# UNIT 3 APPARATUS PROTECTION

Protection of generators:-

A generator is the most important & costly equipment in a power system. It's protection is very complex and elaborate. A modern generating set is generally provided with the following protective schemes.

(i) stator protection:-

a. Percentage differential protection

b. Protection against stator inter-turn faults.

c. Stator - overheating protection.

(ii) Rotor protection:-

a. Field ground-fault protection.

b. Loss of excitation protection.

c. Protection against rotor overheating because of unbalanced three-phase stator currents.

(iii) Miscellaneous:-

a. overvoltage protection

b. overspeed protection

c. Protection against motoring

d. protection against vibration

e. Bearing - overheating protection

f. protection against auxiliary failure

g. protection against voltage regulator failure.

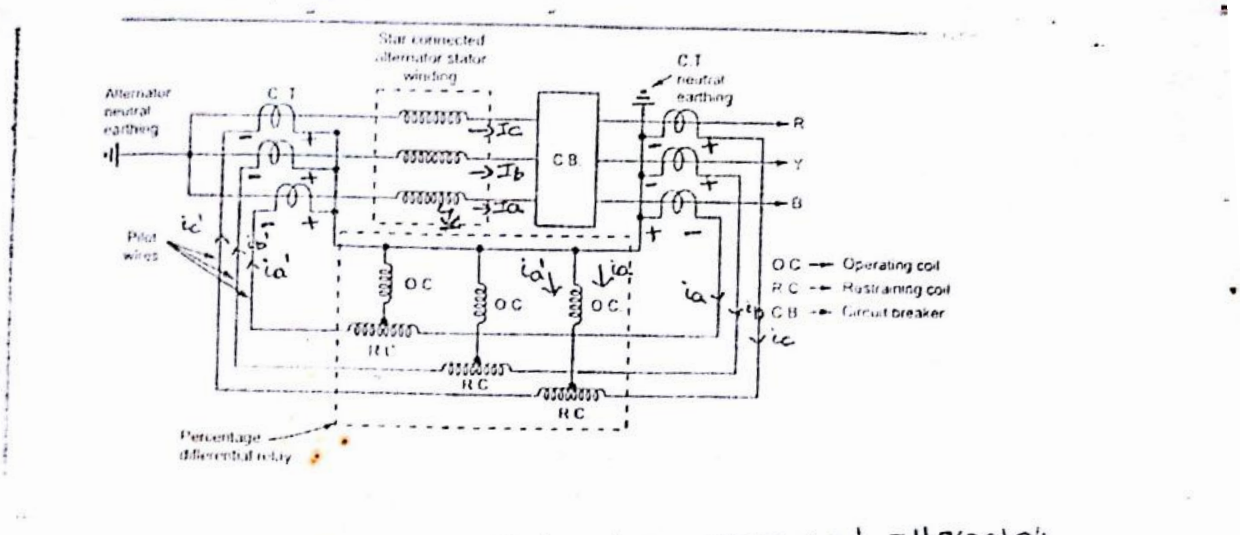
(i) stator protection

a) percentage differential protection:-

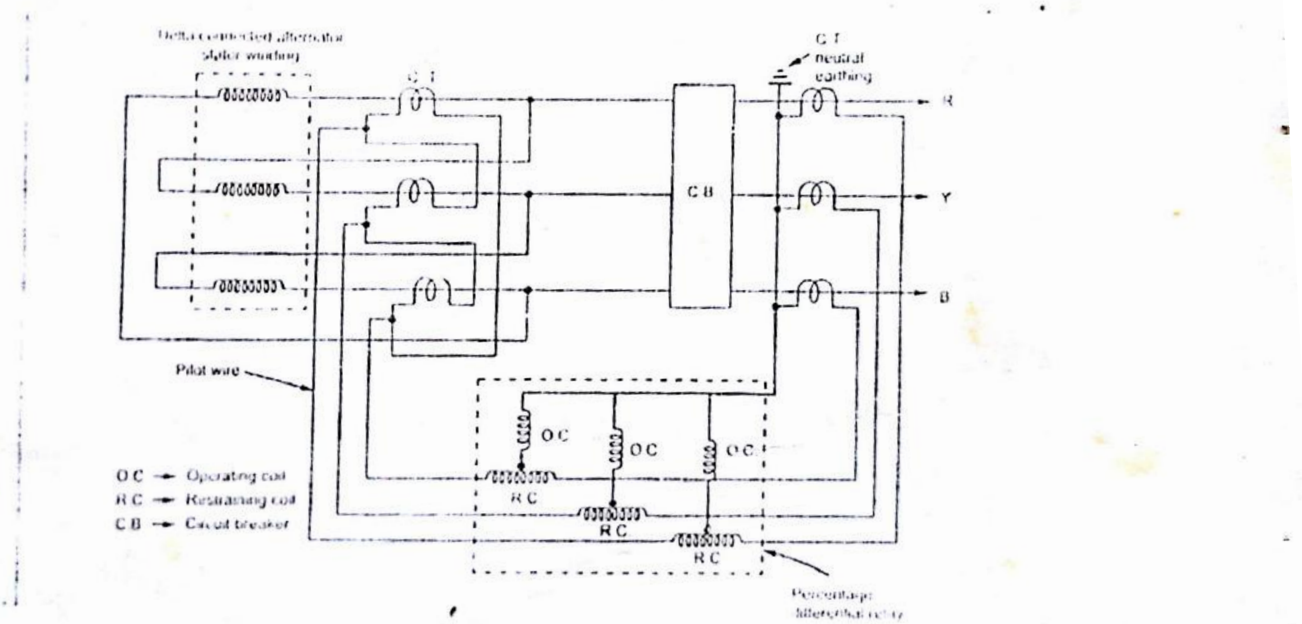
* It is used for the protection of generators above 1 MW.
* It protects against winding faults (ie) Phase to phase & phase to ground
* It is also called biased differential protection or longitudinal differential protection.
* This protection does not respond to external faults & overloads.
* In the operating coil, the current sent by the upper C.T. is cancelled by the current sent by the lower C.T & the relay doesnot operate.
* For internal fault, the polarity of the secondary voltage of the corresponding C.T. is reversed. so now the operating coil carries the sum of the currents of upper & lower CT's & it operates.

* This protection provides complete protection against phase to phase faults.
* It only provide 80 to 85% for phase to ground fault because it is influenced by the magnitude of the earth fault current which depends upon the method of neutral grounding.

Merz Price protection for star connected alternator




Merz-price protection for delta connected alternator

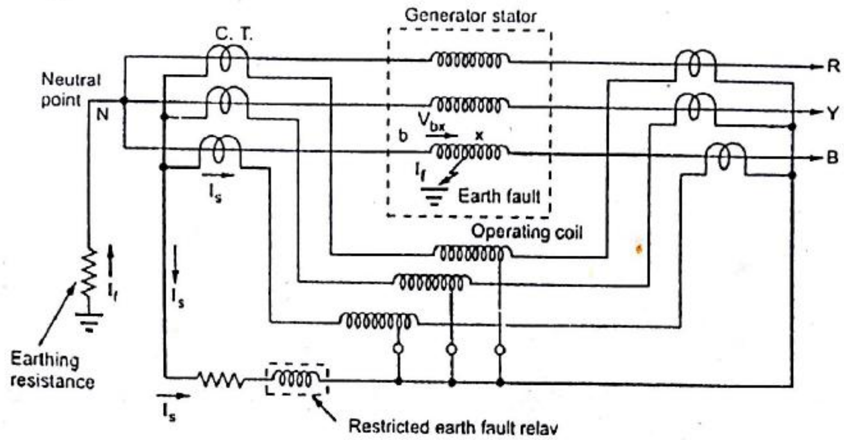



* Due to difference in the magnetising currents of the upper & the lower C.T.'s, the current through the operating coil will not be zero even under normal loading conditions or during external fault conditions.
* Therefore, to provide stability on external faults, a bias coils (restraining coils) are provided. To obtain the required amount of biasing, a suitable ratio of the restraining coil turns to operating coil turns is provided.
* In case of stator faults, the tripping of C.B to isolate the faulty generator is not sufficient, as the generator will still

continue to supply power to the fault until its field excitation is suppressed.

* Therefore, the percentage differential relays initiate an auxiliary relay which in turn trips the main C.B, trips the field C.B, shuts down the prime mover & operates an alarm.

Percentage differential protection for a Y-connected generator with only four leads brought out :-




* When the neutral connection is made within the generator & only the neutral terminal is brought out, the differential protection can be provided as shown in the above fig.
* This scheme protects the generator winding only against ground faults.
* It does not protect it against phase faults. So it is known as restricted earth fault protection.

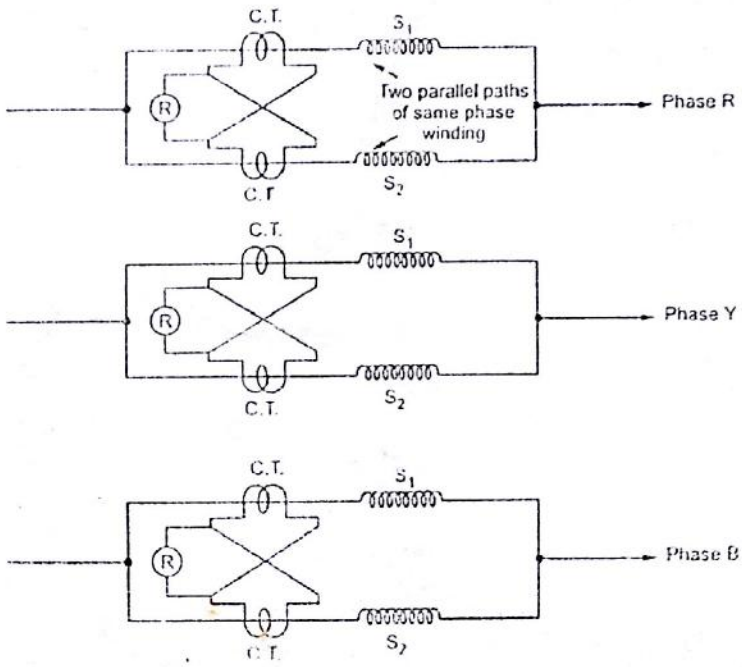
b) Stator protection against interturn faults:-

* Interturn fault is a short circuit between the turns of the same phase winding. The current produced due to such a fault is a local circuit current & it doesn't affect the currents entering or leaving the winding at the two ends where the C.T's are located. Hence Merz Price protection or percentage differential protection does not detect stator interturn faults.

