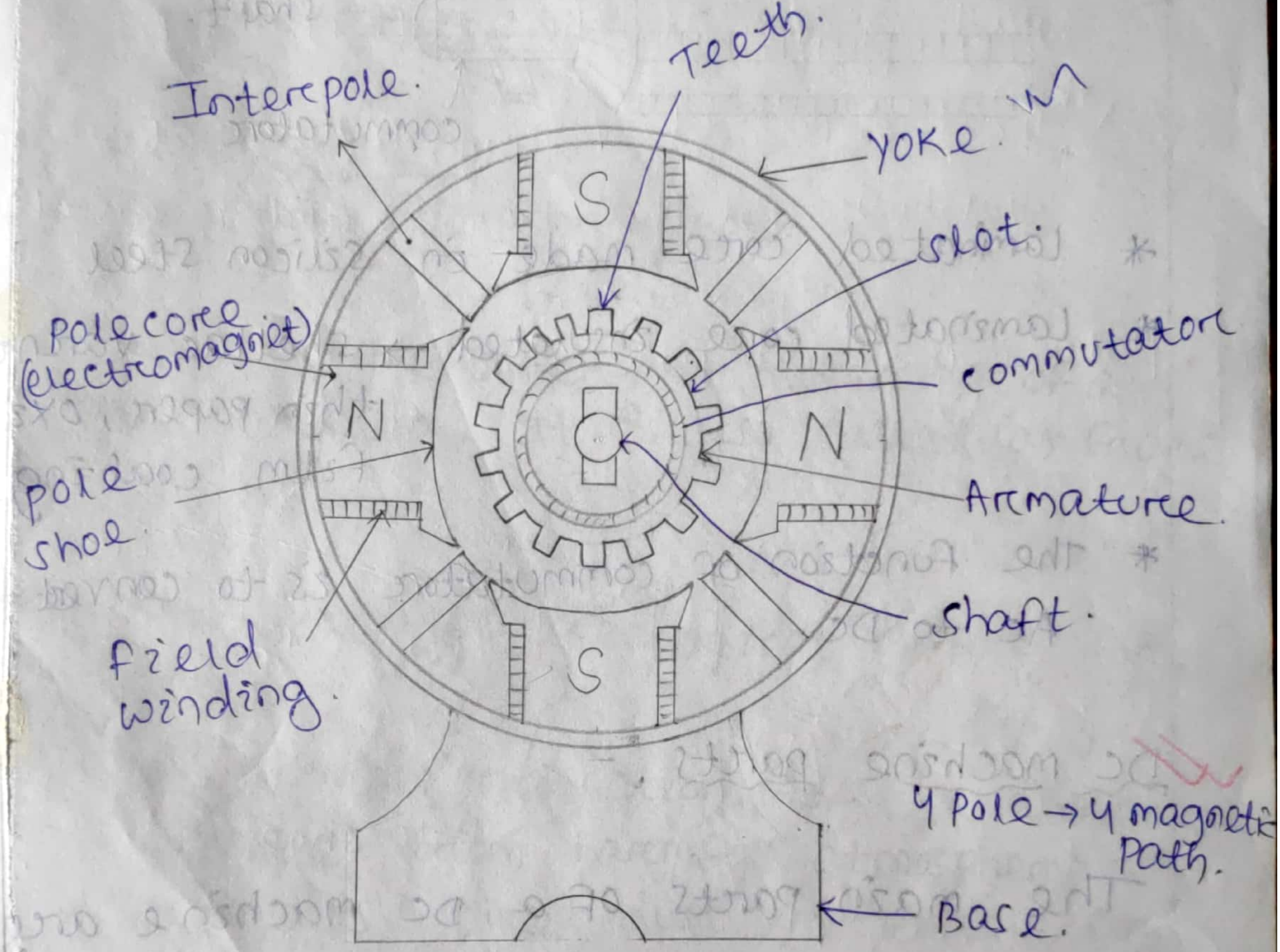
Chapter-1. (DC Generator.)

DC generator

construction :-

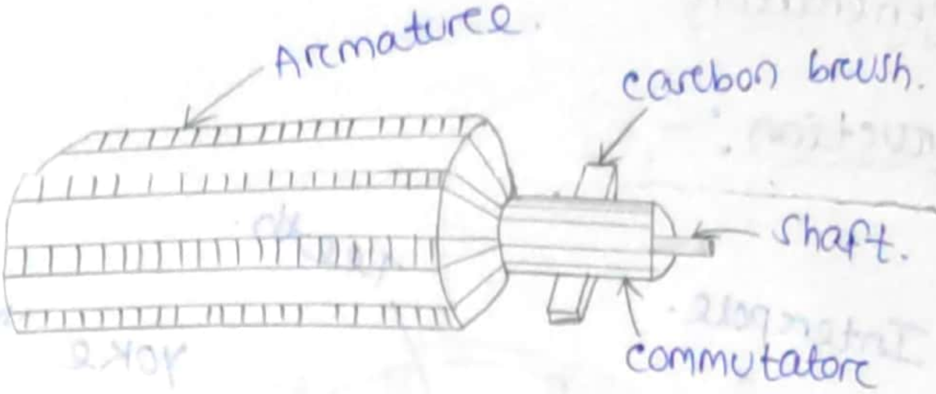


* pole core and pole shoe made in laminated silicon steel.

* Yoke made in cast iron or silicon steel, depending upon size.

small size → cast iron.
big size → silicon steel.

* The working function of interpole to reduce the armature reaction.



* laminated core made in silicon steel.

* laminated core insulated → shellac varnish, thin paper, oxide film coating.

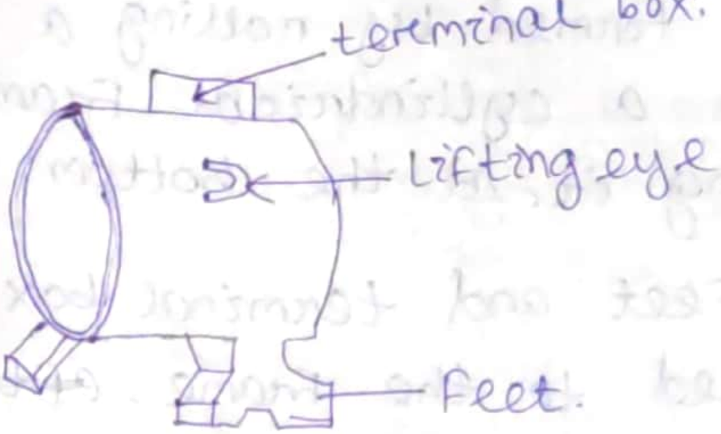
* The function of commutator is to convert AC to DC.

DC machine parts :-

The main parts of a DC machine are

(1) yoke.
(2) pole core and pole shoe.
(3) Field winding.
(4) Armature core
(5) Armature winding or conductor
(6) commutator.
(7) brushes and bearings.
(8) Interpole
(9) shaft. (10) base (11) slot

Yoke :-



(i) Yoke is the outer most covering of a DC machine. It is also called as frame.

Function :-

(i) It provides mechanical support for poles.

(ii) It provides protection to whole machine from harmful atmospheric elements like dust, moisture, SO_2, Acid, etc.

(iii) It also provide protection against mechanical injury.

(iv) It carry the magnetic flux produced by the poles or it provides path for the magnetic flux.

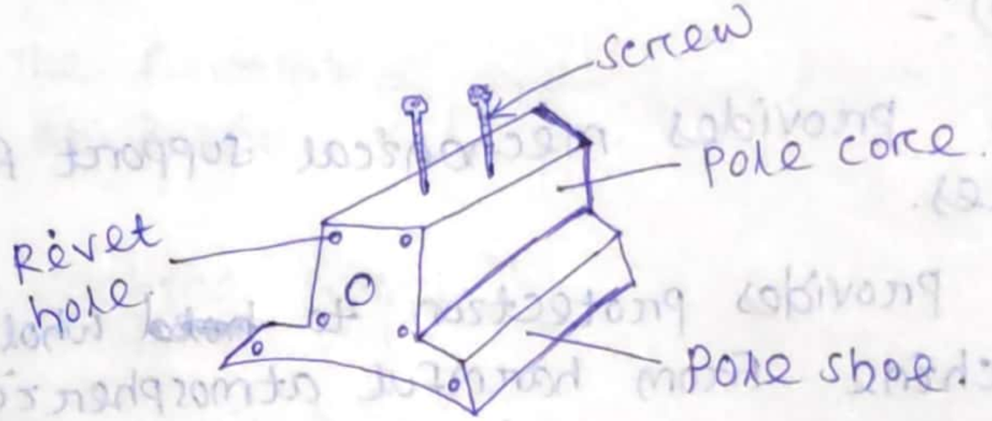
Material used and construction :-

(i) For small machine yoke is made of cast iron and for large machine it is made of silicon steel or cast steel

(ii) It is formed by rolling a steel slab around a cyllindrical frame. then welding it at the bottom.

(iii) Then the feet and terminal box, etc are welded to the frame.

Pole core and pole shoe :-



(i) The field magnet consist of pole core and pole shoe.

(ii) The pole cores are fixed to the magnetic frame or yoke by screw/bolt

(iii) Each pole core has a curved surface which is called as pole shoe.

Function :-

(i) It supports and hold the field winding.

(ii) pole shoe increases the cross sectional area of magnetic ckt as a result the magnetic path is reduced.

(iii) Due to pole shoe the magnetic flux spread in the air gap uniformely.

Material used and construction :-

(i) The pole core and pole shoe are made of thin lamination of cast steel which are rivetted together under hydraulic pressure.

rivet → passing metal pins through holes in two or more metal plates to held them together.

(ii) The thickness of the lamination varied from 0.25 mm to 1mm.

(iii) Lamination of core is required to reduce eddy current loss.

Field winding :-

(i) Field winding are used to form electromagnet and wound on the pole core with a definite direction.

(ii) Field windings carry current to form electromagnet and to produce neccessary flux.

(iii) Field coils are connected series with each other and in such a direction around pole core. so that alternate 'N' pole and S-pole are formed.

(iv) Generally field winding is made of copper.

Armature core :-

(i) It is the rotating part of a DC machine and connected to the shaft.

(ii) A prime mover is connected to the shaft to move the armature.

Function :-

(i) It holds the armature conductor and causes them to rotate.

(i) so the armature conductors cut the magnetic field and an emf is induced in them.

(ii) It provides a path of very low reluctance to the flux through the armature from N-pole to S-pole

material used and construction :-

(i) It is cylindrical or drum shape and made of circular laminated silicon steel sheet or disc.

(ii) The thickness of the Lamination varied from 0.25 mm to 1 mm.

(iii) The sluts are punched on the outer periphery of the disc.

(iv) The Lamination are perforated for airducts which permits axially flow of air through the armature for cooling purpose.

(v) The purpose using lamination is to reduce eddy current loss.

(vi) If the Lamination are thinner, then resistance offer to the current is greater. hence I^2R Loss in core is less.

Armature winding :-

(i) Armature winding is interconnection of armature conductors placed in the slots.

(ii) Armature winding are made of copper and insulated from each other and from armature core.

(iii) Armature winding can be done by two method.

(1) Wave winding.
(2) Lap winding.

→ In lap winding number of parallel path is equal to no. of pole. but in wave winding no. of parallel path is equal to two.

Commutator :- →

(i) The function of commutator is to collect current from the armature conductors

(ii) It convert AC induced in the armature conductor into unidirectional current.

(iii) It is of cylindrical structure and made of wedge shaped segment of hard drawn copper.

(iv) These segments are insulated from each other by thin layer of mica.

brushes and bearings:-

(i) The function of brush is to collect current from the commutator and supplied it to the external ckt.

(ii) Brushes are placed in brush holder which are rest on the commutator.

(iii) Brushes are usually made of carbon and are in the shape of a rectangular box.

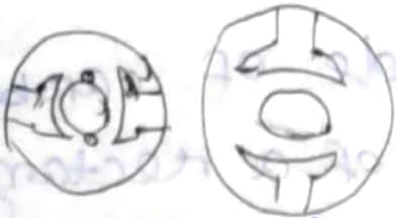
(i) The function of bearings are to reduced friction between rotating and stationary part of the machine.

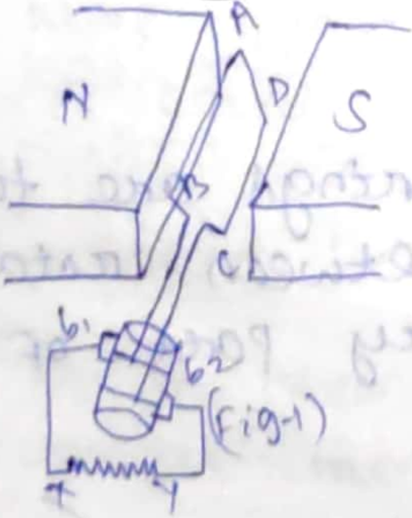
Shaft :-

(i) Rotating Parts like armature core, commutator, cooling fans are mounted on the shaft.

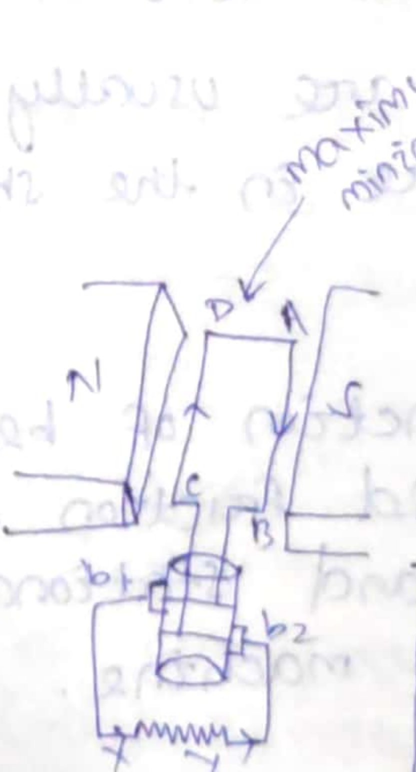
(ii) The shaft is made of mild steel with a maximum breaking strength or mechanical strength.

(iii) The shaft is used to transfer mechanical energy from armature to load or from primemover to armature.

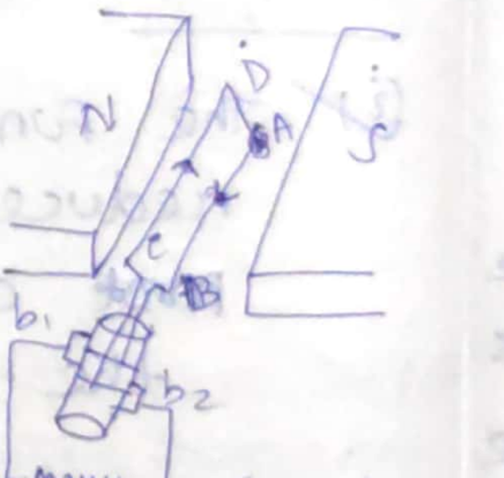




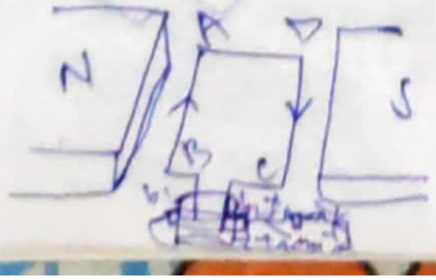
(Fig-1)



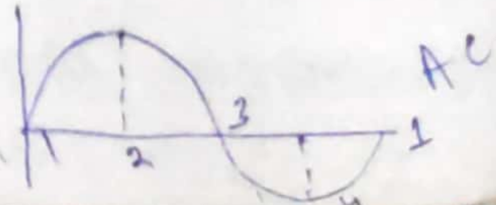
(Fig-2)

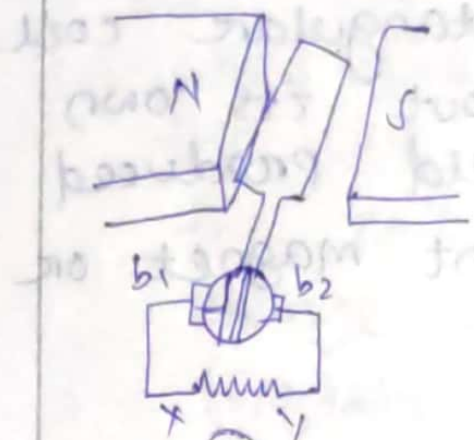


(Fig3)



(fig-4)





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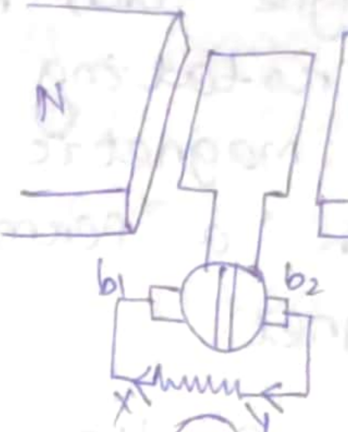

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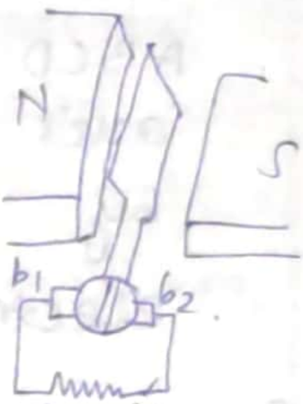

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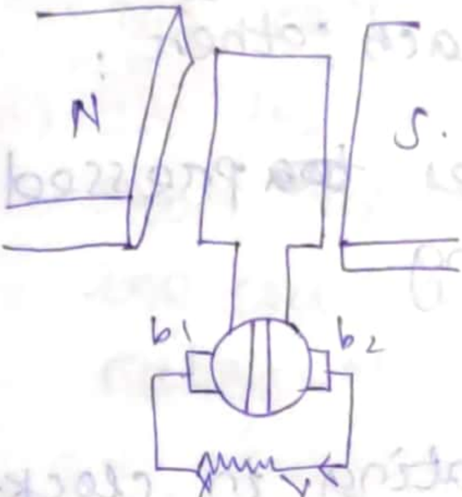

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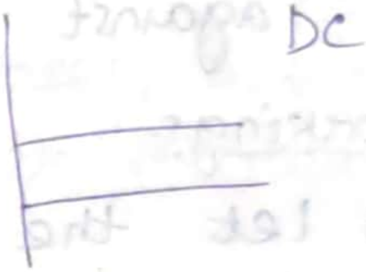


Working principle of DC generator :-

(i) Working of a DC generator based on the principle of Faraday's law of electromagnetic induction. According to Faraday's law of electromagnetic induction whenever a conductor cuts magnetic flux induced emf is produced.

(ii) This emf causes a current to flow if the conductor the ckt is closed.

(iii) Let a single turn rectangulare coil ABCD is rotating about its own axis in a magnetic field produced by either a permanent magnet or electromagnet.

(iv) Two ends of the coils are joined to two slip-rings S_1 and S_2. which are insulated from each other.

(v) Two collecting brushes pressed against the slip ring.

Working:-

(i) Let the coil is rotating in clock-wise direction, when the plane of the coil is at right angle to lines of flux (fig-1). Then the flux linked with coil is maximum but rate of change of flux is minimum.

(ii) Because in this position the coil sides AB and CD donot cut the flux they move parallel to the flux. Hence there is no induced EMF in the coil.

(iii) As the coil continued rotating further the rate of change of flux linkage increases.

(iv) when the coil plane is horizontal to the line of flux, flux linked with the coil is minimum, but rate of change of flux linkage is maximum. (fig-2)

(v) Hence maximum EMF is induced in the coil in this position

(vi) In the next quarter revolution i.e from 90° to 180°, the flux linked with the coil gradually increases, but the rate of change of flux decreases

(vii) when θ = 180° (fig-3), the emf induced in the coil is reduced to zero value.

(viii) In the first half revolution of the coil we find that no emf is induced when θ = 0° and θ = 180° and maximum emf is induced, when θ = 90°. The direction of current can be find by Fleming's right hand rule.

(ix) According to fleming's right hand rule, Here the direction of current flow . AB-XY-CD.

(x) The current through the load resistance are flow from x to y during the first half revolution of the coil.

(xi) In the next half revolution i.e from 180° to 360°, the variation of in the magnitude of emf are similar to those in the first half revolution.

(xii) The value of emf induced is maximum when $\theta = 270°$ (fig-4). but in this half revolution the direction of flow of current is DC-YX-BA. The current through the load resistance are flow from Y to X during the second half revolution of coil i.e just reverse of first half revolution.

(xiii) It is clear that the output current is alternating in nature. For making the flow of current unidirectional in the external ckt the slip-rings are replaced by split-rings or commutatorr.

(xiv) The commutator are made of conducting cylinder which is cut into two half insulated from each other by a thin sheet of mica.

(xv) The coils ends are connected to these segments such that when the coil rotates this segments also move with them.

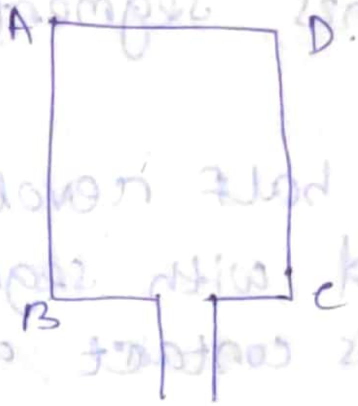
(xvi) In the first half revolution, conductor AB is connected with segment c_1 and segment c_1 is contact with brush b_1. so the current flow will along the path AB-XY-CD. but in the next half revolution segment c_2 will be in contant with brush b_1 so current will flow along the path DC-XY-BA.

(xvii) current in the load resistance flow from X to Y in both half revolution so this output current is unidirectional but not continuous like pure direct current.

Armature winding :-

Conductor :-

The length of a wire laying in the magnetic field and in which an emf is induced is called a conductor.



AB = CD = conductor.

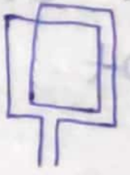
Coil :-

(i) Two conductors AB and CD along with their end connection constitute one coil of the armature winding.

(ii) coil may be of two types.

(1) single turn. → 

(2) multi turn. →



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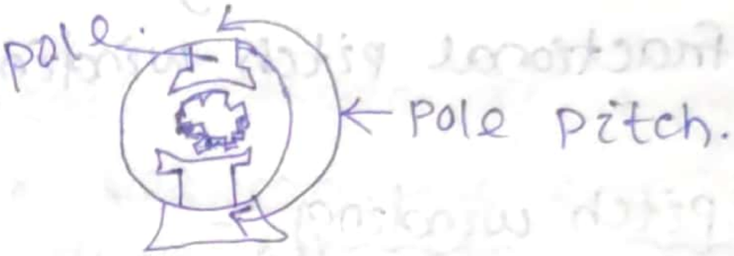
Pole Pitch :-

(i) The distance between adjacent two pole is called pole pitch.



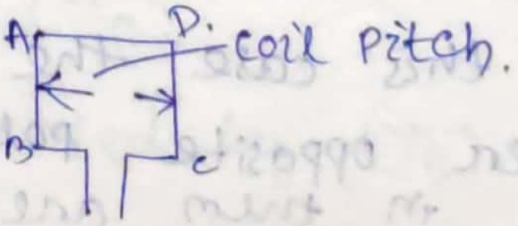
(ii) It is equal to the no. of armature conductors or armature slots per pole.

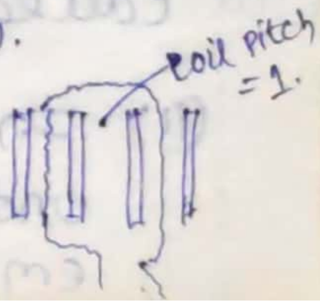
e.g → If there are 48 conductors and 4 poles in a generator. then pole pitch.

$$\text{Pole pitch} = \frac{48}{4} = 12$$

Coil pitch / coil span :-

(i) The distance between two sides of a coil is called coil pitch.





(ii) According to length of coil pitch, winding of armature is divided into two types.

(1) full pitch winding.

(2) fractional pitch-winding.

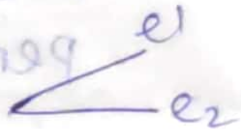
full pitch winding :-

$5+5=10 \leftarrow$ emf.

pole pitch = coil pitch. [emf induced maximum.]

Fractional pitch winding :-

coil pitch < pole pitch.



emf induced is less than full pitch winding

$$\sqrt{5^2+5^2+25.5\times\cos30} = \boxed{7.29} \leftarrow \text{emf}$$

Full-Pitch winding :-

(i) If coil pitch is equal to pole pitch, then winding is called full-pitch winding.

(ii) In this case the coil sides lies under opposite pole, Hence induced emf in them are addidive in nature

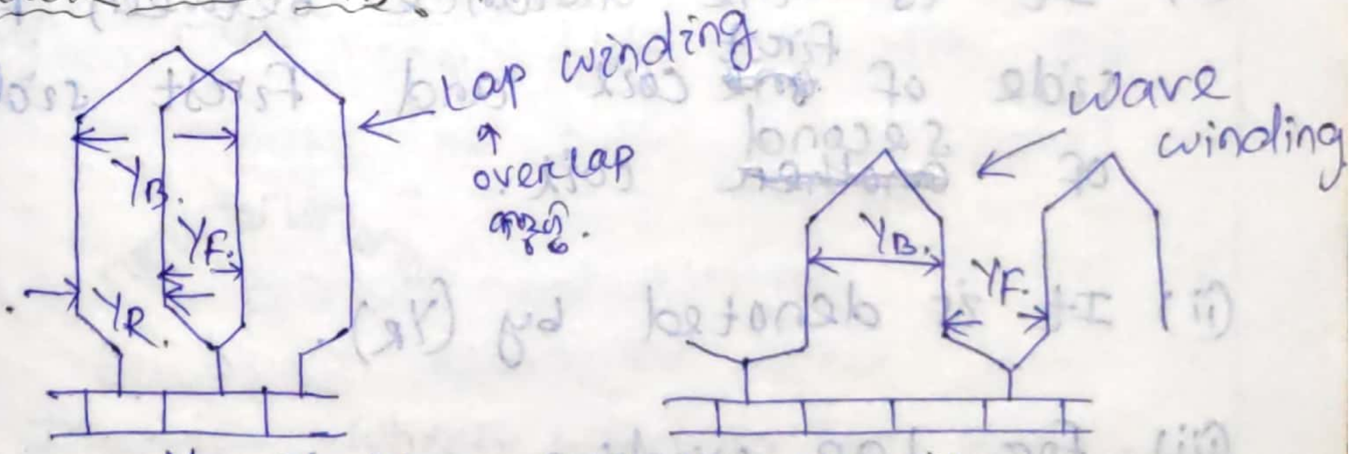
fractional pitch winding :-

(i) If coil pitch is less tha pole pitch, then the winding is called fractional pitch winding.

(ii) In this case, there is a phase difference between the emf in two sides of the coil, Hence total emf around the coil is the vector sum of emf in the two coil sides.

(iii) The main advantage of is saving of copper at the end connection.

Back pitch Y_B :-



$Y_R = Y_B - Y_F$ $\qquad$ $Y_R = Y_B + Y_F$.

(i) The distance covered by a coil on the back side of the armature is called back pitch (Y_B).

(ii) It is denoted by (Y_B).

Front pitch :-

(i) The number of armature conductor covered by a coil on the front end of the armature is called front pitch.

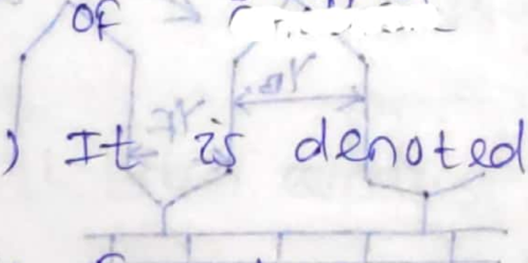
(i) It is denoted by (Y_F).

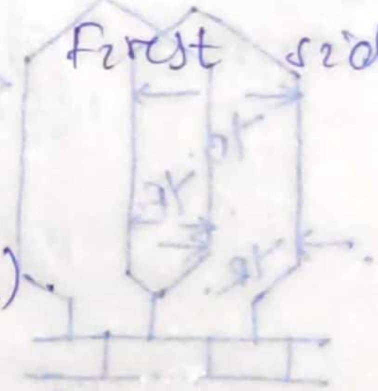
(ii) Front pitch may be defined as the distance between second conductor of one coil and the first conductor of an other coil.

Resulatant pitch :-

(i) It is the distance between first side of first coil and first side of second coil.

(ii) It is denoted by (Y_R).

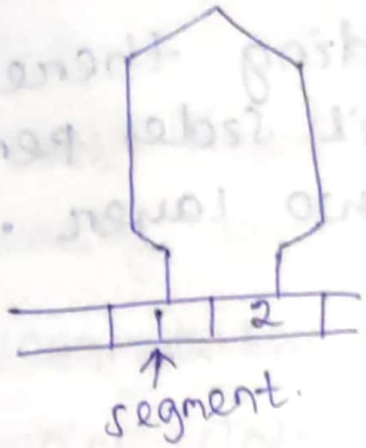


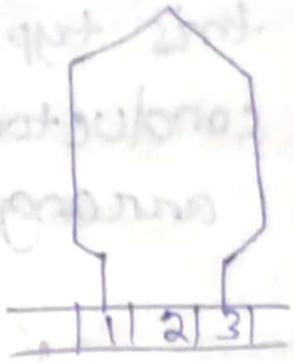


(iii) for lap winding $Y_R = Y_B - Y_F$

for wave winding $Y_R = Y_B + Y_F$

Commutator Pitch :-





$Y_c = 2-1 = 1$

$Y_c = 3-1 = 2.$

(i) It is the distance between the segments to which the two ends of a coil are connected.

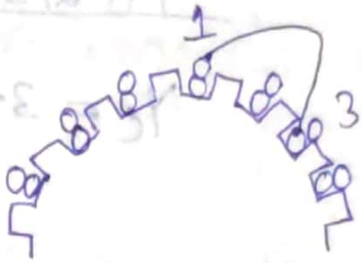
(ii) It is denoted by 'Y_c'

Single Layer winding :-

(i) In which winding, one conductor or one coil sides is placed in each armature slot is called single layer winding.

Two layer winding :-

(i) In this type of winding there are two conductor or coil sides per slot arranged in two layer.



Simplex lap winding :-

rules :-

(1) Both front pitch and back pitch should be odd, other wise it would be difficult to place the coil properly on the armature.

(2) No. of commutator sagment is equal to no. of slots or coils. because the front end of the conductors are joined to the sagment in pairs.

(3) The back pitch and front pitch can not be equal, they differ by two or some Multiple of two.

$Y_B = Y_F \pm 2m$ $(m = 1, 2, 3 \ldots\ldots)$.

↑ simplex   duplex   multiplex.

(4) Both front pitch and back pitch should be nearly equal to pole pitch.

(5) commutatore pitch (Y_c) is equal ±1.

(6) No. of slots for a two layer winding is equal to the no. of coils

(7) The no. of parallel path in the armature is equal no. of poles.

(8) (i) Progressive winding.

$Y_F = \frac{Z}{P} - 1$ $Y_B = \frac{Z}{P} + 1$ $\boxed{Y_B > Y_F}$

(ii) Retrogressive winding.

$Y_F = \frac{Z}{P} + 1$ $Y_B = \frac{Z}{P} - 1$ $\boxed{Y_F > Y_B}$

Z → no. of conductor.

P → pole.

Wave winding :-

Rules :-

(1) Both back pitch and front pitch are odd.

(2) Back pitch and front pitch are nearly equal to pole pitch, they may be equal or differ by two.

(3) Resultant pitch $Y_R = Y_B + Y_F$

(4) commutator pitch $(Y_C = Y_A)$.

(5) $$Y_C = \frac{\text{no. of commutator bar} \pm 1}{\text{No. of pair of poles.}}$$

(6) Average pitch $$Y_A = \frac{Z \pm 2}{P}$$

or

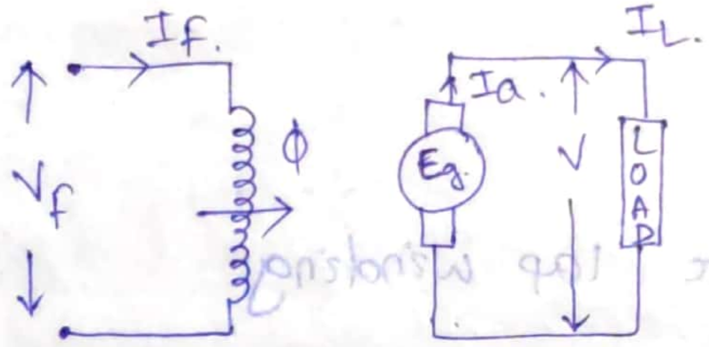
$$\frac{\text{No. of commutator bares} \pm 1}{\text{No. of pairs of poles.}}$$

Classification of DC generator :-

Depending upon the excitation of field DC generator is divided in to two types

(1) separately excited DC generator
(2) self excited DC generator

Separately excited DC generator :-



(i) In separately excited DC generator a separate voltage source is used to excite the field

$$E_g = I_aR_a + V + V_B$$

$$I_a = I_L$$

(ii) The field and armature ckt are electrically isolated and magnetically coupled.

Uses :-

(i) Because of their ability of giving wide range of voltage output, they are used as source of DC motors.

(ii) used for testing purpose in laboratories

self excited DC generator :-

(i) In self excited generator the field winding is excited by the current produced by the generator itself.

(ii) A part of current or entire current produced can be used for exciting the field winding

(iii) Due to residual magnetism, some magnetic flux always remains present in the coil of magnetic poles to start the generator.

(iv) There are three types of self excited generator.

(1) series generator.
(2) shunt generator.
(3) compound generator.

(1) A separately excited DC generator running at 1200 rpm, supplies 200 A at 125 V. to a ckt of constant resistance. what will be the generated emf when the speed is drop to 1000 rpm and the field current is reduced to 80%, armature resistance is 0.04 Ω and total drop at brushes is 2V.

Given data :-

$N = 1200$ rpm.

$I_a = 200A$

$V = 125V.$ $R_a = 0.04\Omega.$

$V_B = 2V.$

(i) $E_{g_1} = I_aR_a + V + V_B$

$= (200 \times 0.04) + 125 + 2$

$= 135$ V.

$$E_{g_1} = \frac{\phi Z N P}{60 A}$$

$I_F \propto \phi$

I_{F_1} $\quad I_{F_2} = \frac{80}{100} = 0.8 I_{F_1}$

ϕ_1 $\quad \phi_2 = 0.8\phi_1$

$$\Rightarrow 135 = \frac{PZ}{60 A} \times 1200 \times \phi_1 \quad \text{—①}$$

$$E_{g_2} = \frac{PZ}{60 \times A} \times 1000 \times 0.8\phi_1 \quad \text{—②}$$

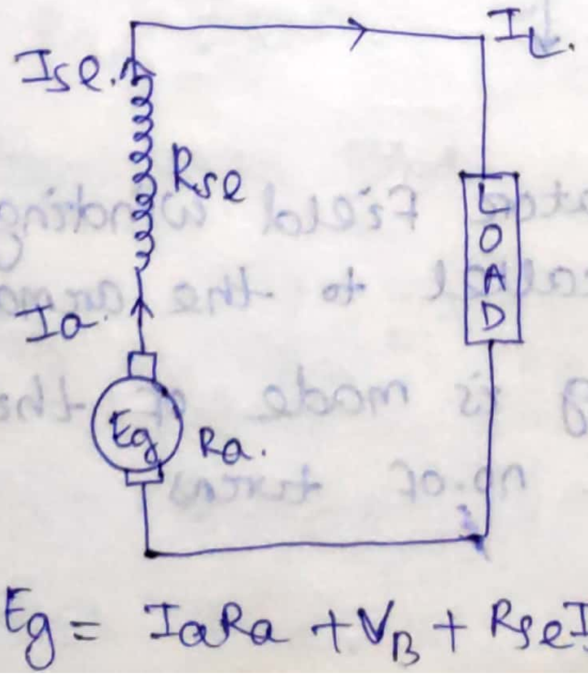
Dividing eqn ① & ②.

$$\Rightarrow \frac{135}{E_{g_2}} = \frac{1200 \times \phi_1}{1000 \times 0.8\phi_1}$$

$$\Rightarrow E_{g_2} = \frac{135 \times 1000 \times 0.8}{1200}$$

$$\Rightarrow E_{g_2} = 90 V.$$

Series Generator :-



$I_a = I_{se} = I_L$

$$E_g = I_a R_a + V_B + R_{se} I_{se} + V.$$

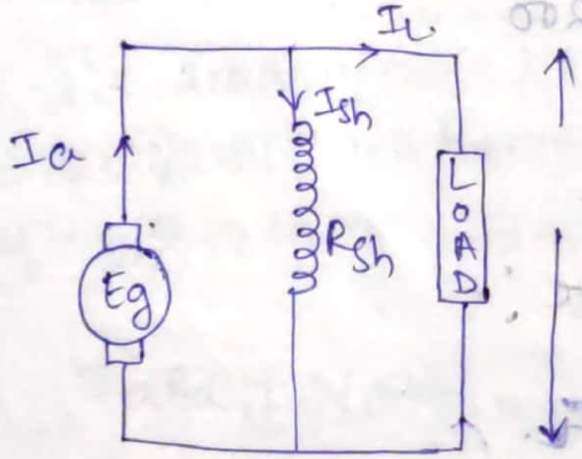
(i) In series generator field winding is connected in series with the armature.

(ii) field winding is made of thick wire with less number of turns.

(iii) It is used where constant Load at constant speed is required.

(iv) It is used as bustor in transmission line to compensate voltage drop.

Shunt Generator :-



$I_a = I_{sh} + I_L$.

$E_g = I_a R_a + V_B + V$.

$\boxed{V = I_{sh} R_{sh}}$

(i) In shunt generator field winding is connected in parallel to the armature

(ii) The field winding is made of thin wire with more no. of turns.

Uses :-

(i) They are used to charge battery, because they can be made to give constant output voltage.

(ii) They are used for giving excitation to alternator.

(1) A shunt generator delivers 450 A at 230V at the resistance of the shunt field and armature are 50 Ω and 0.03 Ω respectively. calculate the generated emf.

Given data

I_L = 450A.

V = 230V.

R_{sh} = 50 Ω.

R_a = 0.03 Ω.

$\boxed{V_B = 0}$

~~Eg= IaRa + Vbd~~

$$I_{sh} = \frac{V}{R_{sh}} = \frac{230}{50} = 4.6 \text{ A.}$$

$$I_a = I_{sh} + I_L = 4.6 + 450 = 454.6 \text{ A.}$$

$$E_g = I_a R_a + V = (454.6 \times 0.03) + 230 = 243.63 \text{ V.}$$

compound generator :-

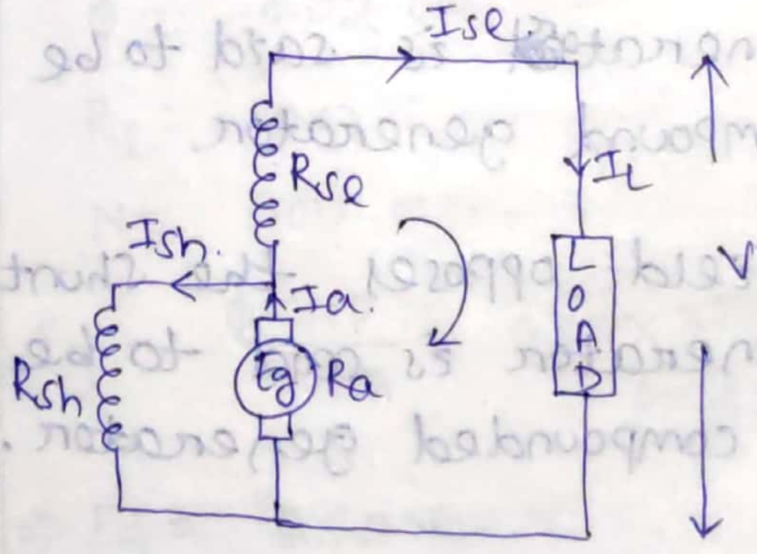
(i) In a generator if both series and shunt windings are present, then it is called as compound generator.

(ii) In a compound generator, series winding has less number of turns and shunt winding has more no. of turns.

(iii) There are ~~two~~ types of compound generator

(1) Short shunt compound generator.
(2) Long shunt compound generator.

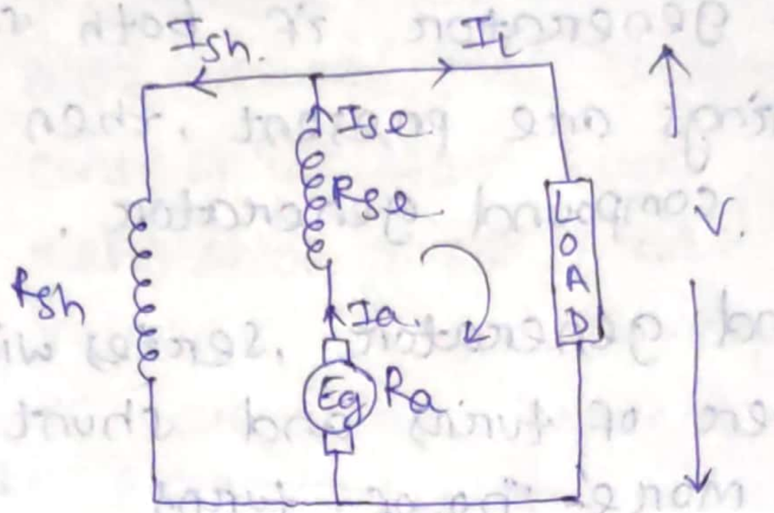
Short shunt compound generator :-



$I_a = I_{sh} + I_{se}$ $(I_{se} = I_L)$.

$E_g = I_aR_a + I_{se}R_{se} + V + V_B$.

Long shunt compound generator



$I_{se} = I_{sh} + I_L$ ($I_{se} = I_a$).

$E_g = I_aR_a + I_{se}R_{se} + V + V_B$.

$$\boxed{V = I_{sh}R_{sh}}$$

→ When the series field aids the shunt field, the generator is said to be commulatively compound generator

→ If series field opposes the shunt field, the generator is said to be differentially compounded generator.

E.M.F equation of DC Generator :

Let,

P = No. of pole.

Z = Total no. of armature conductor.

ϕ = Flux per pole.

N = speed of the armature in R.P.M.

A = No. of parallel path.

According to Faraday's law of electro-magnetic induction induced EMF

$$E = \frac{d\phi}{dt} \quad \text{—①.}$$

∴ Since the flux per pole is ϕ, each conductor cut's flux in one revolution equal to $P \times \phi$

$$d\phi = P \times \phi$$

N revolution in 1min / 60 sec

1 " $= \frac{60}{N}$ sec

So $dt = \frac{60}{N}$ sec.

Now putting the value of $d\phi$ and dt in eqn ①.

$$\text{induced emf} = \frac{d\phi}{dt}.$$

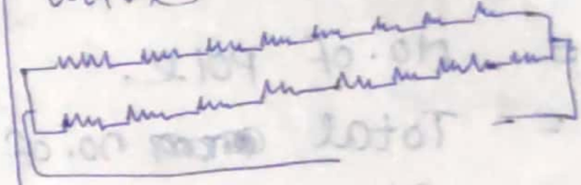
$$E = \frac{d\phi}{dt}$$

$$\Rightarrow E = \frac{P\phi}{\frac{60}{N}}$$

$$\Rightarrow E = \frac{P\phi N}{60}$$

Z=16, P=4

wave



Lap

E=4x8

Emf total = 8 × emf/conductor

$= \frac{Z}{A}$.

Total generated emf will be determined from no. of armature conductor in series in any one path between the brushes

$$\Rightarrow E = \frac{P\phi N}{60} \times \frac{Z}{A}.$$

$$\Rightarrow \boxed{E_g = \frac{\phi Z N P}{60A.}}$$

For wave winding

$$\Rightarrow \boxed{E_g = \frac{\phi Z N P}{60 \times 2} = \frac{\phi Z N P}{120}}$$

For Lap winding

A=P

$$\Rightarrow E_g = \frac{\phi Z N \cancel{P}}{60 \times \cancel{P}}$$

$$\Rightarrow \boxed{E_g = \frac{\phi Z N}{60}}$$

(1) An 8 pole DC generator has 500 armature conductor and a useful flux of 0.05 wb/pole what will be the emf generated if it is lap connected and runs at 1200 rpm. what must be the speed at which it is to be driven produced the same emf if it is wave wound.

Given data :-

$P = 8$

$A = 8$ (Lap).

$\phi = 0.05$

$N = 1200$

$Z = 500$

for lap winding

$$E_g = \frac{\phi Z N P}{60 \times A}.$$

$$= \frac{0.05 \times 500 \times 1200 \times \cancel{8}}{60 \times \cancel{8}}$$

$$= 500 \text{ V}.$$

for wave winding.

$$E_g = \frac{\phi Z N P}{60 \times A}.$$

$$\Rightarrow 500 = \frac{0.05 \times 500 \times N \times 8}{60 \times 2}$$

$$\Rightarrow N = \frac{500 \times 60 \times 2}{0.05 \times 500 \times 8} = 300 \text{ RPM}.$$

Losses in a DC Machine :-

Total Losses
- Copper Losses
  - Armature cu Loss
  - shunt cu Loss.
  - Series cu Loss.
- Iron Losses
  - Hysteresis Loss
  - Eddy current Loss
- mechanical Losses
  - friction Loss.
  - windage Loss.

Iron Loss :-

(i) Due to the rotation of the armature core of the armature in the magnetic flux of the field poles. there are some losses taking place continuously in the core . and are known as iron Loss or iron Loss.

(i) there are two types of iron Loss.

① Hysteresis Loss.

(ii) Eddycurrent Loss.

Hysteresis Loss :-

(i) Hysteressis loss is due to reversal of magnetisation of armature core.

(ii) Every portion of the rotating core passes under N-pole and S-pole alternately.

(iii) This core undergoes one complete cycle of magnetic reversal after passing under one pair of pole.

(iv) If, P is no.of pole and N is armature speed in rpm, then frequency of magnetic reversal is $\boxed{f = \frac{PN}{120}}$.

(v) The loss depends upon the volume and grade of iron maximum value of flux density B-max and frequency of magnetic reversal.

$$\boxed{\text{Hysteresis Loss } (W_h) = \eta B_{max}^{1.6} f V \text{ watts.}}$$

where,

V = volume of core.

B_{max} = maximum flux density.

Eddy current loss :-

(i) when a armature core rotates it also cuts the magnetic flux, hence an emf is induced in the body (surface) of the armature core. According to Faraday's law of Electromagnetic induction.

(ii) This emf is small but can set-up large current on the body of core. This circulating current is known as eddy current.

(iii) The power loss due to flow of this current is known as eddy current loss.

(iv) In order to reduce this loss the core is build up of thin - laminations. This core lamination are insulated from each other by a thin coating of varnish.

(v) when the core body is a single continuous solid iron piece, magnitude of the eddy current is large, because the armature area is large and resistance is very small.

(vi) But when the core is laminated, the cross-sectional area decreases and resistance increase as a result the eddy current loss get reduce.

(vii) Eddy current losses rises the temperature of core and reduce the efficiency of generator.

eddycurrent loss = $K B_{max}^2 t^2 v^2 f^2$ watt.
(W_e / P_e).

where,

B_{max} = flux density.

v = volume of the core.

f = frequency.

t = thickness of lamination.

coppere Loss :-

(i) armature coppere Loss :

$I_a^2 R_a$

where,

I_a = armature current

R_a = armature resistance

(*) It is about 30 - 40 % full Load Losses.

