :—

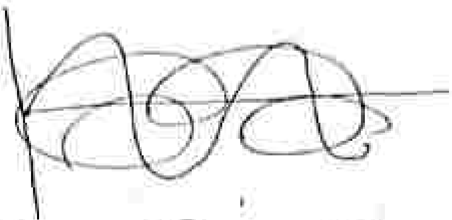
In the initial stage, the resistance is small and contact separates resistance increasing. Immediately after current zero, the electron & hole will be removed from the surface of contact. The ionization at current zero depends upon the power factor and other factors of the circuit like inductance and capacitance

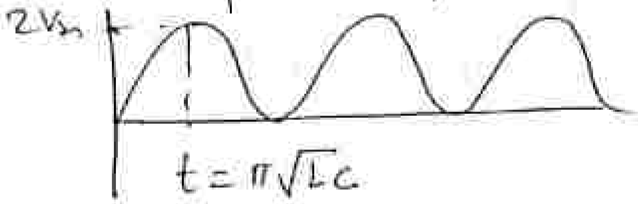
$$v = V\left(1 - \cos\frac{t}{\sqrt{LC}}\right)$$

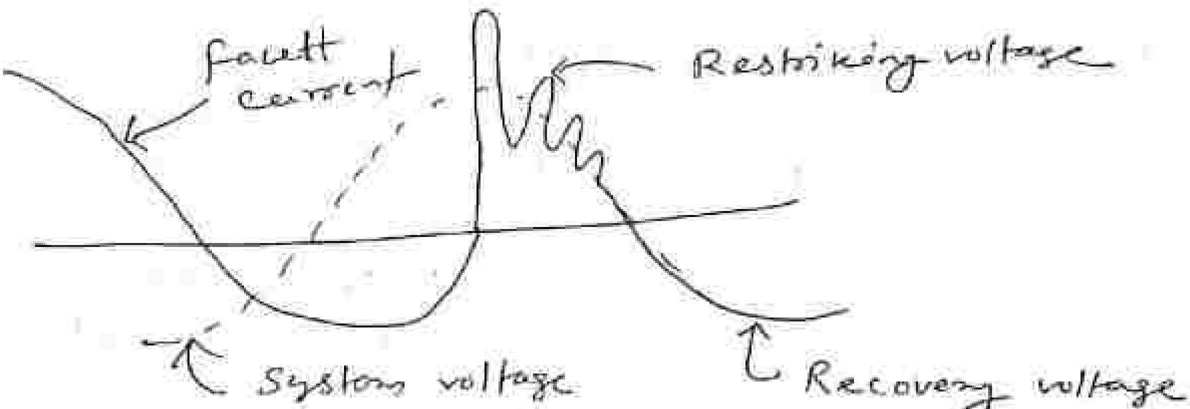
v = restriking the voltage

V = voltage at the instant of interruption
L & C = Series inductance & capacitance

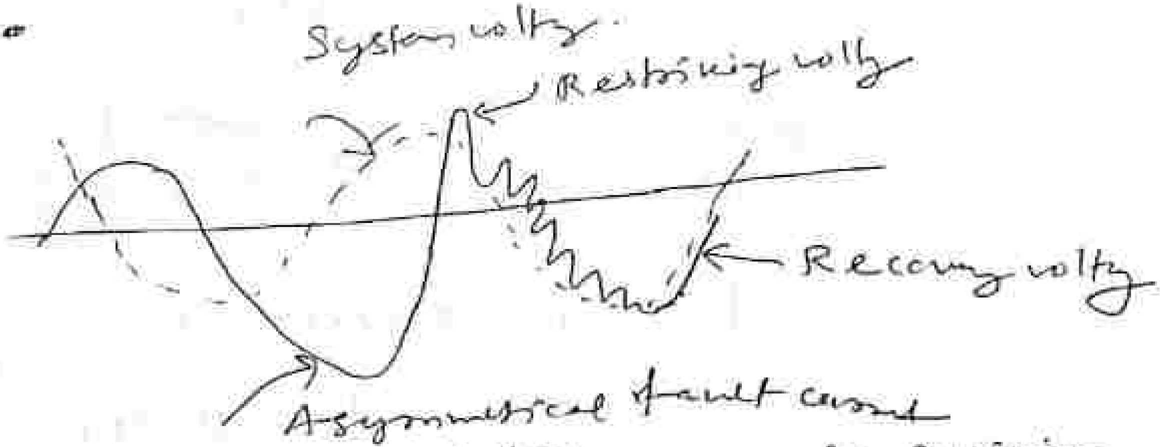
→ Lower the value of inductance & capacitance, higher the natural frequency, sever the effect of restriking voltage.