* So transverse percentage differential protection is employed. In single turn generator, no question of interturn faults but in multiturn generator, this protection is important & is mainly used in Hydroelectric generators.

* Hydroelectric generators have double winding armatures. (ie) each phase winding is divided into two halves due to very heavy currents they have to carry.

* The splitting of single phase winding into two is advantageous in providing interturn fault protection.




* Under normal or healthy conditions, currents in two parallel paths $S_1$ & $S_2$ are equal so currents in secondaries of the C.T's are also equal. The ~~symmetric~~ secondary current flows around the loop & is same at all the points. So no current flows through relay and it is inoperative.

* If a short circuit is developed between the adjacent turns of the part $S_1$ of the winding, then currents through $S_1$ and $S_2$ no longer remain same. Thus unequal currents will be induced in the secondaries of the C.T's & thus difference of the currents flows through the relay R, & the relay operates.

* Such an interturn fault protection system is extremely sensitive but it can be applied to the generators having doubly wound armatures.

c) Stator - overheating protection:-

Overheating occurs due to failure in cooling system, overloading, occurence of short circuits in laminations. For protection there are two methods.

Method - I :-

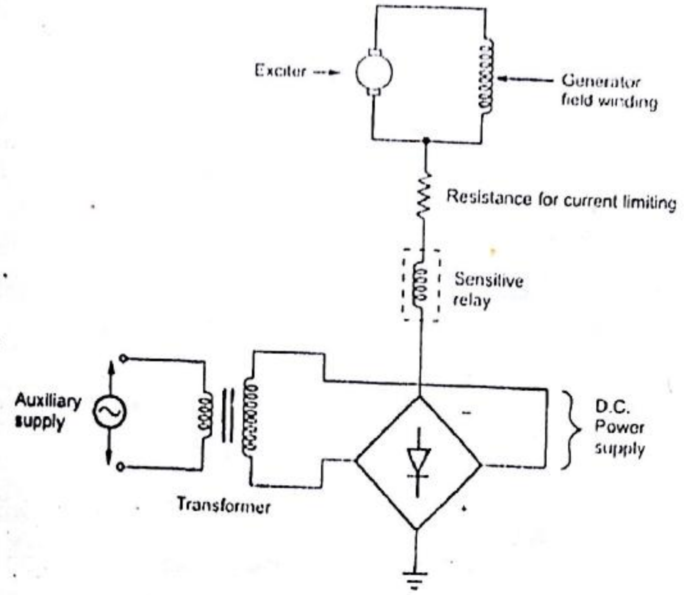
Temperature of coolant like water or Hydrogen is measured at the outlets.

Method - II :-

Sensors like thermocouple or thermistors are placed at different places of the stator and they are connected to a relay. when temperature exceeds a preset value the relay which is connected to the sensors sounds an alarm.

ii) Rotor protection :-

a) Field ground - Fault protection:-




* As Field is ungrounded and if a single line to ground Fault occurs, then it will not cause as much damage to the Field winding.
* But due to transients in stator, if more voltage is induced in rotor Field at that time, then there is a large chance of second Fault occurrence.
* Once when a second Fault occurs, then some part of the field winding is bypassed and more current Flows through the remaining winding. so it leads to a unbalance in air gap Fluxes & unbalance in magnetic Forces, & due to this the rotor shaft rotates eccentric & it causes Vibrations.

* Eventhough the second single line to ground Fault is not so much intense so that field winding is not bypassed, but an arc is created due to that Fault.
* This arc leads to unbalance of magnetic forces & due to it Vibrations are created.

Operation of the relay:-

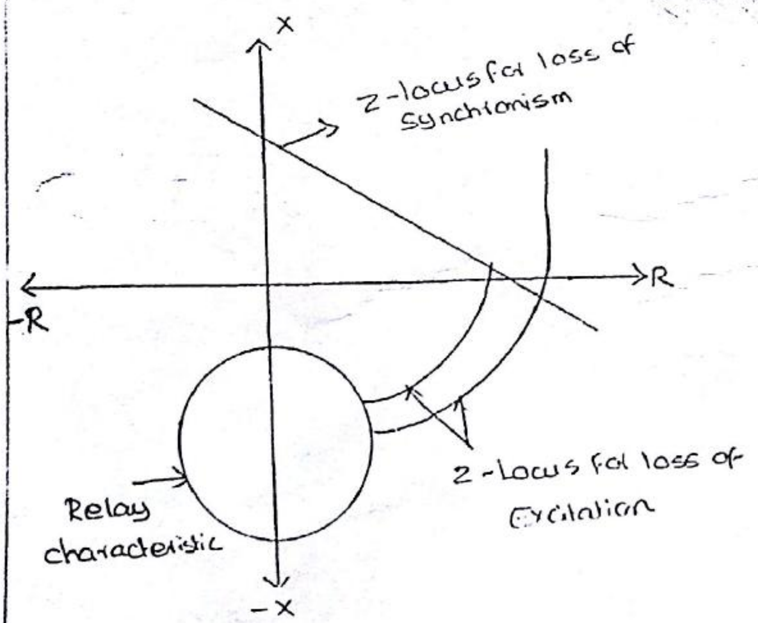
* A dc Voltage is impressed between the Field circuit and earth through a Polarised moving iron relay.

* It is not necessary to trip the machine when a single field earth Fault occurs. usually an alarm is sounded.

* Then immediate steps are taken to transfer the load from Faulty Generator and to shut it down as quickly as possible to avoid Further problems.

b. Loss of Excitation:

* When excitation of generator is lost, it slightly speeds up and operates as an Induction generator.
* Round rotor generator do not have damper winding and it is not suitable for this operation. So rotor gets heated up due to heavy induced currents.
* Salient pole rotor have damper windings and it is not heated up in this operation, since damper windings carries that heavy induced currents.
* But salient or non-salient pole stator may get heated up because of more magnetising current flowing through it.
* Stator overheating does not occur as quickly as rotor overheating.
* Another problem due to loss of excitation in large machine may upset system stability because Induction generators will absorb more reactive power whereas it supplies reactive power when it runs as a generator.
* A large machine with fast acting voltage regulator can run as an Induction generator for several minutes without any harm.
* Field failure may occur due to failure of excitation or malfunction of field breaker.




* A protective offset mho or directional impedance relay characteristic is shown in figure.
* When generator losses its excitation, the locus of the equivalent generator impedance moves from first quadrant to fourth quadrant irrespective of initial conditions.
* This type of locus is not traced in any other conditions. So the relay trips the field breaker and the generator is disconnected from the system.

c. Protection of rotor overheating due of unbalanced 3 phase stator current

* The negative sequence component of unbalanced stator current cause double frequency currents to be induced in rotor and this leads to overheating of rotor.

The unbalance condition arises due to

i) when a fault occurs in a stator winding

ii) open circuiting of a phase.

iii) an unbalanced external fault which is not cleared quickly.

A negative sequence filter and timer unit is used along with a relay for the protection. The timer makes a delay in the alarm to prevent the alarm from sounding unnecessarily for an unbalanced loads for short duration.

Miscellaneous :-

a. overvoltage protection :-

* Overvoltage may be caused by a defective voltage regulator or it may occur due to sudden loss of electrical load on generators.
* When load is suddenly thrown out, there is an increase in speed and hence the voltage also increases. In case of steam power station, the automatic voltage regulator controls the overvoltage which is directly proportional to speed by bypassing the steam.
* In case of hydro power plants, it is not possible to stop or divert water flow so quickly & overspeed may occur. Therefore, overvoltage relays are provided with hydro and gas turbine sets.

b. over speed protection :-

* speed governors normally controls the speed. It is normally designed to prevent any speed rise even with 100% load rejection.
* As water flow cannot be stopped quickly, hydrosets are provided with overspeed protection.

c. protection against motoring :-

* When the steam supply is cut off, the generator runs as a motor. The steam turbine gets overheated because of insufficient steam passes through the turbine to carry away the heat generated by windage loss.
* Hydrosets also needs protection against motoring because cavitation problems arise in water turbines at low water flow.
* Reverse power relay is required for this protection.

d) Protection against Vibrations:-

* Vibrations are caused by overheating of rotor or due to some mechanical failure or due to some abnormality.

* unbalance currents in stator or rotor ground faults also cause vibrations. protection for these faults reduces vibrations.

* Vibration ~~dect~~ detector is used to sense vibrations caused by electrical or mechanical causes.

e) Bearing overheating protection:-

* Bearing overheating is detected by inserting temperature sensing device in a hole in the bearing.

* In larger machines, if lubricating oils are used for cooling of bearings, temperature measurement of lubricating oil is fixed & alarm is activated when bearing gets overheating.

F) protection against auxiliary Failure:-

* The power plant auxiliaries are very important for running the generating sets.

* protection against loss of vaccum, loss of boiler pressure, induced draught fans are provided for large generator sets.

draught fans are provided for large generator sets.

such failures are due to failure of associated auxiliaries.

* such failures are due to failure of associated auxiliaries.

g) protection against Voltage regulator Failure:-

* Modern quick response automatic Voltage regulators are very complex. They are subjected to component failures. suitable protective devices are provided against their failure.

* A definite time d.c overcurrent relay is provided which operates when there is overcurrent in the rotor circuit for a period longer than a prescribed limit.

% of winding unprotected = $\frac{R I_o}{V} \times 100$

$I_o$ - minimum operating current in the primary of C.T.

1. A generator is protected by restricted Earth Fault Protection. The generator ratings are 13.2kV, 10MVA. The % of wdg to be protected against phase to ground fault is 85%. The relay setting is such that it trips for 20% out of balance. Calculate the resistance to be added in the neutral to ground connection.