(ii) shunt copper Loss.

$I_{sh}^2 R_{sh}$

I_{sh} = shunt field current.

R_{sh} = shunt field resistance.

(ii) series copper Loss.

$I_{se}^2 R_{se}$

I_{se} = series field current

R_{se} = series field resistance

Mechanical Losses :-

Mechanical Loss consists of

(i) friction Loss at bearing at commutator

(ii) Air friction or windage loss of rotating armature.

Stray Loss :-

Mechanical Loss + iron Loss.

(i) usually iron loss and mechanical losses are collectively known as stray loss. These are also known as rotational loss.

Constant Loss :-

Armature copper Loss.] → variable
Series field copper loss]

All Losses → constant → Shunt field Loss.

(i) The shunt field copper loss is constant for shunt and compound generators.

(ii) Shunt copper loss and stray loss together known as constant loss.

~~Total Loss = armature copper Loss~~

Total Loss = Variable Loss + constant Loss.

condition for maximum efficiency :-

Generator output = VI watt.

Generator input = output + Losses

$$= VI + \underset{\text{constant loss}}{W_c} + \overset{\text{For shunt}}{I_a^2 R_a}$$

$$\text{efficiency } (\eta) = \frac{o/p}{i/p}$$

$$= \frac{VI}{VI + W_c + I_a^2 R_a}$$

$$= \frac{\cancel{VI}}{\cancel{VI}\left(1 + \frac{W_c}{VI} + \frac{I_a^2 R_a}{VI}\right)}$$

$$= \frac{1}{1 + \frac{W_c}{VI} + \frac{I_a^2 R_a}{VI}}$$

For shunt generator.

$I_a = I_L + I_{sh}$.

$\Rightarrow I_a = I + I_{sh}$.

$\Rightarrow \boxed{I_a = I}$ $[I_{sh}$ very small$]$.

$I_{sh} \approx 0$

$$\Rightarrow \eta = \frac{1}{1+\frac{W_c}{VI}+\frac{I_a^2 R_a}{VI}}$$

$$\Rightarrow \eta = \frac{1}{1+\frac{W_c}{VI}+\frac{I^2 R_a}{VI}}$$

$$\Rightarrow \boxed{\eta = \frac{1}{1+\frac{W_c}{VI}+\frac{IR_a}{V}} \begin{matrix} \rightarrow n. \\ \rightarrow d \end{matrix}}$$

Now, efficiency is maximum, when dinominato is minimum.

i.e when

$$\frac{d}{dI}\left[\frac{IR_a}{V}+\frac{W_c}{VI}\right]=0$$

$$\Rightarrow \frac{R_a}{V} - \frac{W_c}{VI^2} = 0$$

$$\Rightarrow \frac{R_a}{\cancel{V}} = \frac{W_c}{\cancel{V}I^2}$$

$$\Rightarrow \boxed{W_c = I^2 R_a} \rightarrow \left[\text{constant loss} = \text{variable loss}\right]$$

① A shunt generator has a full load current of 196 Amp at 220V. The stray losses are 720 watt and the shunt field resistance is 55 Ω. It has a full load efficiency of 88 %. Find the armature resistance. Also find the load current corresponding to maximum efficiency.

Given data

$I_L = 196$ Amp.

$V = 220$ V.

stray Loss = 720 watt.

$R_{sh} = 55\,\Omega$

$\eta_L = 88\,\% = 0.88$.

output power = VI watt

$= (220 \times 196)$

$= 43120$ watt.

$\eta = \frac{\text{output power}}{\text{input power}}$

$\Rightarrow 0.88 = \frac{43120}{\text{input power}}$

$\Rightarrow$ input power $= \frac{43120}{0.88} = 49000$

$I_{sh} = \frac{V}{R_{sh}}$.

$\Rightarrow I_{sh} = \frac{220}{55}$

$\Rightarrow I_{sh} = 4A$.

$I_a = I_L + I_{sh}$

$\Rightarrow I_a = 196 + 4$

$\Rightarrow I_a = 200\ A$.

Variable loss = Armature Cu. loss.

$\Rightarrow I_a^2 R_a = 4280$

$\Rightarrow (200)^2 R_a = 4280$

$\Rightarrow R_a = \frac{4280}{(200)^2}$

$\Rightarrow R_a \simeq 0.107\ \Omega$. Ans.

Total loss = Input Power − output power

$= 49000 - 43120$

$= 5880$ watt.

Total loss = constant loss + variable loss.

$\Rightarrow 5880 =$ (stray loss + shunt field loss) + variable lo

$\Rightarrow 5880 = [720 + (I_{sh}^2 R_{sh})] +$ variable loss.

$\Rightarrow 5880 = 720 + (4^2 \times 55) +$ variable loss.

$\Rightarrow 5880 = 1600 +$ variable loss.

$\Rightarrow$ variable loss = 4280 watt.

for maximum efficiency.

Constant Loss = variable loss.

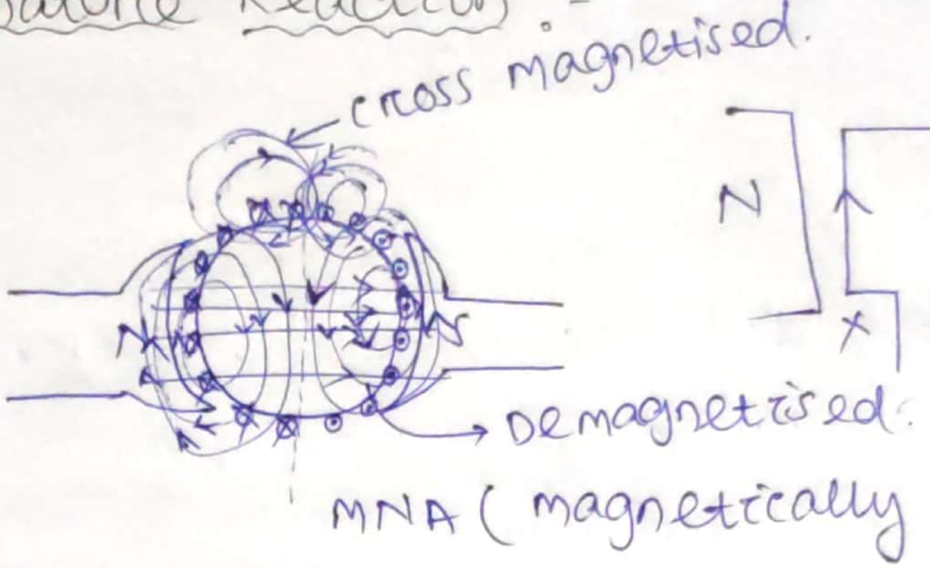
$\Rightarrow I_a^2 R_a = 1600$

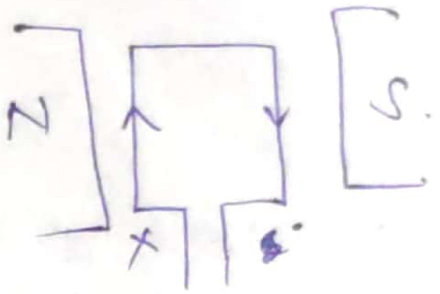
$\Rightarrow I_a^2 \times 0.107 = 1600$

$\Rightarrow I_a = \sqrt{\frac{1600}{0.107}}$

$\Rightarrow I_a = 122.28$ A. (Ans).

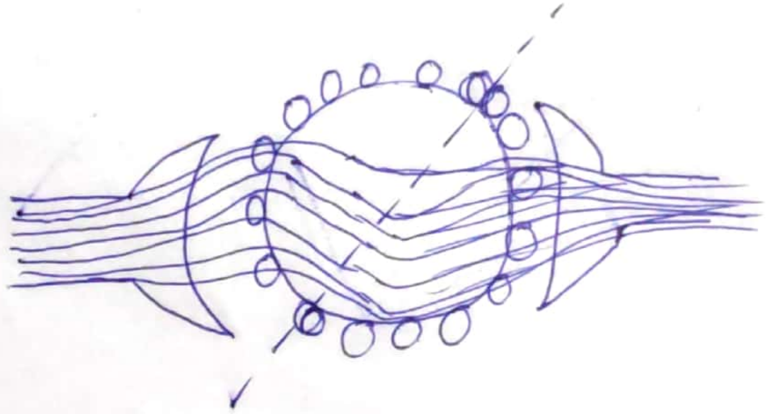
Armature Reaction :-





magnetic field direction → Right hand Screw rule.

Direction of current → Flemings Right hand rule.



(i) Armature reaction is the effect of magnetic field setup by the armature current on the main flux of a generator

(ii) Armature magnetic field has two effects ...

(1) It demagnetised or weakens the magnetic flux.

(2) ∴ It cross magnetised the main flux.

Armature reaction :-

(i) In a DC machine two kinds of magnetic flux are present i.e armature flux and main field flux.

(ii) The effect of armature flux on the main field flux is called armature reaction.

MNA & GNA :-

MNA :(Magnetically Neutral axis) :-

(i) Emf is induced in the armature conductor, when they cuts the magnetic field lines but there is an axis along which armature conductores move parallel to the flux lines and there is no induced emf along that axis. This axis is known as magnetically neutral axis.

(ii) So MNA may be defined as the axis along which no emf is generated in the armature conductores.

(iii) Brushes are always placed along MNA because reversal of current in the armature conductor takes place along this axis.

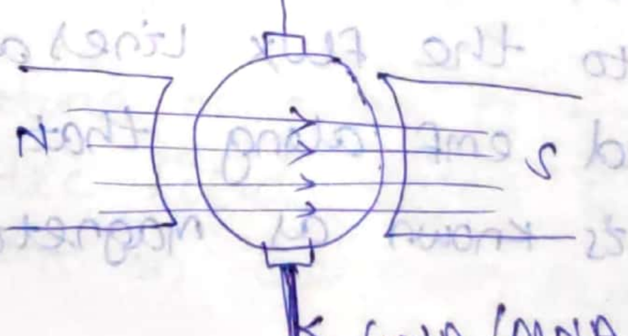
GNA (Geometrical Neutral axis) :-

(i) GNA is defined as the axis which is perpendicular to the main field axis

→ consider no current is flowing in the armature conductor and only field winding is ener

→ In this case magnetic flux lines due to the field pole are uniformed.

→ so MNA coinsides with GNA.



GNA/MNA.

→ when the machine is running both the flux will present at a time.

→ Now the armature flux superimposed

with the main field flux and disturbs it.

→ This armature magnetic field has two effect.

(i) It demagnetised or weakens the main flux.

(ii) It cross-magnetised the main flux.

Cross magnetizing effect :-

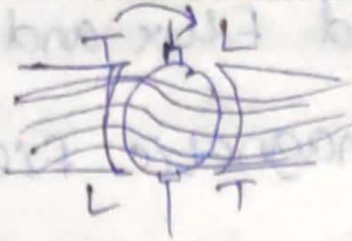
(i) At first MNA is coinside with GNA.

(ii) When the generator starts, current starts flowing through the armature conductor. Their direction found by Flemings right hand rule. So the current direction is inward in the conductors under N-pole and outward under S-pole.

(iii) The direction of lines of force around the armature conductors can be found by applying Right hand screw rule.

(iv) Now it is seen that the flux through the armature is no longer uniform.

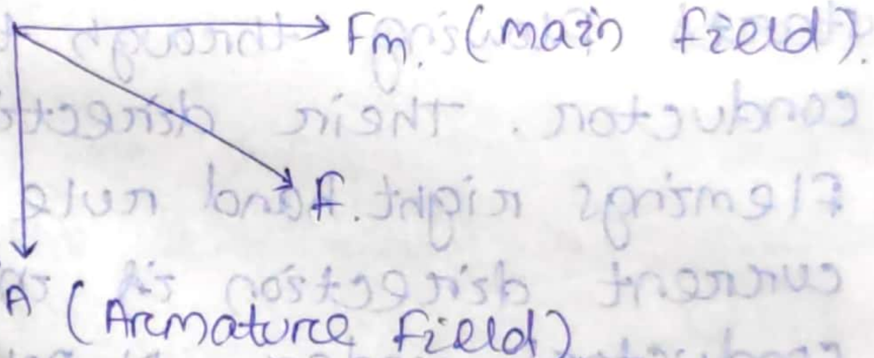
(v) The flux is seen to be crowded at the trailing pole tips but ~~[illegible]~~ weaken or thin Leading pole tips (LPT).



* when conductors move, it cross the first side of a pole is called leading and then trailing.

(vi) Now the MNA will shift to a new position.

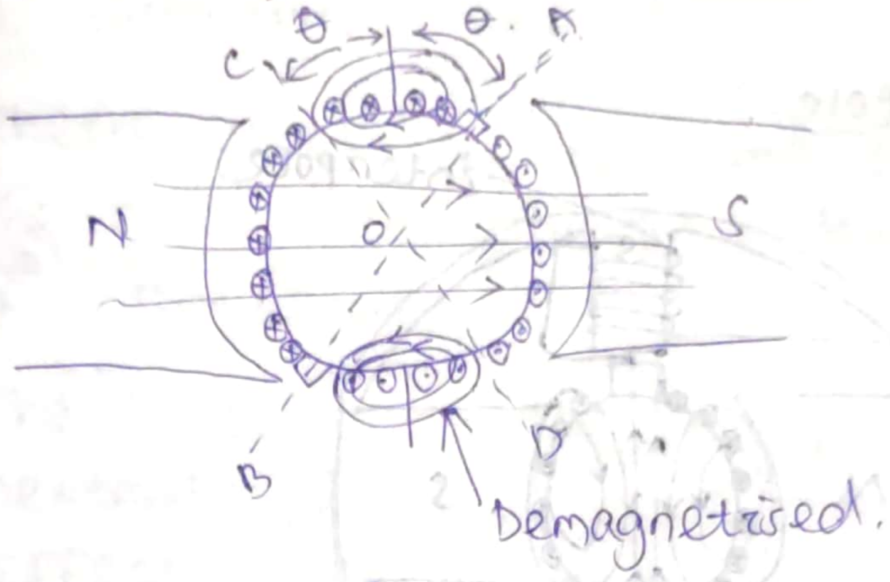
(vii) Here the angle between Main field and armature field is 90°.

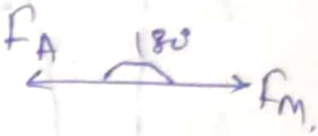


(viii) So the resultant field is found by vector addition of main field and armature field.

(ix) As MNA shift its original position spark produced in armature.

Demagnetising effect :-

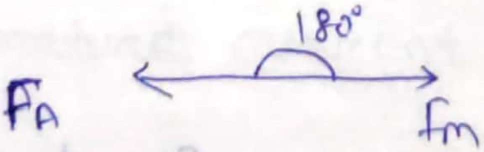




(i) Here the MNA is shift to a new position which is at angle θ from GNA.

(ii) The conductor in region AOC = BOD = 2θ at the top and bottom of the armature are carrying current in such a direction to create flux an armature from right to left.

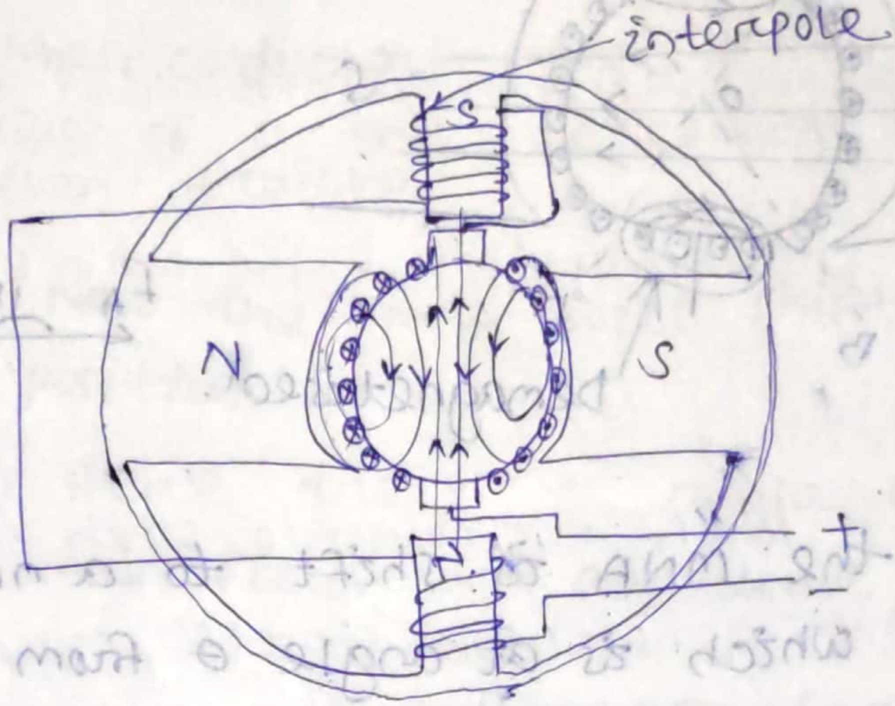
(iii) So the main flux get reduced.



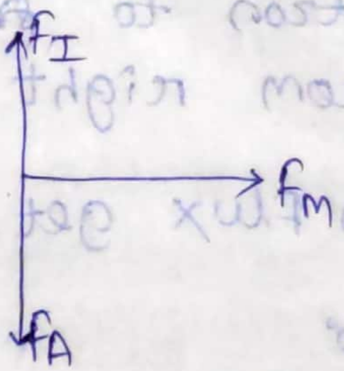
$F = F_m - F_A$.

How to reduce armature reaction :-

(1) Interpole :-



* interpole winding connected in series with armature winding.



(i) These are small poles fixed to the yoke and placed in between the main poles.

(ii) They are wounded with copper wire and connected in series with the armature, so that they carry full armature current.

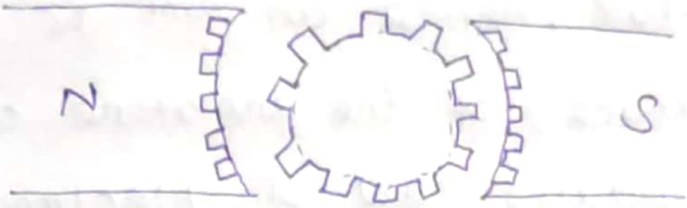
(iii) Their Polarity is same as that of the main pole ahead in the direction of rotation.

(iv) The function of the interpole is to neutralised the cross magnetising effect of armature reaction. Hence brushes are not to be shifted from the original position.

(v) Here the flux produced by the interpole is just opposite to the armature flux. Hence they cancel each other.

(vi) This cancellation of cross magnetisation is automatic and for all loads because both are produced by the same armature current.

(2) By using compensating winding.



(i) These are used for large DC machine which are subjected to large flawctuation in load that is rolling, meal motor, turbo generator, etc.

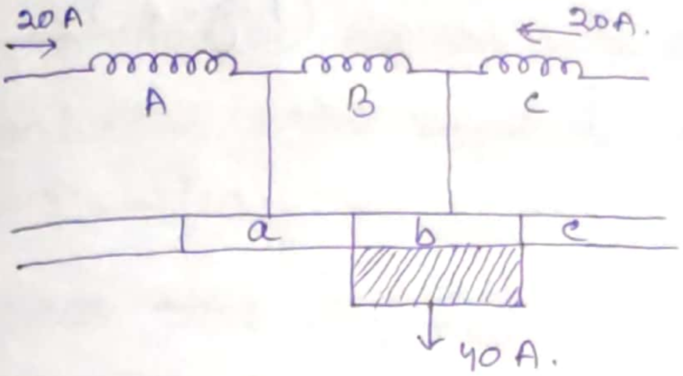
(ii) The function of compensating winding is to neutralize the cross magnetising effect of armature reaction.

(iii) In absence of compensating winding arc can strike between consecutive commutator segment.

(iv) These winding are placed in slots in the poleshoes and are connected in series with armature in such a way that the current in them flows in opposite direction to that of armature conductor directly placed below the poles.

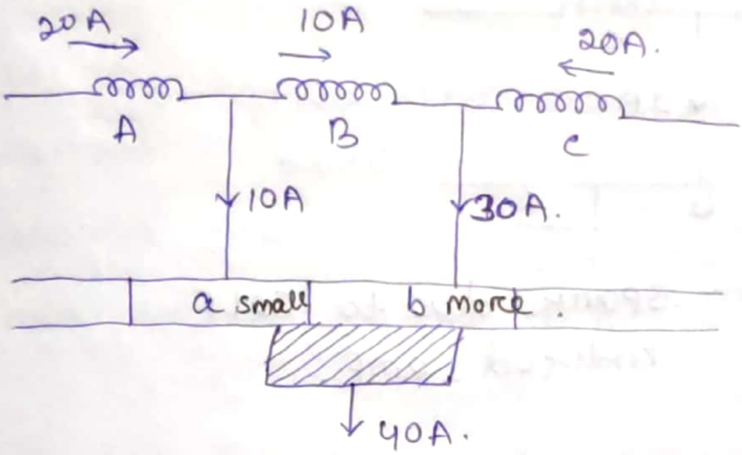
commutation process :-

①



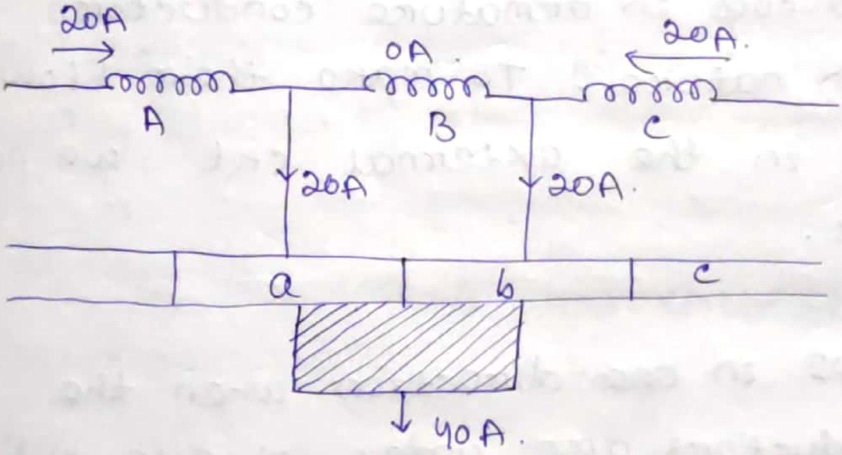
(fig-A.)

②



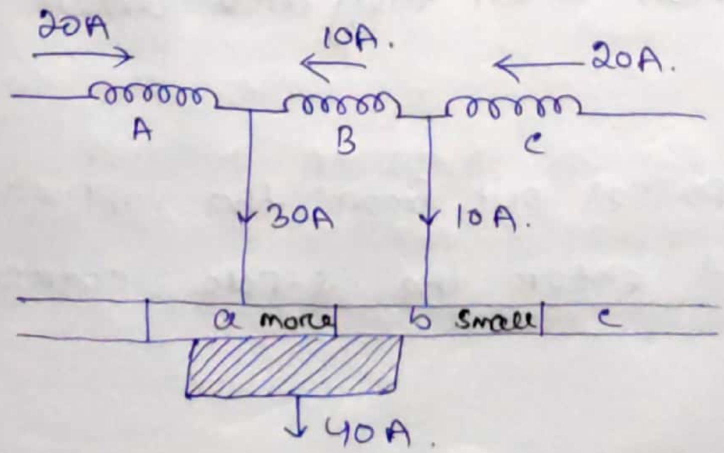
(fig-B.)

③



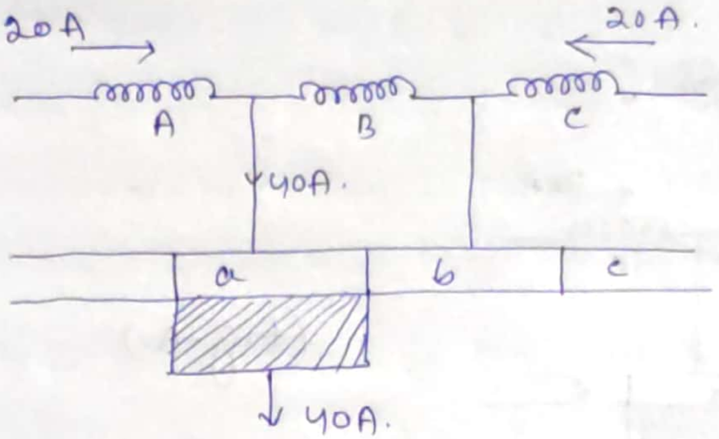
(fig-C.)

④



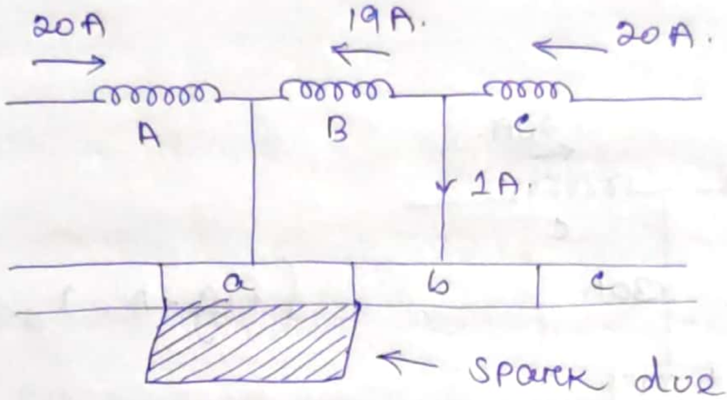
(fig-D.)

⑤



(Fig-e).

⑥



spark due to self induced emf.

(i) current induced in armature conductors are alternating in nature. To make their flow uni-directional in the external ckt, we need a commutator.

(ii) current flows in one direction when the armature conductors are under N-pole and in opposite direction when they are under S-pole.

(iii) As a conductor passes out from the influence of a N-pole and enter the S-pole, current in them reversed.

(iv) This reversal of current takes place along the MNA.

(v) The process by which current is reversed in a conductor while crossing the MNA axis is called commutation.

(vi) Total time required for this process is known as commutation period.

(vii) It is assumed that size of each commutator segment is equal to size of brush and each coil carries 20A current so that total current output from the brush is 40A.

(viii) In fig-A, coil-B is about to be ~~[illegible]~~ short ckt because brush is about to come in contact with commutator segment 'A'. Here the brush current is 40A.

(ix) In fig-B coil-B has entered, it's period of short ckt current through coil 'B' has reduced from 20A to 10A. Because, 10A current flows via segment 'a'.

(x) As area of contact of the brush is more with segment 'b' than with segment 'a'. It receives 30A. So, the total current is again 40A.

(xi) In fig-c, coil-B is in the middle of its short ckt period. Now, current through it has reduce to zero. Two currents of value 20A each passes to the brush directly from coil A & 'c'. Because the brush contact areas with the two segments A and B are equal.

(xii) In fig-D, it is seen that brush contact area with segment 'B' is decreasing rapidly and with segment 'A' is increasing. coil-B now carries 10A in reverse direction. The other 10A supplied by coil-c passes through segment 'B' to the brush.

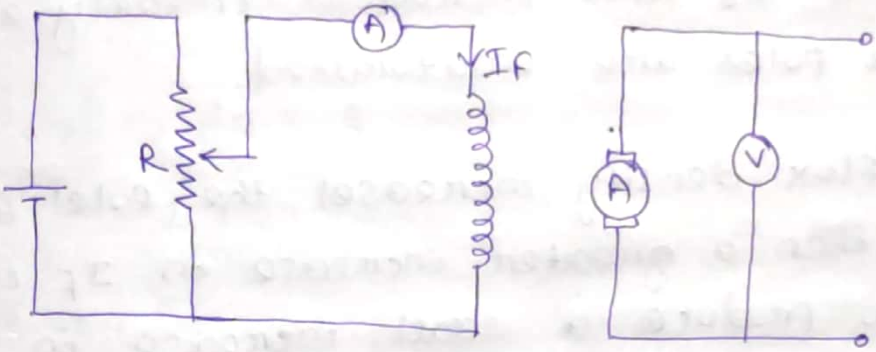
(xii) 10A current of coil 'B' combines with 20A of coil 'A'. As a result total 30A current passes through commutator segment to the breush. Again the total current at the brush is 40A.

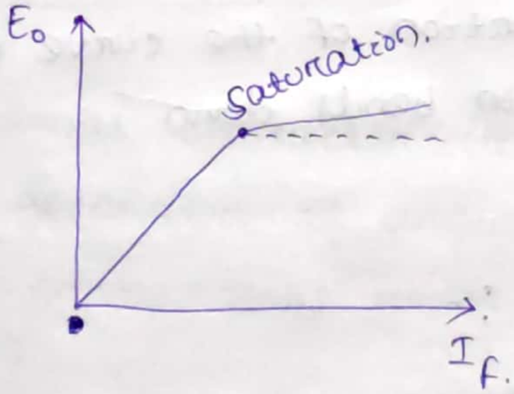
(xiii) In fig-e, the coil 'B' is almost at the end of commutation period (short ckt period). For ideal commutation current in coil B should be completely reversed that is 20A in opposite direction.

(xiv) If current in coil 'B' can not reverse with in the commutation period, remaining current will try to jump from commutator segment 'B' to the brush. As a result spark is produced.

characteristic's of separately excited generator.

open ckt characteristics.:





(i) In a separately excited DC generator field current is obtain from an external independent DC source.

(ii) It's value can be changed from 0 to upward by using a rheostat.

(iii) we know that the voltage equation of DC generator is $\boxed{E_g = \frac{P\phi ZN}{60A}}$, hence if speed is constant, $E_g \propto \phi$

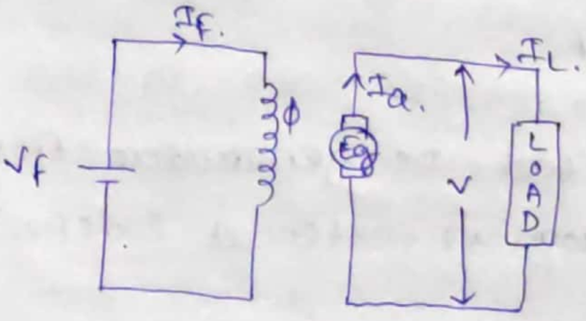
(iv) when field current is zero. flux is also zero. As a result the generated emf is also zero. Therefore the graph start from initial position.

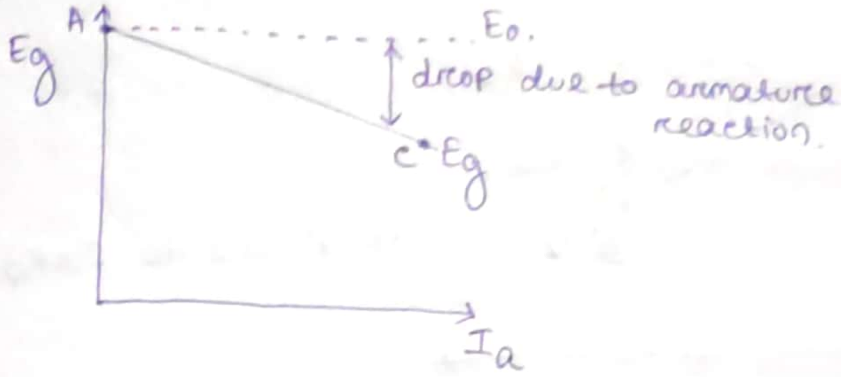
(v) when I_f is increased from its initial zero value, generated emf 'E_0' also increases linearly as long as the poles are unsaturated.

(vi) when the flux density increases the poles become saturated, then a greater increase in I_f is required to produce a small increase in voltage.

(vii) Therefore the lower portion of the curve is almost linear and upper portion bends down.

Internal characteristics :-





let,

Load = 0 , $I_a = 0$.

Armature reaction = 0.

Load = ↑ , I_a = ↑

armature reaction = ↑

Total flux = $\phi_m = \phi_A$

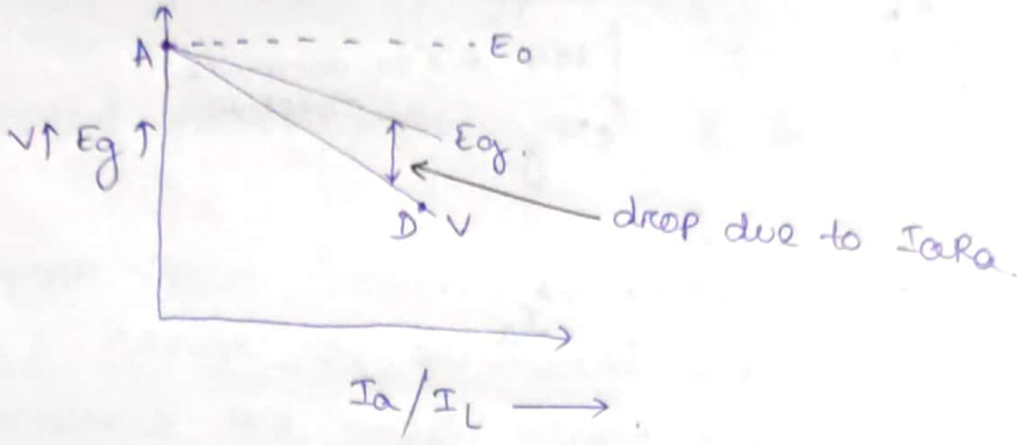
$$\boxed{\phi_A \propto I_a.}$$

(i) Internal characteristics of a separately excited DC generator is obtain by subtracting the drop due to armature reaction from no load voltage (E_0).

(ii) This curve is slightly dropping as armature current increases, voltage drop due to armature reaction also increases gradually.

(iii) The 'Ac' line in the diagram indicate the actual generated voltage 'E_g' w.r.t armature current.

External characteristics :-



$Eg = IaRa + V.$

$V = Eg - IaRa$

(i) External characteristics of a separately excited DC generator is obtain by subtracting the voltage drop due to armature resistance (IaRa) from the generated voltage. 'Eg'.

i.e $\boxed{V = Eg - IaRa}$.

(ii) The external lies below the internal charac-teristics curve.

(iii) Here 'AD' line in the diagram indicates the characteristics curve.

(iv) It can be seen from the curve that when load current increases terminal voltage

(v) This decrease in voltage can be maintain easily by increasing field current.

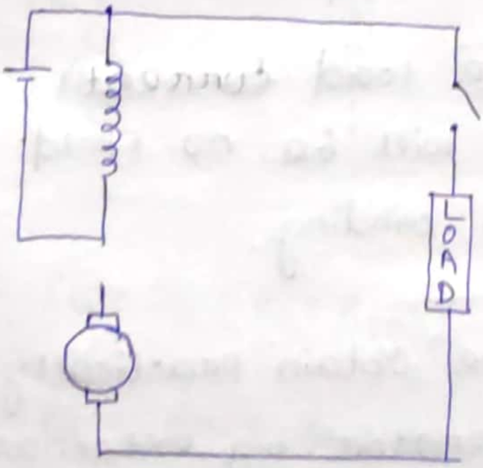
(vi) This type of generator can operate in stable condition with any field excitation and give wide range of output voltage.

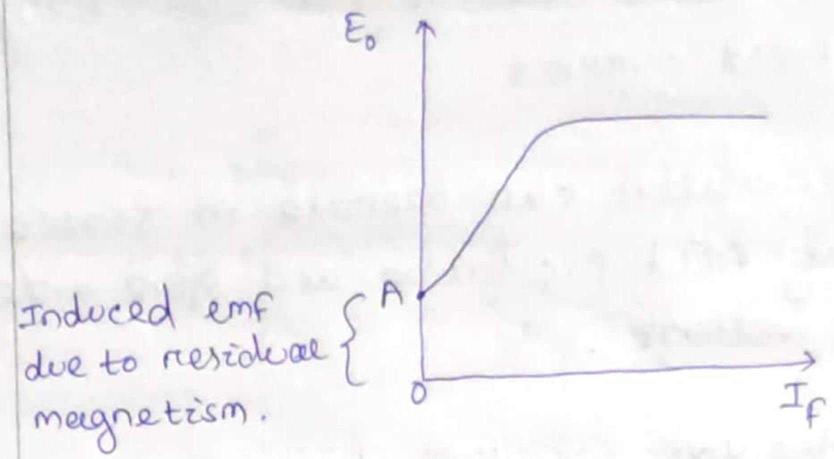
(vii) The main disadvantage of this type of generator is that it is very expensive to provide a separately excited source.

Separately excited generator has slightly dropping characteristics.

DC series Generator.

open ckt characteristics :-





(i) In series generator the armature winding, field winding and external load ckt., all are connected in series with each other.

(ii) Therefore, the same current flow through all Parts of the ckt i.e $\boxed{I_a = I_{se} = I_L}$

(iii) The curve which shows the relation between no load voltage and field current is called OCC (open ckt characteristics).

(iv) As during no load the load terminals are open ckt, there will be no field current in the field winding.

(v) So this curve can be obtain practically by exciting the DC generator by external source.

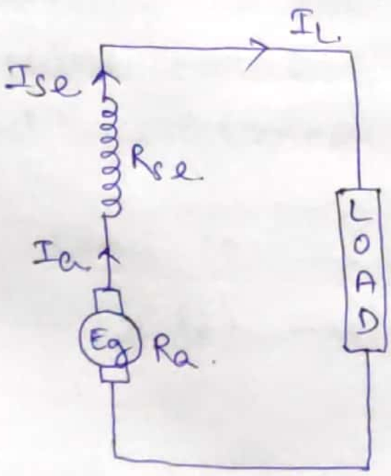
(vi) Due to residual magnetism there will be a small initial voltage across the armature that is why the curve started from a point 'A' which is above the origin 'O'.

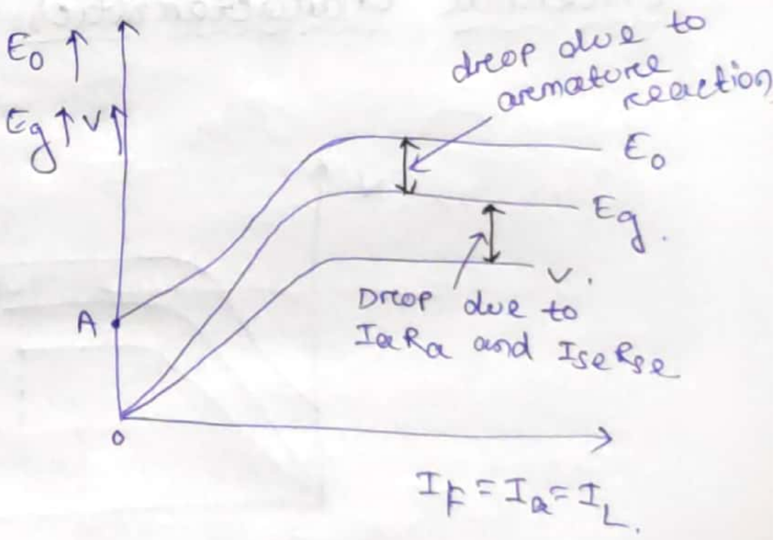
(vii) when field current is increased, generated emf 'E_g' increases directly as long as the poles are unsaturated.

(viii) when the flux density increases the poles become saturated, then a greater increase in I_f is required to produce a small increase in voltage

(ix) Therefore, the lower portion of the curve is almost linear and upper portion bends down.

Internal characteristics.





$$V = E_g - I_a(R_a + R_{se}).$$

$E_g = E_0$ − drop due to armature reaction.

$$E_g < E_0.$$

$$V = E_g - I_a(R_a + R_{se})$$

$$V < E_g.$$

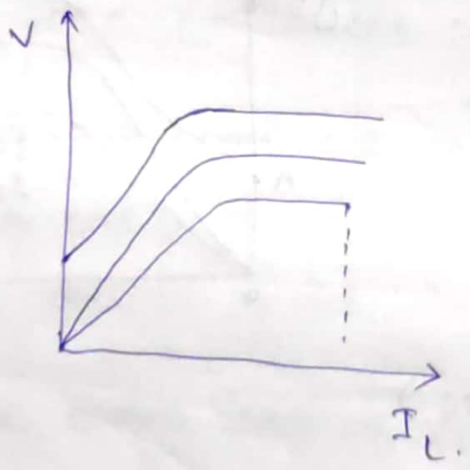
(*) DC series generator has rising characteristics

(i) The internal characteristics curve gives the relation between generated voltage in the armature current 'Ia'.

(ii) This curve is obtain by subtracting the drop due to demagnetising effect of armature reaction from the no load voltage.

(iii) So, the actual generated voltage Eg will be less than no load voltage E_0 that is why the curve is slightly dropping from the occ curve.

External characteristics :-



(i) This curve shows the variation of terminal voltage 'v' with the load current 'I_L'.

(ii) Terminal voltage of this type of generator is obtain by subtracting the ohmic drop or resistive drop due to armature resistance 'Ra' and series field resistance 'Rse' from the actual generated voltage 'Eg'.

$$V = E_g - I_a (R_a + R_{se}).$$

(iii) The external characteristics curve lie below the internal characteristics curve because the value of 'V' is less than 'Eg'.

(iv) But after reaching it's maximum value it starts to decrease due to excessive demagnetising effect of armature reaction.

(v) Dotted portion of the characteristics gives decrease in terminal voltage and approximately constant current irrespective of the external load resistance.

Load (↑) ⟶ I_L (↑).

V (↓) ⟶ I_L (↓).

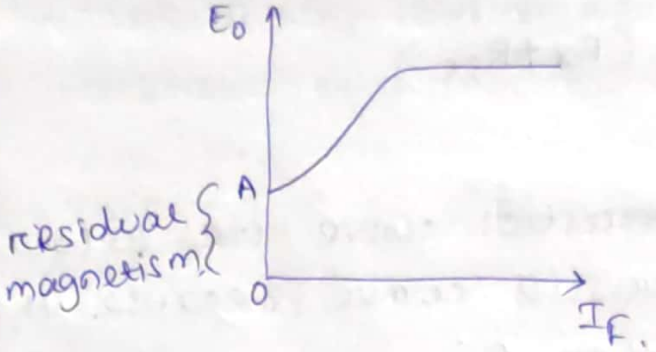
(vi) Because increase in load tends to increase the load current but decrease in load voltage tends to decrease load current (ohm's law)

(vii) Due to these two simultaneous effect there will be no significant in the load current.

DC series generator has constant current characteristics.

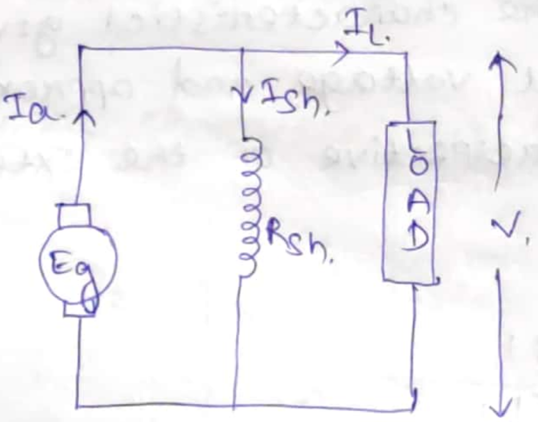
Shunt Generator

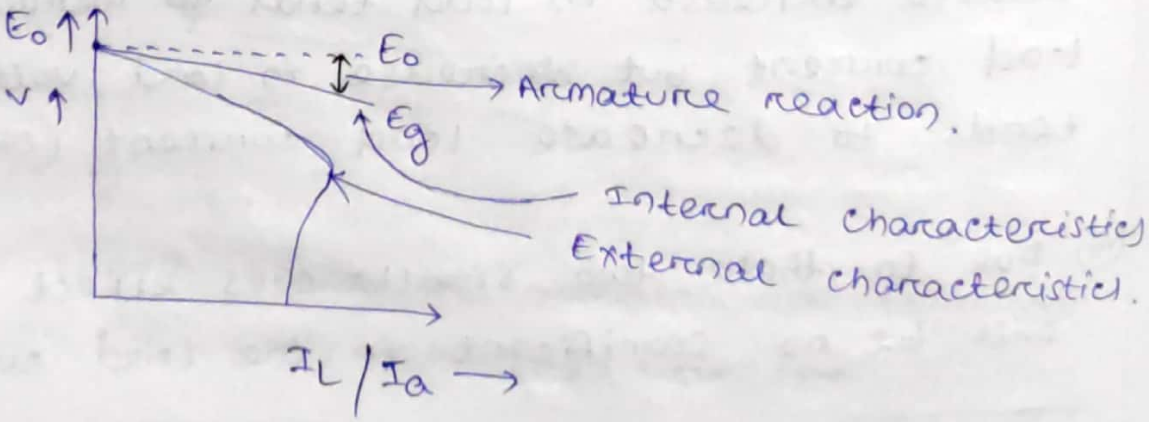
open ckt characteristics



* same as occ of series generator.

Internal characteristics :-





(i) It shows the variation of generated voltage 'E_g' with the armature current 'I_a'.

(ii) when the generator is loaded, the generated voltage is decreased due to armature reaction.

(iii) So, the internal characteristics curve will be below the no load induced emf 'E_0'.

(iv) The drop will increases with increase in armature current.

External characteristics :-

$$V = \underset{\substack{\uparrow \\ \text{constant}}}{\boxed{E_g}} - \underset{\nwarrow \text{ Increase with increase in load.}}{\boxed{I_aR_a}}$$

(i) It shows the relation between terminal voltage 'V' and load current 'I_L'.

(ii) This curve is obtain by subtracting the ohmic drop due to armature resistance from the generated voltage.

$$V = E_g - I_aR_a.$$

(iii) when load is increased terminal voltage will decrease with increase in load current.

(iv) Therefore the external curve always lies below the internal curve.

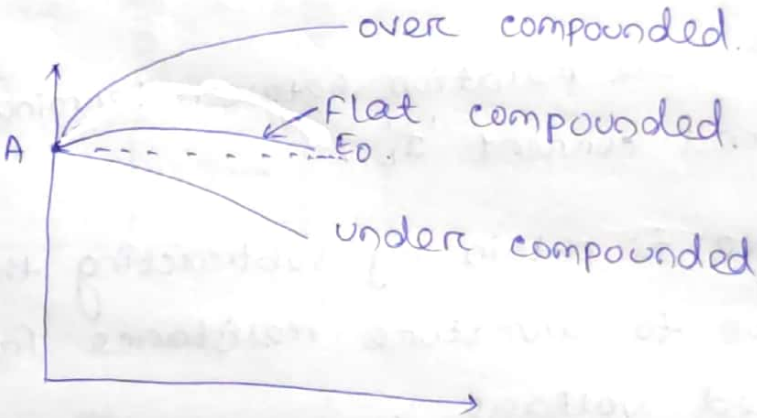
(v) But after a certain point, terminal voltage start to decrease drastically due to excess armature reaction and ohmic drop.

(vi) Just like series generator here also two factor acts simultaneously. Increase in load will try to increase the load current and decrease in load voltage will try to decrease the load current.

(vii) But here the effect of decrease in load voltage is more. As a result the load current will start to decrease.

Compound Generator.

External characteristics.



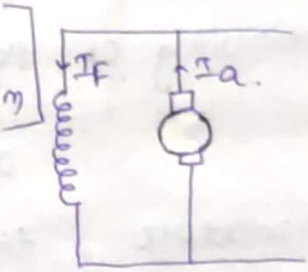
(i) If series and shunt winding ampere turns are adjusted, so that, increase in load current causes increase in terminal voltage, then the generator is called over compounded generator.

(ii) If the series and shunt winding ampere turn are adjusted, so that terminal voltage remains constant even when load current is increased, then the generator is called as flat compounded generator.