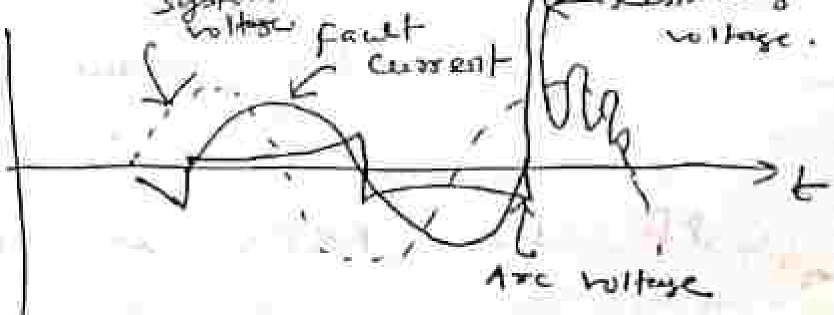




→ Current lags the voltage by 90°. A fault current can have degree of asymmetry depending upon the time in the cycle at which the fault occurs.



~~other effect~~



Restriking voltage: - The instant transient voltage which appears across the breaker contact at the instant of arc extinction is known as the restriking voltage.

Recovery voltage: → The power frequency r.m.s voltage that appears across the breaker contact after transient oscillation die out

Active recovery voltage: - It is defined as the instaneous recovery voltage at the instant of arc extinction

$$V_{ar} = K V_m \sin\phi$$

Rate of rise of restriking voltage (RRRV)

$$\text{average RRRV} = \frac{\text{Peak value of restriking voltage}}{\text{Time taken to reach to peak value.}}$$

$$= \frac{2V_m}{\pi\sqrt{LC}}$$

$$v = V_m\left(1 - \cos\frac{t}{\sqrt{LC}}\right)$$

$$\frac{dv}{dt} = \frac{V_m}{\sqrt{LC}} \sin \frac{t}{\sqrt{LC}}$$

This is maximum when $\frac{t}{\sqrt{LC}} = \pi/2$

$$t = \frac{\pi}{2}\sqrt{LC}$$

and the value is $\frac{V_m}{\sqrt{LC}}$

If the RRRV is smaller than the rate

at which the dielectric between the contact developed the arc will extinguished.