Solu:

$V_L = 13.2kV$, $P = 10MVA$

$P = \sqrt{3}\, V_L I_L$

$I_L = P/\sqrt{3}\, V_L = \frac{10\times10^6}{\sqrt{3}\times 13.2\times10^3} = 437.386A$

relay setting is 20% out of balance (ie) For 20% of rated current the relay activates.

$I_0 = 437.386 \times \frac{20}{100} = 87.477A$

$V_{ph} = V_L/\sqrt{3} = \frac{13.2\times10^3}{\sqrt{3}} = 7621.02\ V$

% of winding unprotected = 15%

as 85% is protected

$15 = \frac{R I_0}{V} \times 100$

$R = \frac{15\times7621.02}{87.477\times100} = 13.068\,\Omega$

2. The neutral point of a 11kV alternator is earthed through a resistance of 12Ω, the relay is set to operate when there is out of balance current of 0.8A. The C.T's have a ratio of 2000/5. what % of the winding is protected against earth faults. what must be the minimum value of earthing resistance required to give 90% of protection to each phase?

Solu: $V_L = 11kV$, $R = 12\,\Omega$, CT ratio $= 2000/5$, $i_0$ = Relay current = 0.8A.

$I_0$ - minimum operating line current.

$I_0 = i_0 \times 2000/5 = 0.8\times2000/5 = 320A$

$$\boxed{i_0 = I_0 \times 5/2000}$$

$V_{ph} = V_L/\sqrt{3} = 11\times10^3/\sqrt{3} = 6350.8529\ V$

% of winding unprotected $= \frac{R I_0}{V} \times 100$

$= \frac{12\times320}{6350.8529} \times 100 = 60.46\%$

i) ∴ % of winding protected = 100 − 60.46% = 39.53%

ii) 90% of winding is protected

% of winding unprotected = 100 − 90 = 10%

$$10 = \frac{R I_0}{V} \times 100$$

$$10 = \frac{R \times 320}{6350.8529} \times 100$$

$$R = 1.9846\ \Omega$$

This is the minimum value of resistance required to give 90% of protection to each phase.

3. A 6.6kV, star connected alternator has a transient reactance of 2Ω/phase and negligible winding resistance. It is protected by circulating current Merz-Price protection. The alternator neutral is earthed through the resistance of 7.5Ω. The relays are set to operate when there is out of balance current of 1A in secondary of 500/5 A, current transformer. How much % of winding is protected against earth fault?

Soln: $V_L = 6.6kV$, $X = 2\Omega$/phase, $R = 7.5\Omega$, CT ratio: 500/5.

Let $x$% of winding is unprotected.

∴ Reactance of unprotected winding $= \frac{x}{100} \times 2 = 0.02x\ \Omega$

$$V_{ph} = V_L/\sqrt{3} = \frac{6.6}{\sqrt{3}} = 3810.511V \rightarrow \text{full Voltage}$$

Let
$V$ = Voltage across unprotected winding

$$= \frac{x}{100} \times 3810.511 = 38.10511x\ V$$

$r = 7.5\Omega$

$Z$ = Impedance offered to the fault

$$= r + j(0.02x)$$

$$Z = 7.5 + j(0.02x)$$

$$|Z| = \sqrt{(7.5)^2 + (0.02x)^2}$$

$I$ = Fault current = out of balance secondary current × CT ratio

$$= 1 \times 500/5 = 100A$$

$$|Z| = V/I \Rightarrow \sqrt{(7.5)^2 + (0.02x)^2} = \frac{38.10511x}{100}$$

$$(7.5)^2 + (0.02x)^2 = 0.1452x^2$$

$56.25 + 4\times10^{-4} x^2 = 0.1452 x^2$

$0.1488 x^2 = 56.25$

$x^2 = 388.4668$

$x = 19.7\%$ → % of winding unprotected

∴ % of winding protected = 100 − 19.7 = 80.29%.

4. A 3φ, 10MVA, 6.6kV, alternator supplies a load of 8MVA at 0.8PF & is being protected through merz-price circulating current system and its relays are so set that they do not operate until the out of balance current occurs at 20% of full load current. Calculate the value of earth resistance, to be provided inorder to ensure that only 10% of alternator winding remains unprotected. Assume alternator reactance drop of 10%. Neglect Resistance of the alternator.

Soln:

$V_L = 6.6kV$, $P = 10MVA$, $V_{ph} = V_L/\sqrt{3} = 3810.5117V$

$P = \sqrt{3} V_L I_L$

$$I_L = \frac{10\times10^6}{\sqrt{3}\times6.6\times10^{3}} = 874.7731A$$ → full load I

$$\%\ \text{Reactance drop} = \frac{IX}{V}\times100$$

$$10 = \frac{874.7731\times x}{3810.5117}\times100$$

$x = 0.4356\,\Omega$

Reactance of unprotected winding $= \frac{10}{100}\times0.4356 = 0.04356\,\Omega$

Voltage induced in unprotected winding $V = \frac{10}{100}\times3810.5117$

$= 381.05117V$

i = Fault current = 20% of $I_L$

$= 20 \times 874.7731 = 174.954$

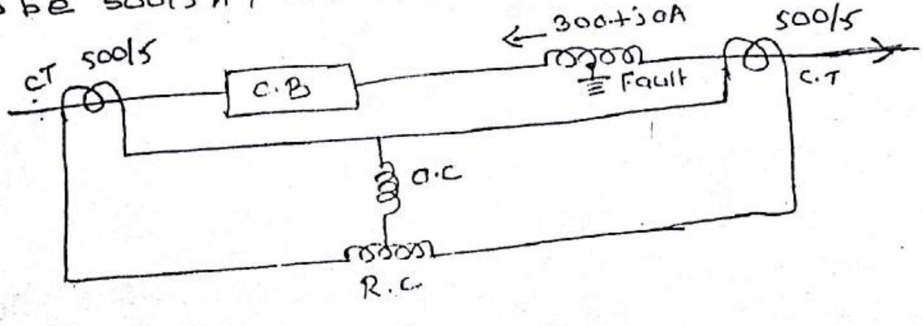
$$Z = V/i = \frac{381.05117}{174.954} = 2.178\,\Omega$$

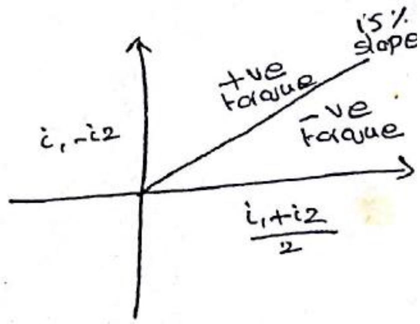
$Z = R + j0.04356$

$|Z| = \sqrt{R^2 + (0.04356)^2}$

$R = 2.177\,\Omega$

5. An alternator stator winding protected by a % differential relay is shown in Fig. The relay has 15% slope of characteristics $(I_1 - I_2)$ against $(I_1+I_2)/2$. The high resistance ground fault has occurred near the grounded neutral end of the generator winding while the generator is carrying load. The current's flowing at each end of the generator winding are also shown. Assuming CT ratio to be 500/5 A, will the relay operate to trip the C.B?




$i_1 = (300+j0) \times 5/500 = 3A$

$i_2 = (340+j0) \times 5/500 = 3.4A$

$O.C\ I = i_1 - i_2 = 3 - 3.4\,A = -0.4A$

$R.C\ I = \frac{i_1+i_2}{2} = \frac{3+3.4}{2} = 3.2A$

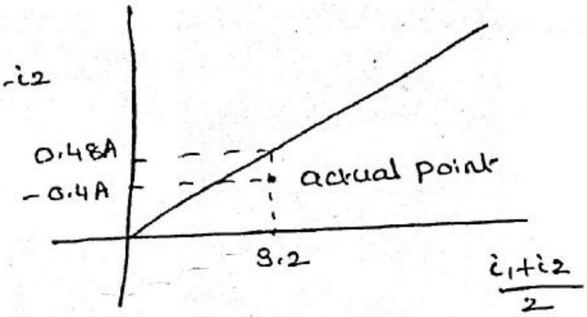
15% slope

$\text{slope} = y/x = \frac{i_1 - i_2}{(i_1+i_2)/2}$

$i_1 - i_2 = \frac{15}{100} \times \frac{i_1+i_2}{2}$

$i_1 - i_2 = \frac{15}{100} \times 3.2$

$= 0.48A$




since actual point lies below the slope line, the relay will not operate.

Transfomer protection:-

* For small size transformers, simple protective devices like Fuses are employed.
* For medium size transformers, overcurrent relays are employed
* For large transformers, differential protection is being employed

Types of Faults :-

1. External Faults :-

* In case of external faults, transformers must be disconnected if other protective devices meant to operate for such faults, fail to operate within a predetermined time. Time graded over current relays are used and it is only a back up protection. For overloads thermal relays are employed.

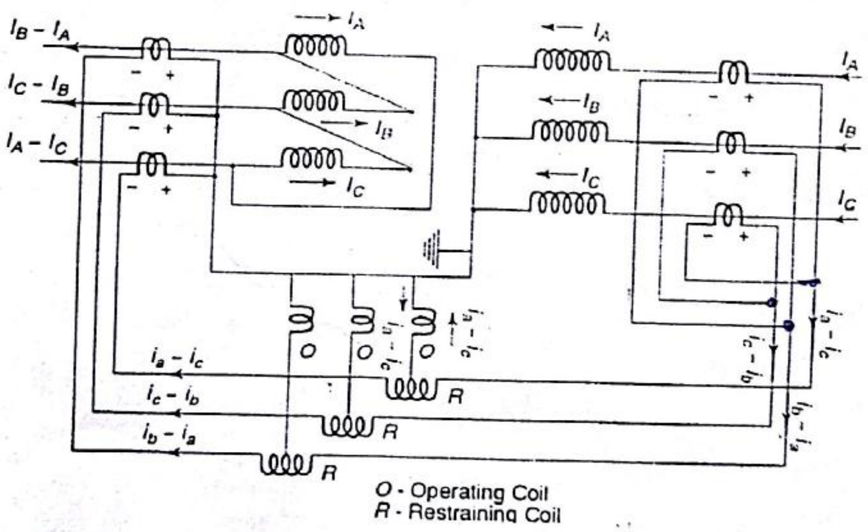
2. Internal Faults :-

It is the primary protection of transformers.

i) Short circuits in the transformer winding and connections :-

* These are electrical faults of serious nature and are likely to cause immediate damage. Such faults are detectable at the winding terminals by unbalances in voltage or current. This type of faults include line to ground or line to line and interturn faults on H.V. and L.V. windings.