(iii) If the series winding has less no. of turns. Increase in load current causes decrease in terminal voltage. This type of generator is called under compounded Generator.

critical resistance :-

$I_f = 0$ $E_0 = \downarrow$ [only due to residual magnetism]



Rotate the armature

$I_f = \uparrow$ $\phi = \uparrow$ $E_0 = \uparrow$

$I_f = \uparrow\uparrow$ $\phi = \uparrow\uparrow$ $E_0 = \uparrow\uparrow$

(i) critical resistance is the value of shunt field resistance above which if it is increase, then voltage build up in a shunt generator is not possible or zero.

(ii) The speed of the shunt generator when its field resistance is equal to critical resistance is called critical speed.

Voltage build up of a shunt generator :-

(i) Before loading a shunt generator, it is allowed to build up it's voltage.

(ii) usually there is always present some residual magnetism in the poles. Hence a small EMF is produced initially.

(iii) This emf circulates a small current in the field circuit which increases the pole flux.

(iv) When the flux is increased generated emf is increased which further increases the flux and so on.

(v) Now the generated emf in the armature has two function

(1) To supply the ohmic drop $I_{sh}R_{sh}$ in the winding

(2) To overcome the opposite self induced emf in the field coil.

Scanned with CamScanner

$$E_g = I_{sh}R_{sh} + L\frac{dI_{sh}}{dt}$$

Condition for voltage build up of a shunt generator

(i) There must be some residual magnetism in the generator poles.

(ii) For the given direction of rotation (the shunt field coils should be correctly connected to the armature).

(iii) If excited on open ckt its shunt field resistance should be less than critical resistance.

(iv) If excited on load, then it's shunt field resistance should be more than a certain minimum value of resistance.

Parallel operation of DC generator :-

→ It is economical to install no.of smaller rated generators in parallel than installing a bigger rated DC generator.

Advantages :-

→ Easy to increase generating plant capacity. The demand of electricity is increasing day by day To meet the requirement of extra load or demand extra generator are connected in parallel with the running generator.

→ Continuity of Power supply :-

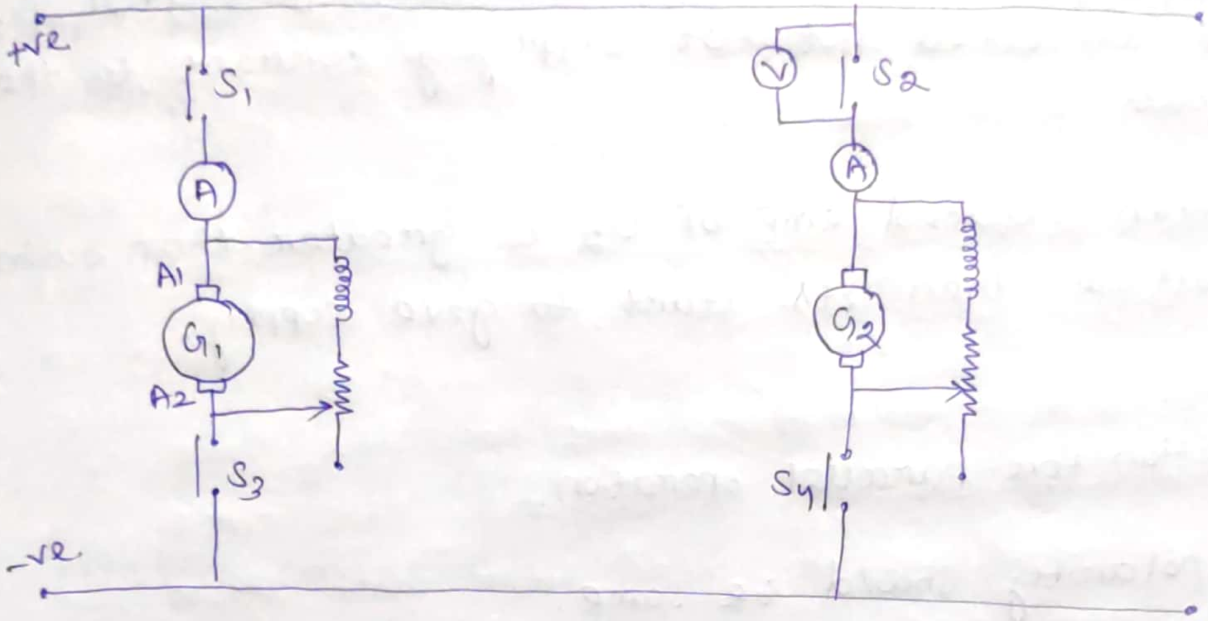
In case of breakdown of one generator, the power supply will not interrupt, because of supply can be maintained by the healthy generator.

→ Easy to maintain :-

The routine maintenance of generator is required time to time. If the generators are connected parallely routine maintenance can be done by one with out interrupting the power supply.

→ Increases system efficiency :-

If generators are connected parallely we can turn on the amount of generator according to demand. If the load is less, one or more generator can be shutdown. As a result efficiency of the system increases.



(i) Generators are connected by heavy thick copper bar called busbar which acts as +ve and -ve terminals. positive terminal of the generator are connected to +ve terminal of busbar and negative terminal of the generator are connected to -ve busbar.

(ii) Let generator-1 (G1) is already connected

(iii) To connect generator-2 parallely with G1 we have to first bring the speed of primemover of second generator to rated speed.

Then switch -4 is closed.

(iv) Excitation of generator-2 is increase with the help of field rheostat, till it's generate voltage is equal to the busbar voltage.

(v) when voltmeter 'V' indicates 0 (zero) reading, switch S_2 is closed. This condition is called floating condition, that means the generator G_2 is connected but not supplying current to the load.

(vi) when induced emf of G_2 is greater than busbar voltage then it start to give supply.

condition for parallel operation.

(i) polarity should be same.

(ii) voltage should be same.

Uses of DC Generator

Series generator :-

(i) These are not used for power supply because of their rising characteristics.

(ii) Their rising characteristics makes them suitable for being used as boosters.

Shunt generator :-

Shunt Generator with field regulators are used for ordinary lighting and power supply purpose.

Compound Generator :-

(i) Cummulatively compounded generator is the most widly used DC Generator because it's external characteristics can be adjusted.

(ii) Hence such generators are used for heavy power service such as Electric railways.

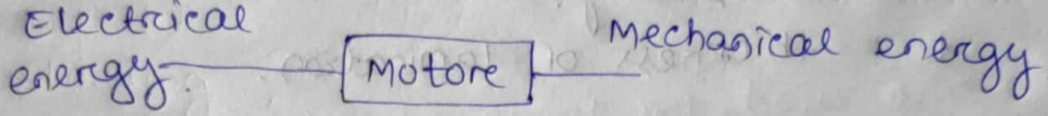
(iii) Lamp loads, for motor which required DC supply and constant voltage.

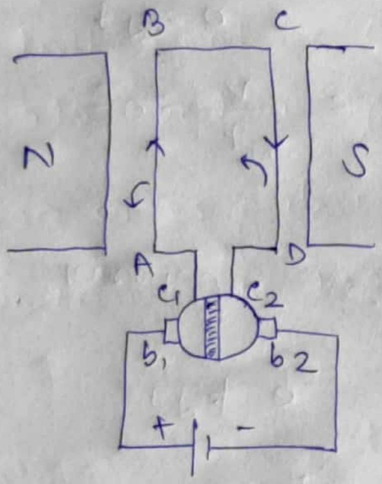
(iv) The differentially compound generator widely used in arc welding where large voltage drop is desirable with increase in current.

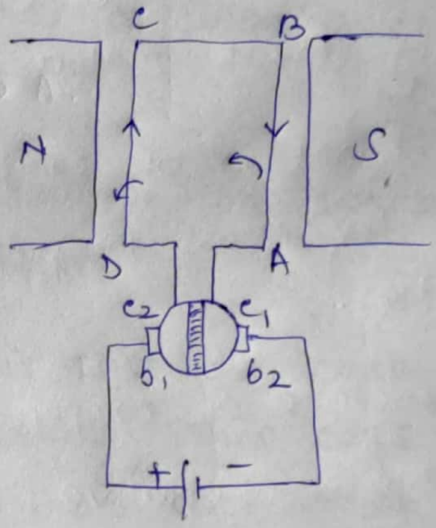
chapter-2 (DC MOTOR)

Motor is a device or machine which converts electrical energy to mechanical energy.

working principle :-







(i) whenever a current carrying conductor placed in a magnetic field it will experience a force (Lorenz law).

(ii) The direction of force experienced is given by fleming left hand rule. According to flemming left hand rule, If we stretched middle finger, force finger and thumb of our left hand perpendicular to each other, then middle finger will indicate the direction of current in the conductor, fore finger indicate the direction of magnetic flux and thumb will indicate the direction of force.

Back emf :-

→ when the motor starts to rotate the armature conductor cuts the flux and emf is induced in the conductors according to faraday's law of electro magnetic induction,

→ Polarity of the induced emf is such that it always opposes the supply voltage

→ This induced emf is called as back emf (E_b).

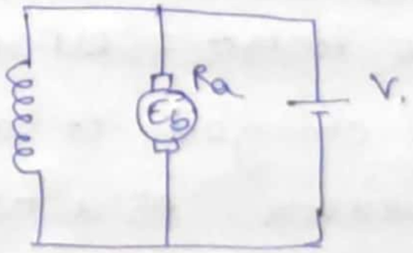
$$\boxed{E_b \propto \phi N} \qquad \boxed{N \propto \frac{E_b}{\phi}}$$

At starting $E_b = 0$,

At rated speed E_b = maximum.

$V = I_a R_a + E_b$.

$\Rightarrow I_a R_a = V - E_b$.



$$\Rightarrow \boxed{I_a = \frac{V - E_b.}{R_a.}}$$

Here V and Ra is constant

so,

$I_a \propto E_b$.

$E_b \propto N$

then,

$$\boxed{I_a \propto N}$$

∴ so current depends upon speed of motor.

At starting,

$E_b = 0$

$I_a = \frac{V}{R_a} = \frac{230}{0.2} = 1150\ A.$

At running

$E_b \neq 0$

$I_a = \frac{V - E_b}{R_a} \downarrow$

Significance of Back EMF. :-

(i) significance of back emf is that it makes the motor self regulating. If load of motor is changed it automatically change the input current. As a result it draws i/P power as the requirement of the load. It draws less input power, if the load is less and it draws more input power, if the load is large.

$N = N_1$ load ↑↑ N_1 ↓↓ E_b ↓↓ I_a ↑↑ $P_{i/p}$ ↑↑

load ↓↓ N_1 ↑↑ E_b ↑↑ I_a ↓↓ $P_{i/p}$ ↓↓

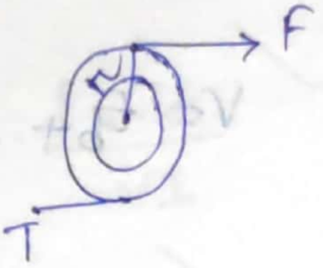
(ii) magnitude of back emf is directly proportional to speed of the motor.

$$E_b \propto N.$$

(iii) let, load on a DC Motor is suddenly reduce, speed of the motor will increase due to excess torque. As a result back emf will increase which decreases the armature current as well as load current. So the input power reduce according to the load.

(iv) on the other hand If a dc motor Load is suddenly increase, speed of the motor will decrease. Due to decrease in speed back emf will also decrease, as a result armature current and load current and input power increases. so the increased armature current increases the torque to rotate the motor. Hence, presence of back emf makes a dc motor self regulating.

Torque :-



$T = F \times r$.

(i) Torque is a measure of how much force acting on an object to rotate it or the turning or twisting movement of a force about an axis is known as torque.

(ii) It is measured by the product of force and the radius at which the force acts.

(iii) consider a pulley of radius r-meter. A force of F newton is acting upon it to rotate it at rpm.

Torque (T) = f×r.

unit = N-m.

workdone by this force on one revolution.

$W = F \times$ distance.

$= F \times 2\pi r$.

$$P = \frac{W}{t}$$

$$= \frac{f \times 2\pi r}{\frac{60}{N}}$$

$$= \frac{f \times 2\pi r}{60/N}$$

$$= \frac{2\pi r f N}{60}$$

$$= (fr) \times \frac{2\pi N}{60}$$

$$= \left[T \times \frac{2\pi N}{60} \right] = \omega t$$

(ω – ohmega).

$$= \frac{2\pi}{60} \times TN \quad = \frac{TN}{9.55} \text{ watt}$$

$= 0.104\ N\ T$ watt.

Armature torque :- (T_a).

let ,

T_a be the torque developed by the armature of a motor running at N rpm, then mechanical power developed

$$P_m = T_a \times \frac{2\pi N}{60} \text{ watt}$$

Electrical power at armature

$$P_e = E_b I_a \text{ watt}$$

$$\boxed{P_m = P_e}$$

$$\Rightarrow T_a \frac{2\pi N}{60} = E_b I_a$$

$$\Rightarrow T_a = \frac{E_b I_a \times 60}{2\pi N}$$

$$T_a = 9.55 \frac{E_b I_a}{N} \qquad \left[T \propto \frac{1}{N} \right].$$

$$\Rightarrow T_a = 9.55 \frac{I_a}{\cancel{N}} \times \phi Z \cancel{N} \times \frac{P}{A} \qquad \left[E_b = \frac{\phi Z N}{60} \times \frac{P}{A} \right)$$

$$\Rightarrow T_a = 9.55 \, I_a \times \frac{\phi Z P}{60 A}$$

$$\Rightarrow \boxed{T_a = 0.159 \, \phi Z \frac{P}{A} I_a}$$

Shaft torque :-

output power of motor $= T_{shaft} \frac{2\pi N}{60}$

$$\boxed{T_{sh} = \frac{O/P\ Power}{N} \times 9.55}$$

$$\Rightarrow T_{sh} = \frac{\text{output power of motor}}{2\pi N} \times 60$$

$$= 9.55 \frac{O/P}{N} \text{ N-m.}$$

$$\boxed{T_a = 9.55 \frac{E_b I_a}{N}}$$

(1) A 4-Pole 240V wave connected shunt motor gives 11.19 KW, when running at 1000 rpm. and drawing armature and field currents of 50 A and 1 A respectively. The armature has 540 and its resistance is 0.1Ω. Assuming a drop of 1V per brush. Find

(i) armature torque.

(ii) shaft torque.

(iii) flux per pole

(iv) rotational losses

(v) efficiency.

Given data :-

$P = 4$ wave wound.

$A = 2$

$V = 240$ V.

$Z = 540$

$I_a = 50$ A $R_a = 0.1\Omega$.

$I_{sh} = 1$A

$V_B = 2$V.

$P = 11.19$ KW. $= 11.19 \times 10^3$ watt.

$N = 1000$

$E_b = \frac{\phi Z N P}{60 A}$

~~$V = E_b = I_a R_a$~~

~~$E_b = I_a R_a$~~ $\Rightarrow$ ~~E_b~~

$E_b = V - I_a R_a - V_B$

$\Rightarrow E_b = 240 - (50 \times 0.1) - 2$

$= 233$V.

$E_b = \frac{\phi Z N P}{60 A}$

$\Rightarrow 233 = \phi \times \frac{540 \times 1000 \times 4}{60 \times 2}$

$\Rightarrow \phi = \frac{233 \times 60 \times 2}{540 \times 1000 \times 4} = 0.012$ wb.

*

$$T_a = 9.55 \times \frac{E_b I_a}{N}$$

$$= 9.55 \times \frac{233 \times 50}{1000}$$

$$= 111.257 \text{ N-m.}$$

i/p Power = $V \times (I_a + I_{sh})$

$= 240 \times 51$

$= 12{,}240$ watt

o/p power = 11.19×10^3 watt

$$T_{sh} = \frac{\text{o/p Power}}{N} \times 9.55$$

$$= \frac{11.19 \times 10^3}{1000} \times 9.55$$

$$= 106.86 \text{ N-m.}$$

$$\text{efficiency} = \frac{\text{o/p}}{\text{i/p}} = \frac{11.19 \times 10^3}{12{,}240} = 0.9142$$

$\boxed{91.42\%}$

Total Losses = Input − O/P

$= 12240 - (11.19 \times 10^3)$

$= 1050$ watt.

copper loss = ~~$(I_a + I_{sh})^2 R_{sh}$~~ $I_{sh} = \frac{V}{R_{sh}} =$

$= I_a^2 R_a + I_{sh}^2 R_{sh}$

$= (50^2 \times 0.1) + (1^2 \times \frac{240}{1})$

$= 490$ watt.

Brush contact losses = $V_b \times I_a$

= 2×50

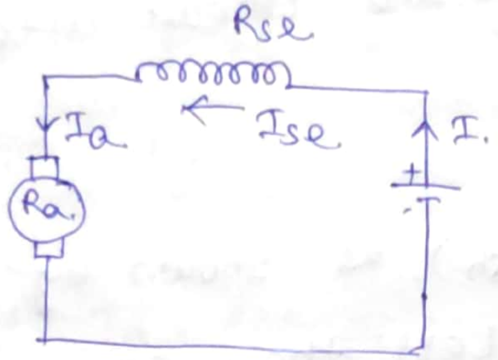
= 100 watt

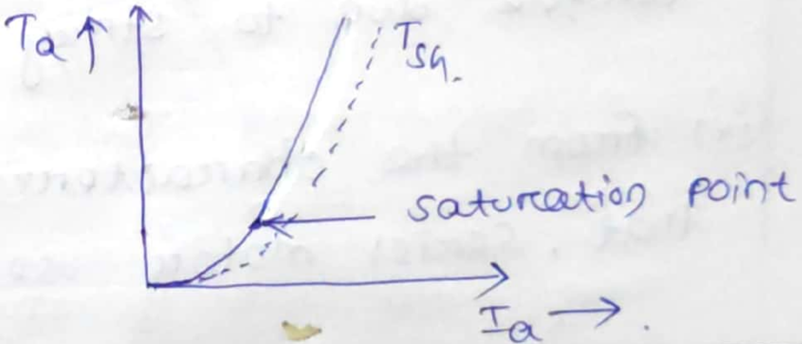
rotational losses = $1050 - (490 + 100)$

= 460 watt.

characteristics of DC series motor

(1) T_a Vs. I_a :-





$T \propto \phi I_a$

$\phi \propto I_{se}$.

$\phi \propto I_a$.

$\Rightarrow \boxed{T \propto I_a^2}$ ← before saturation.

$\boxed{T \propto I_a}$ ← After saturation.

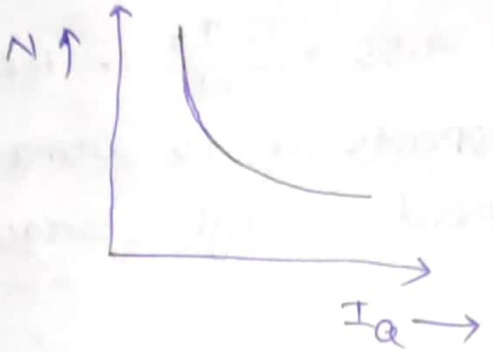
(i) Before saturation torque $\propto I_a^2$. At light load I_a is small, hence flux is small. As I_a increases, armature torque T_a also increases as square of the armature current.

(ii) Hence, initially the torque is parabolic but after saturation the flux is almost independent of I_a, hence torque $(T_a) \propto I_a$. So, the characteristics become linear after saturation.

(iii) The shaft torque (T_{sh}) is shown by the doted line. It is less than armature torque due to stray loss.

(iv) From the characteristics we can conclude that, series motor use where huge starting torque is required for accelerating heavy masses like electric train.

(2). N Vs. Ia :-



$$\left\{ \begin{array}{l} E_b \propto \phi N \\ \downarrow N \propto \frac{E_b \downarrow}{\phi \uparrow\uparrow} \\ E_b = V - I_a R_a \end{array} \right.$$

(i) variation of speed can obtain from the formula $N \propto \frac{E_b}{\phi}$.

(ii) As load increase Ia increase, with increases the flux. Here change in E_b for various load current is very small.

(iii) Hence the speed varies inversely as the armature current. when load is heavy, Ia is large and speed will be low.

(iv) when load is small Ia falls to a very small value. As a result speed become very high.

(3) N Vs. Ta characteristics :-

$T_a \propto \frac{1}{N}$

$T_a = 9.55 \times \frac{E_b I_a}{N}$

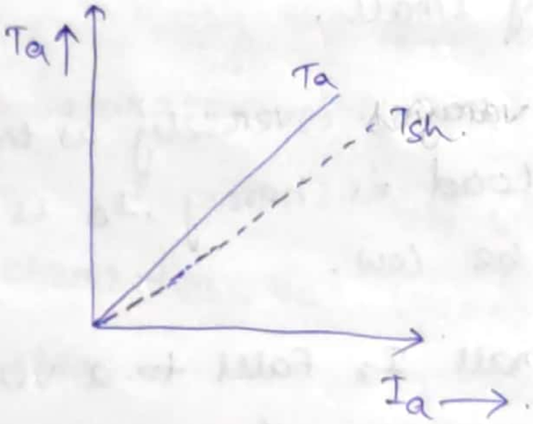
$N \propto \frac{E_b}{T_a}$ because $\phi \propto I_a$

→ we know that $T_a = 9.55 \times \frac{E_b I_a}{N}$. Here speed is inversely proportional to armature torque. so, when speed is high, torque is low.

→ when speed is low, torque is high.

Shunt Motor.

Ta Vs Ia characteristics :-



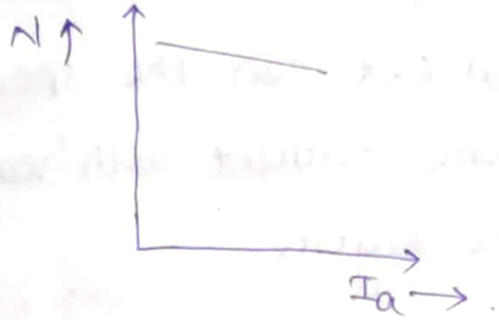
$T_a \propto \phi I_a$

$\boxed{T_a \propto I_a}$ {because ϕ is constant}

(i) we know that $T_a \propto \phi I_a$ but in shunt motor the flux is almost constant only of heavy load. ϕ decrease due to increase in armature reaction.

(ii) Therefore, In a shunt motor $T_a \propto I_a$. So the characteristics is a straight line passing through the origin (linear).

N vs Ia characteristics :-



$$N \propto \frac{E_b}{\phi} \leftarrow \text{constant.}$$

$$N \propto V - I_a R_a$$

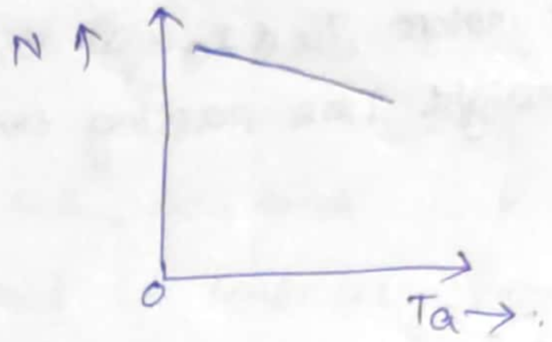
(i) In a shunt motor, flux is almost constant, therefore $N \propto E_b$. But practically both E_b and flux decreases with increase in load

(ii) However, decrease in E_b is more than the flux, as a result there is some decrease in speed.

(iii) From the characteristics we can notice that there is no appreciable change in the speed of DC shunt motor from no load to full load.

(iv) Therefore these motor are used where sudden change in the load takes place like wood cutting, Lathe machine, etc.

N Vs Ta characteristics. :-



(i) This curve is drawn between the speed of the motor and armature current with various amps. as shown in the figure.

(ii) From the curve it is understood that the speed reduces when the load torque increases.

*(iii) with the above three characteristics, it is clearly understood that when the shunt motor runs from no load to full load there is slight change in speed. Thus, it is essentially a constant speed motor. Since the armature torque is directly proportional to the armature current, the starting torque is not high.

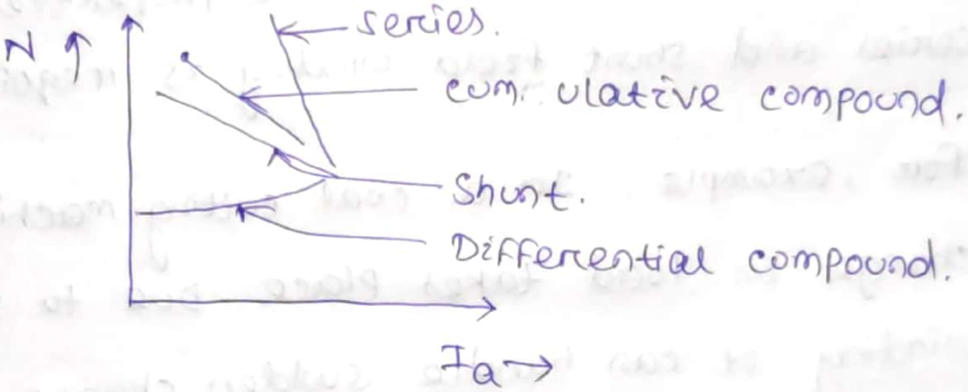
compound Motor :-

(i) These motors have both series and shunt winding

(ii) It Series field flux is in the same direction with shunt field flux, then motor is said to be cumulative compound motor.

(iii) If the series field opposes the shunt field, then the motor is said to be differential compound motor.

N vs Ia characteristics :-



cumulative compound.

$$\phi_t = \phi_{sh} + \phi_{se}$$

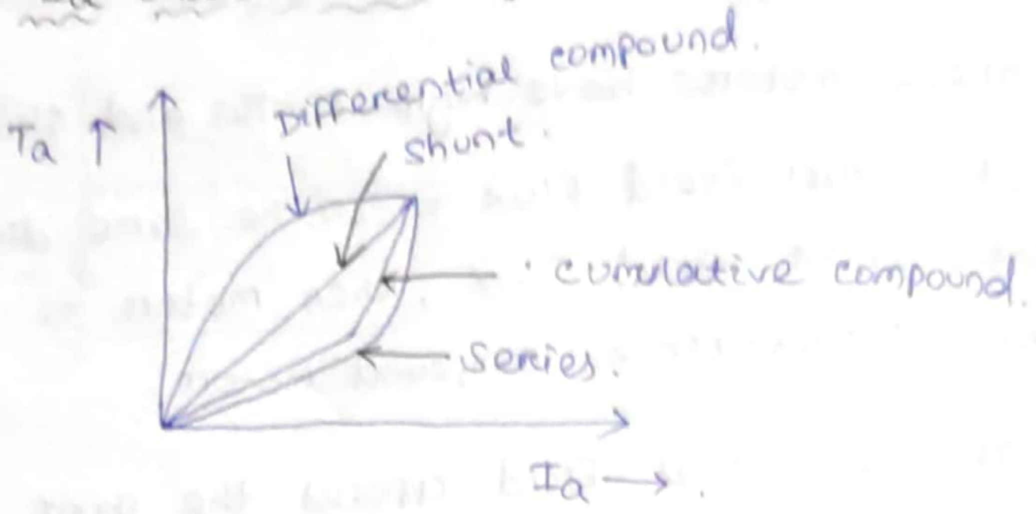
Load ↑ I_a ↑ ϕ_{se} ↑ ϕ_t ↑ N ↓.

Differential compound

$$\phi_t = \phi_{sh} - \phi_{se}$$

Load ↑ I_a ↑ ϕ_{se} ↑ ϕ_t ↓ N ↑

Ta Vs Ia characteristics :-



cumulative compound Motor :-

(i) These motor are used where properties of both series and shunt field winding is required.

(ii) For, example. In a coal cutting machine sudden change in load takes place. Due to shunt winding it can handle sudden change in load and due to series field it will be able to take heavy load.

(iii) cumulative compound motor are used where high starting torque is required with pulsating loads.

Differential compound Motor :-

(i) As series field opposes the shunt field, if Load is increased, total flux will decrease.

(ii) Therefore speed of differential compound motor is constant when Load is less, but speed increases with increase in Load.

(iii) Therefore, these motors are not commonly used.

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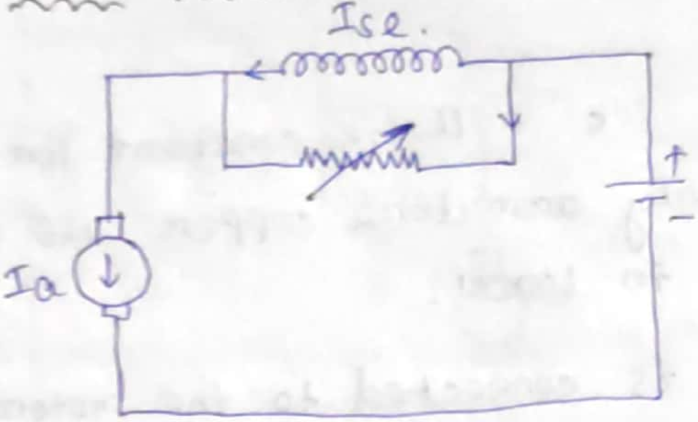
Speed control of DC series motor :-

(1) flux control method :-

(a) field Diverter :-



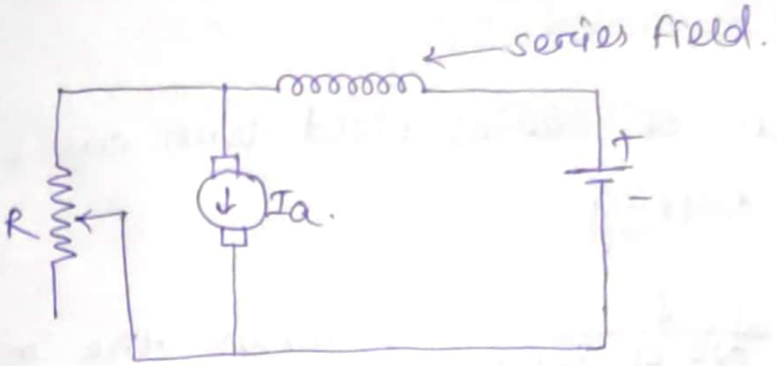
R = max , I_{se} = max , ϕ = max , N= minimum

R = ↓ I_{se} = ↓ , ϕ = ↓ , N = ↑

$$\boxed{N \propto \frac{E_b}{\phi}.}$$

→ In this method series field winding is shunted by a variable resistance known as field diverter. By adjusting the variable resistance, we can varying the field current. As a result flux changes. we know that flux is inversely proportional to speed $(\phi \propto \frac{1}{N})$. Therefore the speed also changes.

(b) Armature Diverter :-



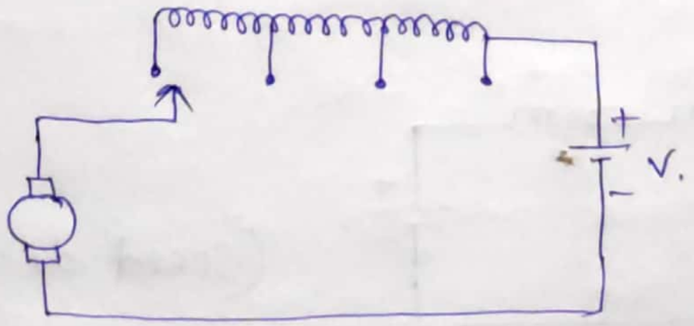
$I_a \downarrow$ $I_{se} \downarrow$ $\phi \uparrow$ $N \downarrow$.

(i) A diverter across the armature can be used for giving speed below rated speed.

(ii) For a given constant load torque, if I_a reduced due to the armature diverter, the torque decrease for a given constant torque

(iii) To maintain constant torque the motor draw more amount of current as a result, I_{se} increase which increase the flux. Therefore the speed of the motor decrease.

(2) Tapped Field Method :-



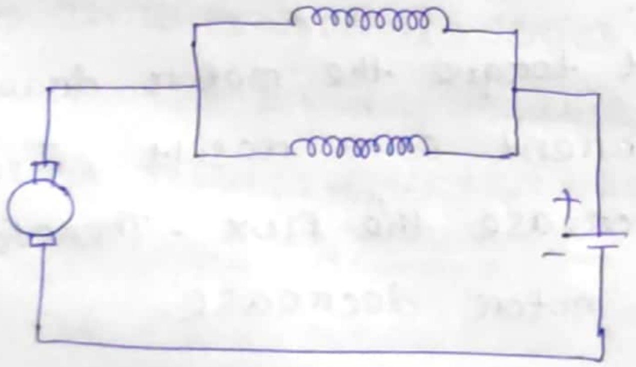
(i) This method is mostly used in electric traction.

(ii) Here number of series field turn can be changed by tapping.

(iii) As, $f \propto \frac{1}{\text{No. of turn}}$, when the motor run with full turn, field flux will be maximum. As a result its speed will be minimum.

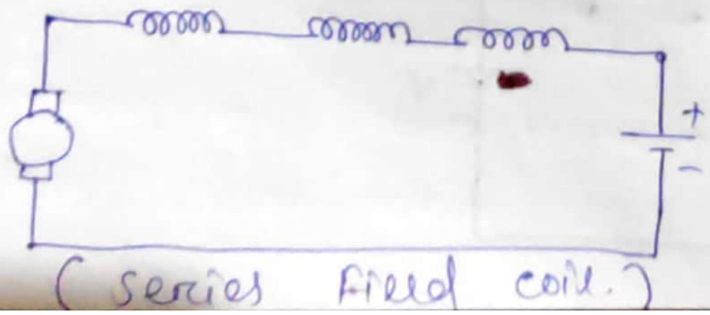
(iv) when the no. of turns decreased, flux decreased with increase in speed.

Series-parallel control method :-



(speed increase).

(parallel field coil.)



(speed decrease)

(series field coil.)

(i) This system is widely used in electric traction, where two or more mechanically coupled series motors are employed.

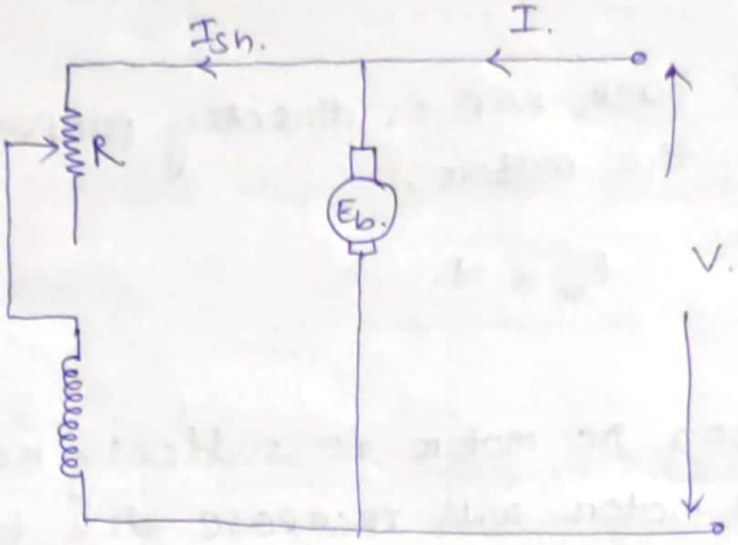
(ii) For low speed, the motors are connected in series and for higher speeds, the motors are connected in parallel.

(iii) When in series, the motors have the same current passing through them, although voltage across each motor is divided.

(iv) When in parallel, the voltage across each Motor is same although the current gets divided.

Speed control of DC shunt motor.

(1) Variable flux or flux control method.



R = 0 $\quad I_{sh}$ = max. $\quad$ N (rated).

R = ↑ $\quad I_{sh}$ = ↓ $\quad \phi$ = ↓ $\quad$ N = ↑

R = ↑↑ $\quad I_{sh}$ = ↓↓ $\quad \phi$ = ↓↓ $\quad$ N = ↑↑

(i) We know that, $N \propto \frac{1}{\phi}$

By decreasing the field flux speed can be increase or vice versa.

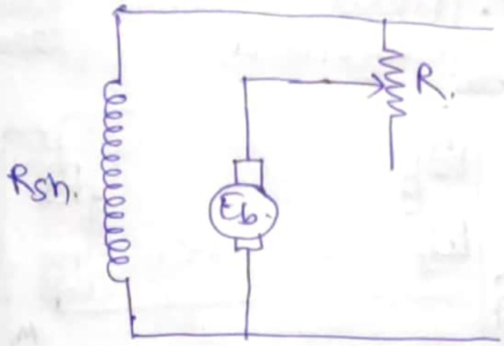
(ii) The flux of a dc motor can be changed by changing I_{sh} with the help of a shunt field rheostat.

(iii) When resistance of the field rheostat is increased I_{sh} decreases. As a result flux decreases which results in increase of speed.

(iv) In the field control method speed of the motor can be increased above the rated speed. It can't be decreased below rated speed.

(v) As magnitude of I_{sh} is small power loss in the rheostat ($I_{sh}^2 R_{sh}$) is small. Therefore, this method is very effective.

(2) Armature voltage control Method :-



$$N \propto \frac{V - I_a (R_a + R)}{\phi}.$$

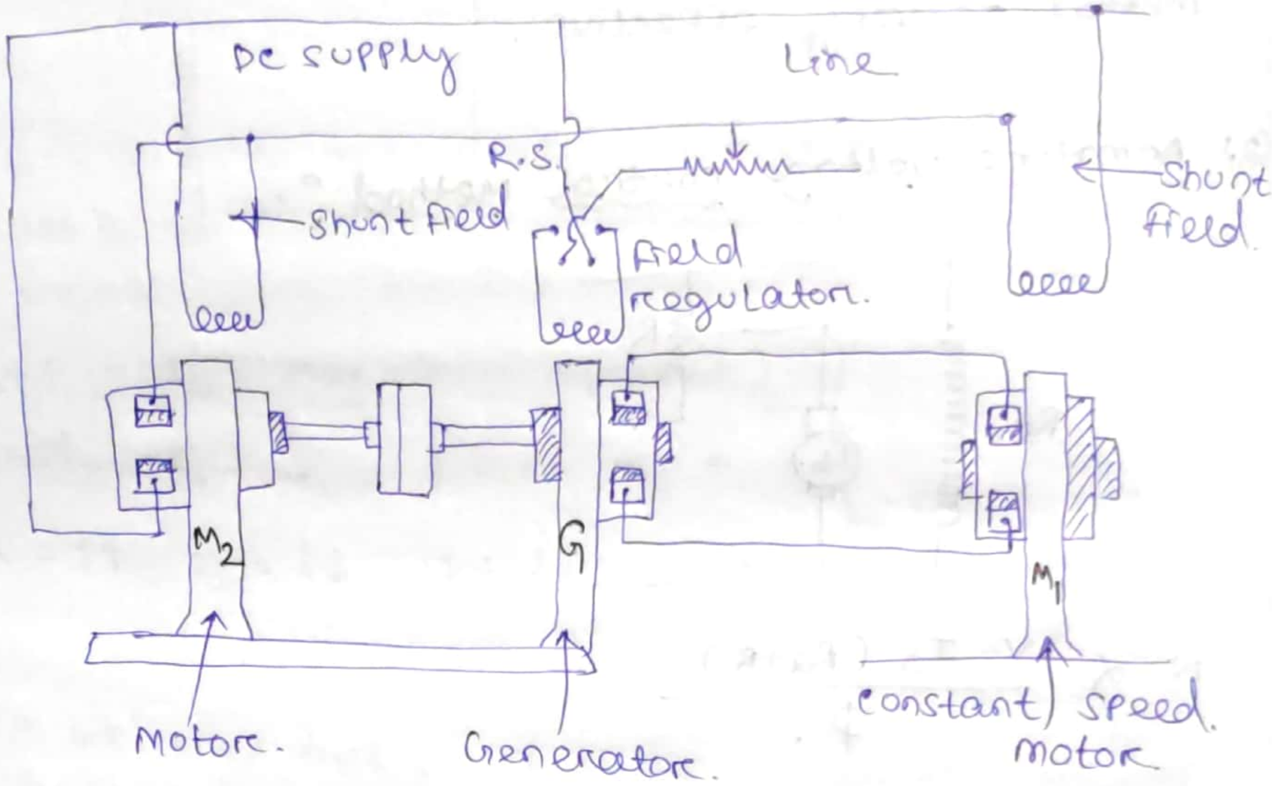
(i) This method is used to decrease the speed below the rated speed.

(ii) As the supply voltage is constant voltage across the armature can be changed by inserting a rheostat in series with the armature circuit.

(iii) As the variable resistance is increased potential difference across the armature (E_b) is decreased. As a result speed of the motor decreases.

(iv) In this method losses will be more because value of I_a is more as compare to I_{sh}.

(3) supply voltage control method.
OR ward Leonard method :-



$N \propto \frac{V - I_aR_a}{\phi}$, $N \propto \frac{E_b}{\phi}$.

V ↑ E_b ↑ N ↑
V ↓ E_b ↓ N ↓

(i) This system is used where a wide and sensitive speed control is required.

(ii) Let M_1 is the main motor whose speed control is required.

(iii) By changing the supply voltage of M_1 any desire speed can be obtained.

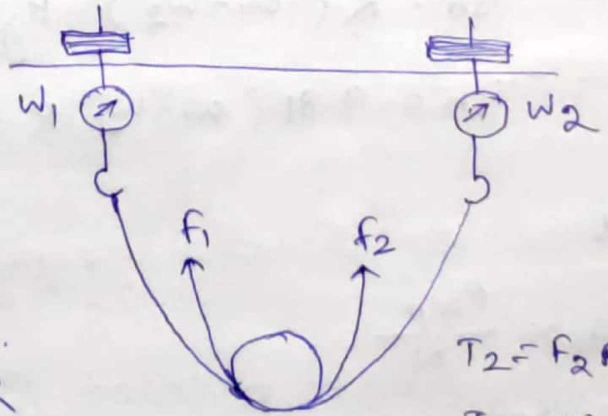
(iv) This variable voltage is supplied by a motor generator set which consists of a DC motor M_2 and a DC generator 'G'.

(v) The motor M_2 runs at approximately constant speed. output of the motor M_2 is given to the generator and output voltage of the generator is directly fed to the main motor M_1.

(vi) output voltage of the generator 'G' can be vary from '0' to maximum by using a reheostat.

(vii) This process of speed control is very expensive and losses will be more.

Brake Test method (Direct method.)



$T_1 = f_1 R.$

$T_1 = W_1 R$

$T_2 = f_2 R$

$T_2 = W_2 R.$

(i) This is the direct method for testing a DC motor from this test we can determine efficiency of a motor.

(ii) A belt is fixed around a pulley and its two ends are attached to the spring balance w_1 and w_2. The pulley is coupled with shaft of a DC motor.

(iii) using belt tightening hand wheels H_1 and H_2, load of the motor is adjusted to its rated value.

(iv) Here two forces F_1 and F_2 are acting on the pulley. Torque because of these two forces are opposing each other. Hence the net torque will be subtracting of the two torque.

So,

$$\text{shaft torque} = (T_1 - T_2)$$

$$= (w_1 R - w_2 R).$$

$$T_{sh} = R(w_1 - w_2) \text{ Kg.m.}$$

$$T_{sh} = 9.81 (w_1 - w_2) R \text{ N/m.}$$

we know that

$$T_{sh} = 9.55 \times \frac{P_{o/p}}{N}$$

$$P_{o/p} = \frac{T_{sh} \times N}{9.55.}$$

Now, putting the value of T_{sh} in above equation we get,

$$P_{o/p} = \frac{9.81 (w_1 - w_2) R \times N}{9.55.}$$

$$\boxed{P_{o/p} = 1.02 (w_1 - w_2) NR}$$

Input power can be calculated from the formula

$$P_{i/p} = VI$$

The input voltage and current can be measure by using voltmeter and ammeter.

Now, we can easily calculate η (efficiency) of the motor.

$$\eta = \frac{P_{o/p}}{P_{i/p}}$$

$$\eta = \frac{1.02 (w_1 - w_2) N \times R}{VI}$$

(η = efficiency.)

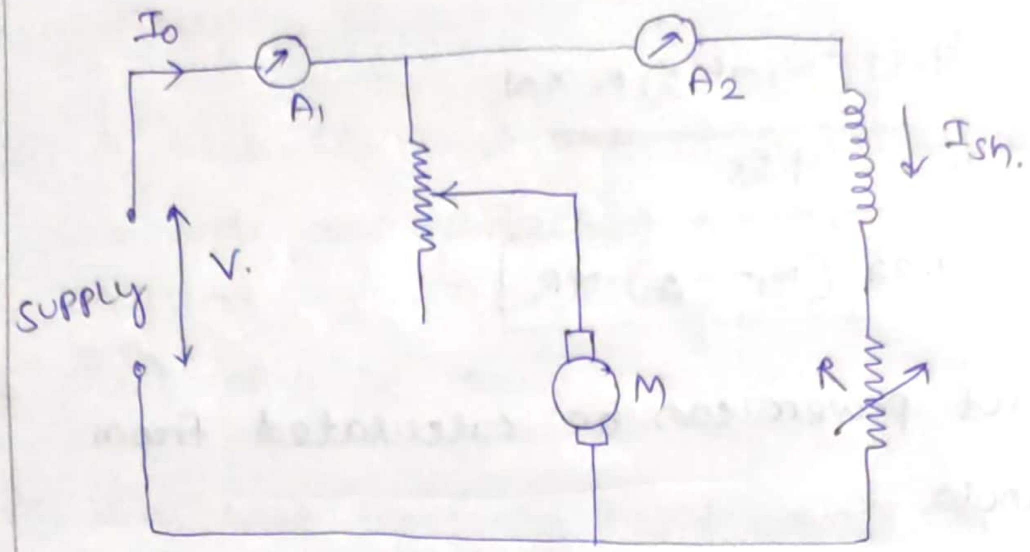
Disadvantages :-

(i) The spring balance reading are not stable.

(ii) The o/p power is wasted.

(iii) It can be use for only small motors.

Swinburnes Test. (Indirect method) :-



(i) Swinburnes test is an indirect method for determining the efficiency (η) of DC machine.

(ii) In this test no load losses or constant losses are determined. From these losses we can calculate efficiency of DC motor at any load.

(iii) Here the machine is run at rated voltage and speed without load.

(iv) 2 ammeters are connected to measure field current I_{sh} and total current I.

(v) As there is no load.

$$P_{o/p} = 0$$

so,

$$P_{i/p} = \text{Losses}.$$

$\Rightarrow P_{i/p} = W_{const.} +$ Armature copper loss.

$W_{const.} = P_{i/p} -$ Armature copper loss.

constant loss 'W_c' will be constant for any change in load. only armature copper loss will vary with change in load.

Let, a load is connected to the motor such that it draws I_1 amount of current from the source.

$$\text{Losses} = W_c + (I_1 - I_{sh.})^2 R_a$$

$$\eta = \frac{P_{o/p}}{P_{i/p}}$$

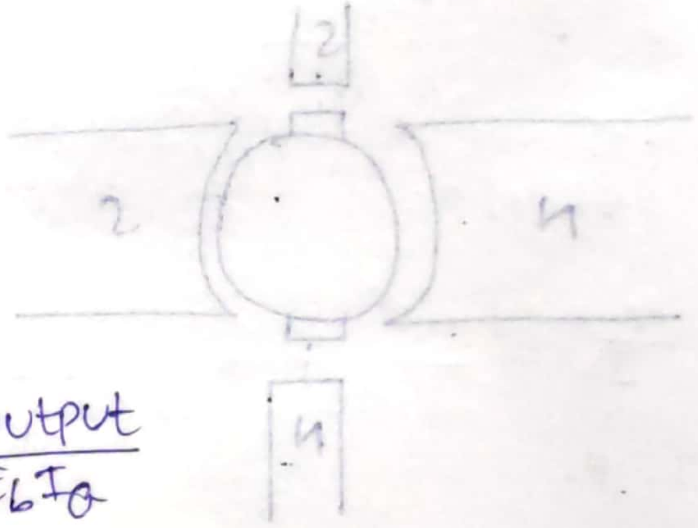
$$= \frac{P_{i/p} - \text{Losses}}{P_{i/p}}$$

$$= \frac{VI_1 - W_c + (I_1 - I_{sh})^2 R_a}{VI_1}$$

Power stages

Motor i/p = VI Watt → Cu. Loss → Power in armature = $E_b I_a$ watt

→ Iron and friction loss → motor output in watt



$$\eta_e = \frac{E_b I_a}{VI}$$

$$\eta_m = \frac{\text{motor output}}{E_b I_a}$$

$$\eta_o = \frac{\text{motor output}}{\text{motor input}(VI)}$$

2) A 220V DC shunt motor has an armature resistance of 0.73 Ω, shunt field resistance of 110 Ω and no load the speed is 1200 rpm and armature current is 2.4A. on rated load the speed drops to 1100 rpm. determine the line current and input power, when the motor delivers rated load.