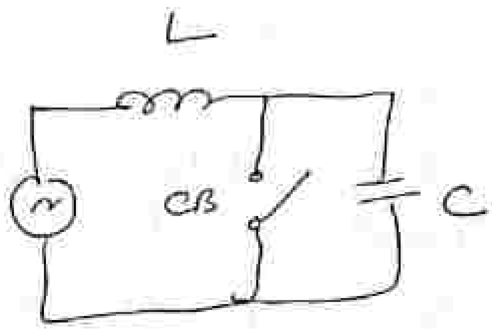
Current chopping

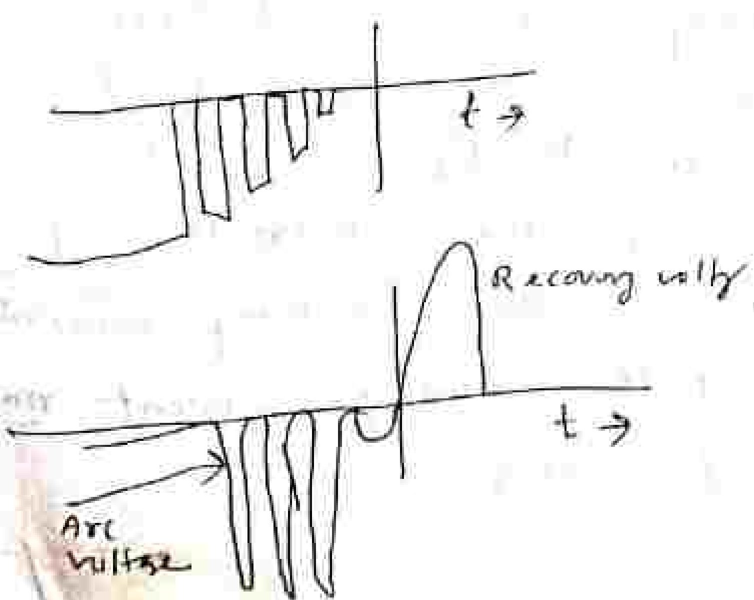
$v = \frac{L\,di}{dt}$

→ When CB is interrupt low inductive current such as current due to no load magnetizing current of a transformer. The breaking of current before it passes through the natural zero is termed as current chopping. At a certain arc current, because of large deionizing force, the current suddenly reduces to zero. The current in arc was flowing form the source through the inductance and the CB contacts.

→ The conversion electromagnetic to electrostatic form of energy i.e current is diverted to the capacitor from the arc. If i_a is the instaneous value of arc current where chop takes place, the prospective value of voltage to which the capacitor will be charge.

$$V = i_a \sqrt{L/C}$$





Rating of Circuit Breaker :-

1. Number of pole
2. Rated voltage & current
3. rated frequency
4. Rated making capacity
5. rated symmetrical and asymmetrical breaking capacity
6. operating duty.

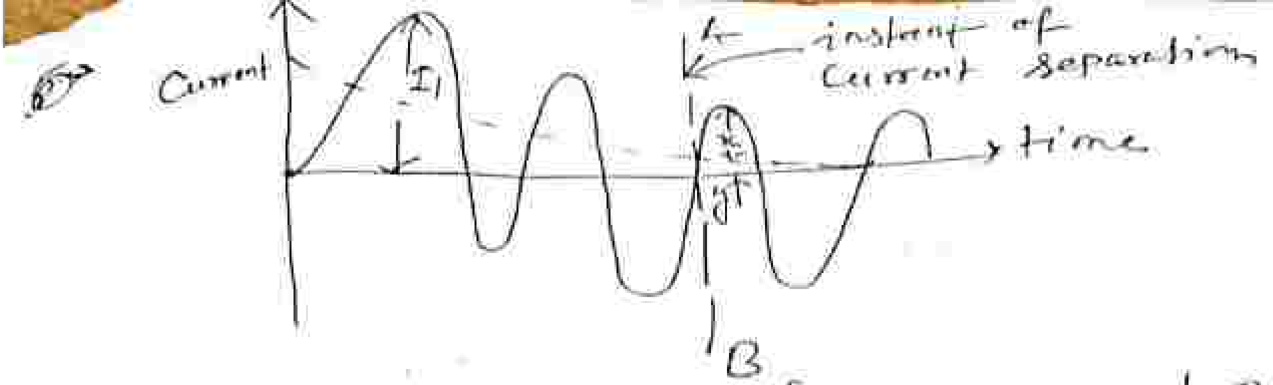
1 → The number of pole per phase of a breaker is a function of operating voltage.

2 → The breaker is expected to operate at a maximum voltage at which normally is higher than rated nominal voltage.

The rated current of CB is the maximum value of current in amp. which it shall carry continuously without exceeding the temperature limits of the various parts of the CB.

3 → The rated frequency of a breaker is the frequency for which it is designed to operate.

4. Making current is the peak value of the maximum current loop, including d.c component in any phase during first cycle of current when CB closed. The making current corresponds to the ordinate I_1. The making current is the peak value rather than in terms of rms value. The making ~~current~~ capacity is the product of the making current and instantaneous value of voltage.



The current in the first one or two cycle is known as subtransient current and 8 to 10 cycle is known as transient current.

The symmetrical breaking current is ~~obtained by~~ known, the making current can be obtained by multiplying this current by $\sqrt{2}$ and again by 1.8 times.