Percentage Differential protection :-




* It is used for the protection of large power transformers having ratings of 5MVA and above.
* It is employed for the protection of transformers against internal short circuits
* It is not capable of detecting incipient faults.
* The current at entering end has been marked as positive & the current at leaving end has been marked as negative.

* Connections are made in such a way that under normal condition & in external fault cases, current flowing in relay is zero. The reason is current flowing in CT's of primary side is equal & opposite to the current flowing in CT's of secondary size of the transformer.

* If fault occurs, the polarity of induced voltage on the C.T in its secondary side is reversed. Now currents flowing from CT's of both primary and secondary winding are in the same direction in the operating coil of the relay & so the relay operates.

1. In a power transformer, the voltage rating of two windings are different. High voltage winding has low current ratings whereas low voltage winding has high current ratings. Thus there always exis difference in current in the primary and secondary sides of power transformer. If same CT ratio's are used in both sides, the relay gets operated during normal conditions & during external fault conditions.

   To overcome this difficulty, CT ratio's are chosen dependin upon the line currents of the power transformer.

2. Due to difference in voltages in two windings and connections (Y-Δ there always exist a 30° phase difference between the voltages induced in high voltage winding and low voltage winding. So there a phase difference in line currents on primary and secondary sid of a power transformer. This introduces a phase difference between the C.T secondary currents.

   Due to this, eventhough different CT ratio's are choosen to balance line currents, once again the relay operates for normal conditions itself.

3. Moreover, zero sequence currents flowing on the star side of the transformer does not produce current outside the delta on the other side. Therefore zero sequence currents should be eliminated from the star side.

   To achieve this, secondary of CT's on star connected side of a power transformer are connected in delta while the secondaries of CT' on delta connected side of a power transformer are connected in star.

* Relay settings are kept higher than alternators.

For alternator:- 10% for operating coil
5% for Restraining coil

For power transformers:- 40% for operating coil
10% for Restraining coil

Reason for higher relay settings in power transformer are:

1. When a transformer is on no-load, there is no load current in the relay. Therefore, it's setting should be greater than no-load current.
2. A transformer is provided with on-load tap changing gear. The C.T ratio is fixed and cannot be changed with varying transformation ratio. Therefore for taps other than nominal, an out of balance current flows through the operating coil of the relay during load and external fault conditions.

To overcome this tappings are also provided in CT's. The neutrals of CT star and power transformers star are grounded.

This differential protection gives protection against short circuit faults between the turns (ie) interturn faults also. The reason is when there is an interturn fault, the turn's ratio of power transformer gets affected. Due to this, the currents on the both sides of power transformer become unbalanced & the current flows through the relay & the relay operates.

Problems encountered:-

1. Unmatched characteristics of C.T's

It is overcomed by usage of percentage differential relay. In this operating coil is balanced by the Restraining coil.

2. Ratio change due to tap changes.

3. Difference in length of pilot wires

Due to difference in lengths of the pilot wires, unbalance condition may result. In percentage differential relays, the taps are provided on the operating coil & restraining coil to achieve balance. In normal differential relays adjustable resistors are adjusted which are in series with pilot wires to achieve balance.

4. Magnetising inrush current:-

When an unloaded transformer is switched on, it draws a large initial magnetising current which will be several times the rated current of transformer. This current is known as magnetising inrush current. This current flows only in primary winding & differential protection will look this as an internal fault. The harmonic contents in the inrush currents are different than those in usual fault current. It is overcomed by harmonic current restraint.

DC component Varies from 40 to 60%.

Second harmonic component Varies from 30 to 70%.

Third harmonic component Varies from 10 to 30%.

other harmonic's are progressively less.

Third harmonics & its multiples do not appear in CT & thus will circulate in delta connection of power transformer or delta connection of C.T.

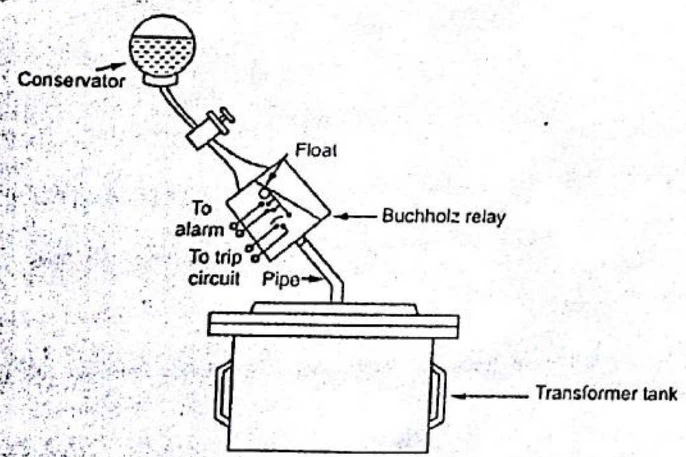
As second harmonic is more in the inrush current than in fault current, this is used to distinguish between a fault & magnetising inrush current.

ii) Incipient Faults:-

These are minor faults but they slowly turns into major faults. They are not detectable by unbalance in voltage or current. so percentage differential relays are not suited for detecting this incipient faults.

This faults include poor electrical connections, core faults, Failure of the coolant, regulator faults & bad load sharing between transformers.

Buchholz Relay:-




* It is a gas operated relay use for the protection of oil immersed transformers against all the types of internal faults.
* The slow developing Faults called incipient faults in the transformer tank below oil level operate this relay which gives an alarm. If faults are severe, it disconnects the transformer from the supply.

Construction & operation:-

* under normal conditions, Buchholz relay is full of oil. It has a upper float to which a mercury switch is attached.
* Another hinged flap value is located in the lower part which is directly in the path of the oil between the tank & the conservator & another mercury switch is attached.

~~* when~~

* The upper float closes the alarm circuit, while the lower flap Value closes the trip circuit in case of internal Fault.

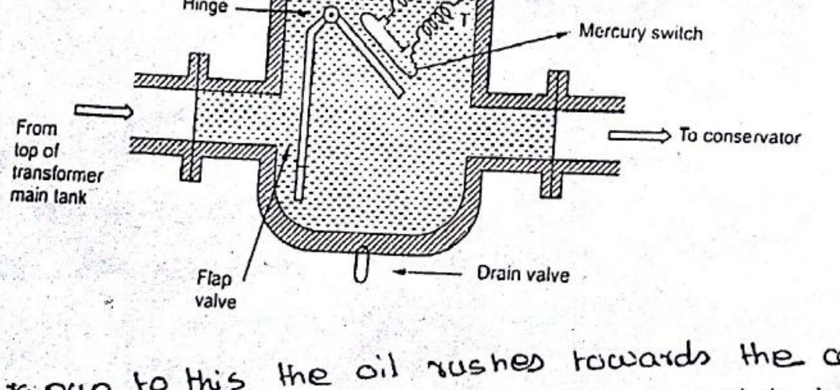
Many types of internal faults are.

1. Insulation Fault
2. core heating
3. bad switch contacts
4. Faulty joints etc...

* when this Fault occurs, oil starts decomposed and gases starts Generated. Major component of such gases are Hydrogen, since they are light it tries to rise up towards conservator but due to the highed flap Valve it starts accumulated in Buchholz relay.

* when gas gets accumulated in the upper part of Buchholz relay, oil in it starts to drop & this is sensed by the float & it tilts so that mercury switch comes in contact and sounds the alarm. The operator will know some incipient Fault has occurred & if the transformer is disconnected & the gas sample is tested to Find what type of fault is started developing.

* so transformer can be disconnected before Fault grows into a Serious one. So the alarm circuit gives indication to only to operator. It does not immediately disconnects the transformer. This is because Some times bubbles in the oil circulating system may operate the alarm circuit though actually there is no fault.




* However if a serious Fault such as internal Short circuit between Phases, earth fault inside the tank etc.., more gas gets generated & it gets accumulated. so the liquid level falls off quickly & pressure in the tank increases.

* Due to this the oil rushes towards the conservator. while doing so, it flows through the flap valve to which the relay is attached, so it

closes the relay & trips the circuit breaker, & transformer is totally disconnected from the supply.

* The connecting pipe between the tank and the conservator should be as straight as possible & should have a slope of 10° to 11°.

* For economic reasons this relays are not provided for transformers having rating below 500kVA.

Advantages:-

1. It gives the indication of the fault at very early stage.
2. It is the simplest protection.

Limitations:-

1. It is only used for oil immersed transformers.
2. only faults below oil level are detected
3. relay will operate due to bubbles, vibrations, earthquakes & mechanical shocks.
4. It's minimum operating time is 0.1sec & average time is 0.2sec. The relay is slow.

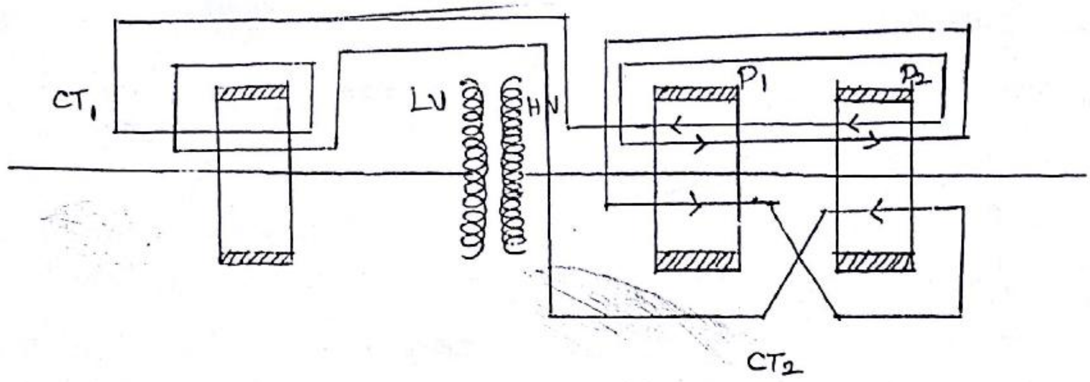
Applications:-

The following types of transformer faults can be protected by the Buchholz relay & are indicated by alarm:

1. Local overheating
2. Entrance of air bubbles in oil
3. core bolt insulation failure
4. short circuited laminations
5. Loss of oil & reduction in oil level due to leakage
6. Bad & loose electrical contacts
7. short circuit between phases.
8. winding short circuit
9. Bushing puncture
10. winding earth faults.