Given data :-

$V = 220$

$R_a = 0.73\Omega$.

$R_{sh} = 110\Omega$.

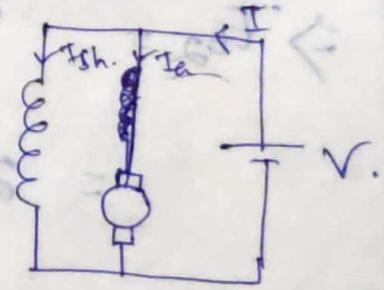
at no load $N = 1200$ rpm.

$I_a = 2.4A$.

at load $N = 1100$ rpm.

$I = ?$

i/p power = ?



$$I_{sh} = \frac{V}{R_{sh}}$$

$$= \frac{220}{110}$$

$$= 2A.$$

$I = I_a + I_{sh} = 2 + 2.4 = 4.4A.$

$E_{b_1} = V - I_aR_a$

$= 220 - (2.4 \times 0.73)$

$= 218.248$ V.

$E_{b_1} \propto N_1$ — ①

$E_{b_2} \propto N_2$ — ①

$E_{b_1} = K \; N_1$

$E_{b_2} = K \; N_2$

$\Rightarrow \frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2}$

$\Rightarrow \frac{218.248}{E_{b_2}} = \frac{1200}{1100}$

$\Rightarrow E_{b_2} = \frac{218.248 \times 1100}{1200}$

$= 200.06$ V.

$E_{b_2} = V - I_aR_a$

$\Rightarrow 200.06 = 220 - I_a(0.73)$

$\Rightarrow I_a = \frac{220 - 200.06}{0.73} = 27.31$ A.

$I_L = I_a + I_{sh}$.

$= 27.31 + 2$

$= 29.31$ A.

i/p power $= V \times I_L$

$= 220 \times 29.31$

$= 6448.2$ watt.

$= 6.448$ kW.

(1) The speed of a 37.3 KW series motor working on 500 V supply is 750 rpm at full load and 90% efficiency. if the load torque is made 350 N-M and a 5 Ω resistance is connected in series with the machine. calculate the speed at which the machine will run. assume the magnetic ckt to unsaturated and the armature and field resistance which is 0.5 Ω.

Given data

$R_a + R_{se} = 0.5\,\Omega$

o/p $P = 37.3$ KW $= 37.3 \times 10^3$ W.

$N_1 = 750$ rpm.

efficiency $(\eta) = 90\% = 0.90$

$T_{sh_2} = 350$ N-M.

$R = 5\,\Omega$

$V = 500$V

$$T_{sh_1} = 9.55 \times \frac{\text{o/p Power}}{N}$$

$$= 9.55 \times \frac{37.3 \times 10^3}{750}$$

$$= 474.95 \text{ N-M.}$$

$\eta = \frac{o/p}{i/p}$

$\Rightarrow i/p = \frac{37.3 \times 10^3}{0.90}$

$\Rightarrow i/p = 41444.44$ watt

$= 41.44$ kW.

Input power $= V.I_{a_1}$

$\Rightarrow 41444.44 = 500 \times I_{a_1}$

$\Rightarrow I_{a_1} = 82.88$ A.

$T_{sh} \propto I_a^2$ $[\because T_a \propto I_a^2$ for series motor$]$.

$\Rightarrow \frac{T_{sh_1}}{T_{sh_2}} = \frac{I_{a_1}^2}{I_{a_2}^2}$

$\Rightarrow \frac{474.95}{350} = \frac{82.88^2}{I_{a_2}^2}$

$\Rightarrow I_{a_2}^2 = \frac{82.88^2 \times 350}{474.95}$

$\Rightarrow I_{a_2} = \sqrt{\frac{82.88^2 \times 350}{474.95}}$

$= 71.14$ A.

(1) A 400 V series motor runs at 500 rpm, taking a current of 40A. calculate the speed and percentage change in torque if the load is reduced, the motor is taking 30A. Total resistance of armature and field is 0.8 Ω.

Given data :-

$V = 400 V.$

$N_1 = 500$ rpm.

$I_{a_1} = 40 A.$

$I_{a_2} = 30 A.$

$R_a + R_{se} = 0.8 \Omega$

$E_{b_1} = V - I_{a_1}(R_a + R_{se})$.

$\Rightarrow E_{b_1} = 400 - 40(0.8)$.

$\Rightarrow E_{b_1} = 368$ V.

$E_{b_2} = V - I_{a_2}(0.8)$.

$= 400 -$ ~~400~~ $30(0.8)$

$= 376$ V.

$\frac{E_{b_1}}{E_{b_2}} = \frac{N_1}{N_2}\frac{I_{a_1}}{I_{a_2}}$

$\Rightarrow \frac{368}{376} = \frac{500}{N_2}\frac{40}{30}$

$\Rightarrow N_2 = \frac{500 \times 376 \times 40}{368 \times 30}$

~~$\Rightarrow N_2 = 510.86$ rpm.~~

[illegible]

$\Rightarrow N_2 = 681.15$ rpm.

$T_{a_1} = \frac{E_{b_1} I_{a_1}(9.55)}{N_1}$

$= \frac{368 \times 40(9.55)}{500} = 281.152$ N-m.

$$\frac{T_{a_1}}{T_{a_2}} = \frac{I_{a_1}^2}{I_{a_2}^2}$$

$$\Rightarrow \frac{281.152}{T_{a_2}} = \frac{(40)^2}{30^2}$$

$$\Rightarrow T_{a_2} = \frac{281.152 \times 30^2}{40^2}$$

$$\Rightarrow T_{a_2} = 158.14 \text{ N-m.}$$

Change in torque $= T_{a_1} - \cancel{8}T_{a_2}$

$= 281.152 - 158.14$

$= 123.012$

% of change in torque $= \frac{123.012}{281.152} \times 100$

$= 43.75$ %

$I_a = I_0 - I_{sh}$.

i/p power $= VI_0$

Armature i/p power $= VI_a$.

Total Losses = i/p power

$= VI_0$

$$\eta = \frac{i/p - losses}{i/p}$$

$$= \frac{VI - (I_0 - I_{sh})^2 R_a - W_c}{VI}$$

↑

Total Losses = W_c + Armature copper Loss.

$= W_c + I_a^2 R_a$.

$$\Rightarrow \boxed{W_c = \text{Total Loss} - I_a^2 R_a}$$

Let,

load is connected, I current flow

$i/p = VI$

Losses $= W_c + I_a^2 R_a$

$$\boxed{\eta = \frac{i/p - loss}{i/p}}$$

Application of DC shunt motor :-

The various applications of DC shunt motor are in.

(i) lathe machines. (ix) Shapers.
(ii) centrifugal pumps.
(iii) Fans
(iv) Blowers
(v) conveyors.
(vi) Lifts.
(vii) weaving machine.
(viii) spinning machines, etc

→ The shunt motors are used where constant speed is required.

Application of series motor :-

Trains, Trollies

(i) Traction system. (iv) vacuum cleaner

(ii) cranes. (v) Hair drier.

(iii) air compressors.

→ The series DC motors are used where high starting torque is required and variation in speed –
are possible.

Application of compound motor :-

(i) presses.
(ii) shears.
(iii) Elevators.
(iv) Rolling mills
(v) Heavy planners.

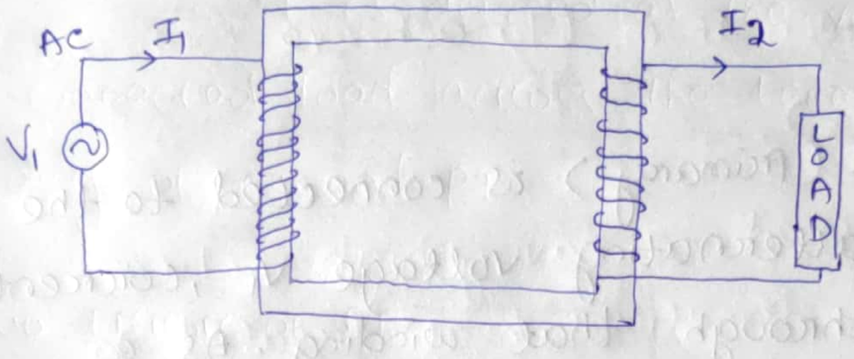
→ The compound motors are used where higher starting torque and flairely constant speed is required.

Application of separately excited DC motor :-

→ By separately varying the field current variable speed can be achieved. so ~~this~~ due to this reason this type motor are u

(Chapter-3) Single phase Transformer.

Single Phase Transformer :-



(i) It is a device which transform voltage from one level is another at constant frequency and constant power, through mutual induction process.

OR

(ii) Transformer is a static device that transfer electric power from one ckt to another with same frequency through the process of mutual induction.

(iii) It is most commonly used to increase and decrease the voltage level between the circuits.

Working Principle of Transformer :-

(i) The basic working principle of transformer is mutual induction between two ckt linked by a common magnetic field.

(ii) Let two inductive coils which are electrically separated but magnetically linked through the path of low reluctance that is transformer core as shown in the above figure.

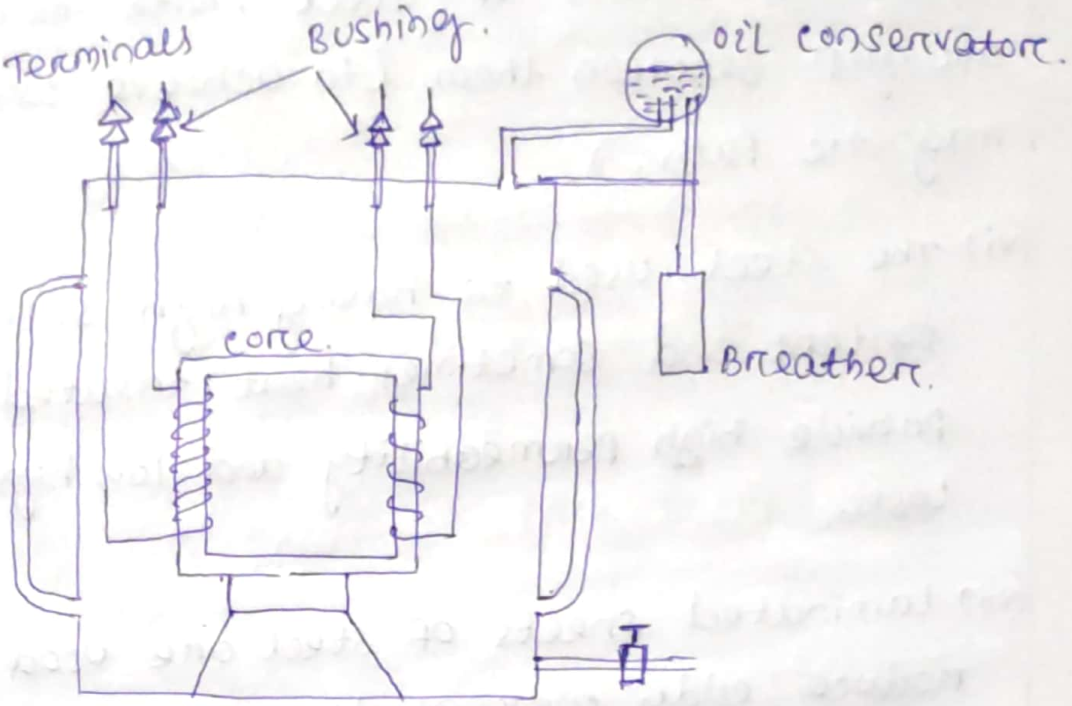
(iii) If one coil (Primary) is connected to the source of alternating voltage V_1, current I_1 flows through that winding. As a result alternating flux is set up in the laminated core.

(iv) This alternating flux linked with the coil and according to Faraday's law of electro-magnetic induction emf is induced in both coils. (E_1 in the primary coil and E_2 in the secondary coil).

(v) when the secondary coil is connected to a load current I_2 will start to flow to the load and power will transfer to it. voltage drop across the load is V_2.

(vi) The induced voltage (E_2) in the secondary coil will depends upon the no. of turns.

Basic construction of Transformer :-



(Transformer.).

(i) Basically a transformer consists of two inductive winding and a laminated steel core.

(ii) The coils are insulated from each other as well as from the steel core.

(iii) A transformer may also consist of a container for winding and core assembly (called as tank) Suitable bushing to take out the terminals.

(iv) Oil conservator to provide oil in the transformer tank for cooling purpose etc.

(v) The figure shows the basic construction of a transformer. In all types of transformers core is constructed by assembling (stacking) laminated sheets of steel, with minimum air gap between them (to achieve continuous magnetic path).

(vi) The steel used is having high silicon content and sometimes heat treated, to provide high permeability and low hysteresis loss.

(vii) Laminated sheets of steel are used to reduce eddy current loss. The sheets are cut in the shape as 'E', I and 'L' to avoid high reluctance at joints.

Main parts of transformer :-

(1) Laminated Iron core.
(2) winding of the Transformer.
(3) Insulating material.
(4) Tap changer.
(5) Transformer tank.
(6) oil conservator tank
(7) Breather
(8) Buchholz Relay
(9) Bushing.

(10) cooling Tube and Radiator

(11) Explosion vent.

1. Laminated iron core :-

(i) Transformer core is made up of iron or silicon steel or ferromagnetic material.

(ii) core provides support's to the winding. It also provide a low reluctance path to the magnetic flux to flow.

(2) winding of the transformer :-

(i) Two sets of winding are wound over the transformer core and insulated from each other.

(ii) According to the connection of source and load it is classified into two types.

① **Primary winding :-**

This type of winding to which source is connected.

② **secondary winding :-**

This is the winding to which load is connected.

→ According to the voltage level winding is classified into two types.

① High voltage winding (H.V).

In this winding magnitude of the induced emf is high.

② Low voltage winding (L.V). :-

In this winding magnitude of the induced emf is less.

3. Insulating material :-

(i) Insulating papers, cardboard are used in the transformer to isolate the primary and secondary winding from each other and from the transformer core.

(ii) Transformer oil is used in transformer to provide insulation and cooling to the core and coil assembly.

(iii) The transformer core and winding must be completely immersed in the oil. Normally hydrocarbon mineral oil is used as transformer oil.

4. Tap changer :-

(i) Tap changers are used to change the output voltage by increasing or decreasing no. of turns in the high voltage side.

(ii) There are 2 types of tap changer.

① Off-load Tap changer :-

Tap changing is done when the transformer is disconnected from both source and load.

② ON load Tap changer :-

Here tap changing is done when the transformer is connected to both source and load.

5. Transformer tank :-

(i) laminated core and windings are placed in transformer tanks.

(ii) 3/4th part of the transformer tank is filled with transformer oil (mineral oil).

(iii) Transformer tank is made up of cast steel.

6. Oil conservator tank :-

(i) The oil conservator tank look like a rectangular tank. It stores the extra oil and directly connected with the transformer tank.

(ii) The oil conservator tank is played an important role in the transformer.

(iii) The purpose of the conservator tank is to protect the expansion of oil in the main tank of the transformer.

(iv) The oil used in the transformer two purposes.

① insulation.
② cooling.

(v) when the oil level reduces due to losses or leakage, the conservator will be delivering oil to the transformer. Thus it acts as a reservoir oil.

7. Breather :-

(i) Breather is connected with the conservator tank.

(ii) It is a cylindrical vessel which filled blue colour silica gel.

(ii) They have two purposes - remove the moisture from the air and to have the capacity to absorb the moisture in a transformer.

(iii) It plays a role to act as the air filter and provide the free moisturizing air to the conservator tank.

(iv) Initially the colour of silica gel is blue. When the silica gel soak a lot of moisture it turns to pink. once the silica gel turns pink it can not absorb more moisture.

8. Buchholz's Relay :-

(i) It is a protective device placed on the connecting pipe from main tank to conservator tank.

(ii) It senses the fault which occurs in the transformer.

9. Bushing :-

(i) The bushing is an insulating device that is made up of porcelain materials.

(ii) The terminal of the bushing is provided a path of the conductor to the transformer tank.

(iii) with the help of the terminal, the transformer gives and provides the supply to another system.

10. Cooling Tube and Radiator :-

(i) The cooling tube is necessary for maintaining the temperature and circulating cooling oil in the transformer.

(ii) The radiator is connected with the transformer tank. It is also made of a number of metal strips or pipes.

(iii) Both the cooling tube and the radiator provide the same function in a different way.

(iv) It is divided into two types of cooling system
① Natural cooling system.
② Forced cooling system.

(11) Explosion vent :-

(i) The explosion vent is located at the topmost position on the transformer. The conservator tank is directly connected to the explosion tank with the help of a pipe.

(ii) The main purpose to prevent damage transformer oil tank by expelling boiling oil during an internal fault. and it is necessary to remove heated oil (in the form of gas). in the transformer.

(iii) This explosion tank use only for emergency purpose. It mostly works when a breather and Buchholz relay will not doing work properly.

classification of Transformer :-

(i) According to phase, T/f are two types.

① Single phase Transformer.
② Three phase Transformer.

(ii) According to voltage level it is 2 types.

① Step up Transformer.
② Step down Transformer.

(iii) According to use, it is 3 types.

① Power Transformer (used in transmission Line).
② Distribution Transformer (used in distribution Line).
(3) Instrument T/F (used to measure 'v' and I)

(iv) According to construction it is divided into 3 types.

① core type.

② shell type.

③ Berry type.

Cooling methods of A Transformer :-

Different cooling methods of transformers are

① For dry type transformers.

ⓐ Air Natural.

ⓑ Air Blast.

(2) For oil immersed transformers

ⓐ oil Natural Air Natural.

ⓑ oil Natural Air forced.

ⓒ oil forced Air Forced

ⓓ oil forced water Forced.

Air Natural or Self Air cooled transformer :-

This method of transformer cooling is generally used in small transformers (upto 3 MVA). In this method the transformer is allowed to cool by natural air flow surrounding it.

Air Blast cooling :-

(i) For transformers rated more than 3 MVA, cooling by natural air method is inadequate.

(ii) In this method, air is forced on the core and windings with the help of fans or blowers.

(iii) The air supply must be filtered to prevent the accumulation of dust particles in ventilation ducts. This method can be used for transformers up to 15 MVA.

Oil Natural Air Natural :-

(i) This method is used for oil immersed transformer.

(ii) In this method, the heat generated in the core and winding is transferred to the oil.

(iii) According to the principle of convection, the heated oil flows in the upward direction and then in the radiator.

(iv) The vacant place is filled up by cooled oil from the radiator. The heat from the oil will dissipate in the atmosphere due to the natural air flow around the transformer.

(v) In this way, the oil in transformer keeps circulating due to natural convection and dissipating heat in atmosphere due to natural conduction.

(vi) This method can be used for transformers upto about 30 MVA.

Oil Natural Air forced :-

(i) The heat dissipation can be improved further by applying forced air on the dissipating surface.

(ii) forced air provides faster heat dissipation than natural air flow.

(iii) In this method, fans are mounted near the radiator and may be provided with an automatic starting arrangement, which turns on when temperature increases beyond certain value. This transformer cooling method is generally used for large transformers upto about 60 MVA.

Oil Forced Air forced :-

(i) In this method, oil is circulated with the help of pump.

(ii) The oil circulation is forced through the heat exchangers. Then compressed air is forced to flow on the heat exchanger with the help of fans.

(iii) The heat exchangers may be mounted separately from the transformer tank and connected through pipes at top and bottom.

(iv) This type of cooling is provided for higher rating transformers at substation or power station.

oil forced water forced :-

(i) This method is similar to OFAF method, but here forced water flow is used to dissipate heat from the heat exchangers.

(ii) The oil is forced to flow through the heat exchanger with the help of a pump, where the heat is dissipated in the water which is also forced to flow.

(iii) The heated water is taken away to cool in separate coolers. This type of cooling is used in very large transformers having rating of several hundreds MVA.

Maintenance of Transformer :-

A power transformer is most costly and essential equipment of an electrical transformer. so for getting high performance and long functional life of the transformer, it is desired to perform various maintenance activities.

Monthly Basis maintenance of transformer :-

(i) The oil level in oil cap under silica gel breather must be checked in one month interval. If it is found the transformer oil inside the cup comes below the specific level, oil to be top up as per specified level.

(ii) Breathing holes in silica gel breather should be checked monthly and properly cleaned if required, for proper breathing action.

Daily Basis maintenance and checking :-

(i) Reading of MOG (magnetic oil gauge) of main tank and conservator tank.

(ii) colour of silica gel in breather.

(iii) leakage of oil from any point of a transformer.

Yearly Basis Transformer maintenance schedule

(i) The auto, remote, manual function of cooling system that means, oil pumps, air fans and other items engaged in cooling system of transformer, along with their control ckt to be checked in the interval of one year.

(ii) All the bushings of the transformer to be cleaned by soft cotton cloths yearly.

(iii) Mechanical inspection of Buchholz relays to be carried out on yearly basis.

(iv) All the relay, alarms and control switches along with their ckt, in R and c panel (Relay and control panel). and RTCC (Remote Tap changer control panel) to be cleaned by appropriate cleaning agent.

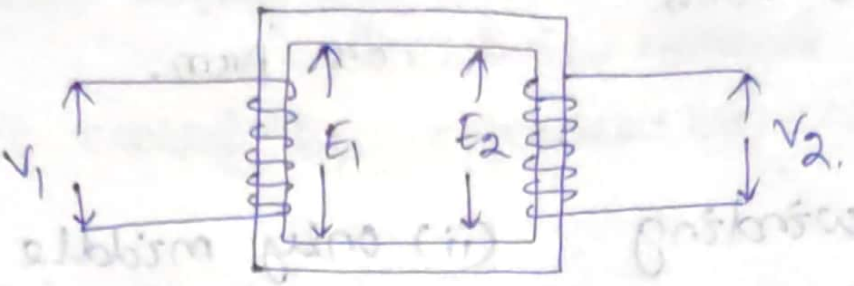
(v) Insulation resistance and polarization index of transformer must be checked with battery operated megger of 5KV range.

(vi) Resistive value of earth connection and rizer must be measured annually with clamp on earth resistance meter.

Half yearly Basis maintenance of transformer

(i) The transformer oil must be checked half yearly basis that means once in 6 month, for dielectric strength, water content, acidity, sludge content, flash point, resistivity for transformer oil.

EMF equation of a transformer :-



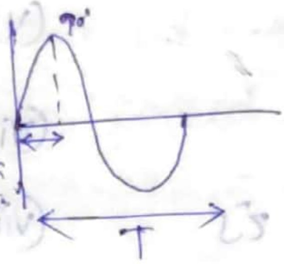
Let,

N_1 = No. of turns in primary

N_2 = No. of turns in secondary.

ϕ_m = maximum flux in core.

f = frequency of AC input in HZ.



max^m flux in $T = \frac{T}{4} = \frac{1}{4f}$

$T = \frac{1}{f}$

Flux increases from its zero value to maximum value in one quarter of cycle i.e $\frac{1}{4f}$ second.

So the average rate of change of flux

Avg emf/turn $= \dfrac{\phi_m}{\frac{1}{4f}} = 4f\phi_m$ volt

→ If flux ϕ vary sinusoidally then rms value of induced emf is obtained by multiplying the average value with form Factor

→ rms value of emf per turn $= 1.11 \times 4 f \phi_m$ volt

$$= 4.44 f \phi_m \text{ volt.}$$

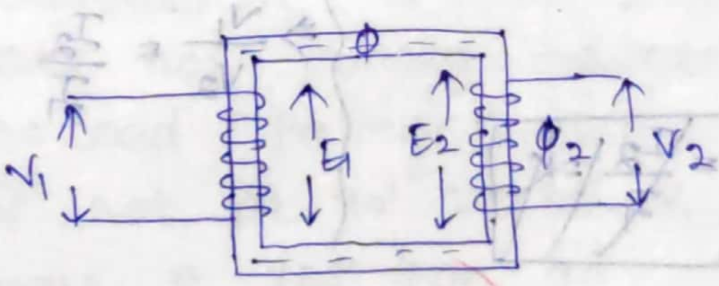
Now rms value of induced emf in whole primary winding is = induced emf per turn × no. of primary turns.

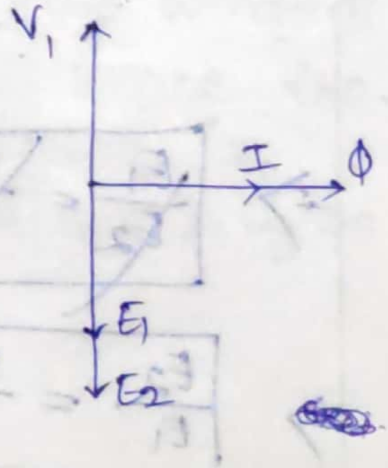
$$\boxed{E_1 = 4.44 f \phi_m \times N_1} \text{ volt} \quad \text{—— ①}$$

Similarly rms value of emf induced in secondary $(E_2) = 4.44 f \phi_m \times N_2$ volt.

$$\boxed{E_2 = 4.44 f \phi_m \times N_2} \quad \text{—— ②}$$

Ideal Transformer :-





(i) An ideal t/f is one which has no losses. i.e it's winding have no ohmic resistance.

(ii) In other words an ideal transformer is consists of to purely inductive coils wound on a loss free core.

Voltage Transformation ratio (K) :-

$$E_1 = 4.44 \phi f N_1 \quad \text{—} ①$$

$$E_2 = 4.44 \phi f N_2 \quad \text{—} ②$$

$$\frac{E_1}{N_1} = 4.44 \phi_m f \, , \quad \frac{E_2}{N_2} = 4.44 \phi_m f.$$

$$\frac{E_1}{N_1} = \frac{E_2}{N_2} = 4.44 \phi_m f = K$$

$$\boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = K}$$

$$\frac{\text{eq}^n\ 2}{\text{eq}^n\ ①}$$

$$\Rightarrow \boxed{\cancel{\frac{E_1}{E_2}} = \cancel{\frac{N_1}{N_2}} = \cancel{K}}$$

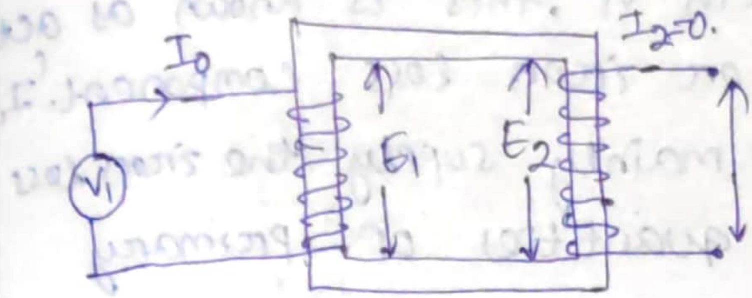
$$V_1 I_1 = V_2 I_2$$

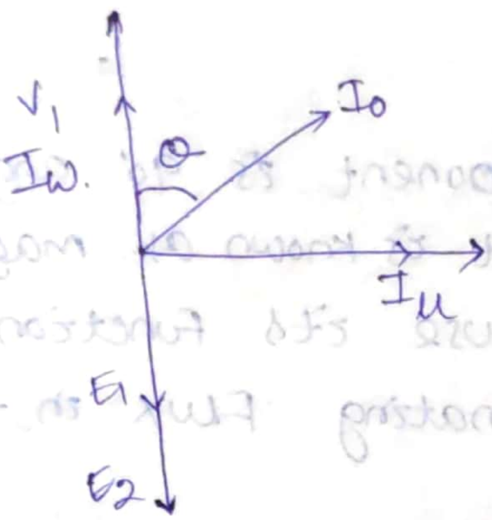
$$\Rightarrow \frac{V_1}{V_2} = \frac{I_2}{I_1}$$

$$\Rightarrow \boxed{\cancel{\frac{E_1}{E_2}} = \cancel{\frac{N_1}{N_2}} = \cancel{\frac{I_2}{I_1}} = \cancel{K}}$$

$$\Rightarrow \boxed{\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K}$$

Transformer on No-load :-





(i) In ideal transformer there are no core losses and copper losses, so the windings are purely inductive in nature. and primary current lags behind the supply voltage by 90°. but when the transformer is not ideal, the windings are not purely inductive. Hence the no load primary i/p current 'I_0' is not at 90° behind V_1 but lags it by an angle θ less than 90°.

(ii) The primary current 'I_0' has two component

(1) In phase with V_1, this is known as active or working or iron loss component. 'I_w' because it mainly supply the iron loss plus small quantities of primary copper loss.

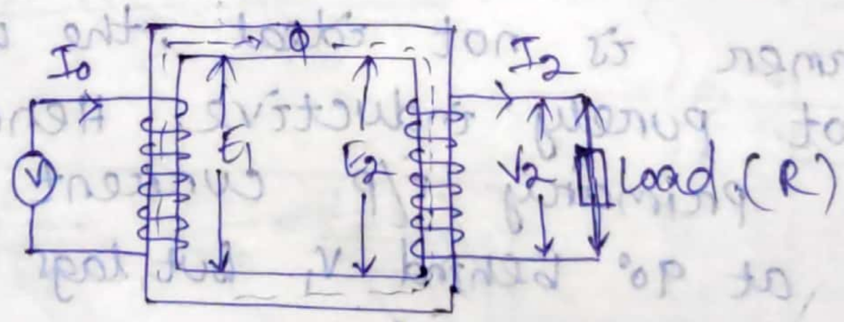
$$\boxed{I_W = I_0 \cos\theta}$$

(2) The other component is 90° angle with V_1 (Lagging). It is known as magnetising component. because its function is to maintain alternating flux in the core.

$$\boxed{I_\mu = I_0 \sin\theta}$$

$$I_0^2 = I_W^2 + I_\mu^2$$

Transformer on load :-



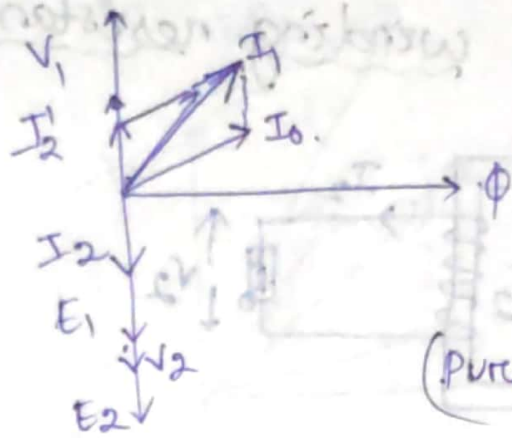
$$\phi = \phi_m \sin\omega t.$$

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}\phi_m \sin\omega t.$$

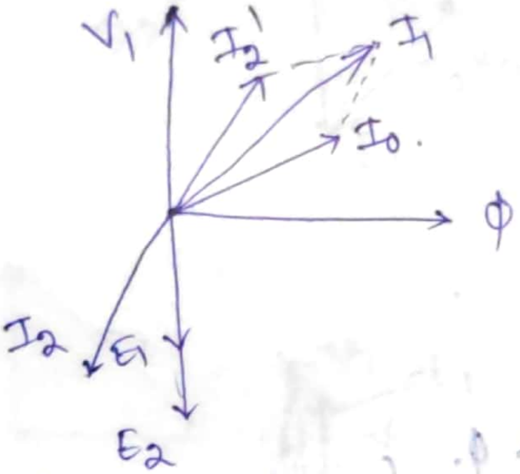
$$= -\phi_m\omega \cos\omega t.$$

$$= \phi_m \omega(-\cos\omega t)$$

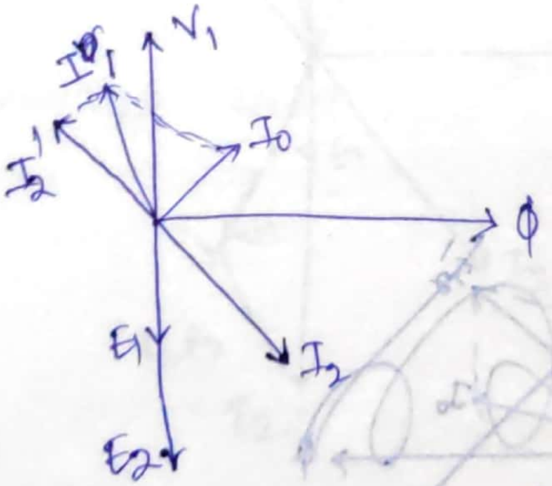
$$e = \phi_m\omega \sin(\omega t - 90)$$



(purely resistive load).

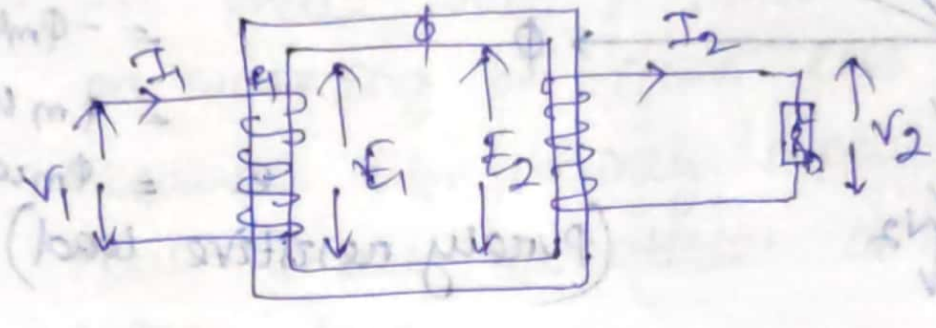


(Load is inductive)



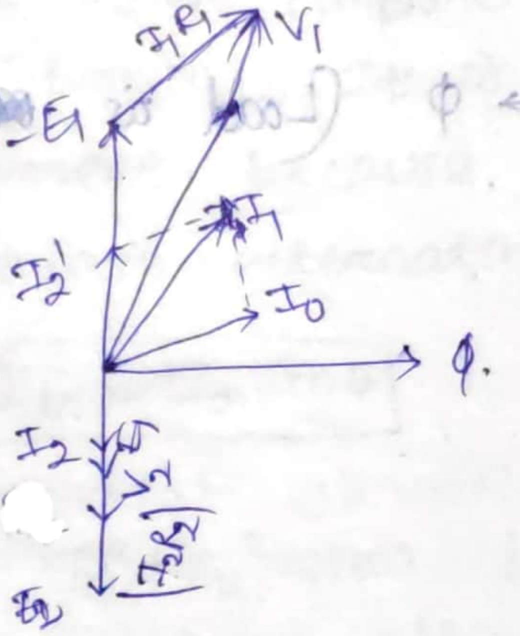
(load is capacitive).

Transformer with winding resistance :-



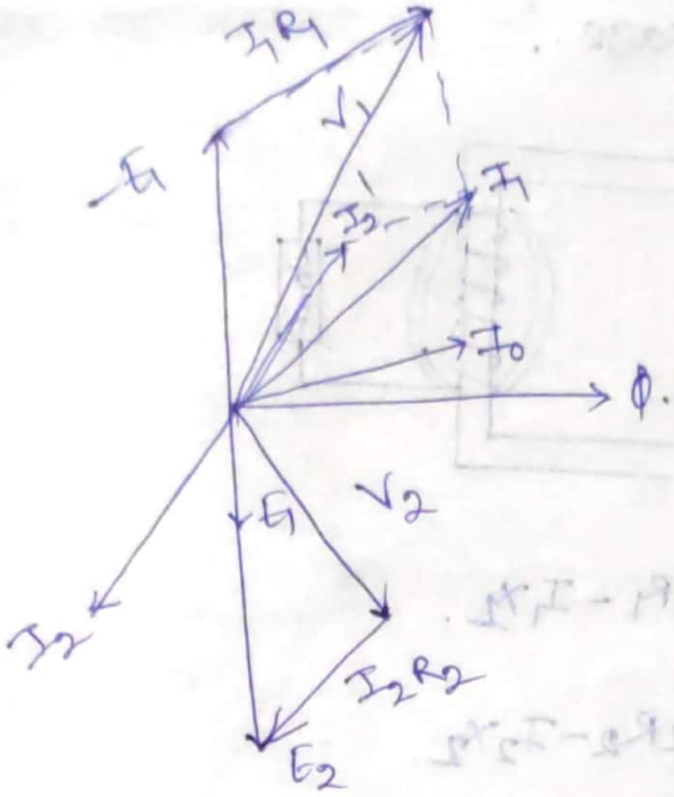
$E_1 = V_1 - I_1R_1$

$E_2 = V_2 + I_2R_2$.

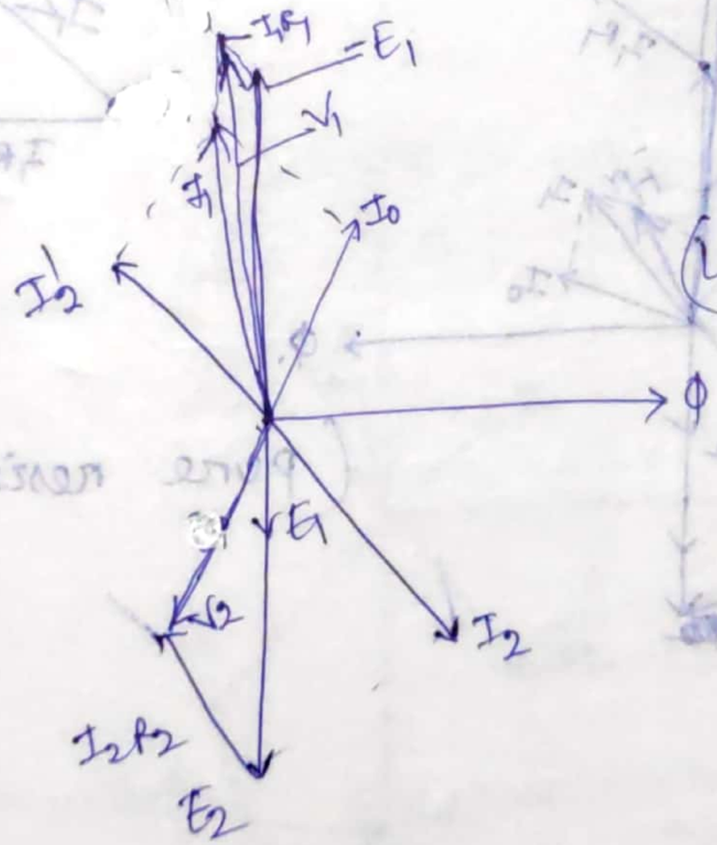


(Load is Resistive)

$(I_1 \parallel I_1R_1)$.

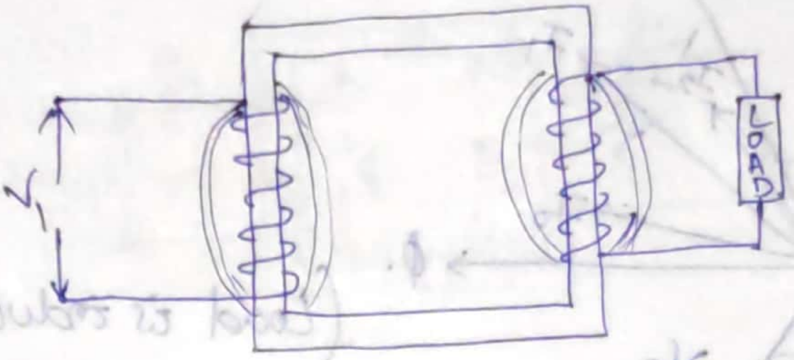


(Load is inductive)



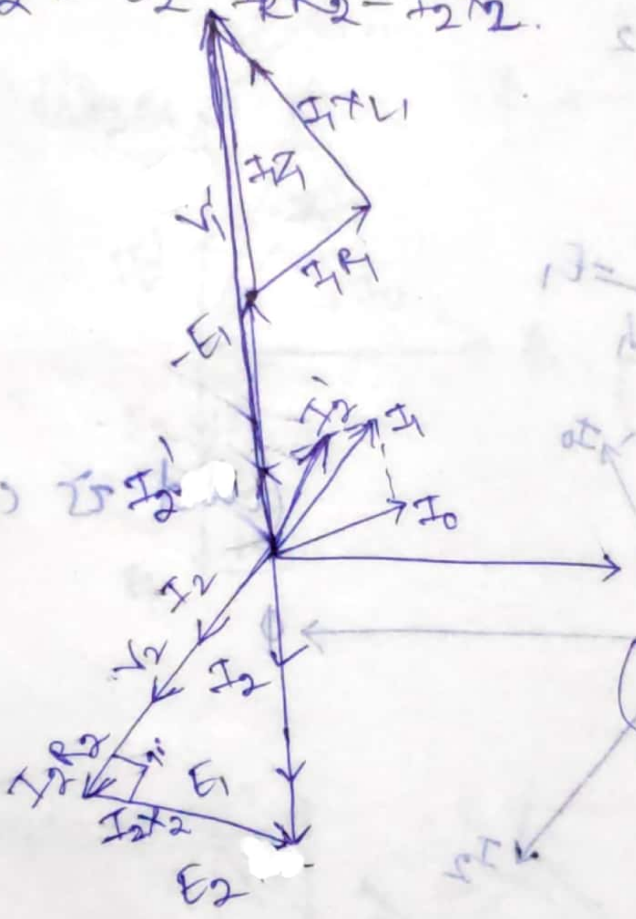
(Load is capacitive).

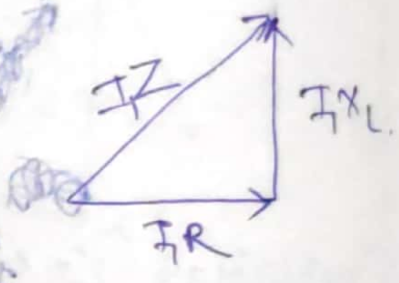
Magnetic Leakage :-



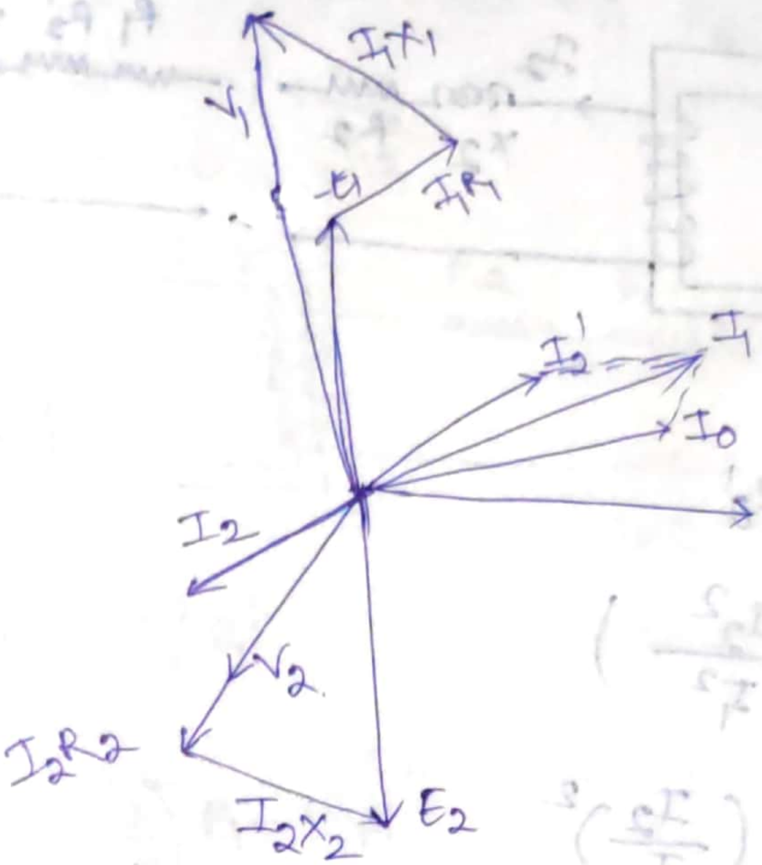
$$E_1 = V_1 - I_1R_1 - I_1X_1.$$

$$V_2 = E_2 - I_2R_2 - I_2X_2.$$

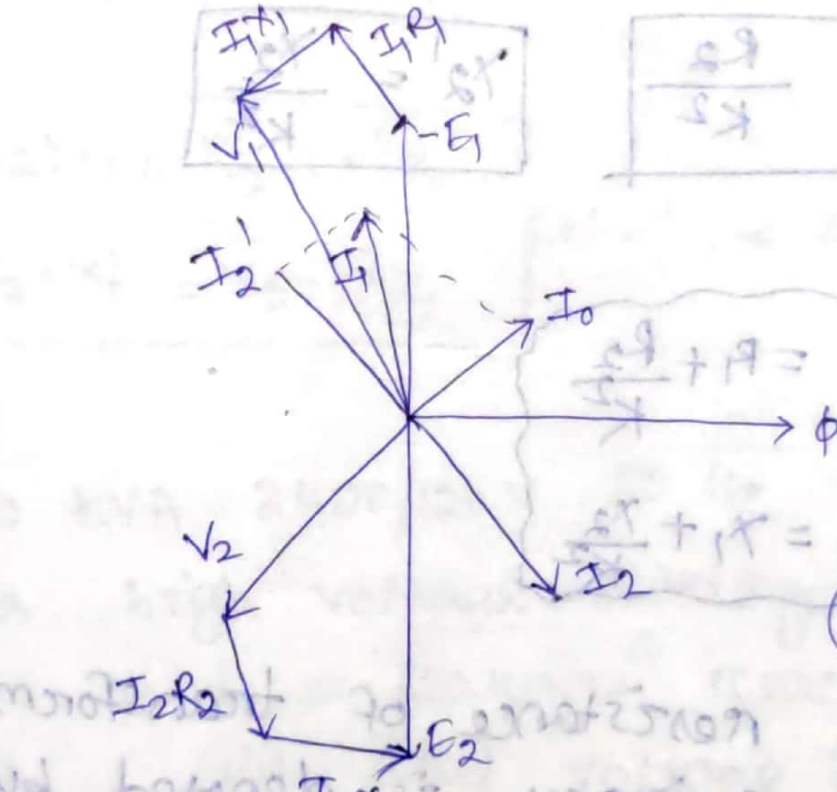




(Pure resistive load)

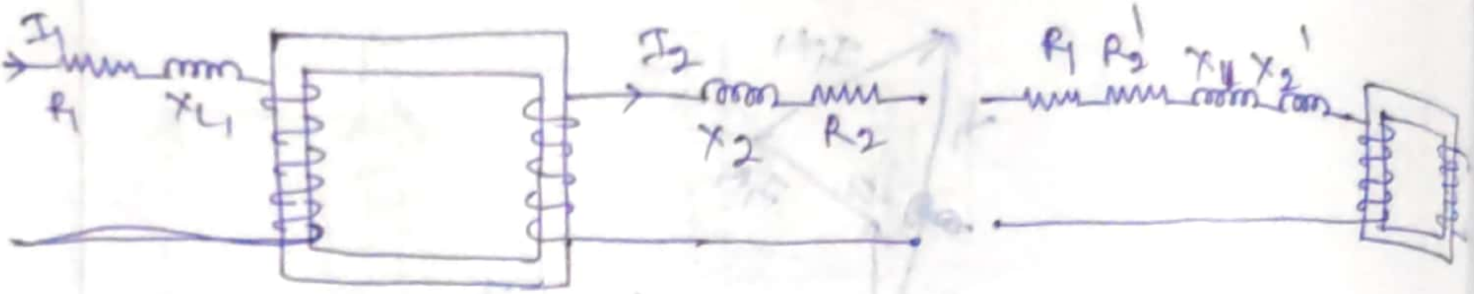


(RL Load)



(RC Load)

Equivalent resistance and reactance of T/F



$$I_2^2 R_2 = I_1^2 R_2'$$

$$\Rightarrow \frac{R_2'}{R_2} = \left(\frac{I_2^2}{I_1^2}\right)$$

$$\Rightarrow R_2' = R_2\left(\frac{I_2}{I_1}\right)^2$$

$$\Rightarrow R_2' = R_2\left(\frac{1}{K}\right)^2$$

$$\Rightarrow \boxed{R_2' = \frac{R_2}{K^2}} \qquad \boxed{X_2' = \frac{X_2}{K^2}}$$

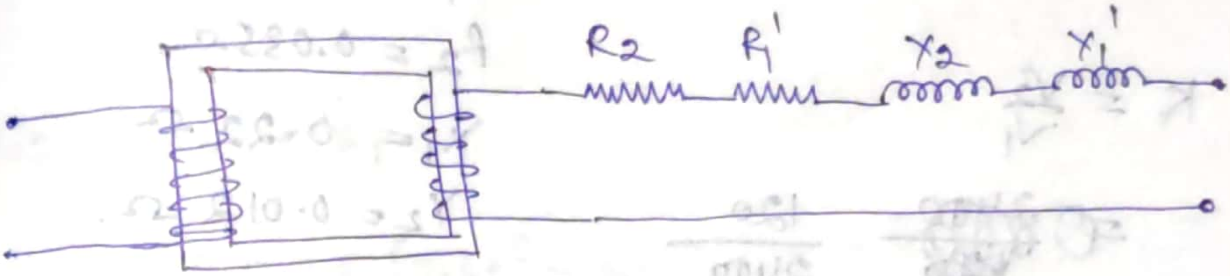
$$\boxed{\begin{aligned} R_{01} &= R_1 + R_2' = R_1 + \frac{R_2}{K^2} \\ X_{01} &= X_1 + X_2' = X_1 + \frac{X_2}{K^2} \end{aligned}}$$

equivalent resistance of transformer as refer to primary is denoted by R_{01}

$$R_{01} = R_1 + R_2' = R_1 + \frac{R_2}{K^2}$$

equivalent reactance of transformer is refer to Primary is denoted by X_{01}

$$X_{01} = X_1 + X_2' = X_1 + \frac{X_2}{K_2^2}.$$



$$I_1^2 R_1 = I_2^2 R_1'$$

$$\Rightarrow R_1' = \left(\frac{I_1}{I_2}\right)^2 R_1 = K^2 R_1$$

$$\boxed{R_1' = K^2 R_1} \qquad \boxed{X_1' = K^2 X_1}$$

$$\boxed{\begin{aligned} R_{02} &= R_2 + R_1' = R_2 + K^2 R_1 \\ X_{02} &= X_2 + X_1' = X_2 + K^2 X_1 \end{aligned}}$$

(1) A 30 KVA 2400/120 V 50 Hz transformer has a high voltage winding resistance of 0.1Ω and a leakage reactance of 0.22Ω. The low voltage winding resistance is 0.035Ω and the leakage reactance is 0.012Ω. Find the equivalent winding resistance, reactance, impedance refer

to

(1) High voltage side

(2) Low voltage side.