The symmetric breaking current is given by $x/\sqrt{2}$ and assymmetric breaking current is given by $\sqrt{\left(\frac{x}{\sqrt{2}}\right)^2 + y^2}$

The breaking capacity of a breaker is the product of breaking current and recovery voltage.

Short time rated current is the current that can be safely applied, with the CB in its normal condition, for 3 seconds.

$$B - 3 - MB - 3 - MB$$

CB with autoreclose

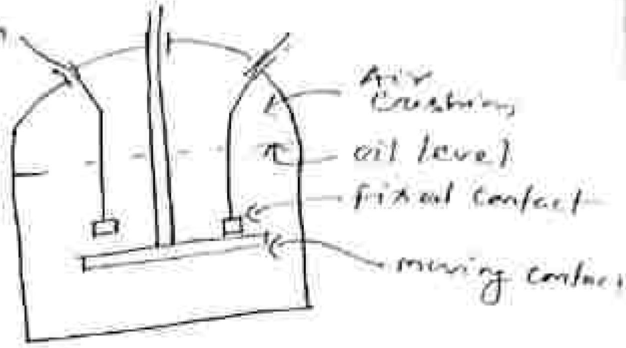
$$B - D_t - MB$$

D_t = Dead time

Plain oil circuit breaker :-

→ Air cushion is required between the oil surface and tank

→ The air cushion also serves to absorb the mechanical shock of the upward oil movement.



→ ~~Add~~ The minimum oil head is required to provide substantial oil pressure. The gas generated from the arc to the oil surface is produced. The gas is partially ionized and low dielectric strength. so appreciable amount of oil depending upon the working voltage should always exist between the contact and the tank.

principle :- The final arc extinction process involves increasing the the length of the arc. The length of the arc depends upon the arc current and recovery voltage. Initially, the separation is very small and high voltage gradient between the contact ionize the oil. The gas obtained mainly hydrogen gas and is dissociated in its atomic form. releasing lot of heat. The volume of oil increases. So the oil is therefore pushed away from the arc. Final arc extinction of the arc takes place at a current zero, when the power input to the arc is less than that dissipated between the contact.

MOCB :- one of the most important characteristic of OCB is to reduce the oil needed.

ⓐ Reduction in tank size ⓑ Reduction in total weight

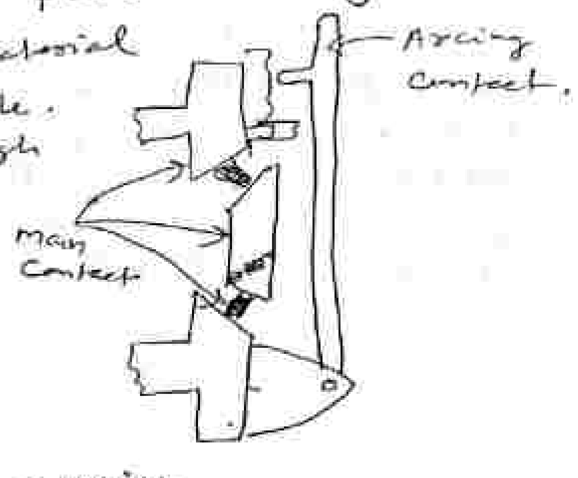
ⓒ Reduction in cost.

The minimum OCB ~~OB~~ uses solid material for insulating Purpose. The minimum oil CB can be self blast type, or external blast type.