Self-stabilising Magnetic Balance protection system:-

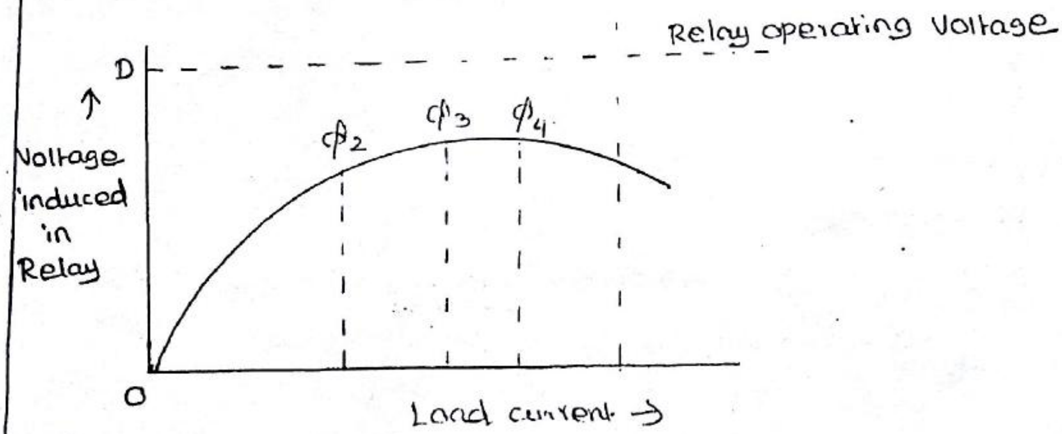
* For the protection of power transformers having tappings it is necessary that the protective CT connected to HV side must also be capable of changing its current ratio whenever power transformer tappings are changed. (ie) CT windings need some modification.




* In this circuit, the magnetic core of $CT_2$ is divided into two halves $P_1$ & $P_2$ and the secondary winding is so wound that the flux developed by the two halves $P_1$ & $P_2$ is equal & opposing each other. Thus in normal operating conditions, no emf is induced in the secondary winding & the relay operating coil remains inoperative.

* when the transformer is operating under normal operating conditions & carrying full load current, the flux developed by the two halves is equal & relay winding is unenergized.

* when tappings of the main transformer are changed, mmf's of two halves are changed causing the flux developed by them to be different. So an emf proportional to difference of two fluxes will be induced in the relay coil.




* If under this tap changed condition, the load on the transformer is increased, mmf of the two halves will increase but the difference of fluxes developed will decrease. Thus with the increase in load on power transformer, the difference in fluxes developed by the two halves of the core of $CT_2$ decreases.

* If the relay is designed such that if its minimum operating voltage is much more than the induced voltage under any desirable load condition, but with no fault, stability is ensured. In practice OD is made twice the minimum ordinate.

1. A 3$\phi$, 200kVA, 11kV/400V transformer is connected in delta-star. The CT's on low voltage side have turns ratio of 500/5. Determine the CT ratio on high voltage side.

Solu:

Star

$I_L = I_{ph}$

$V_{ph} = V_L/\sqrt{3}$

Delta

$V_{ph} = V_L$

$I_{ph} = I_L/\sqrt{3}$

200kVA, 11kV/400V

$\Delta / Y$

Since secondary side of power transformer is in Y, so CT connection will be in $\Delta$.

$$I_{L2} = \frac{200 \times 10^3}{400} = 500A$$

Secondary current in CT = $500 \times 5/500 = 5A$ /phase

$I_{phase} = 5A$

$I_{Line} = \sqrt{3}\, I_{phase} = 5\sqrt{3}$ A

This current will be same through each secondary of star connected C.T on HV side.

$I_{Line} = 5\sqrt{3}$ A

$I_{phase} = 5\sqrt{3}$ A

Apparent powers on both sides of transformers are same.

$\sqrt{3}\, V_{L1} I_{L1} = \sqrt{3}\, V_{L2} I_{L2}$

$\sqrt{3} \times 11{,}000 \times I_{L1} = \sqrt{3} \times 400 \times 500$

$$I_{L1} = \frac{400 \times 500}{11000} = 18.18A$$

This is the value of current through each primary of CT's connected in star.

$\therefore$ current ratio of CT's on High voltage side = $\frac{18.18}{5\sqrt{3}} = 2.099 : 1$

## Busbar protection:-

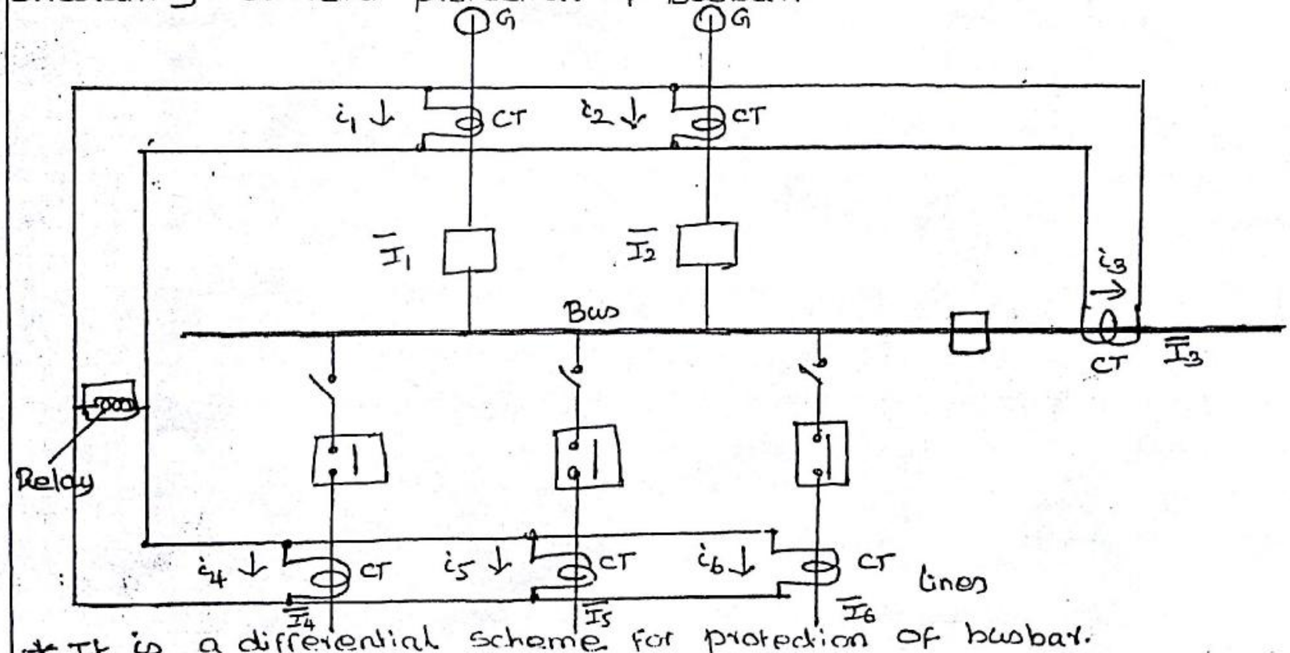
Busbar plays an important role in the supply system. The busbar faults are rare but if occurs, more damage & loss will occur & interruption of supply also occur. Hence protection to it must be fast, stable & reliable.

This protection not only protect the busbar but also the apparatus associated with it like circuit breakers, isolating switches, instrument transformers etc.

## Busbar Faults:-

1. Insulation failure
2. circuit breaker failure
3. Flashover due to excessive overvoltages
4. Flashover due to heavily polluted insulator
5. Earth fault due to failure of support insulator
6. Errors in operation & maintenance of switchgear
7. Accidents due to foreign bodies falling across the busbars
8. Earthquake & mechanical damage.

## Circulating current protection of Busbar:-




* It is a differential scheme for protection of busbar.
* Principle states that under normal working conditions or external fault conditions, sum of currents entering is equal to sum of currents leaving the bus.
* under abnormal conditions, in the protected zone (ie) short circuit or phase to phase faults, the current condition gets disturbed & the relay will operate.

$I_1, I_2 \dots I_6$ → are currents in the circuits connected to the busbar.

under normal condition, $\Sigma I = 0$

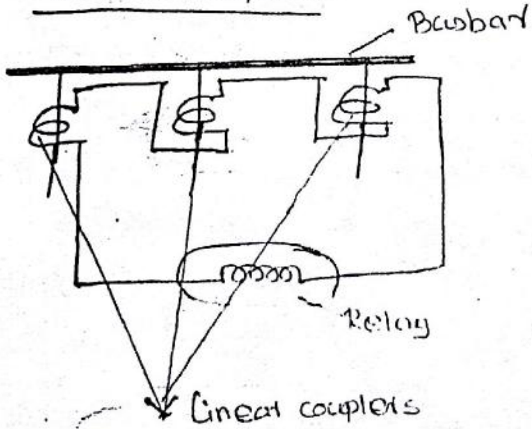
(ie) $\bar{I}_1 + \bar{I}_2 + \bar{I}_3 + \bar{I}_4 + \bar{I}_5 + \bar{I}_6 = 0$

currents in the secondaries of CT balance each other & no current flows through the relay, & it is inoperative.

under Fault conditions,

$\bar{I}_1 + \bar{I}_2 + \dots + \bar{I}_6 = \bar{I}_f$ . Now the relay operates.