$R_1 = 0.1 \Omega$.

$R_2 = 0.035 \Omega$

$X_1 = 0.22 \Omega$

$X_2 = 0.012 \Omega$.

$$K = \frac{V_2}{V_1}$$

$$= \frac{120}{2400}$$

$$= 0.05$$

With reference to High voltage side.

$$R_{01} = R_1 + \frac{R_2}{K^2}$$

$$= 0.1 + \frac{0.035}{0.05^2}$$

$$= 14.1 \Omega$$

$$X_{01} = X_1 + \frac{X_2}{K^2}$$

$$= 0.22 + \frac{0.012}{0.05^2}$$

$$5.02$$

$$Z_{01} = \sqrt{14.1^2 + 5.02^2}$$

$$14.96 \Omega$$

with reference to low voltage side.

$R_{o2} = R_2 + R_1 K^2$

$= 0.035 + \{0.1 \times (0.05)^2\}$

$= 0.035$

$X_{o2} = X_2 + K^2 X_1$

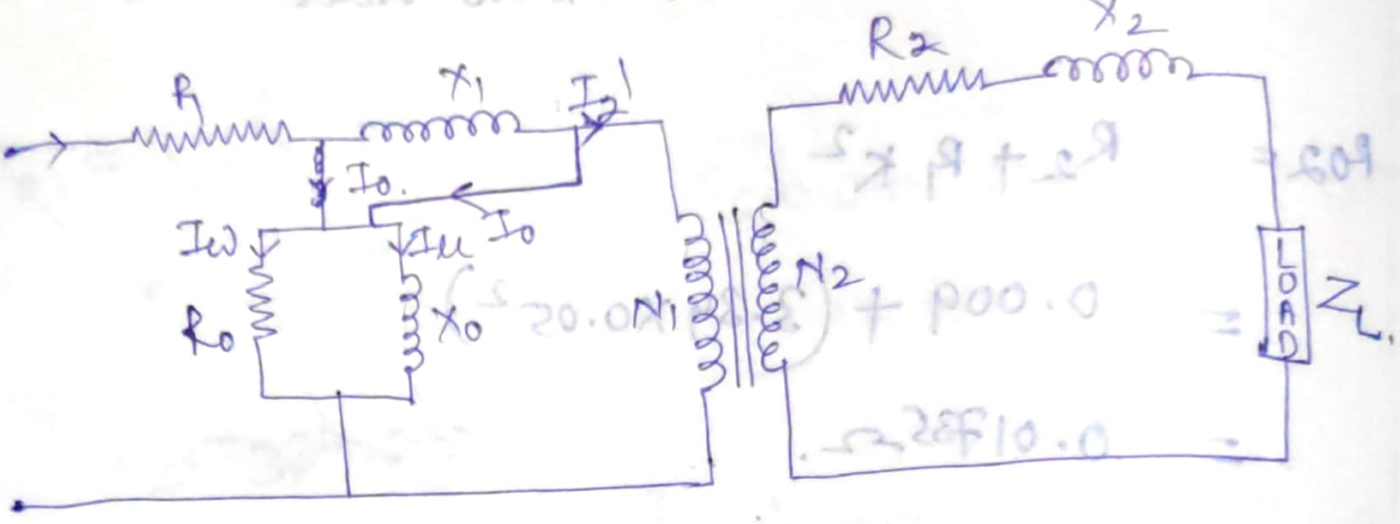
$= 0.012 + (0.05^2 \times 0.22)$

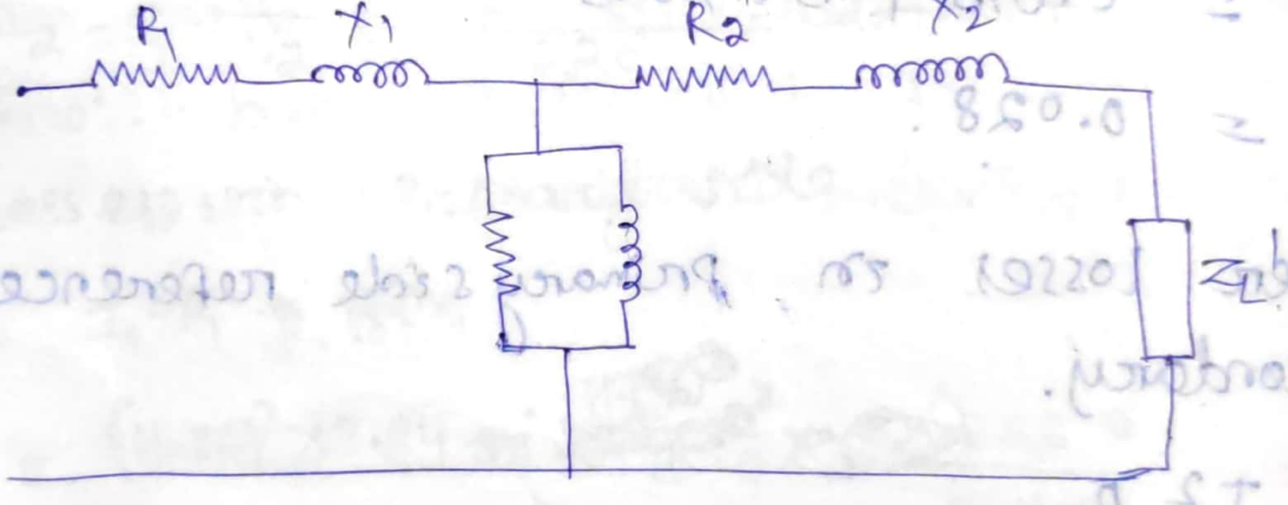
$= 0.012$

$Z_{o2} = \sqrt{0.035^2 + 0.012^2}$

$= 0.037 \ \Omega.$

Equivalent ckt diagram of Transformer :-

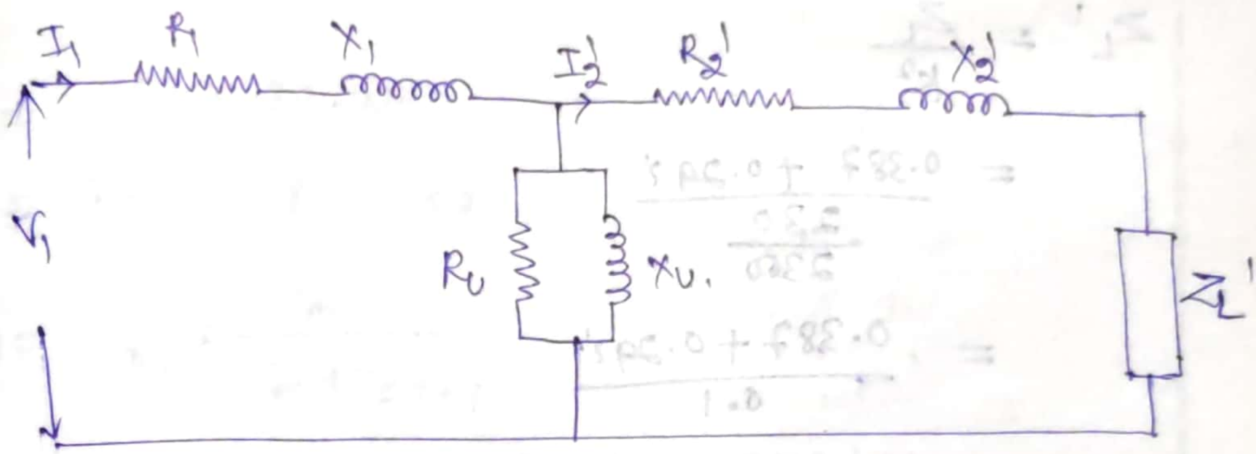




$$I_1 = I_0 + I_2'$$

$$R_2' = \frac{R_2}{K^2}, \quad X_2' = \frac{X_2}{K^2}, \quad Z_L' = \frac{Z_L}{K^2}$$

(1) A 2300/230V, 50Hz transformer has $R_1 = 0.286\,\Omega$, $X_1 = 0.73\,\Omega$, $R_2' = 0.319\,\Omega$, $X_2' = 0.73\,\Omega$, $R_0 = 250\,\Omega$, $X_0 = 1250\,\Omega$, The secondary load impedance $Z_L = 0.387 + 0.29j$. find input power, output power, primary copper loss, secondary copper loss and Efficiency.



$$Z_L' = \frac{Z_1}{K^2}$$

Primary cu. Loss $= I_2^2 R_1$

Secondary cu. Loss $= I_2' R_2'$

$$Z_{eq} = \{(Z_L' + Z_2') \parallel Z_m\} + Z_1$$

$$I_1 = \frac{V_1}{Z_{eq}}$$

$$I_2' = I_1 \times \frac{Z_m}{Z_m + Z_2' + Z_L'}$$

$Z_1 = R_1 + jX_1$ $\qquad Z_m = R_0 \parallel X_0 = \dfrac{R_0 \times X_0}{R_0 + X_0}$

$Z_2 = R_2 + jX_2$

$Z_1 = 0.286 + 0.73i$

$Z_2' = 0.319 + 0.73i$

$Z_m = 250 \parallel 1250i$

$= \frac{250 \times 1250i}{250 + 1250i}$

$= 240.38 + 48.07i$.

$Z_L' = \frac{Z_L}{K^2}$

$= \frac{0.387 + 0.29i}{\frac{230}{2300}}$

$= \frac{0.387 + 0.29i}{0.1}$

$= 38.7 + 29i$

$Z_{eq} = \{(Z_1' + Z_2') \parallel Z_m\} + Z_1$

$= (38.7 + 29i) + (0.319 + 0.73i) \parallel (240.38 + 48.07i) + 0.286 + 0.73i$

$= (39.019 + 29.73i) \parallel (240.38 + 48.07i) + 0.286 + 0.73i$

$= \frac{(39.019 + 29.73i) \times (240.38 + 48.07i)}{(39.019 + 29.73i) + (240.38 + 48.07i)} + (0.286 + 0.73i)$

$= (34.751 + 22.614i) + (0.286 + 0.73i)$

$= 35.03 + 23.34i$

$= 42.10 < 33.67$

$$I_1 = \frac{V_1}{Z_{eq}}$$

$$= \frac{2300}{35.03 + 23.34i}$$

$= 45.47 - 30.29i$

$= 54.64 \; ; \angle -33.67.$

$$I_2' = I_{21} \times \frac{Z_m}{Z_m + Z_2' + Z_l}$$

$$= 45.47 - 30.29i \times \frac{240.38 + 48.07i}{(240.38 + 48.07i) + (0.319 + 0.73i) + (38.7 + 29i)}$$

$= 45.47 - 30.29i \times 0.84 - 0.06i$

$= 38.32 - 33.13i$

$= 46.01 \, \angle -37.75$ A.

Primary copper loss $= I_1^2 R_L.$

$= (54.64)^2 \times 0.286$

$= 853.86.$

Secondary copper loss $= I_2'^2 R_2'$

$= (46.01)^2 \times 0.319$

$= 675.29.$

Input power $= V_1 I_1 \cos\phi$

$= 2300 \times 54.65 \times \cos(-33.68)$

$= 2300 \times 54.65 \times 0.83$

$= 104326.85$ watt.

$= 104.32$ KW.

O/P power $= (46.01)^2 \times 0.387$ watt

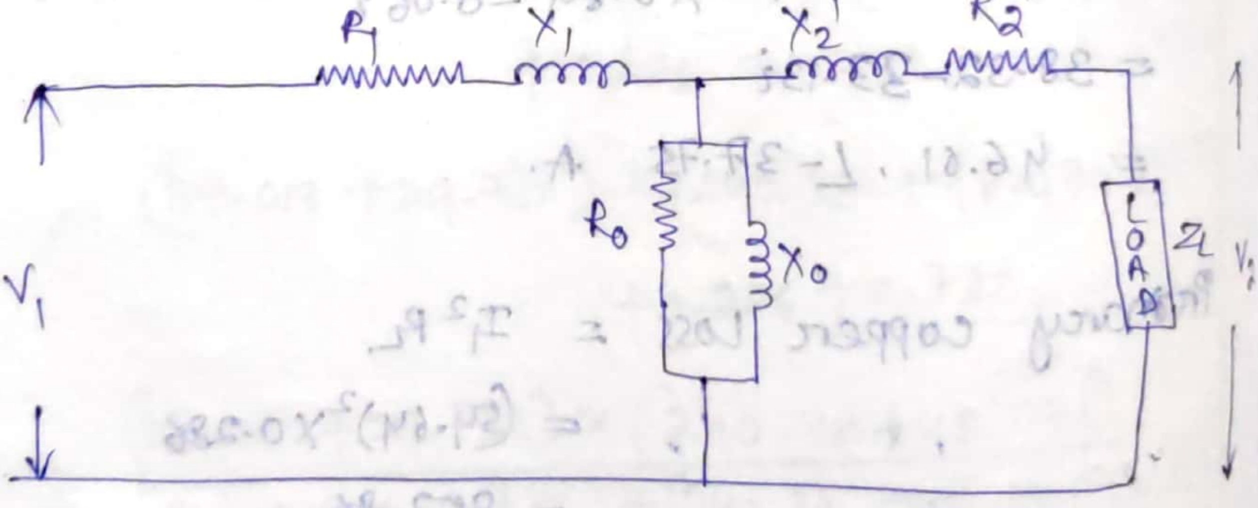
$= 0.81$. KW.

$$\eta = \frac{\text{O/P power}}{\text{i/P power}}$$

$$= \frac{0.81}{104.32}$$

$= 7.76 \times 10^{-3}$

Approximate voltage drop Transformer :-



$R_{eq} = R_1 + R_2' = R_{01}$

$X_{01} = X_1 + X_2'$

i/p voltage $= V_1$

drop $= I_1 R_{01}$

$= I_1 X_{01}$

o/p voltage $= V_2$

$V_2 = V_1 - I_1 R_{01} - I_1 X_{01}$

(1) A single phase T/f has 1000 turns on primary 200 turns on secondary, the no-load current is 2.5 Amp and at a p.f of 0.25 lagging. calculate the primary current and power factor when the secondary current is 250 A at a P.f 0.9 lagging.

Given data

$N_1 = 1000$

$N_2 = 200$

$I_0 = 2.50 A.$

$I_2' = 2.50 A.$

p.f = 0.25 lagging.

angle between I_2' & I_0

$\phi = 75.52 - 25.84$

$= 49.68°$

$\cos\phi = \cos(49.68°)$

$= 0.64$

$$I_1 = \sqrt{(I_2')^2 + I_0^2 + 2 I_2' I_0 \cos\phi}$$

$$= \sqrt{50^2 + 2.5^2 + 2 \cdot 250 \cdot 2.5 \cos(40.68)}.$$

$= 51.63$ Amp.

(2) A 1-ϕ T/F 400 primary and 1000 secondary turn the net cross-sectional area of the core is 600 m^2. If the primary winding is connected to a 50 Hz supply and 520V, calculate the peak value of flux density in the core. voltage induced in the secondary winding.

Given data

$N_1 = 400$

$N_2 = 1000$

$A = 60\ cm^2 = 0.6\ m^2$

$f = 50$

$v_1 = 520v.$

$E_2 = ?$ B_m

$E_2 = 4.44\ \phi N_2 f.$

$\Rightarrow E_2 = 4.44\ B_m A f N_2$

$K = 4.44\ B_m A f N_2$

$$K = \frac{N_2}{N_1} = \frac{V_2}{V_1}$$

$$= \frac{1000}{400} = \frac{V_2}{520} \Rightarrow V_2 = 1300$$

$\frac{E_1}{N_1} = 4.44\, \phi_m F$ $[V_1 = E_1]$

$\Rightarrow \phi_m = \frac{520}{400 \times 4.44 \times 50}$

$\Rightarrow \phi_m = 5.85 \times 10^{-3}$ wb.

$B_m = \frac{\phi_m}{A}$

$= \frac{5.85 \times 10^{-3}}{0.6}$

$= 9.75 \times 10^{-3}$ wb.

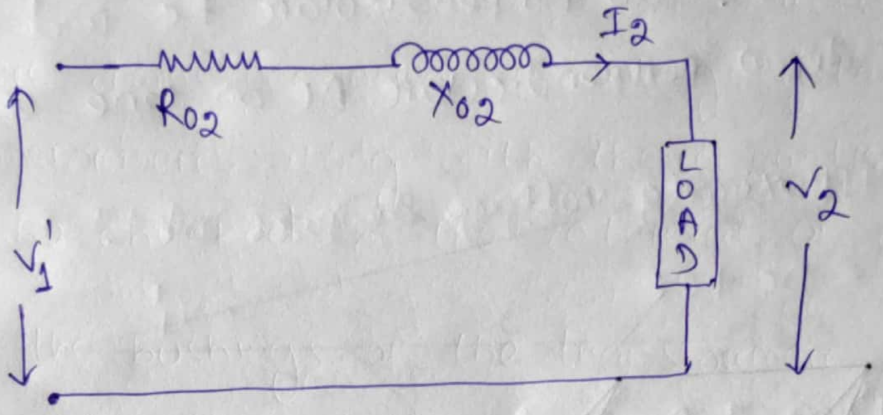
$E_2 = 4.44 \times f \times \phi_m \times N_2$

$= 4.44 \times 50 \times 5.85 \times 10^{-3} \times 1000$

$= 1298.7.$

Approximate voltage drop in a Transformer :-

Equivalent ckt of a transformer with reference to secondary is given below.



Here,

R_{02} = Equivalent resistance of the transformer with respect to secondary

X_{02} = Equivalent reactance of the transformer with respect to secondary.

Now, applying KVL on the ckt, we get

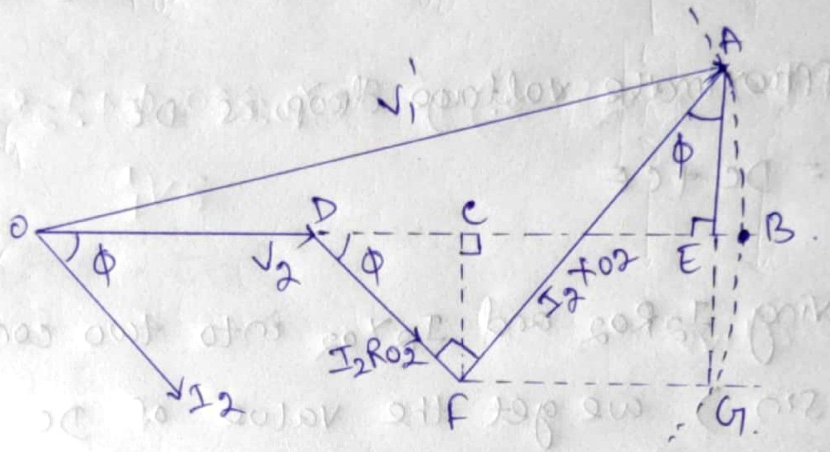
$$\vec{V_1'} = \vec{I_2} R_{02} + \vec{I_2} X_{02} + \vec{V_2}$$

$$= \vec{I_2} Z_{02} + \vec{V_2}$$

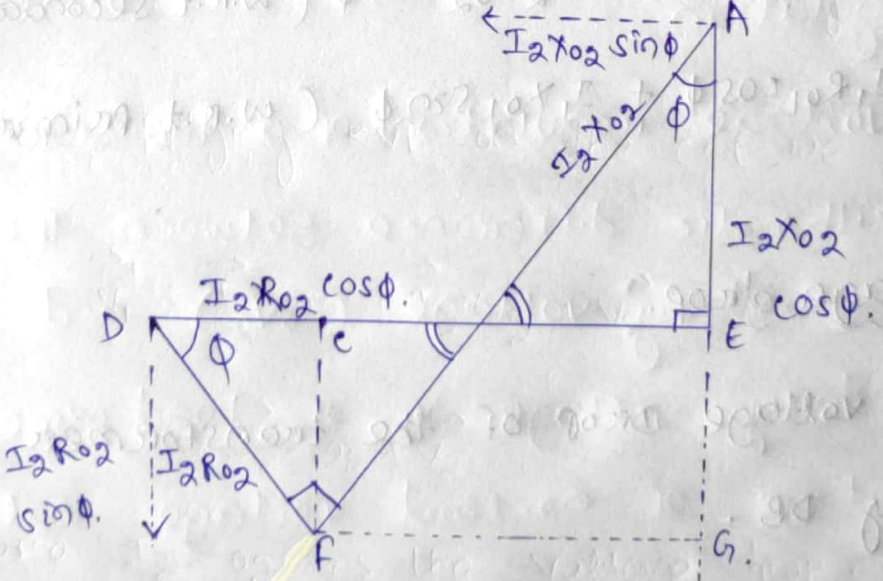
Here $I_2 Z_{02}$ is the voltage drop in the transformer.

If we represent the above equation the form of phasor diagram, we get figure as below.

Let, Load is inductive.



(fig-1)



(fig-2)

→ with 'o' as centre and OA as redius as arc is drawn.

→ Extend OD with dotted line which cut the arc at point B.

→ from point F, draw perpendicular FC and from point A draw perpendicular AE on line OB.

→ Here Approximate voltage drop is DE.

DE = DC + CE

→ By resolving I_2R_{02} and I_2X_{02} into two component (cos and sin) we get the value of DC and CE

→ $DE = I_2R_{02}\cos\phi + I_2X_{02}\sin\phi$

Approximate voltage drop.

$= I_2R_{02}\cos\phi + I_2X_{02}\sin\phi$ (w.r.t secondary)

$= I_1R_{01}\cos\phi + I_1X_{01}\sin\phi$ (w.r.t primary).

Exact voltage drop :-

Exact voltage Drop of the transformer is given by DB.

DB = DC + CB.

In Δ AOB in Fig 1,

$$AE^2 = OA^2 - OB^2$$

$$= (OA+OB)(OA-OB)$$

$$= 2OA \times (OE+EB-OB).$$

$$= 2OA \times EB$$

$$\Rightarrow EB = \frac{AE^2}{2\,OA}.$$

$$EB = \frac{(AG - EG)^2}{2\,OA}.$$

$$= \frac{(I_2X_{02}\cos\phi - I_2R_{02}\sin\phi.)^2}{2V_1'}$$

Exact voltage drop = DB.

= DE + EB.

= Approximate voltage drop + EB.

$$=(I_2R_{02}\cos\phi + I_2X_{02}\sin\phi.).$$

$$+ \frac{(I_2X_{02}\cos\phi - I_2R_{02}\sin\phi.)^2}{2V_1'}$$

Load in capacitive.

Approximate voltage drop

$$= I_2 R_{02} \cos\phi - I_2 X_{02} \sin\phi.$$

Exact voltage drop

$$= \left(I_2 R_{02} \cos\phi - I_2 X_{02} \sin\phi.\right) + \frac{\left(I_2 X_{02} \cos\phi + I_2 R_{02} \sin\phi.\right)}{2V_1'}$$

Load in Resistive :-

Exact voltage drop and approximate voltage drop $= I_2 R_{02}$.

Voltage regulation :-

Voltage regulation of a transformer is the arithmatic difference between the no-load secondary voltage ($_0V_2$) and the secondary voltage 'V_2' on load expressed as percentage of no-load voltage that is

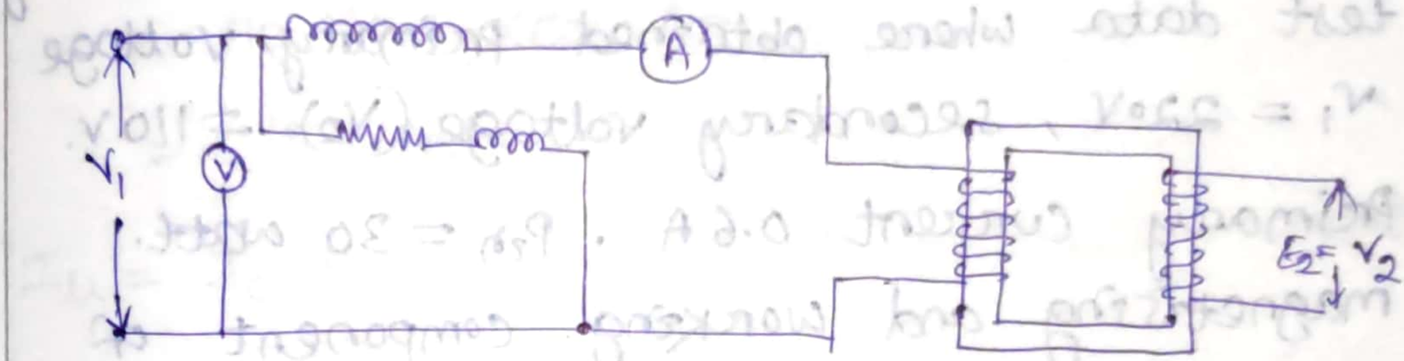
$$\% \text{ Voltage Regulation} = \frac{_0V_2 - V_2}{_0V_2} \times 100$$

$_0V_2$ = No-load secondary voltage.

V_2 = secondary voltage on load.

$$_0V_2 - V_2 = I_2 R_{02} \cos\phi_2 \pm I_2 X_{02} \sin\phi_2$$

open circuit Test of T/F



$W = P_{in}$ $\qquad$ $p = V \underbrace{I_0 \cos\phi}_{I_w}.$

$V = V_1$

$A = I_0$

$W =$ Iron Loss + Primary cu. Loss.

Primary cu. Loss $= I_0^2 R_L$.

$\boxed{\text{Iron Loss} = W - I_0^2 R_L}$

$\boxed{P = V_1 I_0 \cos\phi.}$ ✓

$$\Rightarrow \cos\phi = \frac{P_{in}}{V_1 I_0}$$

$$\boxed{\phi = \cos^{-1}\left(\frac{P_{in}}{V_1 I_0}\right)}$$

$$\boxed{I_\mu = I_0 \sin\phi.}$$

$$\boxed{I_W = I_0 \cos\phi.}$$

$$\boxed{R_0 = \frac{V_1}{I_W}} \quad \boxed{X_0 = \frac{V_1}{I_\mu}}$$

(1) In No-load text of 1-ϕ T/F the following test data where obtained primary voltage $V_1 = 220V$, secondary voltage $(V_2) = 110V$. Primary current 0.6 A . $P_{in} = 30$ watt. magnetising and working component of No-load current Iron loss R_0 and $X_0 = ?$ Resistance of primary winding $= 0.6\Omega$

Given data

$V_1 = 220V.$

$V_2 = 110V.$

$P_{in} = 30$ watt

$I_0 = 0.5A.$

$R_1 = 0.6\Omega$

$P = VI\cos\phi = ?$

$\phi = \cos^{-1}\left(\frac{P}{VI_0}\right)$

$= \cos^{-1}\left(\frac{30}{220 \times 0.5}\right)$.

$= 74.17$.

$P_1 = V_1 I_0 \cos\phi$.

$= 220 \times 0.5 \times \cos(74.17)$

$=$ 30 watt.

$P_2 = V_2 I_0 \cos\phi$.

$= 110 \times 0.5 \times \cos(74.17)$

$=$ 15 watt.

$I_\mu = I_0 \sin\phi$.

$= 0.5 \times \sin(74.17)$.

$= 0.48$

$I_W = I_0 \cos\phi$.

$= 0.5 \times \cos(74.17)$

$= 0.13$

$R_0 = \frac{V_1}{I_W}$

$= \frac{220}{0.13} = 1692.30\ \Omega = 1.69\ k\Omega$

$$X_0 = \frac{V_1}{I_\mu}$$

$$= \frac{220}{0.48}$$

$= 458.83\ \Omega$

$= 0.45\ k\Omega$

Primary Iron Loss $= W - I_0^2 R$

$= 30 - 0.5^2 \times 0.6$

$= 29.85$

Copper Loss $= I_0^2 R_1$

$= (0.5)^2 \times 0.6$

$= 0.15$

Short circuit test of T/f :-

Total loss.

W = Total cu. Loss + Iron Loss.

$\Rightarrow W =$ total cu. Loss.

$\Rightarrow W = I_1^2 R_{01}$

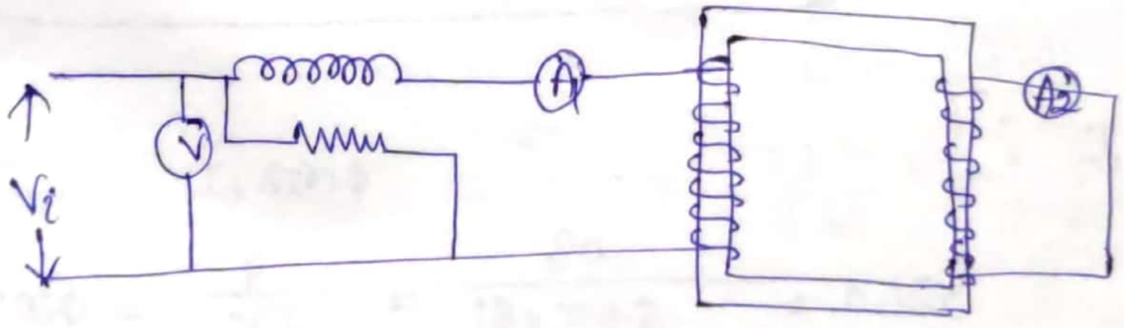
$Z_{01} = R_{01} + jX_{01}$

$= (R_1 + R_2') + j(X_1 - X_2')$.

$$\boxed{R_{01} = \frac{W}{I_1^2}}$$

$$\boxed{Z_{01} = \frac{V_{se}}{I_1}}$$

Total iron loss is neglated as the input voltage is very small.



with reference to primary

$V_1 = V_{se}$

$Z_1 = \frac{V_{se}}{I_1}$

$Z_{01} = R_{01} + j X_{01}$

$= (R_1 + R_2') + (j X_1 + X_2')$

$\boxed{Z_{01} = \frac{V_{se}}{I_1}}$

$\boxed{R_{01} = \frac{W}{I_1^2}}$ $X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

(1) The instrument readings obtain from open and short ckt test on 10KVA, 450/120 V., 50Hz Transformer.

Open ckt Test : $V_1 = 120V$

$I_1 = 4.2A$

$W_1 = 80W$.

Short ckt Test : $V_1 = 9.65V$

$I_1 = 22.2A$.

$W_1 = 120W$.

calculate equivalent impedance, reactance, with respect to primary

(ii) Efficiency for an 80% lagging P.F Load.

with reference to primary

I_1

$R_{01} = R_1 + R_2'$

copper Loss $= I_1^2 (R_1 + R_2')$.

with reference to secondary

I_2

$R_{02} = R_2 + R_1'$

copper Loss $= I_2^2 (R_2 + R_1')$.

$I_\mu = I_0 \sin\phi$ $[\because I_0 = I_1]$.

$\cos\phi = \frac{P}{VI} = \frac{80}{120 \times 4.2} = 0.158$

$\phi = \cos^{-1}(0.158) = 80.90$

$\sin\phi = \sin(80.90) = 0.98$

$I_\mu = I_0 \sin\phi = 4.2 \times 0.98 = 4.116$ A.

$I_W = I_0 \cos\phi$

$= 4.2 \times 0.158$

$= 0.66 A.$

$R_0 = \frac{V_1}{I_W}$

$= \frac{120}{0.66}$

$= 181.81 \Omega$

$X_0 = \frac{V_1}{I_\mu}$

$= \frac{120}{4.11}$

$= 29.19 \Omega$

$R_{01} = \frac{W}{I_1^2}$

$= \frac{120}{22.2^2}$

$= 0.24 \Omega$

$Z_{01} = \frac{V_{sc}}{I_1.} = \frac{9.65}{22.2} = 0.43 \Omega.$

$Z_{01}^2 = R_{01}^2 + X_{01}^2$

$\Rightarrow X_{01} = \sqrt{Z_{01}^2 - R_{01}^2}$

$= \sqrt{(0.43)^2 - (0.24)^2}$

$= 0.356 \Omega$

(ii) $\cos\phi = 0.8$ (80% lagging).

Total loss = O.C loss + S.C loss.

$= 80 + 120$

$= 200$ W.

O/P power $= VI\cos\phi$.

$= 10 \times 10^3 \times 0.8$

$= 8000$ W.

$$\eta = \frac{\text{O/P power}}{\text{O/P + losses}} \times 100$$

$$= \frac{8000}{8000+200} \times 100$$

$= 97.56$ %.

Scanned with CamScanner

core type	Shell type
(i) It has two limb or Arm.	(i) It has 3 limb or Arm.
(ii) It has winding in both arm.	(ii) only middle arm has winding.
(iii) It has one path for the flux.	(iii) It has two path for flux.
(iv) maximum leakage flux.	(iv) less leakage flux.
(v) more losses	(v) less losses
(vi) less output	(vi) more output.
(vii) maintainance is simple	(viii) maintanance is complex.
(viii) It is used for high voltage transformer.	(viii) It is used for low and medium voltage transformer.

Efficiency of a Transformer :-

The efficiency of a T/F at a particular load and power factor is defined as o/p power divided i/p power being measured in the same unit.

$$\eta = \frac{o/p}{i/p} = \frac{o/p}{o/p + losses}$$

$$= \frac{i/p - losses}{i/p}$$

Condition for maximum efficiency :-

$i/p = V_1 I_1 \cos\phi$

$Losses = W_i + W_c$

with reference to primary

$W_c = I_1^2 R_{01}$

$$\eta = \frac{I_1 V_1 \cos\phi - (W_i + I_1^2 R_{01})}{I_1 V_1 \cos\phi} \quad \left\{ \frac{i/p - Loss}{i/p} \right\}$$

$$= 1 - \left(\frac{W_i + I_1^2 R_{01}}{I_1 V_1 \cos\phi} \right)$$

$$= 1 - \frac{W_i}{I_1 V_1 \cos\phi} - \frac{I_1^2 R_{01}}{I_1 V_1 \cos\phi}.$$

for maximum efficiency.

$$\frac{d}{dI}(\eta) = 0.$$

$$\Rightarrow 0 + \frac{W_i}{I_1^2 V \cos\phi} - \frac{R_{01}}{V_1 \cos\phi} = 0$$

$$\Rightarrow \frac{W_i}{I_1^2 V_1 \cos\phi} = \frac{R_{01}}{V_1 \cos\phi}.$$

$$\Rightarrow \frac{W_i}{I_1^2} = R_{01}$$

$$\Rightarrow \boxed{W_i = I_1^2 R_{01}}$$

for maximum efficiency $\boxed{W_i = W_c}$

ALL day efficiency :-

(i) The ordinary or commericial efficiency of the transformer is given by the ratio $\frac{\text{o/p in watt}}{\text{i/p in watt}}$.

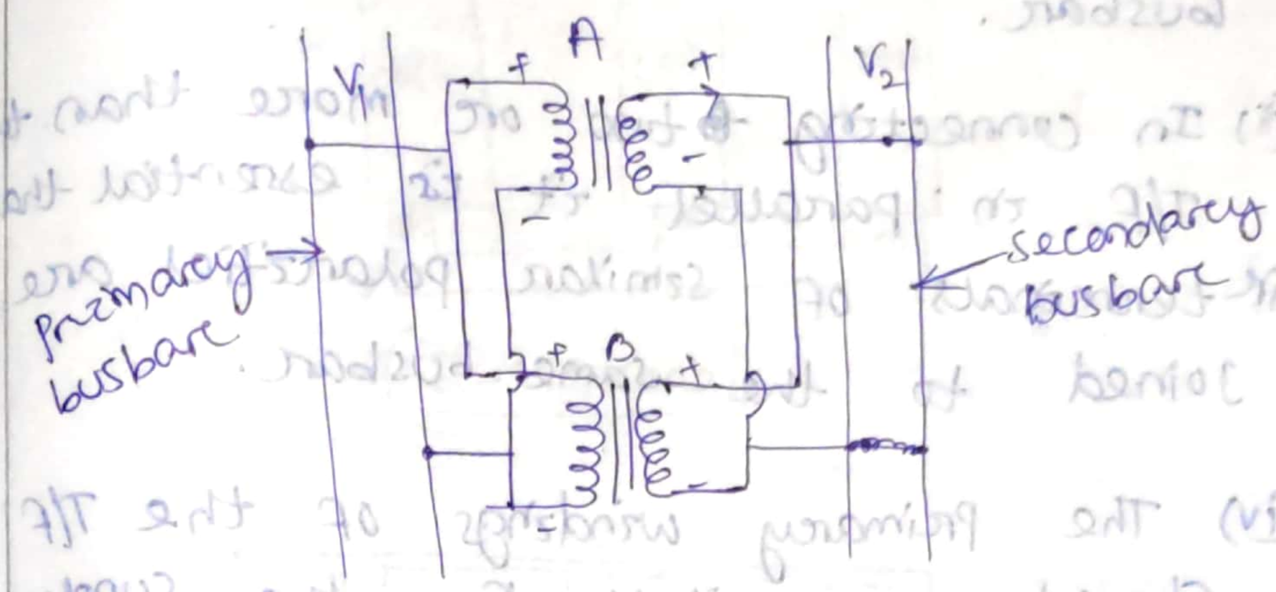
(ii) But There are certain types of T/F whose performance can not be judged by this efficiency.

(iii) for example distribution T/f have their p/m winding energized all the 24 hours.

(iv) But Load connected in the secondary changes through out the day, therefore in this case all day efficiency of the T/f is calculated.

$$\eta_{all\ day} = \frac{o/p \text{ in KWh}}{i/p \text{ in KWh}} \quad (\text{for 24 hour}).$$

parallel operation of T/F :-



condition for parallel operation.

(i) polarity should be same

(ii) percentang of impedance should be same.

(iii) Rating should be same.

(i) If load connected to a T/F increases beyond its rating, a second T/F may be connected in parallel with it to supply the extra load.

(ii) The P/m windings are connected to the supply busbar or P/m busbar and secondary windings are connected to the load busbar or secondary busbar.

(iii) In connecting two or more than tw T/F in parallel it is essential that their terminals of similar polarities are joined to the same busbar.

(iv) The primary windings of the T/F should be suitable for the supply voltage and frequency.

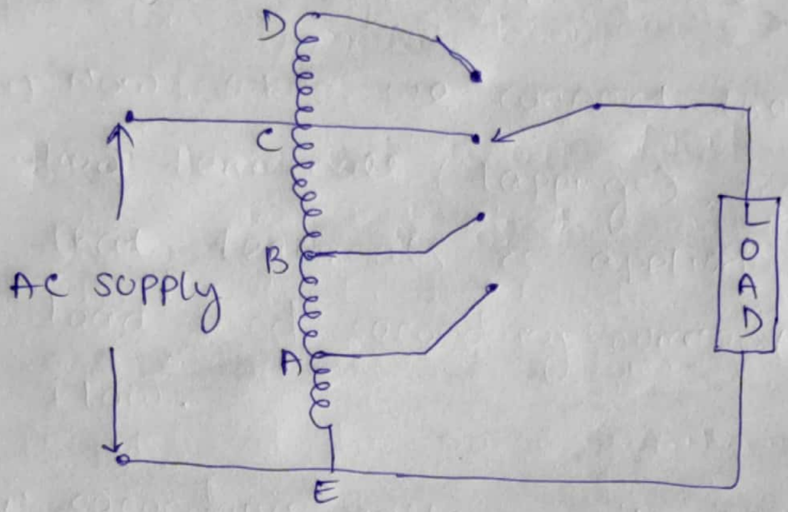
(v) The voltage rating of both P/m and secondary should be identical. In other words the T/F should have same transformation ratio

(vi) The percentage impedance of the T/F should be equal in magnitude to avoid circulating current and operation at different power factor.

Chapter-4 Auto Transformer.

Auto Transformer :-

An auto transformer is an electrical transformer having one winding with more than two terminals.



Advantages :-

(i) They are smaller in size.

(ii) cheap in cost.

(iii) low leakage reactance.

(iv) Low exciting current.

construction :-

(i) An auto transformer consists of a single copper wire, which is common in both primary as well as secondary circuit.

(ii) The copper wire is wounded on a laminated silicon steel core with more than two tapping.

Both primary and secondary circuit share the same neutral point.

(iii) The above figure shows ckt diagram of a Auto transformer. we can see that variable turns on the secondary can be obtained by tapping of the winding.

(iv) Here the primary and secondary circuits are connected electrically as well as magnetically.

(v) The same Transformer can be used as step down or step-up transformer due to presence of tapping. for example, if the load is connected to tapping 'D', then the transformer will act as step-up Transformer. Because, here primary turns are 'CE' where as secondary turns are 'DE'. we can clearly see that CE < DE. so secondary voltage will be greater than primary. But if load is connected to tapping B or A, then it will act as a step down transformer.

Working principle of Auto transformer :-

(i) It's working principle and operation is similar to a two winding transformer.

(ii) when supply is given to the primary circuit

AC current flows through the winding. Therefore an alternating flux is created around the conductor or winding.

(iii) According to Faraday's law of electromagnetic induction emf will induce in the coil.

(iv) Now, when we connect the load between two terminals (tappings), induced emf between that terminals is applied across the load and secondary current starts to flow.

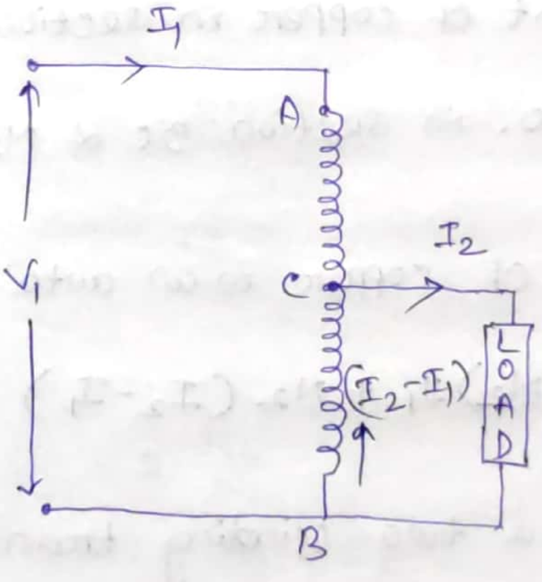
(v) secondary voltage will depends on the number of turns and no.of turns depends upon tapping on winding.

Comparision between two winding T/F and Auto Transformer :-

Two winding T/F.	Auto T/F.
(i) It has two winding i.e primary and secondary.	(i) It has one winding only.
(ii) primary and secondary circuits are electrically separated but	(ii) primary and secondary circuits are connected electrically

magnetically coupled	as well as magnetically.
(iii) size is large	(iii) Size is small.
(iv) copper requirement is more	(iv) copper requirement is less.
(v) cost is more.	(v) cost is less.
(vi) Losses are more and efficiency is less.	(vi) Losses are Less and efficiency is more.
(vii) Poor voltage regulation.	(vii) Better voltage regulation.
(viii) output is constant.	(viii) output is variable.

Saving of copper in an Auto Transformer :-



Here AB is the primary winding having N_1 turns and BC is secondary winding having N_2 no. of turns. so,

$$\frac{V_2}{V_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K.$$

current in section BC is vector difference of I_2 and I_1. As it is a step down transformer $V_2 < V_1$ and $I_2 > I_1$. so current in section 'BC' is $I_2 - I_1$

we know that weight of copper is proportional to the length and area of cross-section of the conductors. Again length is proportional to no. of turns and cross-sectional area depends on current. Hence weight is proportional to the product of current and number of turns.

So, weight of copper in section $AC \propto (N_1 - N_2) I_1$

weight of cu. in section $BC \propto N_2 (I_2 - I_1)$.

$\therefore$ Total weight of copper in an auto transformer

$$= (N_1 - N_2) I_1 + N_2 (I_2 - I_1).$$

Let, we take a two winding transformer.