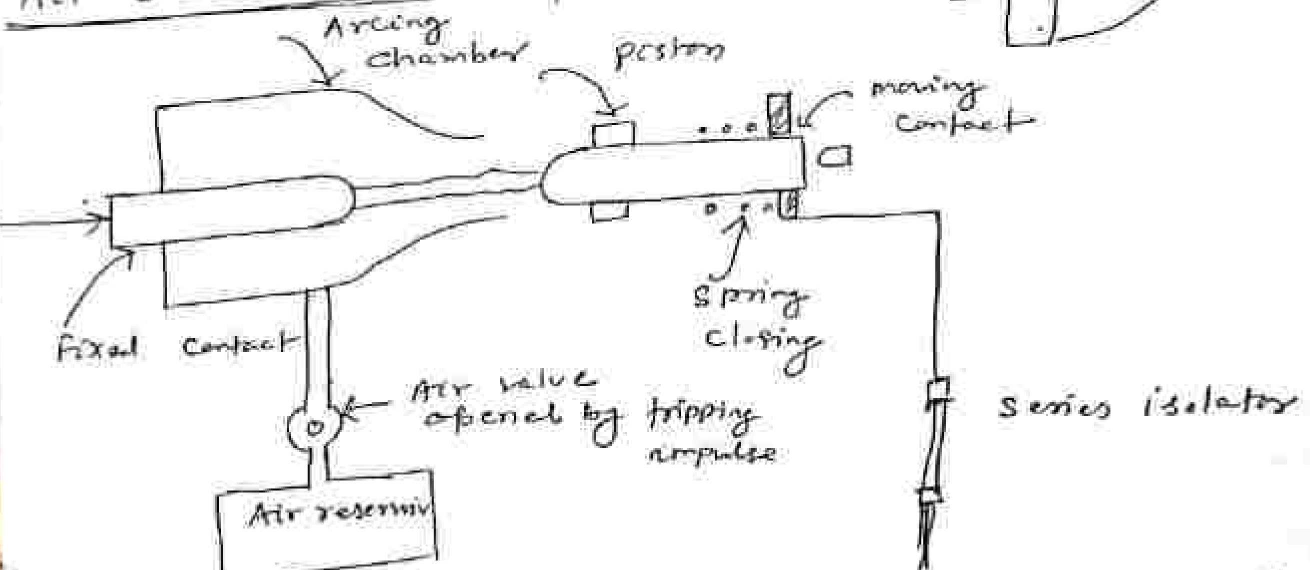
In case of self blast type, gas pressure developed depends upon current to be interrupted. Higher the current interrupted, larger the gas pressure and hence effective for arc quenching. The insulating material are glass fibre,

The arcing chamber is designed in terms of
(a) axial venting (b) radial venting.
In axial venting gas produced are longitudinal direction.
In radial venting the arc is transverse direction.
In axial venting, high gas pressure is generated with high dielectric strength. It is low current and high voltage. In radial venting is used heavy current and low voltage.
This type of CB is used voltage upto 8000 MVA at 245 kV with a total break times 3 to 5 cycle.

Air CB (i) Fire risk and maintenance are eliminated.
(ii) Arcing produced in air completely removed.
(iii) Heavy mechanical stress are set up by gas pressure.
Air CB is used for low voltage circuit as well as highest transmission voltage.
Principle :- It has two pairs of contacts per phase. The main pair made up copper and carries current under normal operating condn. The other pair is arcing electrodes which made up carbon. The material used for contact should be non volatile.
The principle of operation is based on high resistance method.



Air blast CB (ABC)



→ The breaker reservoir tank is connected to the arc chamber when a tripping impulse opens the air valve.
→ The air entering the arc chamber exerts a pressure on the moving contact

→ The air moves with high velocity through the nozzle. The diameter of the arc is reduced. The temperature gradient set up. When the current passes through the zero, the air blast is more effective. The total heat loss is proportional to arc diameter, whereas the total energy content of the arc is roughly proportional to the square of the diameter.

→ Most of the CBs upto 11kV are either air break type or oil break type. Between 11kV and 66kV mainly oil CB while 132kV and 275kV the market is shared by oil.

<u>VCB</u> In vaccum type discharge, the mean free path of particle is small and electron avalanche is formed. In VCB 10^{-5} torr (1 micron = 10^{-3} torr) (one mm of Hg is known as torr) mean free path is produced. When electrode separated by a few mm an electron crosses the gap without any collision. Due to electron avalanche current growth can not takes. In vaccum arc is the neutral atom, ions and electrons do not come. Due to large mean free path, dielectric strength is thousand times more than the gas interrupted device.

→ A high vapour pressure and low conductivity metal is more desirable to limit the current chopping whereas low vapour pressure metal are more desirable from the arc extinction point of view