* To get exact balance of currents, all CT's must have same ratio. But in practice due to saturation of CT's at heavy currents, False operation of relay is possible at external Faults. To overcome this difficulty, a special type of CT having no iron core is used. It is called Linear coupler.




* The linear coupler has a property that its Secondary voltage is directly proportional to primary current & the secondary windings of all the linear couplers are connected in series to the relay.

* The sum of voltage outputs of linear couplers is equal to the vector sum of the voltages in the circuits connected to the busbars. Hence under normal conditions, overall voltage in the secondary circuit is zero & relay is inoperative. under Faulty conditions, there is a resultant voltage in the secondary & the relay operates.

* A high impedance relay can easily differentiate the internal & external Faults compared to normal load impedance relays. A high resistance is connected in series with relay operating coil to get high impedance relay. This resistance is called stabilizing resistance.

Difficulties in Busbar protection:-

1. current levels for different circuits are different.
2. Large Number of circuits are to be Protected.
3. Due to various bus sections, the scheme becomes complicated.
4. with large load changes, relay settings need to be changed.
5. saturation of cores of CT's produces ratio error.

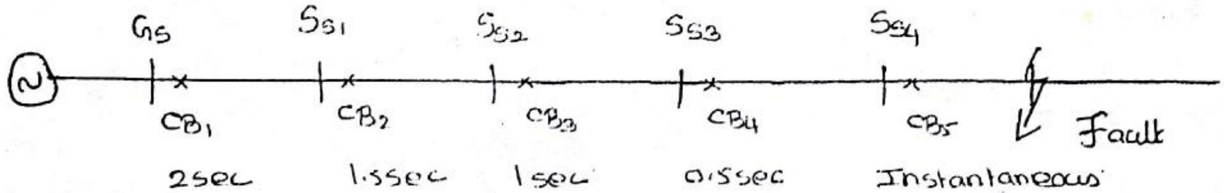
# Protection of Transmission lines & Feeders :-

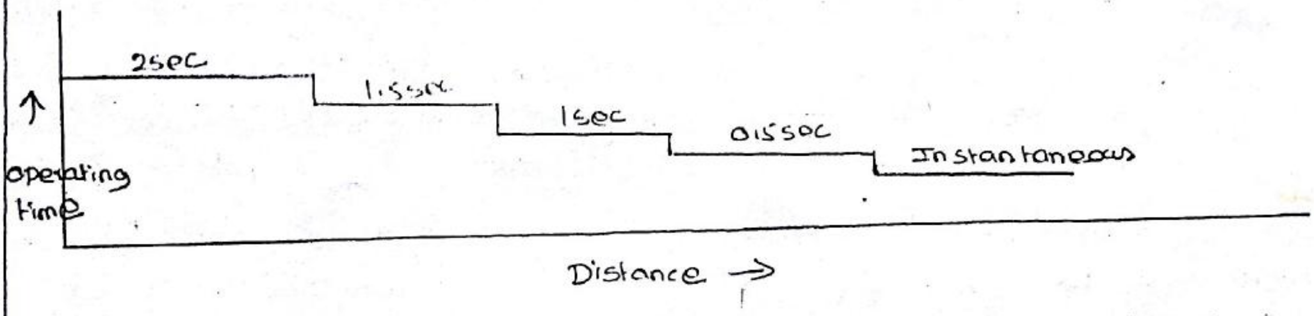
1- Non-unit type protection

a) Time graded protection
b) current graded protection
c) over current protection
d) over load protection
e) Distance protection.

a) Time graded protection:-

i) protection of Radial feeders:-



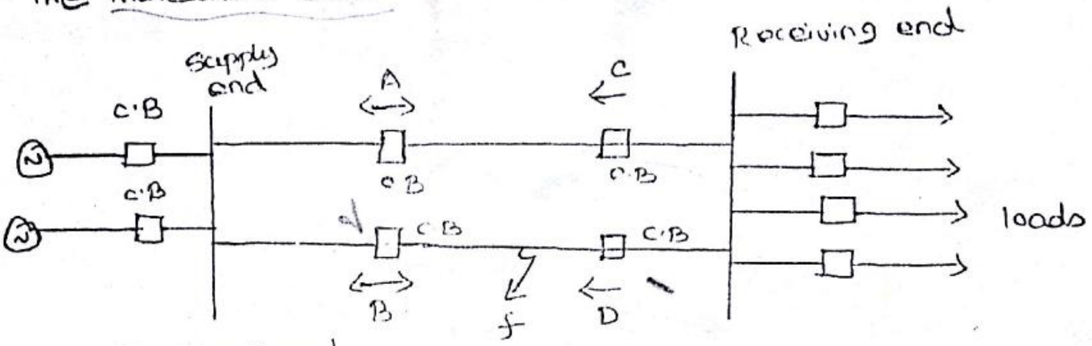

* In radial feeder, power can flow in one direction only. (ie) From generation or supply end to the load end. It has the drawback that continuity of supply cannot be maintained at the load end in the event of fault.

* In addition to this grading, it is also essential to have the time of operation dependent on the severity of fault. For severe fault the time of operation should be automatically less. This is achieved by using time limit fuses in parallel with the trip coils. It's additional advantage is that the relay will not operate under normal overload conditions of very short duration. IDMT relays are used for this operation.

ii) Protection of parallel feeders:-

* To have continuity of supply, atleast two lines are used & are connected normally in parallel so as to share the load. These lines may or may not run on the same tower or the same right of way.

* In the event of a fault occuring, protective device will select & isolate the defective feeder while the other instantly assumes the increased load.

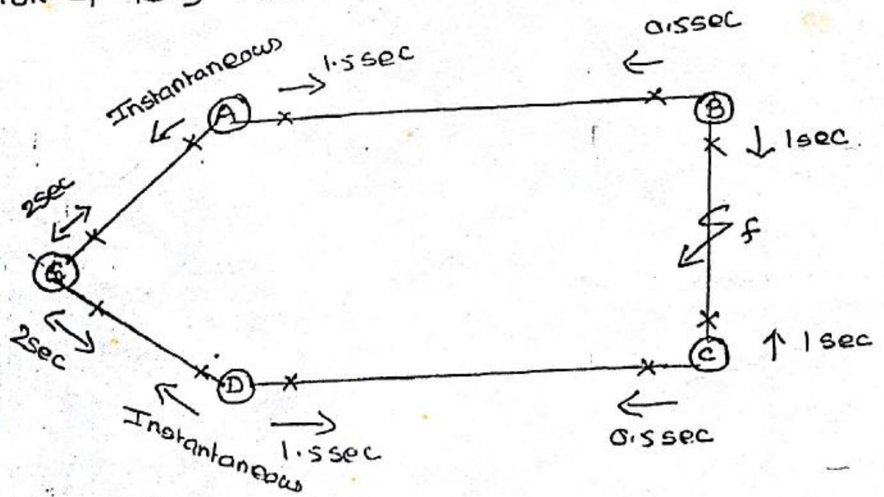



↔ Non - Directional
→ Directional

* Simplest method of protection is by providing time graded overload relays with inverse time characteristic at the sending end & instantaneous reverse power or directional relays at the receiving end.

* When fault occurs & heavy short circuit current flows through any one feeder say feeder 2, the power is fed into the fault from sending end & also from receiving end. The direction of power flow will be reversed through relay D which will open. The excess current is then confined to C.B 'B' until its overload relay operates & trips the C.B, thus completely isolating the faulty feeder & supplying power through healthy feeder.

Protection of Ring Main system:-

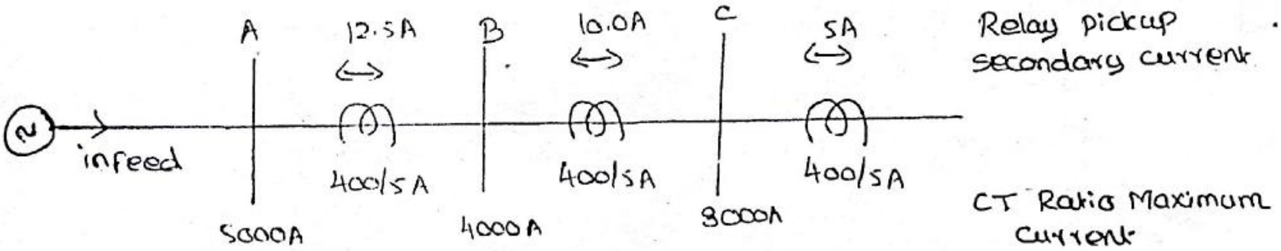


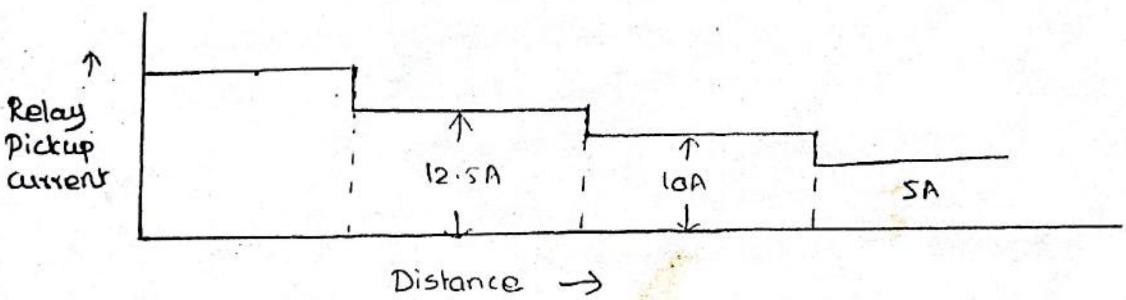

↔ Non Directional
→ Directional

* The ring main is a system of interconnection between a series of power stations by an alternative route. The peculiarity of the ring main is that direction of power flow can be changed at will, particularly when an inter-connector is used.
* At the generating stations, the power flow is in one direction (ie) away from the busbars. so non directional time lag overload relays

* The time graded relays are used at both ends of the substation & they are set so that they will only trip when an overload flows away from the substation which they protect.
* If a fault occurs at 'F', the fault current flows from ABF & DCF. So a relay & C.B between B & C will work & clear the fault.
* Thus fault on any section will cause the relays on that section only to operate & the healthy sections will be operating uninterruptedly.
* The reverse power relays are set so as to operate only when power flows away from the substation at which they are installed. So only two adjacent C.B's will operate for a fault.