Here weight of copper in primary $\propto N_1 I_1$

Similarly weight of copper in secondary $\propto N_2 I_2$

∴ Total weight of copper in a two winding

$$= N_1 I_1 + N_2 I_2.$$

$$\frac{\text{weight of cu. in auto T/F.}}{\text{weight of cu. in two winding Transformer}} = \frac{(N_1 - N_2) I_1 + N_2 (I_2 - I_1)}{N_1 I_1 + N_2 I_2}$$

$$\Rightarrow \frac{W_a}{W_0} = \frac{N_1 I_1 - N_2 I_1 + N_2 I_2 - N_2 I_1}{N_1 I_1 + N_2 I_2}$$

$$\Rightarrow \frac{W_a}{W_0} = \frac{N_1 I_1 + N_2 I_2 - N_2 I_1 - N_2 I_1}{N_1 I_1 + N_2 I_2}$$

$$= 1 - \frac{N_2 I_1 - N_2 I_1}{N_1 I_1 + N_2 I_2}$$

$$= 1 - \frac{\frac{2 N_2 I_1}{N_1 I_1}}{\frac{N_1 I_1}{N_1 I_1} + \frac{N_2 I_2}{N_1 I_1}}$$ [dividing by $N_1 I_1$].

$$= 1 - \frac{2 \frac{N_2}{N_1}}{1 + \frac{N_2}{N_1} \times \frac{I_2}{I_1}}$$

$$= 1 - \frac{2 \times K}{1 + \frac{1}{K} \times K}$$

$$\Rightarrow \frac{W_a}{W_0} = 1 - \frac{2K}{2}$$

$$\Rightarrow \frac{W_a}{W_0} = 1-K.$$

$$\Rightarrow W_a = (1-K)\,W_0$$

$$\text{Saving of copper} = W_0 - W_a$$
$$= W_0 - (1-K)W_0$$
$$= W_0(1-1+K).$$
$$= K W_0.$$

Saving = K × weight of ordinary or two winding transformer.

Here, power transfered inductively $=(1-K)\,P_{i/p}$.

power transfered conductively $= K\,P_{i/p}$.

Uses of Auto Transformer :-

(i) To adjust Ac supply voltage. By using it we can vary the Ac voltage (voltage - regulator).

(ii) It is used as a starter for squirrel cage induction motor.

(iii) It is used in power transmission and distribution system.

(iv) It is also used in audio system and railways.

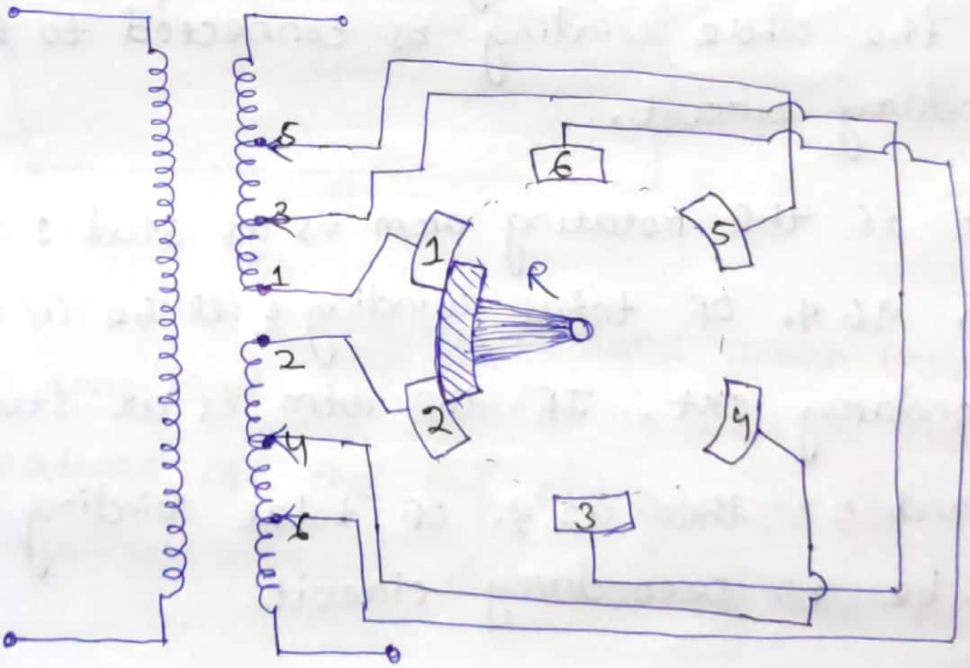
Tap changer :-

Mechanism used to change the tapping of a transformer is called tap changer. Tap changer is mainly classified in to two types.

(1) Off Load tap changer.

(2) ON-Load Tap changer.

1. Off Load Tap changer :-



(i) Here tap changing is done when the transformer is disconnected from the main supply. This tap changing is usually done manually.

(ii) The above fig. shows on off-load tap changer. The secondary winding is tapped from six location.

(iii) This tappings are connected to six studs arranged along a periphery of a cycle.

(iv) The rotable arm R can be rotated by a hand wheel mounted outside the transformer tank.

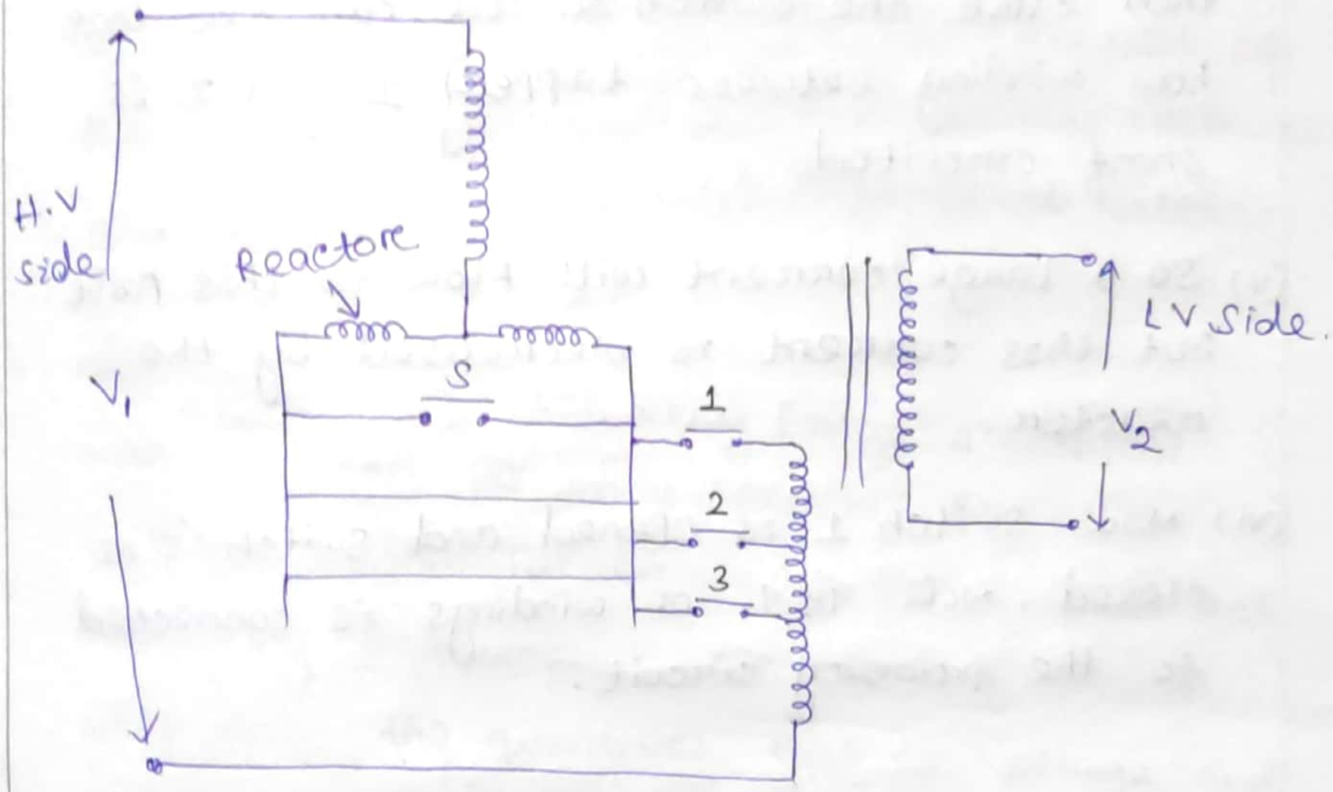
(v) Let, the tappings are at an interval of 2%. If position of rotating arm is at stud 1 and 2, the whole winding is connected to the secondary circuit.

(vi) But if the rotating arm is at stud 1 and 6 then 96% of total winding will be in the secondary ckt. If the arm is at stud 6 and 5, then 92% of total winding will be in secondary circuit.

(vii) In the process by moving the rotating arm, no. of turns in the secondary winding changes. As a result secondary voltage also changes.

(iii) This tap changer is only used in off condition of transformer. If we use it in on condition, then huge spark will produce.

ON-Load Tap changer :-



(i) Here Tap changing is done, when transformer is connected to source as well as load. Main feature of the tap changer is to change tapping without discontinuing the power supply.

(ii) In this type of tap changer a centre tapped reactor provided to prevent short circuit of the tap winding. During normal operation switch 's' remainly closed.

(iii) Let initially switch of tapping one is closed. So whole windings is connected. Now if I required less voltage, the tappers 2 is to be connected.

(iv) for this we have to first open the switch 's', then close the switch 2. we can see that how winding between tapping 1 and 2 is short circuited.

(v) So a large current will flow to this part. But this current is decreased by the reactor.

(vi) Now switch 1 is opened and switch 's' is closed. Now 98% of windings is connected to the primary circuit.

(chapter-5) Instrument Transformers

Instrument transformers :-

(i) Instrument transformers are used in AC system for measurement of electrical quantities like current, voltage, power, energy etc.

(ii) Generally measuring instruments are of low ratings. so by using this instruments we can not measure high electrical quantities. It is very costly to design the measuring instrument for measurement of such high level voltage and current.

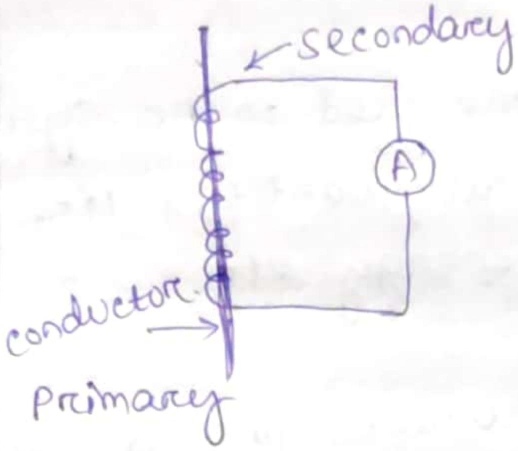
(iii) measurement of such very large electrical quantities can be made possible by using instrument transformer with these small rating measuring instruments. Instrument transformer step down the quantities that is voltage and current. so that they can be measured by low rating instruments.

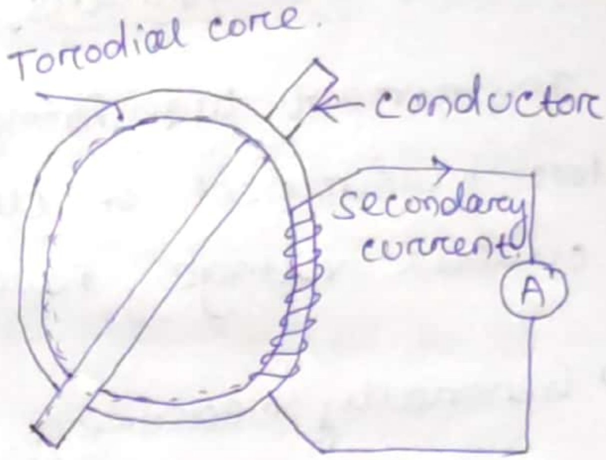
(iv) Mainly there are two types of instrument transformer

(1) current transformer (C.T).

② Potential transformer (P.T).

Current Transformer :-





(i) Current transformer is used to step up the voltage or step down the current so that this stepped down current can be easily measured by measuring instruments.

(ii) Primary of C.T is having very few turns and secondary has large no. of turns. Secondary winding is connected to measuring instrument.

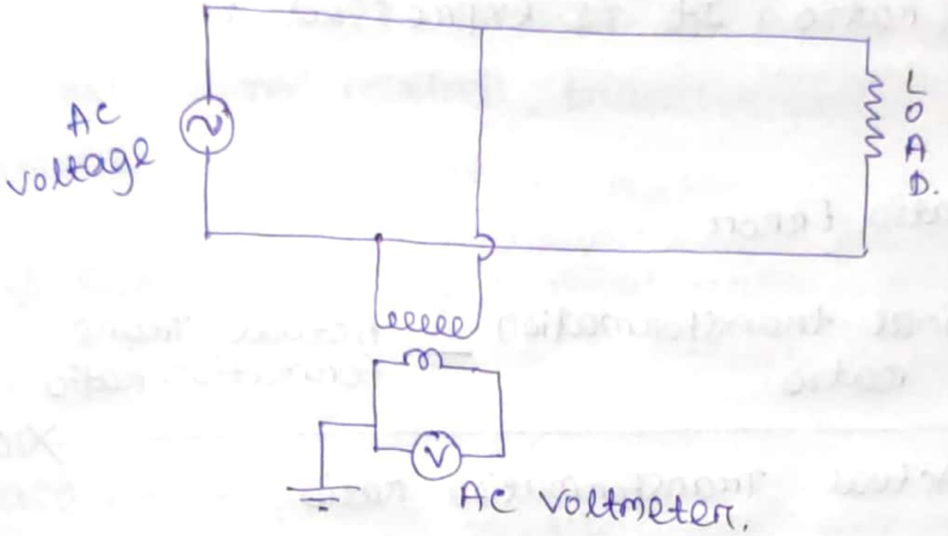
(iii) Current transformers are often constructed by passing a single primary turn (either an insulated cable or an uninsulated busbar) through a well insulated ring shaped (torodial) core wound with many no. of turns.

(iv) One terminal of the secondary is earthed to avoid the chance of insulation breakdown and also protect the operatore against high voltage

(v) Turns ratio of the transformer is

$$\text{Turns ratio} = \frac{N_p}{N_s} = \frac{I_s}{I_p} = \frac{V_p}{V_s}.$$

Potential Transformer (PT) :-



(i) Potential transformers are also known as voltage transformers and they are basically step down transformers.

(ii) They step down the voltage of high magnitude to a lowere value. which can be measured with standard measuring instrument.

(iii) These transformers have large number of primary turns and less number of secondary turns.

(iv) secondary winding is connected to a voltmeter.

(v) one terminal of the secondary is connected to earth for safety of operator.

Ratio Error of C.T. :-

Ratio error of CT is defined as the per unit deviation in transformation ratio from nominal ratio. It is expressed in percentage.

Percentage Ratio Error

$$= \frac{\text{Nominal transformation ratio} - \text{Actual Transformation ratio}}{\text{Actual Transformation ratio}} \times 100$$

nominal transformation ratio = rated transformation ratio.

Phase angle error of CT :-

Ideally the angle between primary and secondary current should be 180 degree. But there is some deviation from 180°. This deviation is called phase angle error.

<u>OR</u>

It is defined as the phase difference between primary current and reversed secondary current.

Burden of CT or PT. :-

It is defined as the volt ampere (VA) of connected load across the terminals of secondary winding of CT and PT.

Ratio Error of PT. :-

Ratio error of PT is defined as the variation in nominal transformation ratio to actual transformation ratio.

$$\% \text{ Ratio Error} = \frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}} \times 100$$

Phase angle error of PT. :-

Ideally angle between primary and secondary voltage should be 180°. But practically there is same deviation from 180°.

OR.

It is defined as the phase difference between the Primary voltage and reversed secondary voltage.

uses of current T/F :-

current transformers are used in a wide variety of applications ranging from Power system control to the Precise current measurement in industrial, medical, automotive and telecommunication system.

Some of the application are.

(1) Extending the range of measuring instruments such as ammeter, energy meter, wattmeter etc.

(2) over current fault Protection.

(3) Distance Protection in Power transmission system.

uses of Potential Transformer :-

Like C.T., Potential transformers are also used in Power system control, industrial, medical, automotive and telecommunication system.

① Extending the range of measuring instruments like voltmeter, energy meter, wattmeter, etc.

② Electrical Protection system.

③ Distance Protection of feeders

④ Impedance protection of generator.

Th2. Analog Electronics and OP-AMP

Name of the Course: Diploma in Electrical Engineering			
Course code:		Semester	4th
Total Period:	60	Examination	3 hrs
Theory periods:	4P/week	Internal Assessment :	20
Maximum marks:	100	End Semester Examination:	80

A. Rationale:

Electrical Engineers use electronic devices and circuits in various fields. The modern electrical plants need help of solid state electronic circuits for control, starting etc. So it was felt to provide a subject having electronic devices and circuits for the electrical students. Study of practical circuits and components have been dealt here with in the theoretical approach.

B. Objectives:

1. To develop knowledge on the characteristics of different types of diodes, transistors, UJT, FET and to draw a comparison in their characteristics and application.
2. To develop knowledge of their application.
3. To develop knowledge of different oscillator circuits and to identify the difference between them and their frequency relation.
4. To develop knowledge of operational amplifiers and their application in the field.

C. TOPIC WISE DISTRIBUTION OF PERIODS

Sl No.	Name of the Topic	Periods
1	P-N JUNCTION DIODE	6
2	SPECIAL SEMICONDUCTOR DEVICES	5
3	RECTIFIER CIRCUITS & FILTERS	7
4	TRANSISTORS	7
5	TRANSISTOR CIRCUITS	7
6	TRANSISTOR AMPLIFIERS & OSCILLATORS	13
7	FIELD EFFECT TRANSISTOR	6
8	OPERATIONAL AMPLIFIERS	9
	Total	**60**

D. Course Content:

1. P-N JUNCTION DIODE:

   1 . 1 P-N Junction Diode

   1 . 2 Working of Diode

   1 . 3 V-I characteristic of PN junction Diode.

   1 . 4 DC load line

   1 . 5 Important terms such as Ideal Diode, Knee voltage

   1 . 6 Junctions break down.

      1.6.1 Zener breakdown

      1.6.2 Avalanche breakdown

   1 . 7 P-N Diode clipping Circuit.

   1 . 8 P-N Diode clamping Circuit

2. **SPECIAL SEMICONDUCTOR DEVICES:**

   - 2 . 1 Thermistors, Sensors & barretters
   - 2 . 2 Zener Diode
   - 2 . 3 Tunnel Diode
   - 2 . 4 PIN Diode

3. **RECTIFIER CIRCUITS & FILTERS:**

   - 3.1 Classification of rectifiers
   - 3.2 Analysis of half wave, full wave centre tapped and Bridge rectifiers and calculate:
     - 3.2.1 DC output current and voltage
     - 3.2.2 RMS output current and voltage
     - 3.2.3 Rectifier efficiency
     - 3.2.4 Ripple factor
     - 3.2.5 Regulation
     - 3.2.6 Transformer utilization factor
     - 3.2.7 Peak inverse voltage
   - 3.3 Filters:
     - 3.3.1 Shunt capacitor filter
     - 3.3.2 Choke input filter
     - 3.3.3 π filter

4. **TRANSISTORS:**

   - 4.1 Principle of Bipolar junction transistor
   - 4.2 Different modes of operation of transistor

4.3 Current components in a transistor

4.4 Transistor as an amplifier

4.5 Transistor circuit configuration & its characteristics

    4.5.1 CB Configuration

    4.5.2 CE Configuration

    4.5.3 CC Configuration

5. **TRANSISTOR CIRCUITS:**

5.1 Transistor biasing

5.2 Stabilization

5.3 Stability factor

5.4 Different method of Transistors Biasing

    5.4.1 Base resistor method

    5.4.2 Collector to base bias

    5.4.3 Self bias or voltage divider method

6. **TRANSISTOR AMPLIFIERS & OSCILLATORS:**

6.1 Practical circuit of transistor amplifier

6.2 DC load line and DC equivalent circuit

6.3 AC load line and AC equivalent circuit

6.4 Calculation of gain

6.5 Phase reversal

6.6 H-parameters of transistors

6.7 Simplified H-parameters of transistors

6.8 Generalised approximate model

6.9 Analysis of CB, CE, CC amplifier using generalised approximate model

6.10 Multi stage transistor amplifier

6.10.1 R.C. coupled amplifier

6.10.2 Transformer coupled amplifier

6.11 Feed back in amplifier

6.11.1 General theory of feed back

6.11.2 Negative feedback circuit

6.11.3 Advantage of negative feed back

6.12 Power amplifier and its classification

6.12.1 Difference between voltage amplifier and power amplifier

6.12.2 Transformer coupled class A power amplifier

6.12.3 Class A push – pull amplifier

6.12.4 Class B push – pull amplifier

6.13 Oscillators

6.13.1 Types of oscillators

6.13.2 Essentials of transistor oscillator

6.13.3 Principle of operation of tuned collector, Hartley, colpitt, phase shift, wein-bridge oscillator (no mathematical derivations)

7. **FIELD EFFECT TRANSISTOR:**

7.1 Classification of FET

7.2 Advantages of FET over BJT

- 7.3 Principle of operation of BJT
- 7.4 FET parameters (no mathematical derivation)
  - 7.4.1 DC drain resistance
  - 7.4.2 AC drain resistance
  - 7.4.3 Trans-conductance
- 7.5 Biasing of FET

8. **OPERATIONAL AMPLIFIERS:**

- 8.1 General circuit simple of OP-AMP and IC – CA – 741 OP AMP
- 8.2 Operational amplifier stages
- 8.3 Equivalent circuit of operational amplifier
- 8.4 Open loop OP-AMP configuration
- 8.5 OPAMP with fed back
- 8.6 Inverting OP-AMP
- 8.7 Non inverting OP-AMP
- 8.8 Voltage follower & buffer
- 8.9 Differential amplifier
  - 8.9.1 Adder or summing amplifier
  - 8.9.2 Sub tractor
  - 8.9.3 Integrator
  - 8.9.4 Differentiator
  - 8.9.5 Comparator

4TH SEMESTER ELECTRICAL

Syllabus coverage up to Internal assessment

Chapters: 1, 2, 3, 4 and 5.

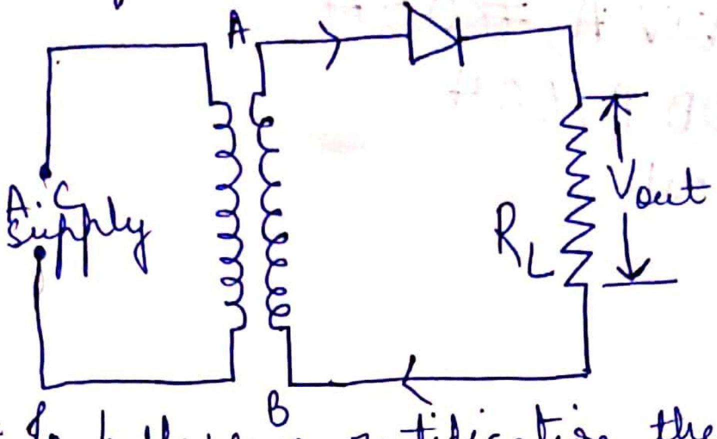
Learning Resources:

Sl.No	**Name of Authors**	**Title of the Book**	**Name of the publisher**
1	Sanjeev Gupta	Electronic Devices and Circuits	Dhanpat Rai Publications
2	R.S SEDHA	Electronics circuit	S.CHAND

Rectifier circuits & Filters

Two rectifier circuits :-

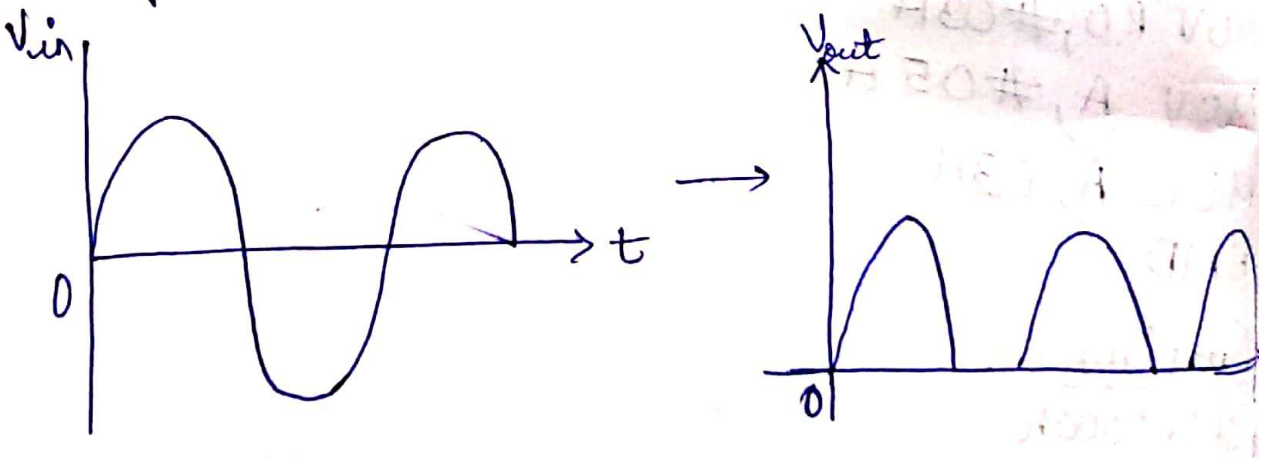
(i) Half Wave Rectifier →



* In half wave rectification, the rectifier conducts curre only during the +ve half cycle of I/p a.c supply.

* The negative half cycles of a.c supply are suppress i.e during negative half cycles, no current is conducted & hence no voltage appears ~~acr~~ across the load.

* Therefore current always flows in one directio through the load



Circuit Details

* It has a single crystal diode which acts as a half-wave rectifier.

* The a.c supply to be rectified is applied in series with the diode and load resistance R_L.

* A.C supply is given through a transformer.

*Transformer used permits two advantages:
Firstly, it allows to step up or step down the a.c i/p voltage
Secondly, it isolates the rectifier circuit from power line and thus reduces the risk of electric ~~sh~~ shock.

Operation

*The AC voltage across the secondary winding AB changes polarities after every half-cycle.
During the +ve half cycle of i/p ac voltage, end A becomes +ve w.r.t end B.
*This makes diode forward biased and hence it conducts current.
*During -ve half cycle, end A is -ve w.r.t end B. The diode is reverse biased and it conducts no current.
*Therefore current flows through the diode during +ve half-cycles of i/p a.c voltage only and it is blocked during -ve half cycle.
*In this way current flows through load R_L always in same direction.
*Hence d.c o/p is obtained ~~accross~~ across R_L.
*O/p obtained is pulsating d.c

Disadvantages

*It requires an elaborate filtering to produce steady ~~cur~~ direct current
*A.C supply delivers power only half the time. Therefore, ~~out~~ o/p is low.

Calculate Analysis of half wave rectifier

DC current

~~$I_{DC} = \frac{I_{max}}{\pi}$~~ $I_{dc} = \frac{V_m}{\pi R_L} = 0.318 \frac{V_m}{R_L}$

~~I_{max} = maximum DC load current~~

V_m = max^m ~~o/p~~ supply voltage

R_L = load Resistance

o/p DC voltage

* It is the voltage appeared at the load resi R_L.

* This is obtained by multiplying the o/p DC current with load resistance R_L

$V_{DC} = I_{DC} R_L$

$\Rightarrow V_{DC} = \cancel{\frac{I_{max} R_L}{\pi}} \; \frac{V_m}{\pi}$

~~$I_{max} R_L = V_{smax}$~~

V_{smax} = Maximum secondary voltage

Ripple Factor

* The DC produced by a halfwave rectifier is not a pure DC but a pulsating DC.

* In the o/p pulsating DC signal, we find ripples.

* These ripples can be reduced by using filters such as capacitors & inductors.

* These ripples can be measured by a factor known as ripple factor.

* Ripple factor tells us the amount of ripples present in the o/p DC signal.

* Ripple factor can be simply defined as ratio of ripple voltage to the DC voltage.

$$\gamma = \sqrt{\left(\frac{V_{rms}}{V_{DC}}\right)^2 - 1}$$

V_{rms} = rms value of AC component of the o/p voltage &

V_{DC} = DC component of o/p voltage.

Peak Inverse Voltage

* It is the maximum reverse bias voltage upto which a diode can withstand.

* If the applied voltage is greater than the PIV, the diode will be destroyed.

$PIV = V_{s\,max}$

$V_{s\,max}$ = max^m^ secondary voltage

Efficiency

* Ratio of o/p DC power to I/p AC power.

* efficiency of half wave rectifier is 40.6%.

RMS value of load current I_{RMS}

$$\cancel{I_{RMS} = \frac{I_m}{2}} \quad \cancel{I_m = \text{peak value of o/p current}} = \cancel{\frac{V_m}{2(R_f + R_L)}}$$

$$I_{rms} = \frac{I_m}{2}$$

RMS value of o/p load voltage

$$\cancel{V_{RMS} = I_{RMS} R_L = \frac{I_m}{2} R_L}$$

$$V_{RMS} = I_{rms} R_L$$

$$= \frac{I_m}{2} R_L$$

$$\cancel{V_{RMS} = I_{rms} \times R_L = \frac{V_m \times R_L}{2(R_f + R_L)}}$$

$$\cancel{= \frac{V_m}{2\{1 + (R_f/R_L)\}}}$$

Percentage of Regulation

It is a measure of the variation of DC o/p voltage for variations in the load.

$$= \frac{V_{NL} - V_{FL}}{V_{FL}} \times 100\%$$

V_{NL} = Voltage at no load

V_{FL} = Voltage at full load

Form Factor

$$F = \frac{\text{rms Value}}{\text{average value}} = \frac{I_m/2}{I_m/\pi} = 1.57$$

Peak Factor

$$\text{Peak Factor} = \frac{\text{Peak Value}}{\text{r.m.s value}} = \frac{V_m}{V_m/2} = 2$$

TUF

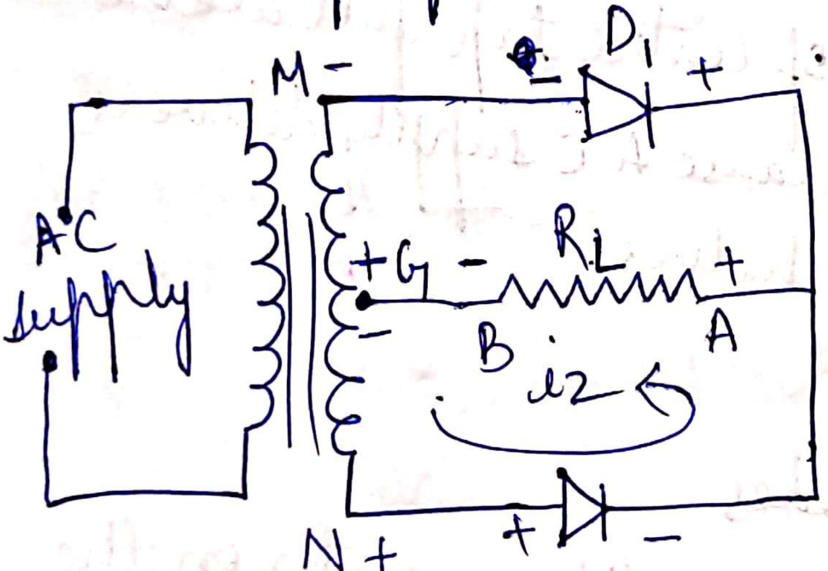
$$\frac{2\sqrt{2}}{\pi^2} = 0.287$$

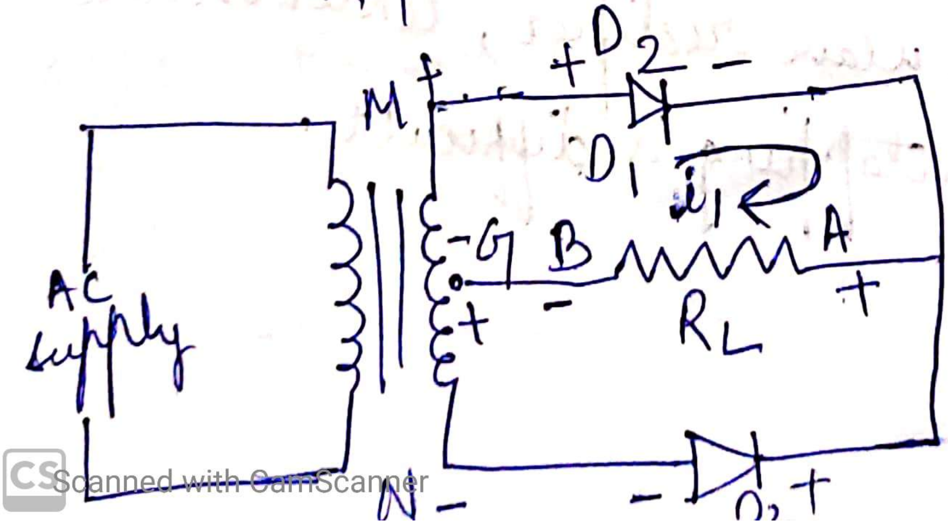
Full Wave Rectifier

* In fullwave rectifier, both half cycle of the input are utilized with the help of two diodes working alternately.

* Therefore in full wave rectifier circuit, current flows through load resistor in the same direction for both half cycles of input a.c voltage.

Centre-Tap full wave rectifier





* When I/P a.c supply is switched on, the ends M & N of the transformer secondary becomes positive & negative alternately.

* During +ve half of a.c input, terminal M is positive and N is at -ve potential.

* Now, diode D_1 is forward biased i.e it conducts and causes a current i_1 in load resistor R_L.

* Diode D_2 remains non conducting being reversed biased.

* During the -ve half cycle, terminal N becomes +ve and M becomes -ve.

* During this cycle, diode D_2 conducts and current i_2 flows in the circuit through load resistor R_L. Diode D_1 is non conducting.

Advantages

* The O/P and efficiency of centre tap full wave rectifier are high because A C supply delivers power during both the halves.

Disadvantages

* It requires two diodes

* In center tap full wave rectifier, center on the secondary winding for tapping is difficult.

Analysis of centre tap full wave rectifier

1) o/p d.c current

$I_{dc} = \frac{2I_m}{\pi}$, I_m = peak value of o/p current

2) DC o/p voltage

$$V_{dc} = \frac{2I_m R_L}{\pi}$$

3) RMS current

$$I_{rms} = \frac{I_m}{\sqrt{2}}$$

4) Efficiency

* $\eta = \frac{P_{dc}}{P_{ac}}$

* The efficiency of a full wave rectifier is 81.2%

5) Ripple factor

$$\gamma = \sqrt{\left(\frac{I_{rms}}{I_{dc}}\right)^2 - 1}$$

6) Form Factor

$$F = \frac{I_{rms}}{I_{dc}} = \frac{I_m/\sqrt{2}}{2I_m/\pi}$$

7) PIV

$PIV = 2V_m$

V_m = max^m supply voltage.

8) TUF (Transformer Utilization Factor)

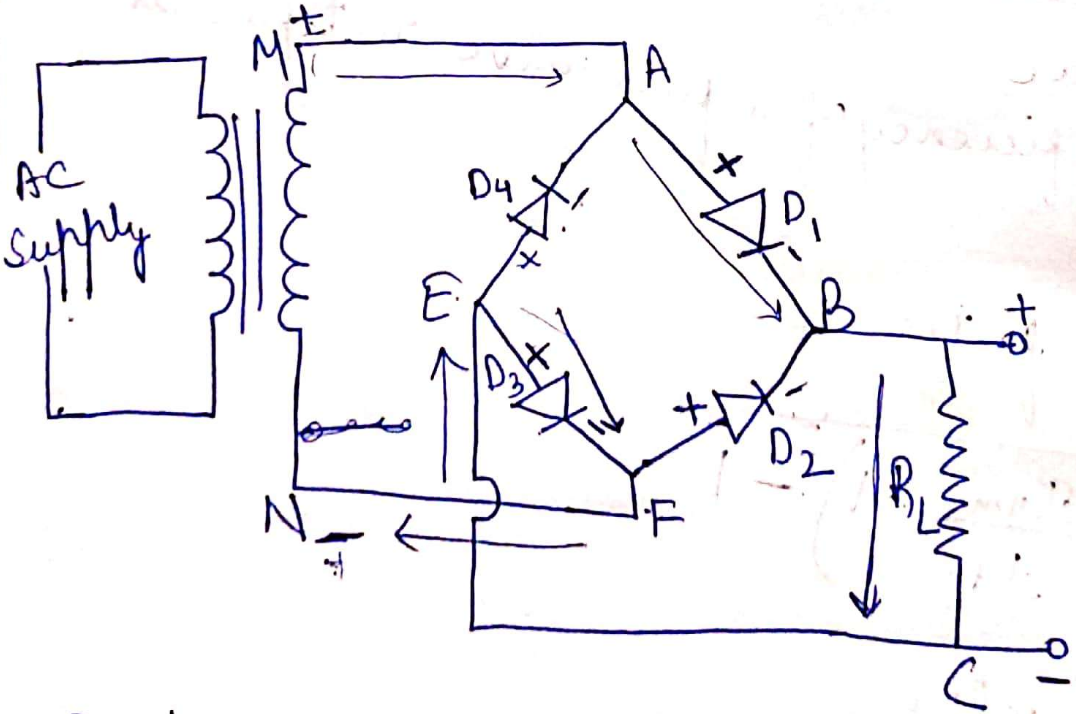
$TUF = 0.573$

9) Voltage Regulation

$$\frac{2V_m}{\pi} - I_{dc} R_f$$

R_f = Diode resistance in ON condition.

Full Wave Bridge Rectifier

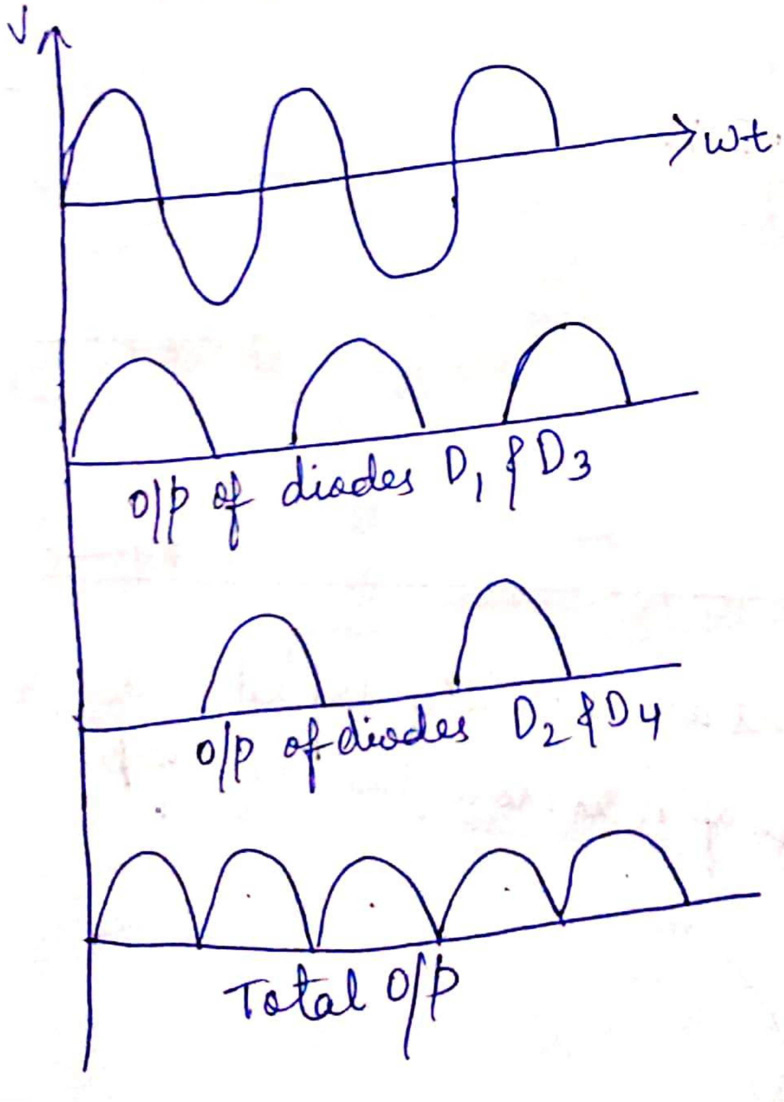


* During +ve input half cycle, terminal M of the secondary of the transformer is +ve while the terminal N is negative. In this

situation diodes D_1 & D_3 are forward biased (ON position) i.e they conduct whereas diodes D_2 & D_4 are reverse biased (OFF position) i.e they do not conduct

* So current flows through MABCEFN.

* During the -ve half cycle, terminal N of the secondary of transformer becomes +ve while the terminal M becomes -ve. Under this situation diodes D_2 & D_4 are forward biased (ON position) i.e they conduct whereas diodes D_1 & D_3 are reverse biased (OFF position), i.e they do not conduct. Now a current flows along NFBCEAM.



Advantages

- * No Centre - tap is required
- * It is suitable for high voltage applications.
- * It has less PIV rating per diode, because two diodes are present in series in each conduction path, PIV is equally shared by the two diodes.
- * Current flows for the entire a.c cycle.

Analysis of Bridge rectifier

* $I_{dc} = \frac{2I_m}{\pi}$

* $V_{dc} = \frac{2V_m}{\pi}$

* $I_{rms} = \frac{I_m}{\pi}$

* Efficiency $\eta = 81.2\%$

* $\gamma = 0.48$
(Ripple factor)

* $PIV = V_m$

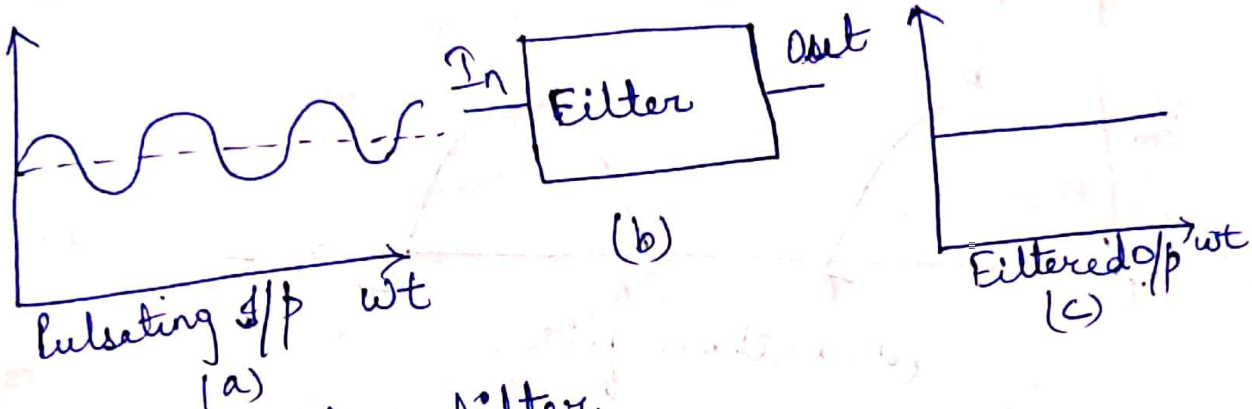
* $TUF = 0.812$

Filters

* It is a device that converts the pulsating output of a ~~rect~~ rectifier into a steady d.c level.

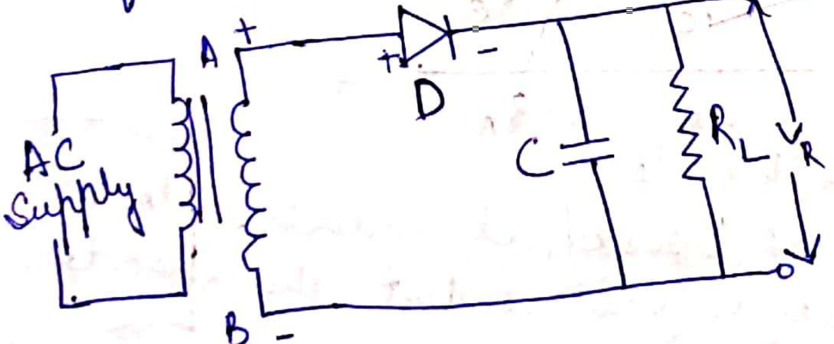
OR

* It is a device which removes the a c component of rectifier O/P but allows the d.c component to reach the load.



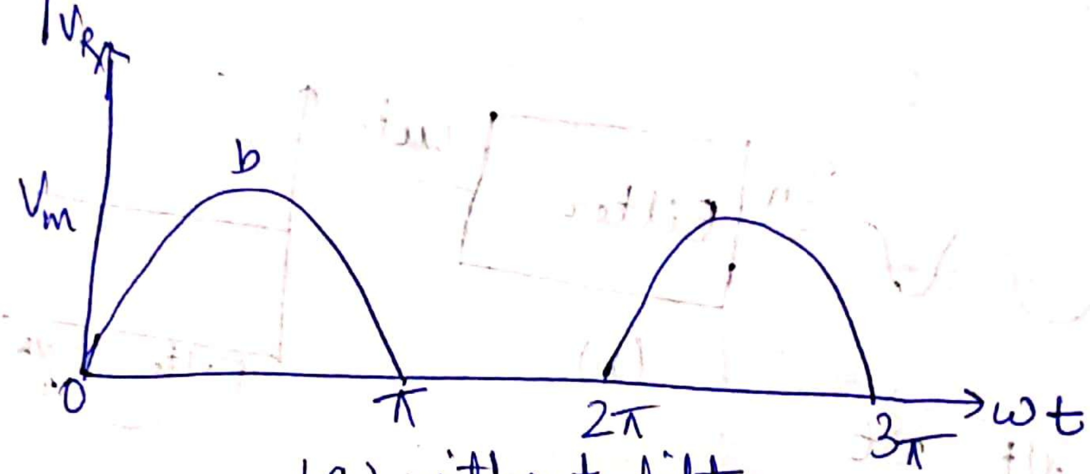
Shunt Capacitor filter

Half wave rectifier with Capacitor filter

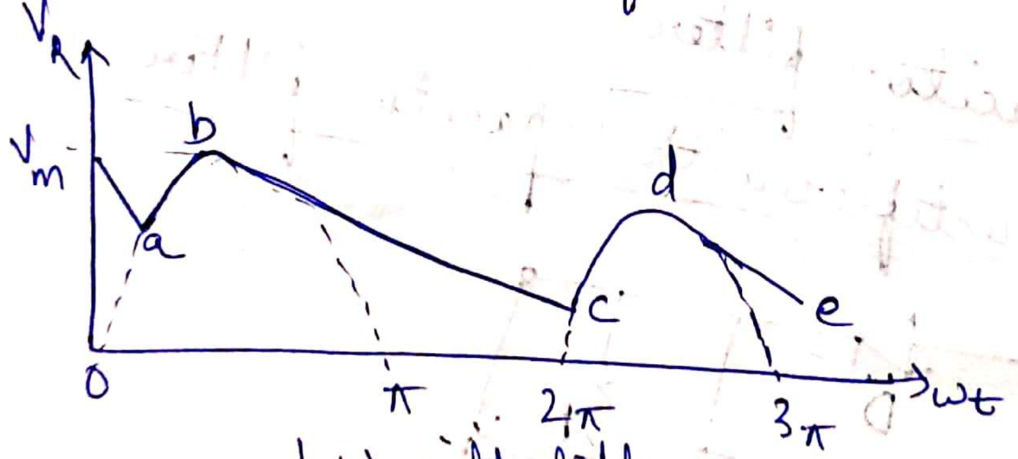


* During +ve half cycle of a.c input, the diode D is forward biased and hence it conducts.
* This quickly charges the condenser C to a voltage V_m because there is no resistance in the charging path except diode forward resistance which is negligible.
* When the condenser is fully charged, it holds the charge till the input a.c supply to the rectifier goes negative.

* During the -ve half cycle, the diode D is reverse biased, i.e it does not conduct,
* So, the capacitor C discharges through R_L ~~from R~~
* During the next +ve half cycle, the capacitor voltage increases ~~from point~~ The process is the repeated.

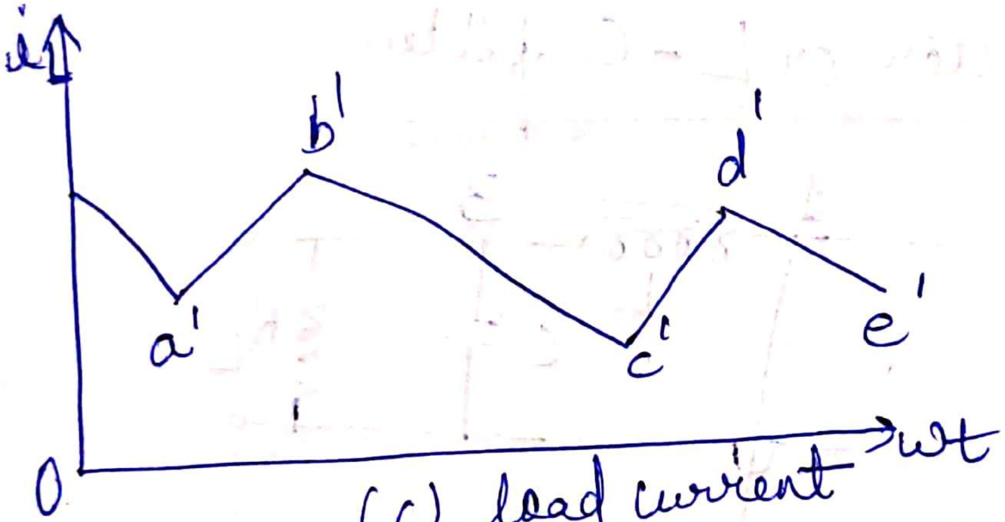


(a) without filter



(b) with filter.

* when diode is forward biased, it conducts upto a point b and when it does not conduct, the capacitor starts discharging (b to c)
* Again during next cycle the diode conducts ~~and~~ (c to d) and during -ve cycle it does not conduct, the capacitor starts discharging (d to e)



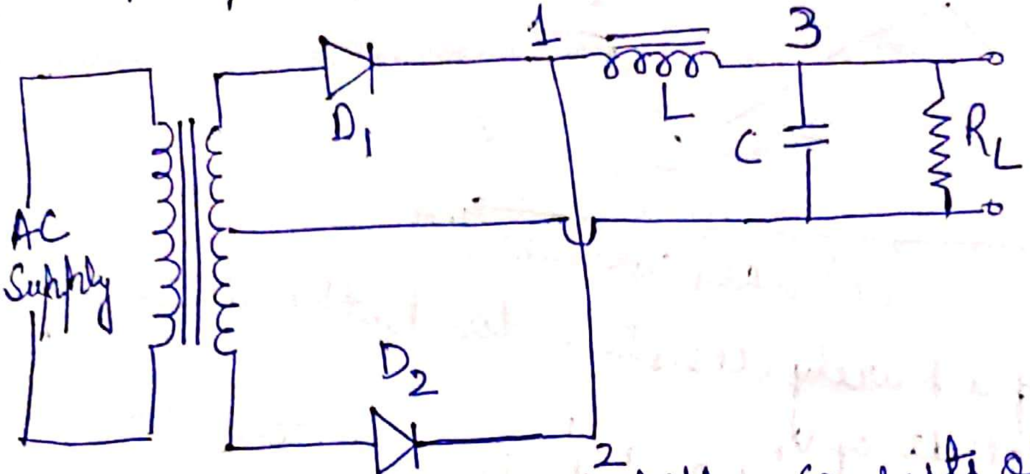
(c) load current

* In case of a purely resistive load, the wave shape is same as that of V_R

* During periods a'b' & c'd' the current is supplied by diode and during periods b'c' & d'e' the current is supplied by capacitor.

* The instant at which conduction starts is called the cut-in point and the instant at which conduction stops is called the cut-out point.

Choke Input filter or L-C filter



* Typical Choke input filter consists of a Choke L connected in series with the rectifier output and a filter capacitor C across the load.

* The pulsating o/p of the rectifier is applied across terminals 1 & 2 of the filter circuit.

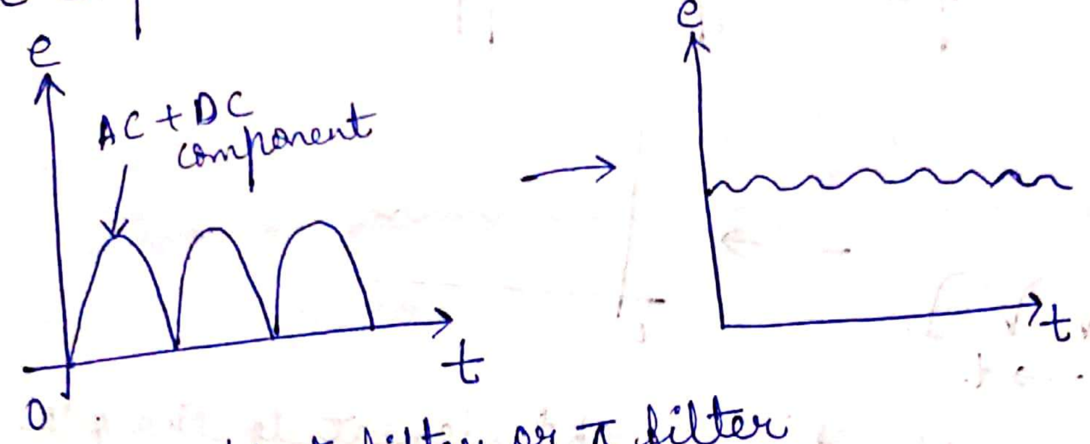
* The pulsating o/p of rectifier contains a.c & d.c components.

* The choke offers high opposition to the passage of a.c component but negligible opposition to the d.c component.

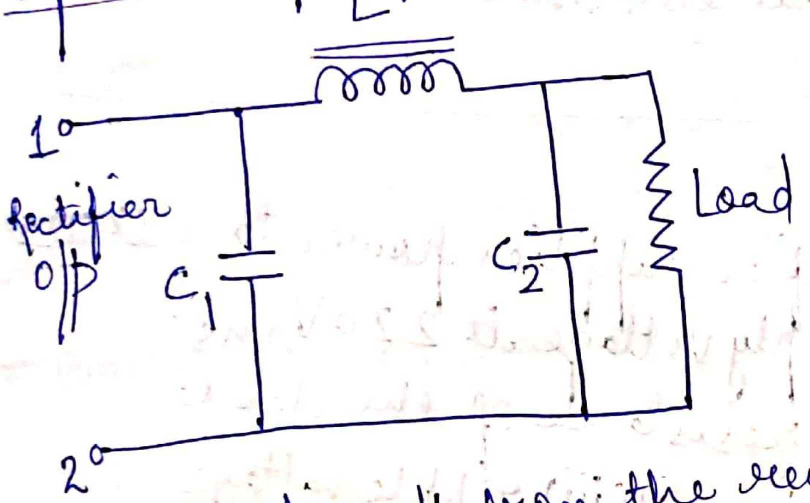
* The result is that most of the a.c component appears across the Choke while whole of d.c component passes through the Choke. This results in the reduced pulsations at terminal 3.

* At terminal 3, the rectifier o/p contains d.c component and the remaining part of a.c component which has managed to pass through the choke. The capacitor offers low reactance to a.c component and infinite reactance to d.c component. Therefore, d.c component reaches the load.

*In this way, the filter circuit has filtered out the a·c component from the rectifier o/p, allowing d·c component to reach the load.



Capacitor Input filter or π filter



*The pulsating o/p from the rectifier is applied across the input terminals 1 & 2 of the filter.

*The filter capacitance C_1 offers low reactance to a·c component of rectifier o/p while it offers infinite reactance to the d·c component. Therefore, capacitor C_1 bypasses a·c component while the d·c component continues its journey to Choke L.

*The Choke L offers high reactance to the a·c component but ~~af~~ it offers almost zero reactance to the d·C component. Therefore, it allows the d·c component to flow through it, while the unbypassed a·c component is blocked.

* The filter capacitor C_2 bypasses the a·c component which the choke has failed to block. Therefore, only d·c component appears across the load.

Reactance → opposition of a ckt element to the flow of current due to that element's inductance or capacitance.

Bipolar Junction Transistor

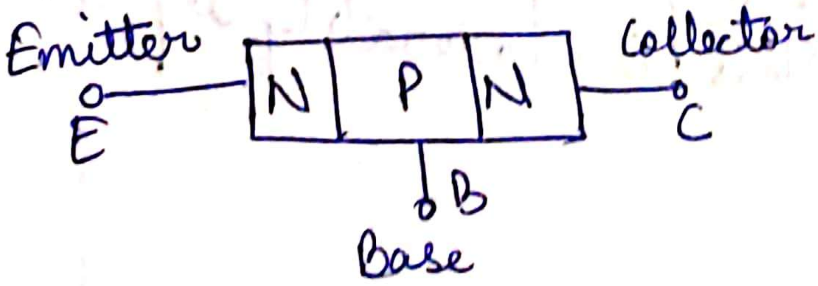
A Transistor is commonly known Bipolar junction transistor. This is due to the fact that the current conduction in BJT is due to both types of charge carriers i.e, electrons and holes.

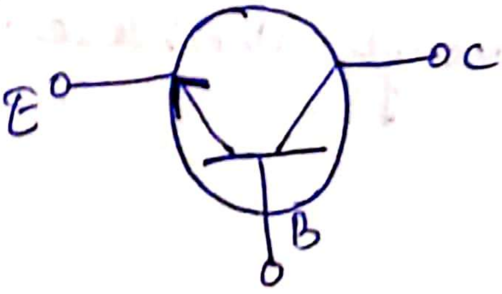
* Bipolar junction transistor is a three terminal, two junction device.

* A junction transistor is simply a sandwich of one type of semi conductor material between two layers of the other type. Accordingly, there are two types of transistors:

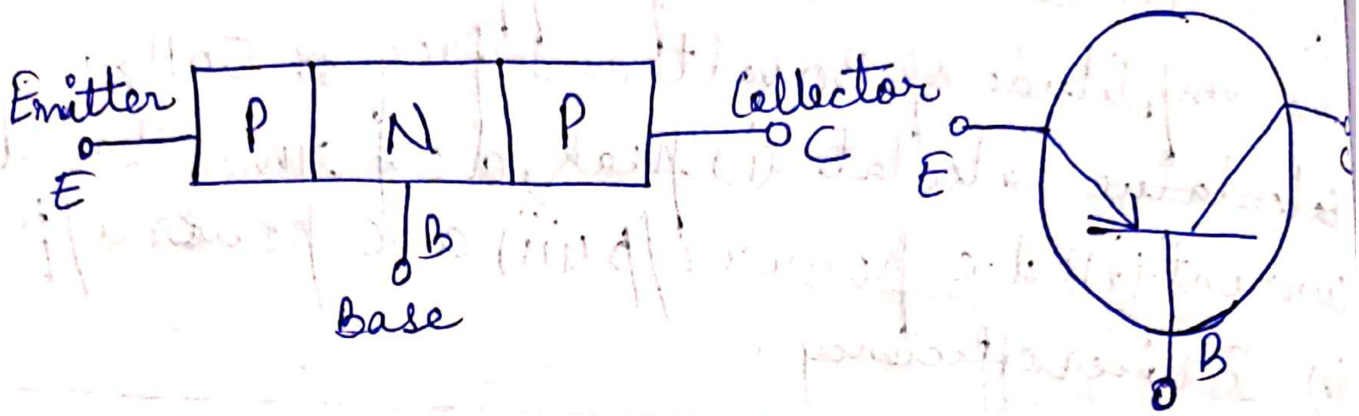
(1) N-P-N transistor and (2) P-N-P transistor

* When a layer of P-type material is sandwiched between two layers of N-type material, the transistor is known as N-P-N transistor.





* When a layer of N- type material is sandwich between two layers of P-type material, the transist is known as P-N-P transistor



A transistor has the following sections :-

(i) Emitter → This forms the left hand section or region of the transistor. The main function of this region is to supply majority charge carriers (either holes or electrons) to the base and hence it is more heavily doped in comparison to other regions

(ii) Base → The middle section of the transistor is known as base. This is very lightly doped and is very thin as compared to either emitter or collector. so that it may pass most of the injected charge carriers to the collector.

(iii) Collector → The right hand section of the transist is called as collector. The main function of the collector is to collect majority charge carriers through the base. This is moderately doped.

*Important points

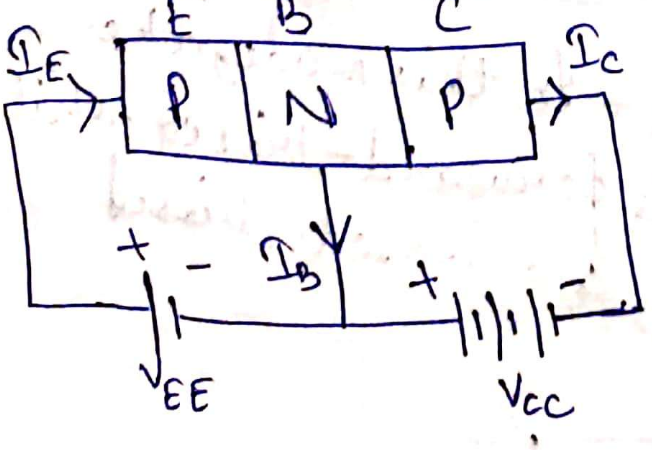
* The arrowhead is always at the emitter. The direction indicates the conventional direction of current flow i.e in case of N-P-N transistor it is from base to emitter (base is positive with respect to emitter) while in case of P-N-P transistor it is from emitter to base (emitter is positive with respect to base).

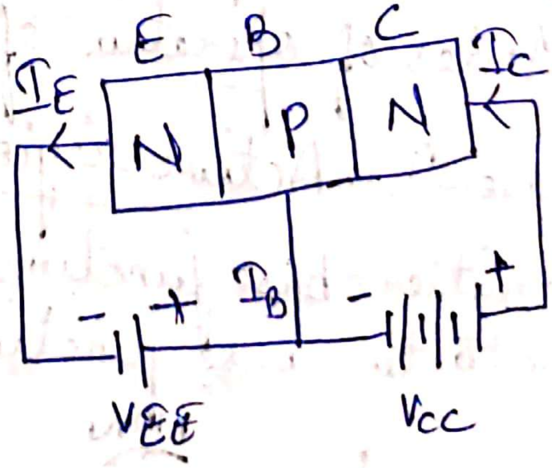
* The emitter is heavily doped because it has to supply the majority carriers. The collector is less heavily doped. The base is lightly doped.

* In most of the transistors, the collector region is made physically larger than the emitter region. This is due to the fact that collector has to dissipate much greater power. Due to this difference collector and emitter are not interchangeable.

Transistor biasing

* The emitter-base junction is always forward-biased while the collector-base junction is always reverse-biased.





* The emitter base junction of P-N-P transistor is forward-biased by connecting the positive terminal of V_{EE} to emitter and -ve terminal to base.

* The emitter base junction of N-P-N transistor is forward biased by connecting the -ve terminal of V_{EE} to emitter and +ve terminal to base.

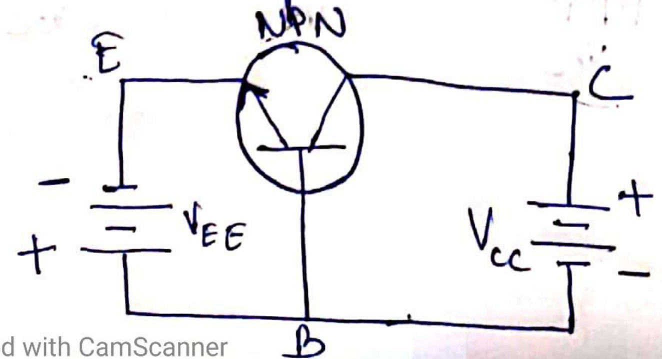
* The collector-base junction of a P-N-P transistor is reverse-biased by connecting the -ve terminal of V_{CC} to collector while ~~p~~ +ve terminal to base

* The collector-base junction of N-P-N transistor is reverse biased by connecting the +ve terminal of V_{CC} to emitter while -ve terminal to base.

* In a transistor, a weak signal is introduced in low resistance circuit and the output is taken from the high resistance circuit

Modes of operation of a transistor

Case-I → Active region → In this mode, the emitter-base junction is forward-biased while collector-base junction is reversed-biased



*In the emitter-base circuit, a battery V_{EE} is connected such that -ve of the battery is connected to emitter while +ve is connected to base.

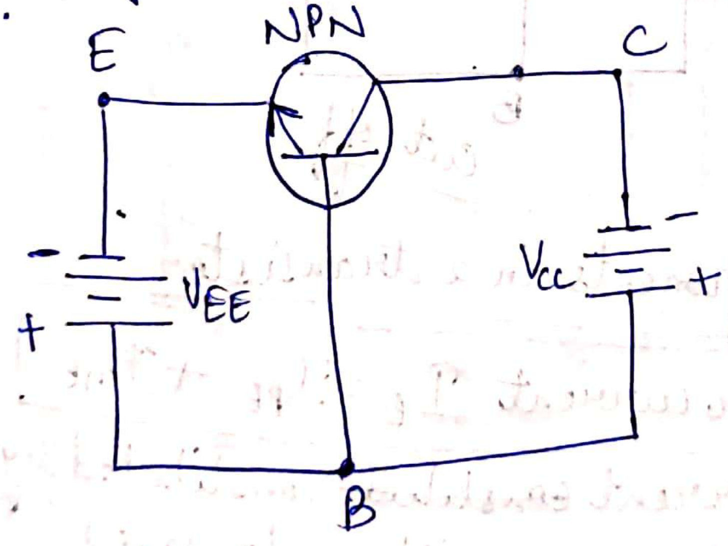
* A battery V_{CC} is connected to collector-base circuit. +ve terminal of battery is connected to collector while -ve is connected to base.

* In this region transistor is used for amplification.

Case-II → Saturation region → In this mode, emitter-base junction aswell as collector base junction both are forward-biased.

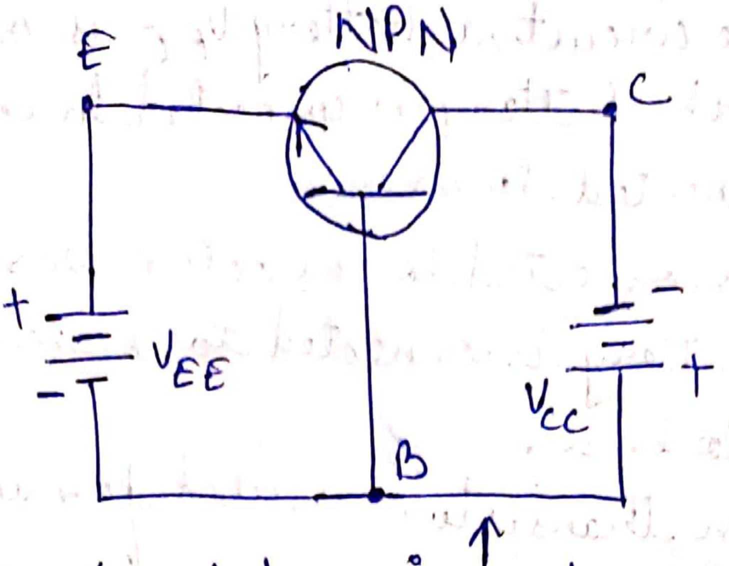
*The -ve of battery V_{EE} is connected to emitter and similarly the -ve of battery V_{CC} is connected to collector. The +ve terminals of both the batteries are connected to base.

* In this region the transistor acts like a closed switch.



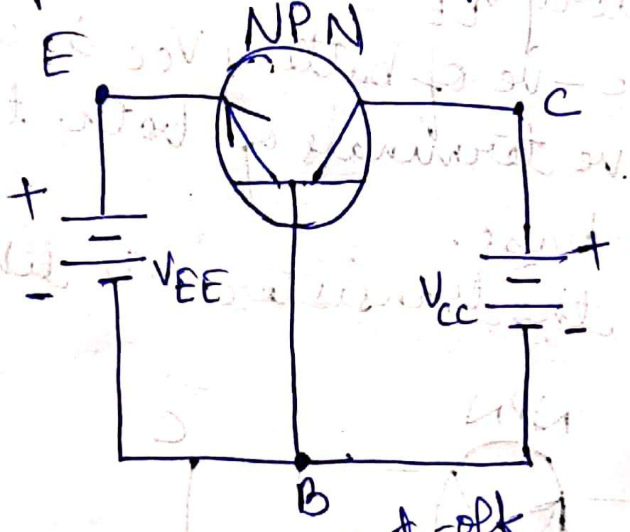
Case-III → cut-off region → In this mode, both the junctions are reversed biased.

* In this region, the transistor has practically zero current because the emitter does not emit the charge carriers to the base. In this situation, the transistor acts as open switch.



Case-IV – Inverted region → In this region, emitter-base junction is reverse-biased ~~which~~ while collector-ba junction is forward-biased.

* In this region, the action of transistor is very poor.



cut-off

Current components in a transistor

$\boxed{\text{Total emitter current } I_E = I_{PE} + I_{nE}}$

I_{PE} = Hole current ~~constituted~~ constituted by holes (holes crossing from emitter into base)

I_{nE} = Electron current constituted by electrons (electrons crossing from base into the emitter)

$$\boxed{I_C = I_{PC} + I_{CO}}$$

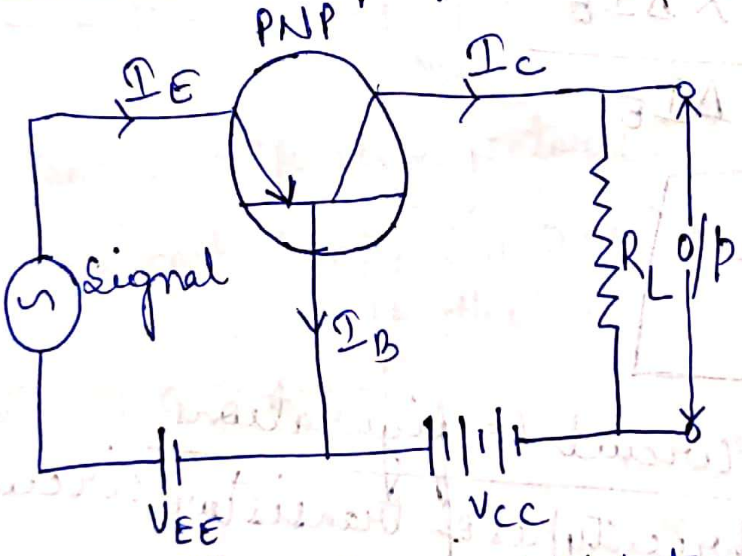
I_{PC} → current caused by holes moving across collector junction J_C from N-region to P-region.

I_{CO} → Reverse saturation current

Thus, for a PNP transistor

$$\boxed{I_E = I_B + I_C}$$

Transistor as an amplifier



Let a small voltage change ΔV_i between emitter and base causes a relatively large emitter-current change ΔI_E.

* We define by the symbol α that fraction of this current change which is collected and passes through R_L. Thus

$$\alpha = \frac{\Delta I_C}{\Delta I_E} \quad \text{i.e} \quad \cancel{\Delta I_C = \alpha \cdot \Delta I_E}$$

$$\Delta I_C = \alpha \cdot \Delta I_E$$

*The Change in output voltage across the load resistor

$$\Delta V_0 = R_L \times \Delta I_C$$
$$= R_L \times \alpha \times \Delta I_E$$

Under these circumstances, the voltage amplification

$$A = \frac{\Delta V_0}{\Delta V_i}$$

$$\Delta V_i = r_e \cdot \Delta I_E$$

r_e = dynamic resistance of the emitter junction

$$A = \frac{R_L \times \alpha \times \Delta I_E}{r_e \cdot \Delta I_E}$$

$$\boxed{A = \frac{\alpha R_L}{r_e}}$$

Transistor circuit configurations

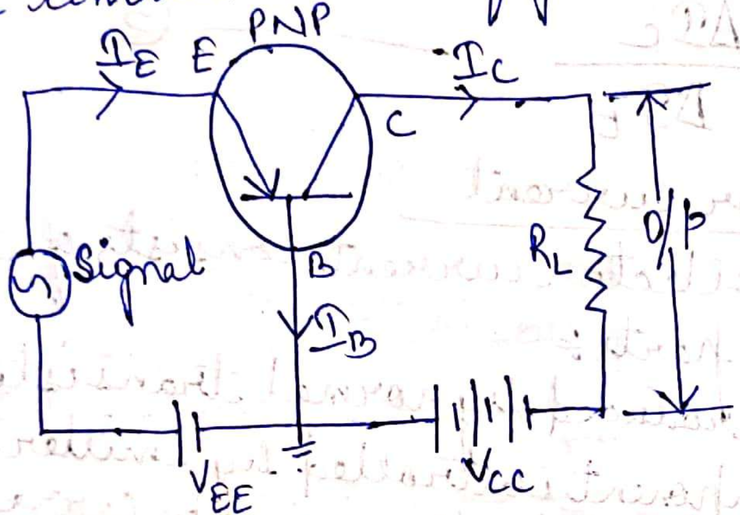
There are three types of transistor circuit configurations:-

1) Common base (CB)
2) Common emitter (CE)
3) Common collector (CC)

Common-Base Configuration

* In this configuration, the input signal is applied between emitter and base while the o/p is taken from collector and base.

* As base is common to input and output circuits, hence common-base configurations



* D.C current amplification factor (α) or d.c gain

→ When no signal is applied, then the ratio of the collector current to the emitter current is called α_{dc} of a transistor

$$\alpha_{dc} = \frac{-I_C}{I_E},$$ (-ve sign signifies that I_E flows into transistor while I_C flows out of it).

$$\Rightarrow \boxed{\alpha = \frac{-I_C}{I_E}} \quad \text{———} ①$$

From eqⁿ ①

$I_C = \alpha . I_E$

$\Rightarrow I_B = I_E - I_C \Rightarrow I_B = I_E - \alpha I_E$

$\Rightarrow I_B = I_E(1-\alpha)$ —— ②

***AC current gain**

→ when signal is applied, the ratio of change in collector current to the change in emitter current at constant collector base voltage is defined as current amplification factor.

$$\alpha_{ac} = \frac{-\Delta I_C}{\Delta I_E} \quad \text{—— ③}$$

Total collector current

→ The total collector current consists of the following two parts:-

- The current produced by normal transistor action i.e component controlled by emitter current. This is due to the majority carrier and its value is αI_E
- The leakage current. This current is due to the motion of minority carriers across base-collector junction on account of it being reverse-biased. The leakage current is abbreviated as I_{CBO} i.e collector-base current with emitter open.

Total collector current

$$\boxed{I_C = \underbrace{\alpha I_E}_{\text{Majority}} + \underbrace{I_{CBO}}_{\text{minority}}} \quad \text{—— ④}$$

$$I_C = \alpha(I_C + I_B) + I_{CBO}$$

$$I_C(1-\alpha) = \alpha I_B + I_{CBO}$$

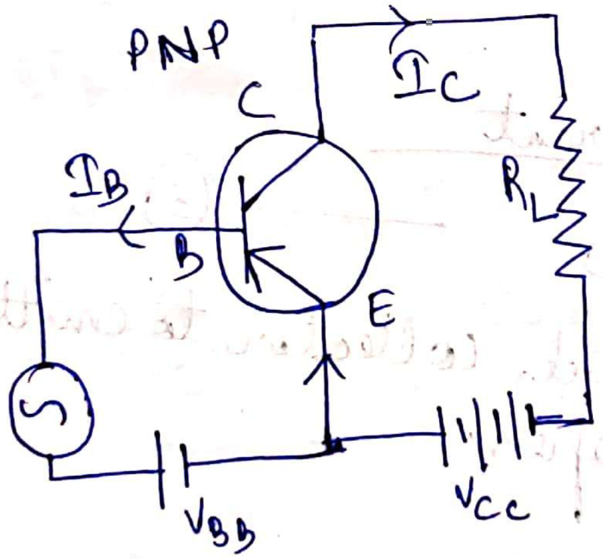
$$I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO} \quad \text{---} ⑤$$

The relation between α & β is given by

$$\alpha = \frac{\beta}{1-\beta}, \quad \beta = \frac{\alpha}{1-\alpha}$$

$$\boxed{I_C = \beta I_B + (1+\beta) I_{CBO}} \quad \text{---} ⑥$$

Common emitter configuration



* In this configuration, the input signal is applied between base and emitter and the output is taken from collector and emitter.

* As emitter is common to input and o/p circuits hence the name common emitter.

Base current amplification factor (β) or d.C current gain

* when no signal is applied, then the ratio of collector current to base current is called dc β_{dc} of a transistor

$$\boxed{\beta_{dc} = \beta = \frac{I_c}{I_B}} \quad \text{——— ①}$$

A.C current gain

* when signal is applied, the ratio of change in collector current to the change in base current is defined as base current amplification factor

$$\boxed{\beta_{ac} = \beta_0 = \frac{\Delta I_c}{\Delta I_B}} \quad \text{——— ②}$$

$\Rightarrow I_c = \beta I_B$

Total collector current

$$I_c = \beta I_B + I_{CEO} \quad \text{——— ③}$$

I_{CEO} – leakage current, collector to emitter current with base open.

$$I_E = I_B + I_C$$

$$I_C = \alpha I_E + I_{CBO}$$

$$I_C = \alpha (I_B + I_C) + I_{CBO}$$

$$I_C (1-\alpha) = \alpha I_B + I_{CBO}$$

$$\boxed{I_C = \left(\frac{\alpha}{1-\alpha}\right) I_B + \frac{1}{1-\alpha} I_{CBO}} \quad \text{—— ④}$$

comparing eq^n ③ & ④ we get

$$\beta = \frac{\alpha}{1-\alpha}, \quad I_{CEO} = \left(\frac{1}{1-\alpha}\right) I_{CBO} \quad \text{—— ⑤}$$

substituting the value of I_{CEO} in eq^n ③

$$I_C = \beta I_B + \left(\frac{1}{1-\alpha}\right) I_{CBO}$$

$$\boxed{I_C = \beta I_B + (\beta + 1) I_{CBO}} \quad \text{—— ⑥}$$

Relation between α & β

$$\alpha = \frac{I_C}{I_E}, \quad \beta = \frac{I_C}{I_B}$$

$$I_E = I_B + I_C \text{ or } I_B = I_E - I_C$$

$$\beta = \frac{I_C}{I_E - I_C} = \frac{I_C / I_E}{1 - (I_C / I_E)}$$

$$\boxed{\beta = \frac{\alpha}{1-\alpha}} \quad \text{—— ⑦}$$

cross multiplying eq^n ⑦, we get

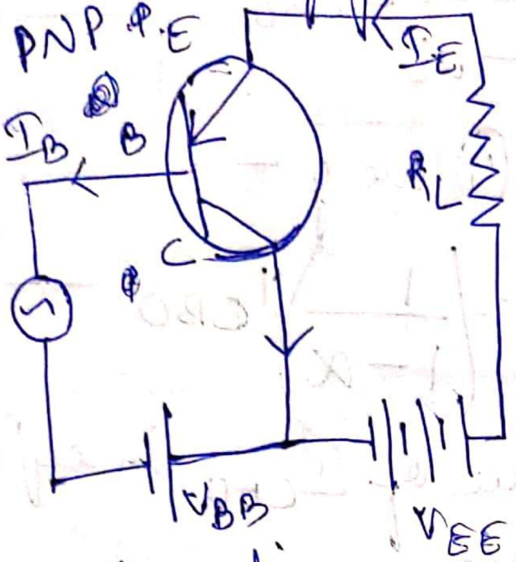
$$\Rightarrow \beta(1-\alpha) = \alpha$$

$$\Rightarrow \beta - \beta\alpha = \alpha$$

$$\Rightarrow \beta = \alpha(1+\beta)$$

$$\Rightarrow \boxed{\alpha = \frac{\beta}{1+\beta}} \quad \text{— ⑧}$$

Common Collector Configuration



* In this configuration, the input signal is applied between base & collector and the o/p is taken from emitter.

* As collector is common to input and o/p circuits, hence, the name common collector configuration.

Current amplification factor (γ) or d.c current gain

* when no signal is applied, then the ratio of emitter current to base current is called as γ_{dc} of the transistor

$$\boxed{\gamma_{dc} = \gamma = \frac{I_E}{I_B}} \quad \text{—— ①}$$

AC current gain

* when signal is applied then the ratio of change in emitter current to the change in base current is known as current amplification factor

$$\boxed{\gamma = \frac{\Delta I_E}{\Delta I_B}} \quad \text{— ②}$$

Total emitter current

$$I_E = I_B + I_C$$

$$\Rightarrow I_C = \alpha I_E + I_{CBO}$$

$$\Rightarrow I_E = I_B + (\alpha I_E + I_{CBO})$$

$$\Rightarrow I_E(1-\alpha) = I_B + I_{CBO}$$

$$\Rightarrow I_E = \frac{I_B}{(1-\alpha)} + \frac{I_{CBO}}{(1-\alpha)} \qquad \because \frac{1}{1-\alpha} = (1+\beta)$$

$$\Rightarrow \boxed{I_E = (1+\beta) I_B + (1+\beta) I_{CBO}} \text{ —— ③}$$

Relation between γ and α

$$\gamma = \frac{I_E}{I_B}, \quad \alpha = \frac{I_C}{I_E}$$

$$I_B = I_E - I_C$$

$$\gamma = \frac{I_E}{I_E - I_C} = \frac{1}{1-(I_C/I_E)} = \frac{1}{1-\alpha} \text{ —— ④}$$

Relation between γ and β

$$\boxed{(1-\alpha) = \frac{1}{(1+\beta)}}$$

Substituting this value in eqⁿ ④

$$\boxed{\gamma = \frac{1}{1-\alpha} = (1+\beta)} \text{ —— ⑤}$$

Transistor circuits

* Transistor Biasing

→ Among the basic functions of a transistor is amplification

→ For faithful amplification, the following three condition must be satisfied :-

(i) the emitter-base junction should be forward biased.

(ii) the collector-base junction should be reverse biased.

(iii) there should be proper zero signal collector current.

→ The proper flow of zero signal collector current and the maintenance of proper collector-emitter voltage during the passage of signal is known as transistor biasing.

→ A transistor is biased ~~at~~ either with the help of battery or associating a circuit with the transistor

→ The circuit used with the transistor is known as biasing circuit.

* Stabilisation

→ The maintenance of the stable operating point is known as stabilisation.

→ Stabilisation of the operating point is necessary due to the following reasons:-

(1) Temperature dependence of I_C
(2) Individual variations
(3) Thermal runaway.

* Temperature dependence of I_C

→ The instability of I_C is principally caused by the following three sources :-

- The collector leakage current I_{CO} is greatly influenced by temperature changes. The I_{CO} doubles for every 10°C rise in temperature.
- Increase of β with increase of temperature.
- Variation of V_{BE} (base to emitter voltage) with temperature. Here it should be remembered that V_{CE} also changes with temperature but the change is very small. Hence I_C is almost independent of V_{CE}.

*Individual variations → when a transistor is replaced by another transistor of the same type the value of β and V_{BE} are not exactly the same. Hence, the operating point is changed. So, it is necessary to stabilise the operating point ~~irrespective~~ irrespective of individual variations in transistor parameters.

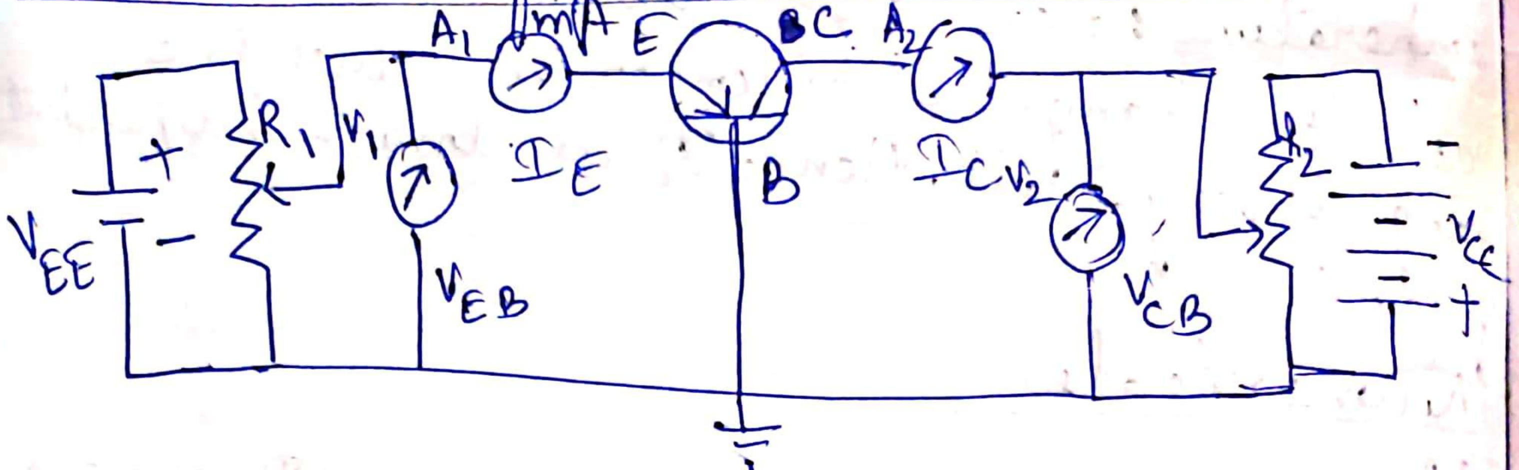
*Thermal runaway → Depending upon the constructⁿ of a transistor, the collector junction can withstand a max^{M} temperature.

→ The increase in the collector junction temperature is due to thermal runaway.

→ When a collector current flows in a transistor it is heated i.e its temperature increases.

→ If no stabilization is done, the collector leakage current also increases. This further increases the transistor temperature. Consequently there is a further increase in collector leakage current.

Common Base Configuration Characteristics



* The battery V_{EE} supplies forward bias to the emitter base junction through potential divider R_1.

* Similarly, the battery V_{CC} supplies reverse-bias to the collector base junction through potential divider R_2.

* In the circuit, milliammeters are connected in series with emitter and collector to measure emitter current I_E and I_C respectively.

* Similarly, voltmeters are connected in parallel across E & B to measure the voltage V_{EB} and across C & B to measure the voltage V_{CB} respectively

* Here, the quantities emitter to base voltage V_{EB} & emitter current I_E correspond to input circuit and collector to base voltage V_{CB} and collector current I_C to the o/p ckt.

Input Characteristics

* The curve between I_E & V_{EB} at constant V_{CB} represents i/p characteristics.

* For plotting the i/p characteristics, the V_{CB} is kept fixed, V_{EB} is varied with the help of potential divider R_1 and the emitter current is noted for each value of V_{EB}

* The following points are noted from the characteristics:-

→ There exists a cut in, offset or threshold voltage V_{EB} below which the emitter current is very small

→ The emitter current I_E increases rapidly with small increase in emitter-base voltage V_{EB}. This shows that i/p resistance is very small

output Characteristics

* The curve between collector current I_C and collector base voltage V_{CB} at constant emitter current I_E represents o/p characteristics

* For plotting o/p characteristics, the emitter current I_E is ~~po~~ kept fixed. With the help of potential divider R_2, the value of V_{CB} is varied in steps and the collector current I_C is noted for each value of V_{CB}.

* Following points are noted from the characteristics

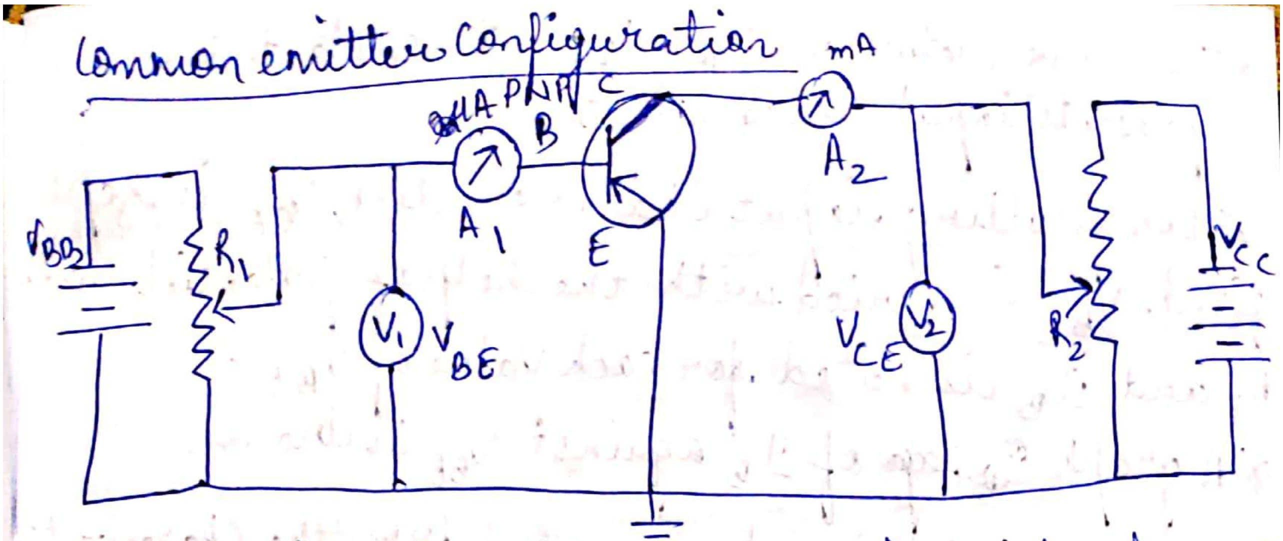
(i) In the active region (wherein the collector junction is reverse biased and emitter junction is forward biased), the collector current is essentially independent of collector voltage and depends only upon the emitter current. Because α is less than, but almost equal to unity, the magnitude of collector current is slightly less than that of the emitter current.

~~(ii) Although I_C is practically independent of V_{CB} over the work.~~

(ii) In the cut off region (when emitter & collector junction both are reverse-biased), a small amount of collector current flows ~~also~~ even when emitter current $I_E = 0$. This is the collector leakage current I_{CBO}.

(iii) In the saturation region (when both emitter & collector junctions are forward biased), the

Common emitter Configuration



* In the circuit, the battery V_{BB} provides forward bias to emitter-base junction with the help of potential divider R_1.

* The Voltmeter V_1 measures the base-emitter voltage V_{BE}.

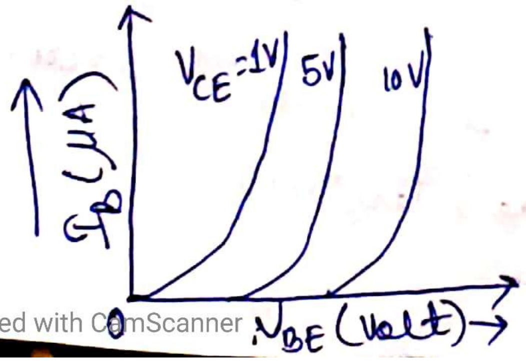
* The microammeter A_1 measures the base current I_B.

* A battery V_{CC} is connected between collector and emitter through potential divider R_2

* The +ve terminal of the battery is connected to emitter while -ve terminal is connected to the collector so that the collector is reverse biased.

* The voltmeter V_2 measures the collector-emitter voltage V_{CE} and the milliammeter A_2 measures the collector current.

Input Characteristics



* The curve between I_B & V_{BE} at constant V_{CE} represents input characteristics.

* For plotting input characteristics, V_{CE} is kept fixed. V_{BE} is varied with the help of potential divider R_1 and I_B is noted for each value of V_{BE}.

* A graph ~~against~~ of I_B against V_{BE} is drawn.

* The following points are noted from the characteristics.

→ The characteristics resembles that of a forward biased diode curve.

→ In this case, I_B increases less rapidly with V_{BE} as compared to common base configuration. This shows that the i/p resistance of common-emitter circuit is higher than that of common-base circuit.

Input Resistance r_i → The ratio of change in ~~base emitter~~ V_{BE} to the resulting change in I_B at constant V_{CE}.

$$r_i = \frac{\Delta V_{BE}}{\Delta I_B}\Bigg|_{V_{CE}=\text{constant}}$$

Output Characteristics → * The curve between I_C and V_{CE} at constant I_B represents o/p characteristics.

* For plotting o/p characteristics, I_B is kept fixed. With the help of potential divider R_2, the value of V_{CE} is varied and the I_C is noted for each value of V_{CE}.

* A graph of I_C against V_{CE} is drawn. The ~~cur~~ curve so obtained is known as o/p characteristics.

* Following points are noted :-

→ In the active region, for small values of I_B, the effect of collector voltage over I_C is small while for large base current values this effect increases. The shape of characteristics is same as in common base configurat^n but with the difference that collector current is larger than I_B.

→ when V_{CE} has very low value, the transistor is said to be saturated and it operates in the saturation region. In the saturated region, the change in I_B does not produce a corresponding change in I_C

→ When V_{CE} is allowed to increase too far, collector-base junction completely breaks down and due to this avalanche breakdown, collector current increases rapidly. In this case, transistor is damaged.