Current Graded protection:-




* It is used when the impedance between two substations is sufficient. It is based on the fact that the short circuit current along the length of the protected circuit decreases with the increase in distance between the supply end & the fault point.
* It uses high speed high set overcurrent relays.

Disadvantages:-

* For ring mains, parallel feeders, interconnected systems where power can flow to the fault from either direction, a system without directional control is not suited.

## Unit type protection of Transmission lines & Feeders :-

### Pilot Relaying schemes:-

* In these scheme, some electrical quantities at the two ends of transmission line are compared & hence they require some sort of interconnecting channel over which information can be transmitted from one end to the other. Such a interconnecting channel is called a pilot.

Three different types of such channels are presently in use, are

1. wire pilot protection
2. carrier current pilot protection
3. Microwave pilot protection

### wire pilot Protection:-

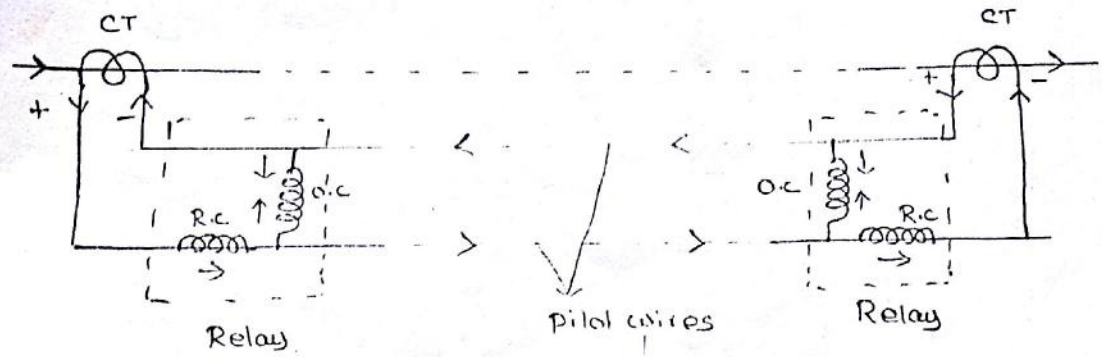
* The wire pilot may be a buried private cable, private telephone lines or a pair of overhead auxiliary wires other than the power line conductors.
* It is suitable for distances upto 30km. (15-30km)
* In this scheme, two wires are used to carry information signals from one end of the protected line to the other. It is a unit protection & operates on the principle of differential protection.
* For short lines it is economical because terminal equipment is simpler & cheaper. It is more reliable because of its simplicity.
* The distance for its protection is limited to 15-30km due to attenuation of the signal caused by distributed capacitance & series resistance rather than the cost.

Two basic principles are

1. circulating current principle
2. balanced voltage principle

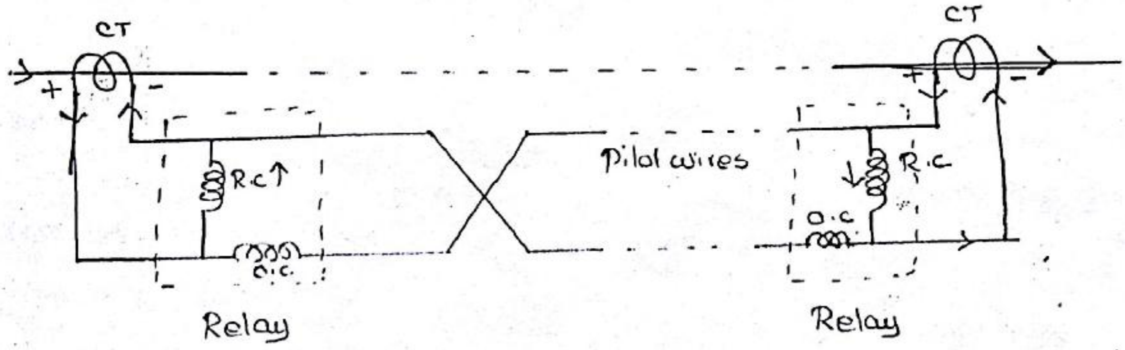
Mostly wire-pilot schemes use amplitude comparision in circulating current scheme since they are easier to apply to multi-ended lines & are less affected by pilot capacitance.

Circulating current scheme:-




This scheme is suitable for pilot loop resistance upto 1000Ω & inter Capacitances upto 2.5 μf.

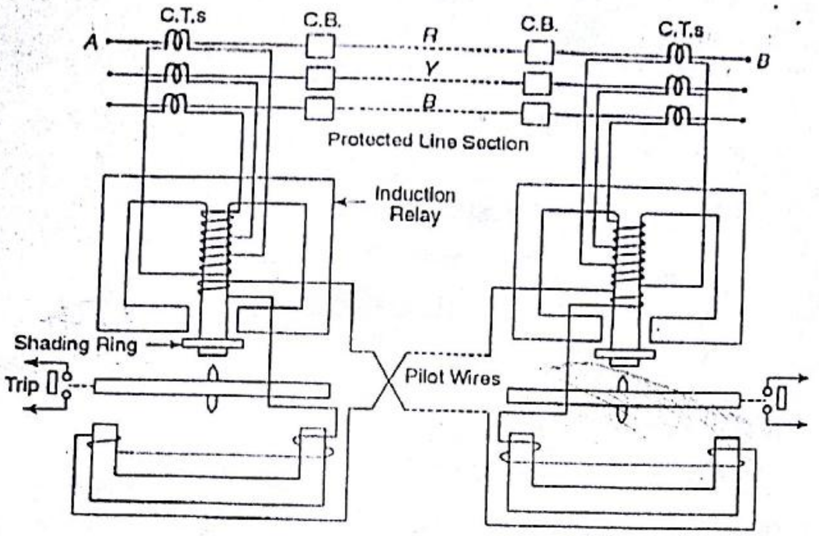
Balanced voltage (or opposed voltage) scheme:-




* In this scheme, current does not normally circulate through pilot wires.
* The operating coil of the relay is placed in series with the pilot wire & hence current doesnot flow through the pilot wires under normal conditions & in case of external faults.
* In case of internal faults, the polarity of the remote end CT is reversed & hence current flows through the pilot wires & operating coils of the relays.

Translay scheme:-

* It is a balanced voltage scheme with the addition of a directional feature.
* An induction disc type relay is used at each end of protected line section.
* The secondary windings of the relay are interconnected in opposition as a balanced voltage system by pilot wires.
* The upper magnet of the relay carries a summation winding to receive the output of CT.
* under normal conditions & in case of external faults, no current circulates through the pilot wires & hence through the lower magnets of the relays. In these conditions, no operating torque is produced.




* In case of internal faults, current flows through the pilot wires & the lower electromagnets of the relay. In this condition, the relay torque is produced from the interaction of the two fluxes, one of which is produced directly from the local CT secondary current flowing through the upper magnet of the relay. The second flux is produced by the current flowing through the lower magnet. The current flowing through the lower magnet may be relatively small. Therefore it is suitable for long pilots having a loop resistance of 1000Ω. In static relays, phase comparision voltage balanced scheme is used.

2. Carrier current pilot protection:-

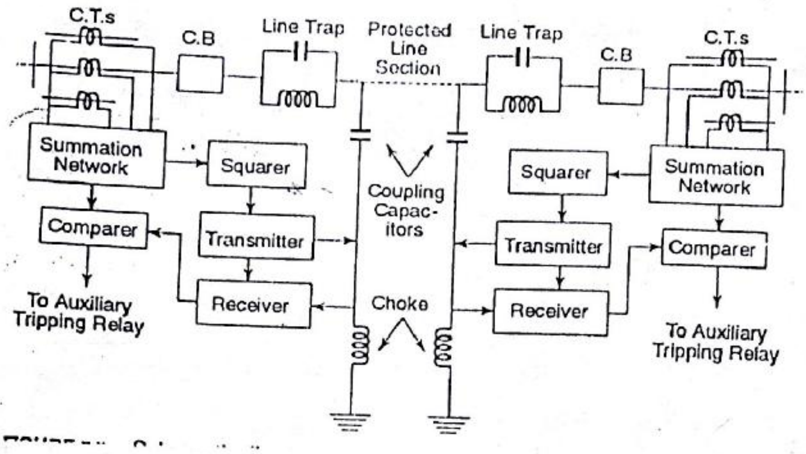
* It is the one in which a low voltage, high frequency signals (50kHz - 700kHz) is used to transmit information from one end of the line to the other. In this scheme, the pilot signal is coupled directly to the same high voltage line which is to be protected. This type of pilot is also called as power line carrier. The link may operate upto 40 to 60km.

Phase comparison carrier current protection of Transmission lines:-

* In this scheme, the phase angle of the current entering one end of the protected line section is compared with the current leaving the other end.

Line trap is a parallel resonance ckt tuned to the carrier frequency connected in series with the line conductor at each end of the protected line section. This keeps carrier signal confined to the

the protected line section & does not allow the carrier signal to flow into the neighbouring sections. It offers very high impedance to the carrier signal but negligible impedance to the power frequency current.




* There are carrier transmitters & receivers at both the ends of the protected line.

* The transmitter & receiver are connected to the power line through a coupling capacitor to withstand high voltage & grounded through an Inductance.

* The coupling capacitor consists of a procelain-clad oil filled stack of capacitors connected in series. It offers very high impedance to power frequency current but low impedance to carrier frequency current.

* Thus transmitter & receiver are insulated from the power line & effectively grounded at power frequency current. But at carrier frequency they are connected to the power line & effectively insulated from the ground.

* For the transmission of carrier signal either one phase conductor with earth return (phase to earth coupling) or 2 phase conductors (phase to ~~phase~~ coupling) can be employed.

* Phase to earth coupling :- is less expensive as number of coupling capacitor & line trap required is half that needed for phase - phase coupling.

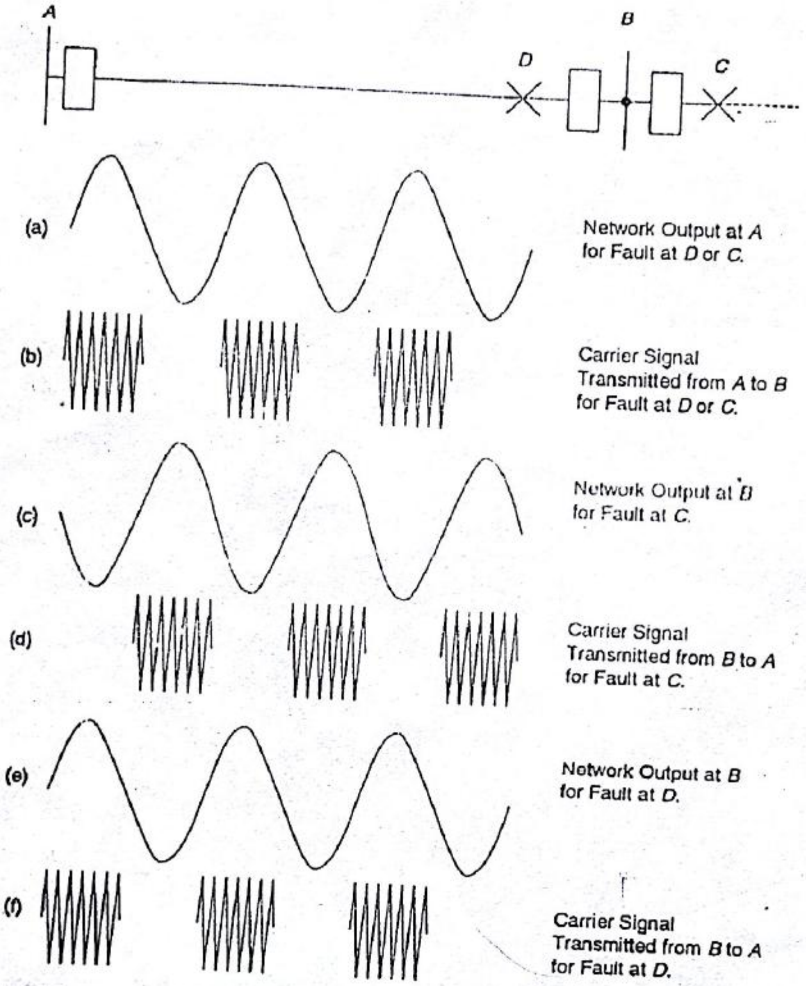
* Phase to Phase Coupling :- Performance is better because of lower attenuation & lower interference levels.

* The half - cycle blocks of carrier signals are injected into the transmissionline through the coupling capacitor.

* Fault detectors control the carrier signal so that it is started only during faults.

* The voltage outputs of the summation network at stations A & B are 180° out of phase during normal conditions. This is because the C.T connections at the two ends are reversed.

* The carrier signal is transmitted only during positive half cycle of the network output.




* For External fault, carrier signals are always present in such a way that during one half cycle, signals are transmitted by the transmitter at A & during next half cycle by the transmitter at B.

* As carrier signal is a blocking signal & it is always present, the relay does not trip.

* For internal fault, polarity of the network output voltage in B is reversed. So carrier signals are transmitted only during one half cycle & no signal in other half.

* The comparator when it doesn't receive the carrier signal, it gives an output to the auxiliary tripping relay.

* The ideal phase difference between carrier blocks is 180° for internal faults & zero degree for external faults. In practice it is kept 180° ± 30° for internal faults because of

1. Phase displacement between emfs at the ends of the protected line section.
2. current being added to the fault current at one end & subtracted at the other.
3. Error's are produced by C.T's.

* The phase comparison scheme provides only primary protection.
* For backup protection, it is provided by 3 step distance relays for phase & ground faults.
* In phase comparison scheme, the relay does not trip during swings of out of step condition or because of zero sequence currents induced from a parallel line.
* This scheme is used as a primary protection for all long distance overhead EHV & SHV transmission lines.

Phase comparison scheme is limited by phase shifts due to following factors:

1. The propagation time (ie) the time taken by the carrier signal to travel from one end to other end of the protected line section. (upto 0.06°/km).
2. Time of response of band pass filter (about 5°)
3. Phase shift caused by transmission line capacitance (upto 10°)

Advantages of carrier-current protection:-

1. High speed fault clearing which improves power system stability.
2. Fast, simultaneous operation of C.B's at both ends.
3. Fast clearing prevents shocks to systems.
4. No separate wires are required for signalling as the power lines themselves carry power as well as communication signalling.

Applications of powerline carrier:-

1. Supervisory control
2. Telephone communication
3. Telemetering
4. Relaying.

Microwave pilot protection:-

* It is a radiochannel of very high frequency 450 – 10,000 MHz.
* It covers distance upto 160 km in a flat country. The distance is limited by hills & building.
* when number of services requiring pilot channels exceeds the technical or economical capabilities of carrier-current pilot, the microwave pilot is employed.
* This system is applicable only when there is a clear line of sight between stations.
* power required for signal transmission is less than a watt because highly directive antennas are employed.

Relay co-ordination:-

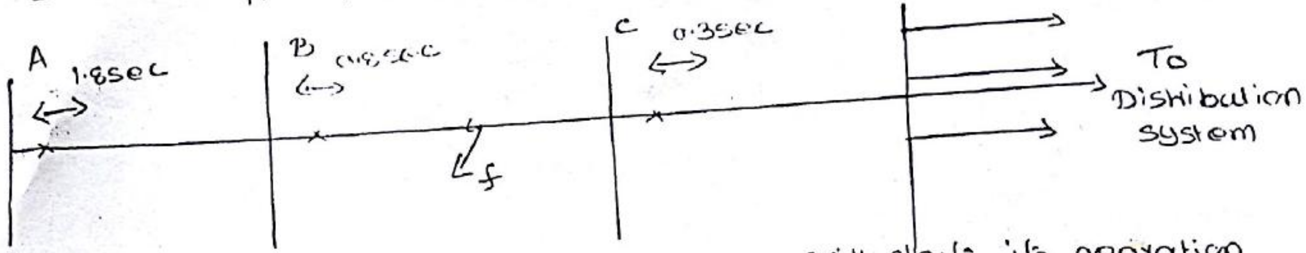
* Co-ordination of protective relays refers to corelating the settings of various relays or protection systems for harmonious & selective protection.
* Basic requirements of a good protection system include selectivity, discrimination, adequateness, stability, sensitivity, reliability & time characteristics.
* To achieve these desirable requirements, proper co-ordination of relay settings is essential.
* Neighbouring protective zones overlap. Hence there is a need for co-ordinating the time settings so that only the faulty part gets quickly disconnected without disturbance to healthy part.

Data for Relay co-ordination:-

1. Single line diagram of the system indicating neutral earthing, circuit diagram, various apparatus in the system, ratings, voltage levels, generating capacities etc.
2. Transformer details such as tap changer, ratios, earthing, rating etc..
3. Maximum & minimum values of fault currents, voltages at various locations.
4. Normal current
5. peak load current
6. permissible overcurrents
7. protection philosophy, primary protection, back up protection, Type, scheme, C.T ratios, PT ratios, characteristics, provision of settings etc
8. Local conditions, constraints if any, operating conditions such as starting currents, transients, swings etc.

## Settings of overcurrent Relays:-

* While determining the current setting & time setting of IDMT relays, it should be ensured that relay does not pickup when the line or the transfer of the apparatus is carrying permissible overload currents (peak load current). Hence a factor of safety should be applied to avoid undue tripping.




* For a fault in section BC, relays A & B will starts its operation. But for proper discrimination the settings should be so co-ordinated that for a fault for section BC, relay B operates first & clears fault & relay A gets reset so that the section AB remains in operation.

The plug settings should be selected such that following aspects are considered:

CT ratio
Peak load current
Factor of safety
Reset /pick up ratio

$$\text{plug setting of relay} = \frac{\text{Primary peak load current}}{\text{CT ratio}} \times \frac{\text{Factor of safety}}{(\text{Reset}/\text{pickup})}$$

**eg:-**

Consider Normal primary current = 800A
Peak load primary current = 1000A
CT ratio = 1000/5

It is desired to select plug setting for relay (2) at station B

Factor of safety = 1.1
Reset / pick up ratio = 0.7

$$\therefore \text{plug setting} > \frac{1.1}{0.7} \times \frac{1000}{1000/5} = 7.85$$

Relay at location B will be set for plug setting > 7.85A
Time setting - 0.8 sec.

Plug setting for minimum fault current to operate at short circuit fault.

$$\text{plug setting} < \frac{\text{minimum primary fault current}}{\text{CT ratio}} \times \frac{1}{\text{Factor of safety}}$$

Factor of safety = 1.3

min $I_f$ = 10kA

CT ratio = 1000/5

$$\text{plug setting} < \frac{10000}{1000/5} \times \frac{1}{1.3} = 38.5A$$

Thus to avoid tripping, an overload current & to allow reset for faults in next zone, the plug setting for relay 2 in station B should be > 7.85A & to ensure tripping for minimum fault current, the plug setting should be < 38.5A.

This is a general method for selecting plug setting of an overcurrent relay.

Time setting for relay in station B

$T_B = T_C + CB_2 + OB + F$

$T_B$ -- operating time for relay in station B

$T_C$ - operating time for relay in station C (Assume 0.6 sec)

$CB_2$ -- circuit time in station C, say 0.1 sec

F - Factor of safety for time, say 0.2 sec

OB - overtravel time, say 0.1 sec

$T_B = 0.6 + 0.1 + 0.1 + 0.2 = 1.00\,sec$

Hence time in station B = 1.00 sec

Setting of Directional overcurrent Relays:- The procedure is

1. Single line diagram of the loops, branches etc is drawn indicating both directional & non-directional relays.
2. Calculate values of normal currents, overload currents, fault currents via forward path & via reverse path assuming the loop - opened due to opening of a C.B.
3. Select timings of relays which are situated away from generating station step-by-step select time settings of relays nearer to generating station.
4. Review & finalise settings.

Directional overcurrent relays are used for parallel feeders & ring mains.