→ In the cut off region, a small amount of collector current flows even when base current $I_B = 0$. This is called I_{CEO}

o/p resistance - ~~chan~~ ~~ro~~ $r_o = \left.\frac{\Delta V_{CE}}{\Delta I_C}\right|_{I_B = \text{constant}}$

CB configurat^n

$$r_i = \left.\frac{\Delta V_{EB}}{\Delta I_E}\right|_{V_{CB} = \text{constant}}$$

$$r_o = \left.\frac{\Delta V_{CB}}{\Delta I_C}\right|_{I_E = \text{Constant}}$$

*Stability Factor

→The stability factor S is defined as the rate of change of I_C with respect to the reverse saturation current I_{CO}, keeping β & V_{BE} constant

$$S = \frac{\Delta I_c}{\Delta I_{CO}}$$

Stability factor for common base configuration

$$I_C = \alpha I_E + I_{CO} \quad \text{——} \; ①$$

Differentiating eq^n ① we get

$$\frac{dI_C}{dI_{CO}} = 0+1$$

$$\frac{dI_c}{dI_{CO}} = 1$$

$$\Rightarrow \boxed{S = 1}$$

Stability factor for common emitter configuration

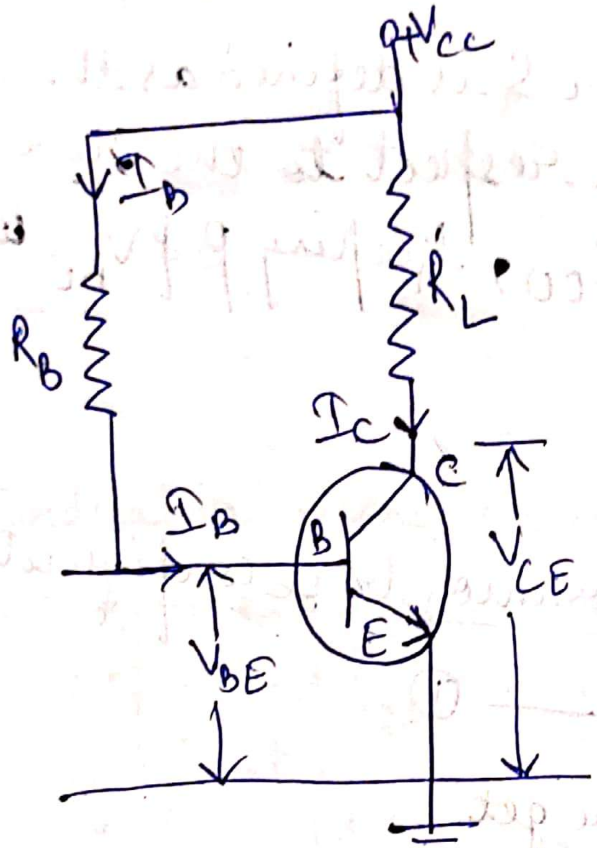
$$I_C = \beta I_B + (1+\beta) I_{CO}$$

$$\cancel{\frac{dI_c}{dI_0}} \; \frac{dI_c}{dI_{CO}} = (1+\beta)$$

$$\boxed{S = 1+\beta}$$

*Different methods for transistor biasing

→ Base resistor method / Fixed bias



Acc to kirchoff's voltage law

$$V_{CC} = I_B R_B + V_{BE}$$

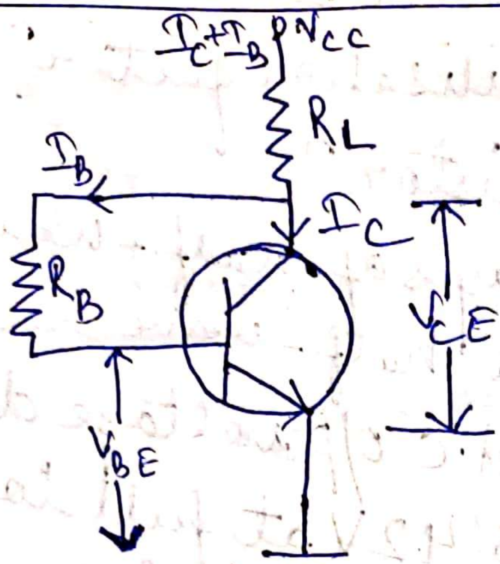
$$R_B = \frac{V_{CC} - V_{BE}}{I_B}$$

$$\Rightarrow I_B = \frac{I_C}{\beta}$$

$$\Rightarrow \boxed{R_B = \frac{(V_{CC} - V_{BE})\beta}{I_C}}$$

Stability factor $\boxed{S = 1+\beta}$

Collector to base bias



*This circuit is same as base bias ~~ex~~ except that base resistor R_B is returned to collector rather than to V_{CC}

circuit analysis

Voltage drop across $R_L = (I_C + I_B) R_L \simeq I_C R_L$

$$V_{CC} = I_C R_L + I_B R_B + V_{BE}$$

$$\Rightarrow R_B = \frac{V_{CC} - I_C R_L - V_{BE}}{I_B}$$

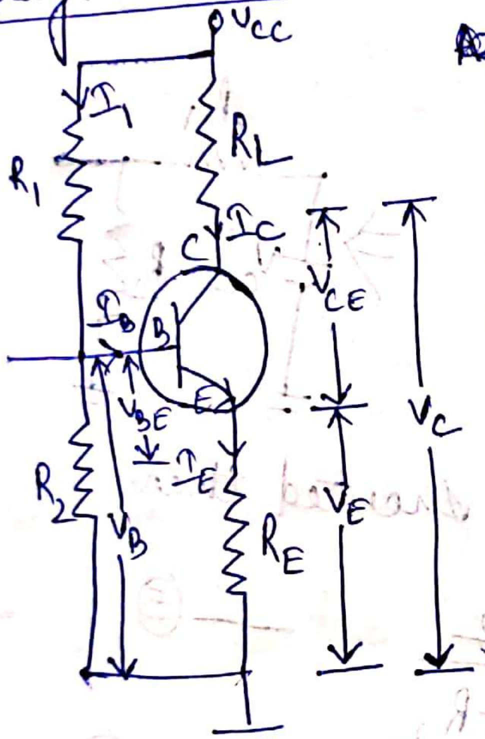
$$I_B = \frac{I_C}{\beta}$$

$$\boxed{R_B = \frac{(V_{CC} - I_C R_L - V_{BE})\beta}{I_C}}$$

Stability factor

$$\boxed{S = \frac{1+\beta}{1+\beta\left(\frac{R_L}{R_L+R_B}\right)}}$$

Voltage divider bias



~~According~~ circuit analysis

Let us assume I_1 flows through R_1. As the base current I_B is very small the current flowing through R_2 can also be taken as I_1

The calculation of I_C is as follows:-

$$I_1 = \frac{V_{cc}}{R_1+R_2} \quad \text{--- ①}$$

The voltage V_2 developed across R_2 is given by

$$V_2 = \left(\frac{V_{cc}}{R_1+R_2}\right)R_2 \quad \text{--- ②}$$

Applying KVL to the base circuit

$$V_2 = V_{BE} + I_E R_E \qquad (I_E \approx I_C)$$

$$V_2 = V_{BE} + I_C R_E$$

$$I_C = \frac{V_2 - V_{BE}}{R_E} \quad \text{--- ③}$$

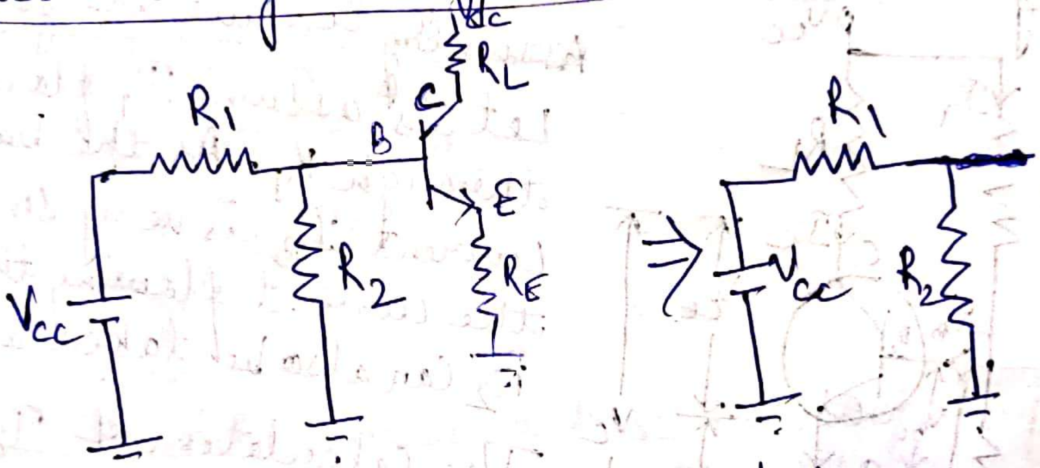
collector emitter voltage can be calculated as:
Applying KVL to the collector side

$$V_{CC} = I_C R_L + V_{CE} + I_E R_E$$

$$= I_C R_L + V_{CE} + I_C R_E$$

$$\Rightarrow V_{CE} = V_{CC} - I_C (R_L + R_E) \quad \text{—— ④}$$

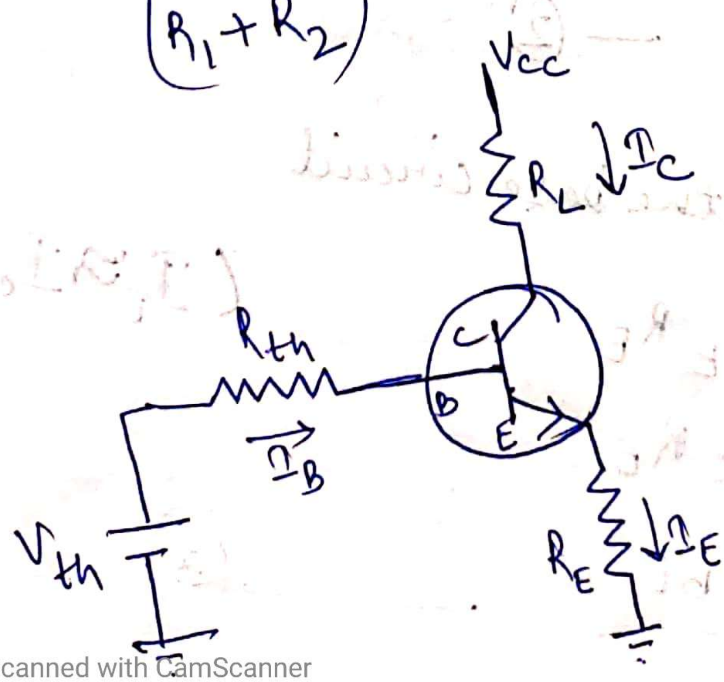
circuit analysis using thevenin theorem



If voltage source is shorted then

$$R_{th} = (R_1 \| R_2) = \frac{R_1 R_2}{R_1 + R_2} \quad \text{—— ⑤}$$

$$V_{th} = \left(\frac{R_2}{R_1 + R_2}\right) V_{CC} \quad \text{—— ⑥}$$



Applying KVL to the base emitter circuit

$$V_{th} = I_B R_{th} + V_{BE} + I_E R_E$$

$$= I_B R_{th} + V_{BE} + (I_B + I_C) R_E \quad — ⑦$$

Applying KVL to emitter-collector circuit

$$V_{CC} = I_C R_L + V_{CE} + (I_B + I_C) R_E$$

$$V_{CE} = V_{CC} - I_C (R_L + R_E) \quad — ⑧$$

From eqⁿ ⑧

$$I_C = \frac{V_{CC} - V_{CE}}{R_L + R_E}$$

substituting value of I_C in eqⁿ ⑦ we have

$$V_{th} = I_B R_{th} + V_{BE} + \left(I_B + \left(\frac{V_{CC} - V_{CE}}{R_L + R_E} \right) \right) R_E$$

$$V_{th} = I_B R_{th} + V_{BE} + I_B R_E + \frac{V_{CC} R_E}{R_L + R_E} - \frac{V_{CE} R_E}{R_L + R_E} \quad — ⑨$$

Stability factor

$$\frac{R_B}{R_E} = \frac{(S-1)(1+\beta)}{(1+\beta-S)}$$

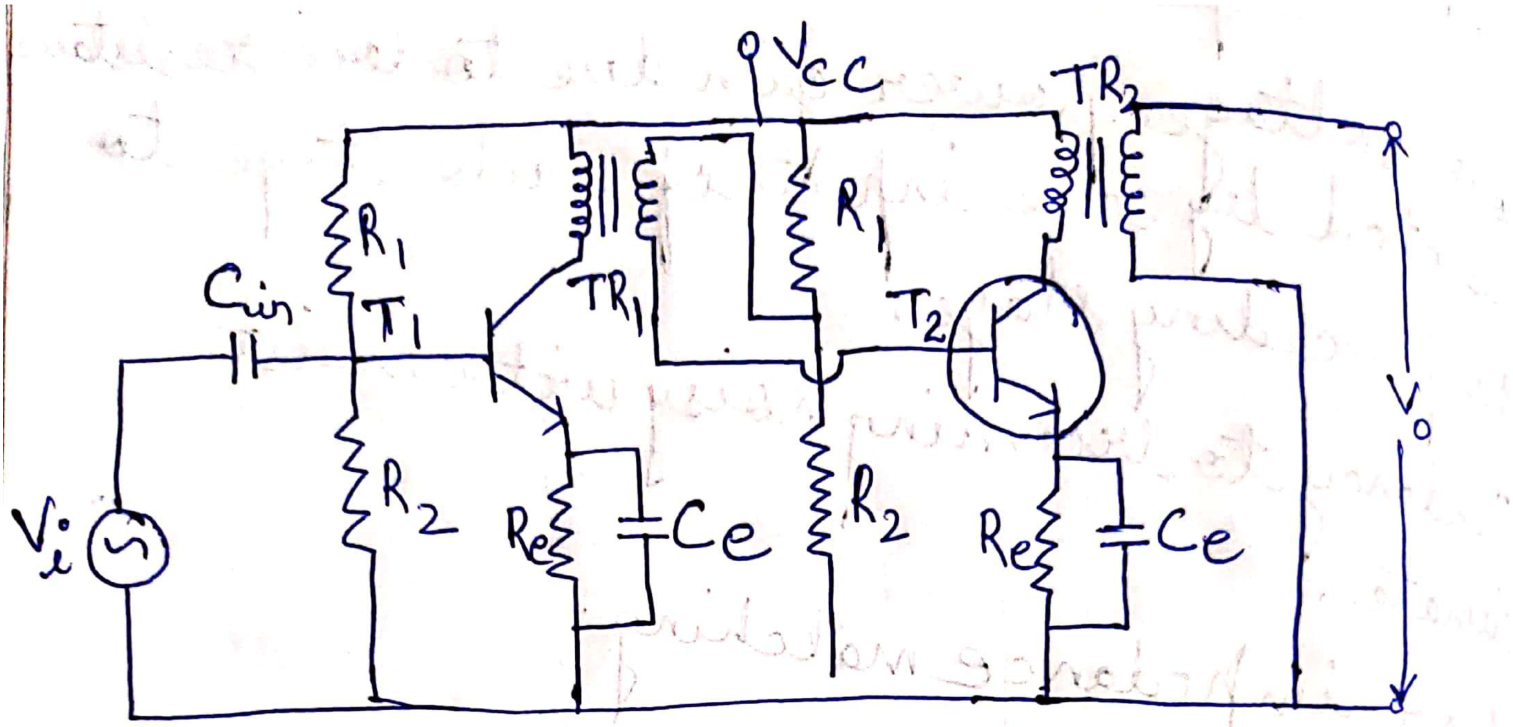
Advantages and disadvantages of RC coupled amplifier

Advantages

- Excellent frequency response
- Very Compact circuit
- cheaper in Cost

Disadvantages

- Low voltage power gain due to low resistance presented by the input of each stage to the preceding stage.
- Tendency to becoming noisy with moist climate.
- Poor impedance matching.



* A Coupling transformer TR1 is used to feed the output of first stage to the input of next stage.

* The collector load is replaced by primary winding of the transformer.

* The secondary is connected between base of the second stage and voltage divider i.e, the secondary of transformer gives input to the next stage.

* The transformer TR 2 is the output transformer. The other components are same as in R-C coupled amplifier.

* There is no coupling capacitor. The d.c isolation between the two stages is provided by the transformer itself.

* When the input is applied to the base of transistor T_1, it is amplified and appears across the primary of transformer TR_1.

* By magnetic induction, it is passed to the secondary of the transformer.

* Now, the output is applied to the base of transistor T_2. The amplified output appears across the primary of the transformer TR_2.

Advantages

* The absence of resistor R_L in the collector circuit eliminates the unnecessary power loss in the resistor.

* The operation of a transformer coupled system is more efficient because of low d.c.

* Due to excellent impedance matching, the transformer coupling provides higher gain.

Disadvantages

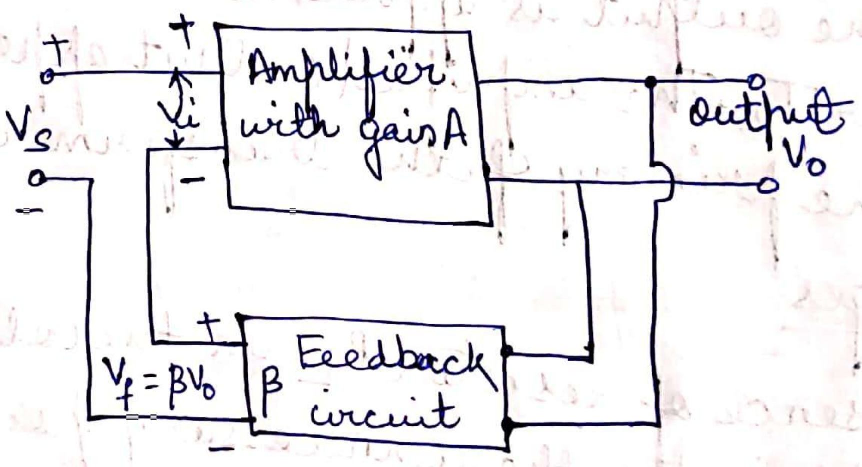
* It has poor frequency response

* The coupling transformer is bulky and costly.

Feedback Amplifiers

Feedback – The process of combining a fract of output energy back to the input is kn as feedback.

General theory of feedback



* The feedback amplifier has two parts i.e amplifier and feedback circuit.

* The feedback circuit usually consists of resistors.

* This returns a fraction (say β) of the output voltage back to the input.

* Let A be the gain of the amplifier i.e the ratio of output voltage V_o to the input voltage V_i. This is the gain of the amplifier without feedback.

* The feedback network extracts a voltage $V_f = \beta V_0$ from the output V_0 of the amplifier.

* $V_i = V_S + V_f = V_S + \beta V_o$ (Positive feedback)

* $V_i = V_S - V_f = V_S - \beta V_o$ (Negative feedback)

* The quantity $\beta = V_f / V_0$ is called as feedback ratio or feedback fraction.

* consider the case of negative feedback. The output V_0 must be equal to the input voltage $(V_S - \beta V_0)$ multiplied by the gain A

$$*(V_S - \beta V_0)A = V_0$$

$$\Rightarrow AV_S - A\beta V_0 = V_0$$

$$\Rightarrow AV_S = V_0(1 + A\beta)$$

$$\Rightarrow \frac{V_0}{V_S} = \frac{A}{1 + A\beta}$$

* Let A_f be the overall gain of the amplifier. This is defined as the ratio of output voltage V_0 to the applied signal voltage V_S

$$A_f = \frac{\text{output Voltage}}{\text{Input voltage}} = \frac{V_o}{V_s}$$

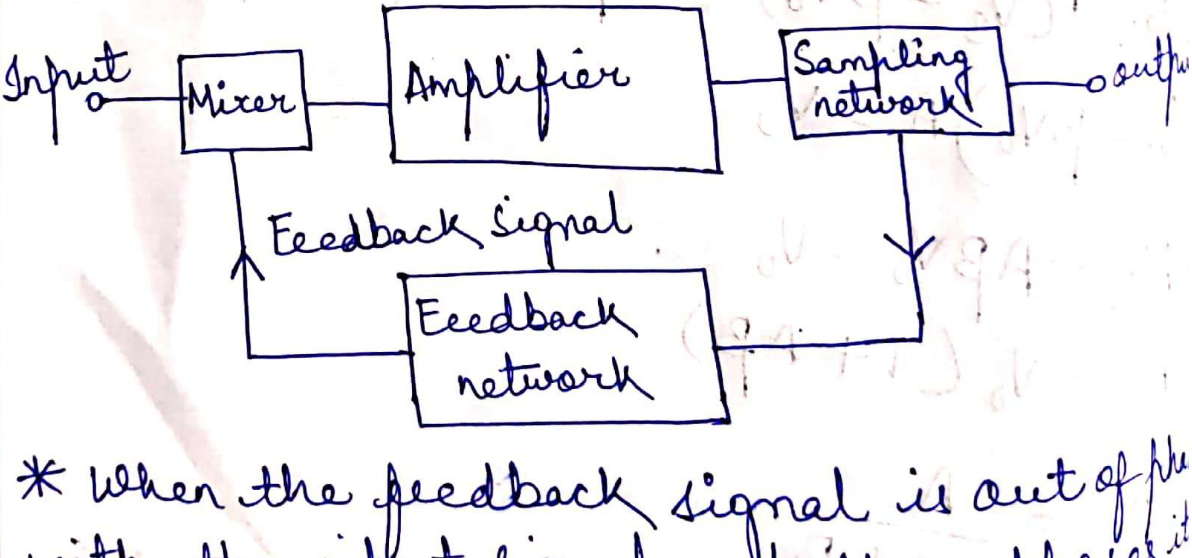
$$* A_f = \frac{A}{1+A\beta}$$ (For negative feedback)

$$* A_f = \frac{A}{1-A\beta}$$ (For positive feedback)

* Consider the following three cases

- For negative feedback $A_f < A$
- For positive feedback $A_f > A$

Negative feedback circuit



* When the feedback signal is out of pha with the input signal and thus opposes it then the feedback is called negative feedback

* The negative feedback amplifier introduces a phase shift of 180° in the input while the feedback network introduces no phase shift.

* There are two types of negative feedback circuits i.e

(a) <u>Negative voltage feedback</u> - In this method, the voltage feedback to the input of amplifier is proportion to the output voltage. This is further classified into following two categories:

(i) Voltage - series feedback

(ii) Voltage - shunt feedback

(b) <u>Negative current feedback</u> - In this method, the voltage feedback to the input of the amplifier is proportional to output current. This is further classified into following two categories:-

(i) current - series feedback

(ii) current - shunt feedback

Advantages of negative feedback

(i) Stabilization of gain
(ii) Reduction in distortion
(iii) Reduction in noise
(iv) Change in input impedance
(v) Change in output impedance
(vi) Increase in bandwidth.

Power amplifier

* The power amplifiers are large signal amplifiers which raise the power level of the signals. It is a device which converts d.c pauer to a.c power and whose action is controlled by the input signal.

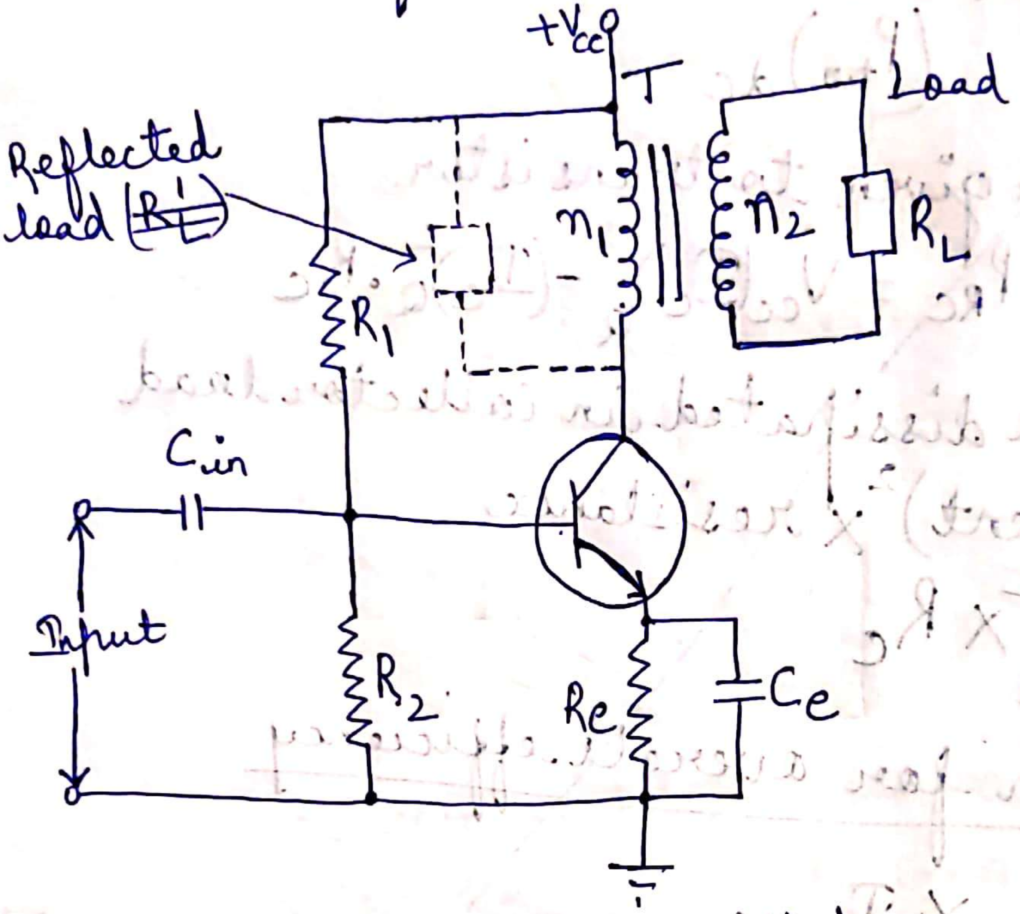
* On the basis of the mode of operation, the power amplifiers may be classified as

(i) Class A power amplifier
(ii) Class B power amplifier
(iii) Class C power amplifier

Difference between voltage amplifier and power amplifier

Characteristic	Voltage amplifier	Power amplifier
β	high	low
R_C	high	low
Input voltage	low	high
Power output	low	high
Collector current	low	high
output impedance	high	low
Coupling	usually R-C coupling	invariably transformer or tuned circuit

Transformer coupled class A amplifier



R_L' = effective input resistance

$$= \frac{V_1}{I_1}$$

R_L = effective output resistance

$$= \frac{V_2}{I_2}$$

$$R_L' = \left(\frac{n_1}{n_2}\right)^2 R_L = n^2 R_L$$

$$n = \frac{\text{number of turns in primary}}{\text{number of turns in secondary}} = \frac{n_1}{n_2}$$

$$(\eta)_{collector} = \frac{(P_o)_{ac}}{(P_{tr})_{dc}}, \quad (P_{tr})_{dc} = V_{cc} \times (I_c)_Q$$

$$(P_o)_{ac} = V_{rms} \times I_{rms} = \frac{V_{cc}}{\sqrt{2}} \times \frac{(I_c)_Q}{\sqrt{2}}$$

$$V_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max} - (V_{ce})_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(V_{ce})_{max}}{2}\right]$$

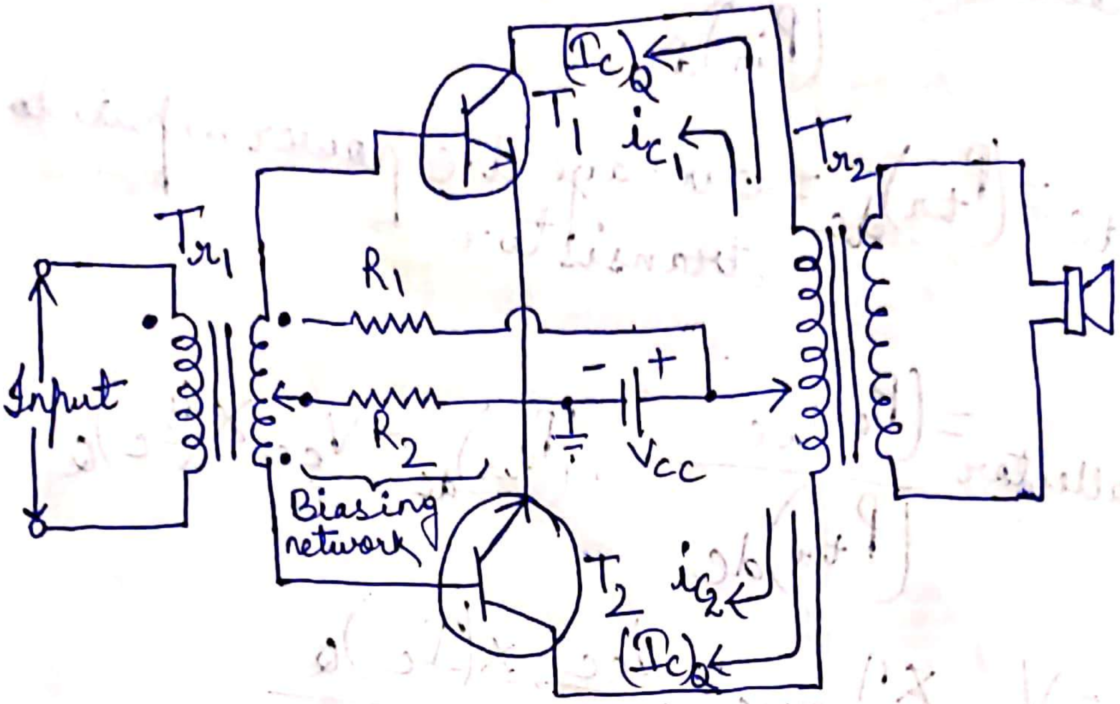
$$= \frac{2V_{cc}}{2\sqrt{2}} = \frac{V_{cc}}{\sqrt{2}}$$

$$I_{rms} = \frac{1}{\sqrt{2}}\left[\frac{(I_c)_{max} - (I_c)_{min}}{2}\right] = \frac{1}{\sqrt{2}}\left[\frac{(I_c)_{max}}{2}\right]$$

$$= \frac{2(I_c)_Q}{2\sqrt{2}} = \frac{(I_c)_Q}{\sqrt{2}}$$

$$(\eta)_{collector} = \frac{V_{cc} \times (I_c)_Q}{2 \times V_{cc} \times (I_c)_Q} = \frac{1}{2} = 50\%$$

Class-A push pull amplifier



Circuit arrangement

* Two identical transistors T_1 and T_2 are used. The emitter terminals of the two transistors are connected together.

* The input signal is applied to the inputs of two transistors through centre tapped transformer, Tr_1. This transformer provides opposite polarity signals to the two transistor inputs.

* The collectors of both the transistors are connected to the primary of output transformer Tr_2

* The collector terminals of the two transistors are connected to the supply V_{cc} through the primary of output transformer.

* Resistors R_1 & R_2 provide biasing arrangement

circuit operation

* The two transistors T_1 & T_2 carry d.c components of collector currents $(I_C)_Q$. These currents are equal in magnitude and flow in opposite directions through the primary of transformer T_2.

* When the input signal voltage is positive, the base of transistor T_1 is more positive while the base of transistor T_2 is less positive

* Hence the collector current i_{c_1}, of transistor T_1 increases while the collector current i_{c_2} of transistor T_2 decreases.

* These currents flow in opposite directions in two halves of the primary of output transformer.

* Similarly, for the negative input signal, the collector current i_{c_2} will be more than i_{c_1}.

* The voltage developed across the load will again be due to the difference $(i_{c_2} - i_{c_1})$

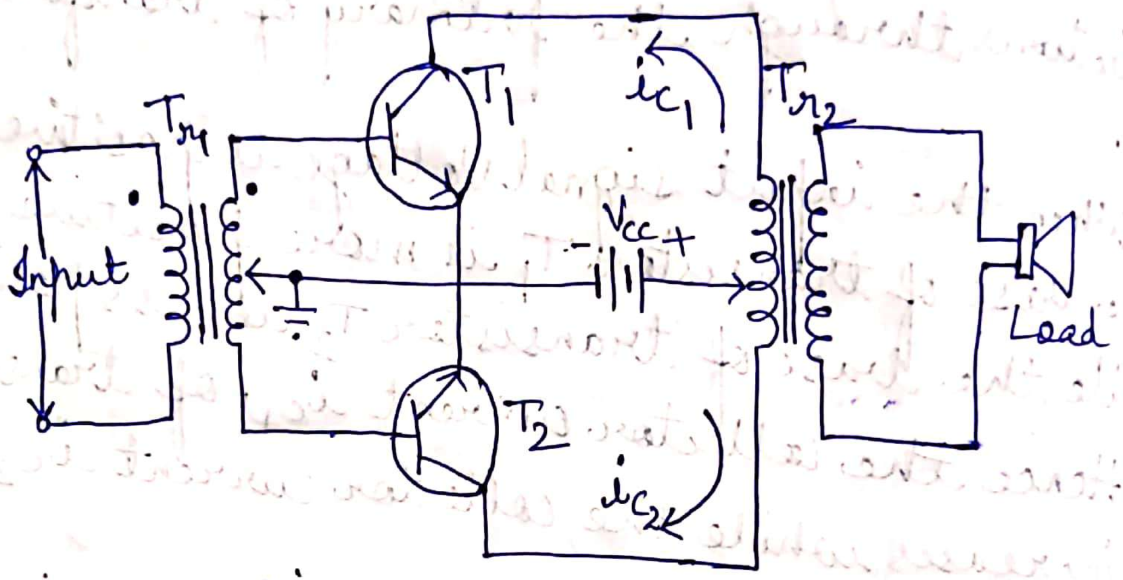
* The difference of two collector currents is

$$i_{c_1} - i_{c_2} = i_{c_1} + (-i_{c_2})$$

* It is obvious that during any given half cycle of input signal, one transistor is

being driven (or pushed) into conductio while the other being non-conducting (pull out). Hence, the name push-pull amplifier.

Class B push-pull amplifier



Circuit operation

* When no signal is applied, both the transistors are cut-off. Hence, no current is drawn from supply source V_{cc}.

* When the input signal is applied, the transformer T_{r_1} produces two signals which are 180° out of phase with each other.

* The transistors T_1 and T_2 are driven by these two signals

* During positive half cycle of the signal, transistor T_1 conducts because its base is driven positive. Now, collector current i_{c_1} flows.

* Transistor T_2 does not conduct because its base is negative. Thus, i_{c_2} is zero.

* During negative half of the input signal, transistor T_2 conducts and allows a current i_{C_2} to flow, while transistor T_1 becomes non-conducting.

Oscillators

* An Oscillator is a device which generates an alternating voltage. It may also be defined as a circuit which generates an a.c output signal without requiring any externally applied input signal.

Types of oscillators

* According to the nature of generated waveform:-

(i) Sinusoidal or harmonic oscillator - The oscillators which produce sinusoidal or nearly a sinusoidal waveform of a definite frequency are known as sinusoidal oscillators

(ii) Relaxation or non-sinusoidal oscillator → The oscillators which produce square waves, triangular waves, pulses or sawtooth waves are known as relaxation oscillators.

* According to the frequency of generated signals

(i) <u>Audio frequency oscillators</u> → The oscillators which generate signals in the audio frequency range are known as audio frequency oscillators.

(ii) <u>Radio frequency oscillator</u> → The oscillator which generate signals in the radio frequency range are called radio frequency oscillators.

*Sinusoidal oscillators may be further subdivided into following categories:-

(i) <u>Tuned circuits or LC feedback ~~circuits~~ oscillators</u> -

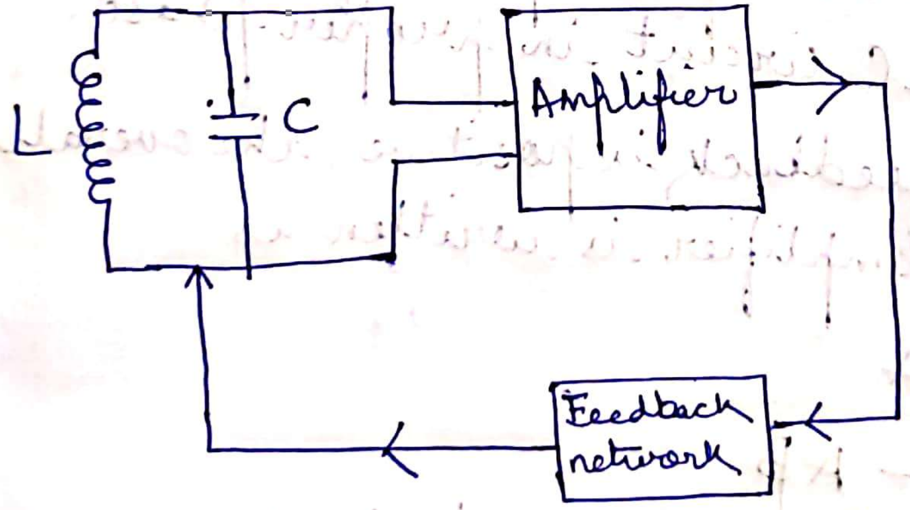
Oscillators using tuned circuits are known as LC feedback oscillators. Ex- Tuned collector, Harley, Colpitts etc.

(ii) <u>RC phase shift oscillators</u> → Oscillators using RC network are known as RC phase shift oscillators. Ex- phase shift oscillator and Wein-bridge oscillator.

(iii) Negative resistance oscillator → The oscillators which use an active device that possesses a current voltage characteristic curve of negative slope within some range of operation are known as negative resistance oscillators. Ex - tunnel diode oscillator

(iv) Crystal oscillators → when Piezoelectric crystals are used in place of LC ~~or~~ circuit for higher frequency stability, the oscillators are called as ~~cr~~ crystal oscillators.

* Essentials of transistor oscillator



(i) Tank circuit → The tank circuit consists of an inductance L connected in parallel with capacitor C. It is known as frequency determining network. The frequency of oscillations in the circuit depends upon the values of inductance and capacitance.

(ii) Transistor amplifier → The function of the amplifier is to amplify the oscillations produced by L C circuits. The amplifier receives d.c power from battery and converts it into a.c power for supplying to the tank circuit. The oscillations produced in tank circuit are applied to the input of the transistor. The transistor increases the output of these oscillations.

(iii) Feedback circuit → The function of feedback circuit is to transfer a part of the output energy to LC circuit in proper phase.

When the feedback is positive, the overall gain of the amplifier is written as

$$A_f = \frac{A}{1 - A\beta}$$

$A\beta$ = feedback factor or loop gain.

* If $A\beta = 1$, $A_f = \infty$. Thus the gain becomes infinity i.e there is output without any

input. The condition $A\beta = 1$ is known as Barkhausen criterion of oscillation.

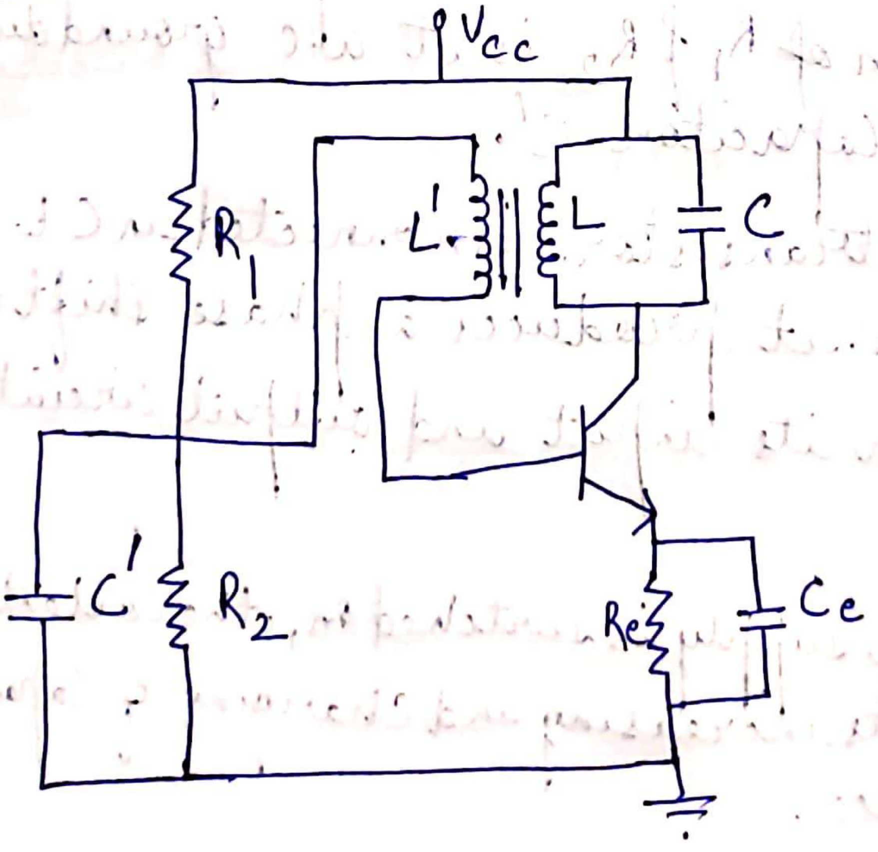
Barkhausen Criterion of oscillation

It states that:-

1) The total phase shift around the loop, as the signal proceeds from input through amplifier, feedback network and back to input again, is precisely 0° or 360°

2) The magnitude of the product of the open loop gain of amplifier A and feedback factor β is unity i.e. $A\beta = 1$.

Tuned Collector oscillator



* The Capacitance C and L form the tank circuit. As the tank circuit is connected in the collector circuit, the oscillator is known as tuned collector oscillator.

* The resistors R_1, R_2 and Re are used to d.c bias of the transistor.

* Capacitors C_e & C' are bypass capacitor They bypass resistances R_e and R_2 respectivel so that they have no effect on the a.c operation of the circuit.

* The secondary of the transformer provide a.c feedback voltage. The feedback voltage appears across base-emitter junction becau the junction of R_1 & R_2 is at a.c ground due to bypass capacitor C'.

* As the transistor is connected in CE configuration it produces a phase shift of 180° between its input and output circuit.

<u>Working</u>

* When the supply is switched on, the collector current starts increasing and charging of capacito C takes place.

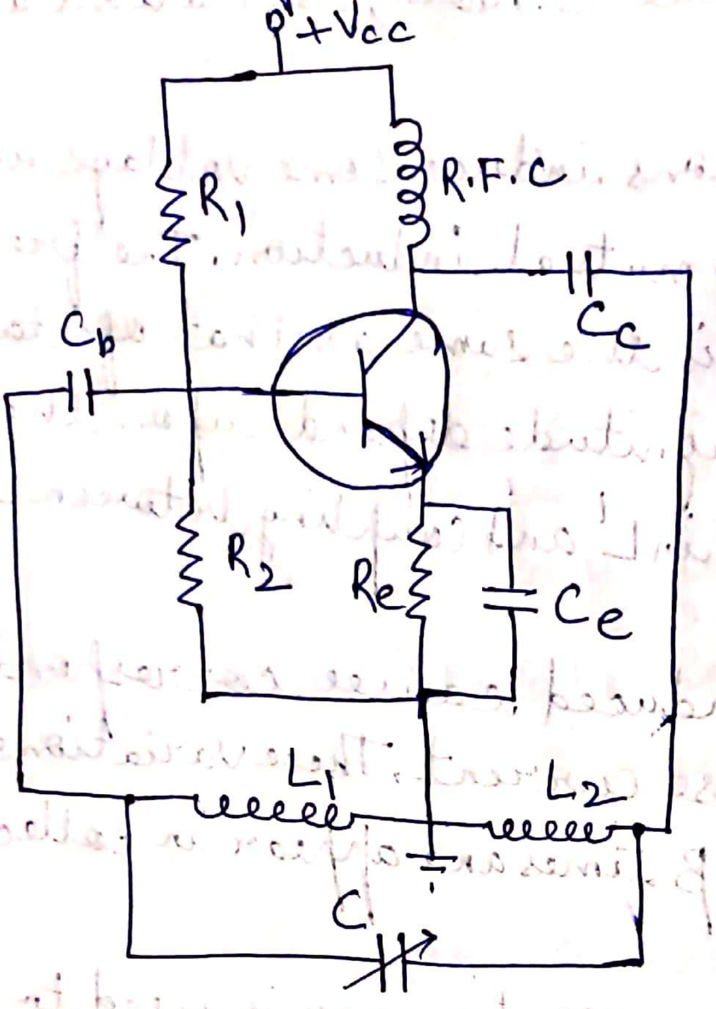
* when the capacitor is fully charged, it discharges through inductance L. Now, oscillations are produced.

* These oscillations induce some voltage in inductance L' by mutual induction. The frequency of voltage in L' is the same as that of tank circuit and its magnitude depends upon the number of turns in L' and coupling between L and L'.

* The voltage induced causes corresponding variations in base current. These variations in I_B are amplified β times and appear in collector circuit.

* A part of the amplified energy is used to overcome the losses of tank circuit and rest is radiated in the form of electromagnetic waves.

Hartley oscillator



* Hartley oscillator is very popular and is commonly used as a local oscillator in radi receivers.

* The resistors R_1, R_2 and R_e provide necess bias conditions for the circuit.

* Capacitor Ce provides a.c ground thereby preventing any signal degeneration.

* The Radio Frequency Choke (R.F.C) offers ver high impedance to high frequency currents i.e acts like a d.c short and a.c open. Thus, it provides dc load for collector and keeps a.c currents out of d.c supply source.

* The function of C_c and C_b to block d c and to provide an a.c path.

* The frequency determining network is a parallel resonant circuit consisting of inductors L_1 & L_2 and variable capacitor C.

Working

* when the collector supply voltage is switched On, a transient current is produced in the tank circuit. The oscillatory current in the tank circuit produces a.c voltage across L_1.

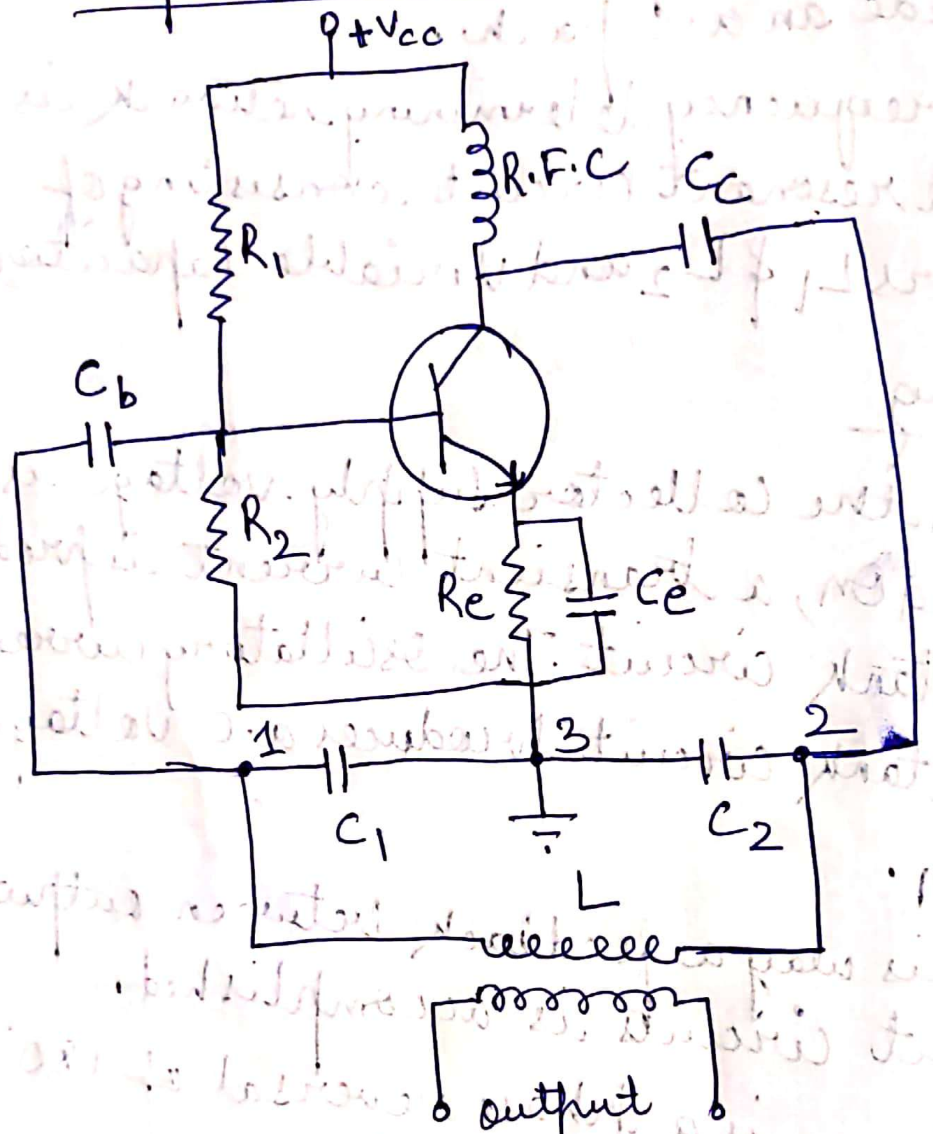
* In this way a feedback between output and input circuits is accomplished.

* So, there is a phase reversal of 180° between output and input.

* The common-emitter amplifier also produces a further 180° phase shift between input and output voltages.

* Thus, total phase shift becomes 360°. This makes the feedback positive which is the essential condition for oscillations.

Colpitt's oscillator



* The frequency determining network is a para resonant circuit consisting of Capacitors C_1 a C_2 and the inductor L.

Working

* When the collector supply voltage i switched on, a transient current is produ in the tank circuit.

* The oscillations across C_1 are applied to the base emitter junction and appear in th amplified form in the collector circuit an

supply losses to the tank circuit.

*If terminal 1 is at positive potential with respect to terminal 3 at any instant, then terminal 2 will be at negative potential with respect to 3 at that instant because terminal 3 is grounded.

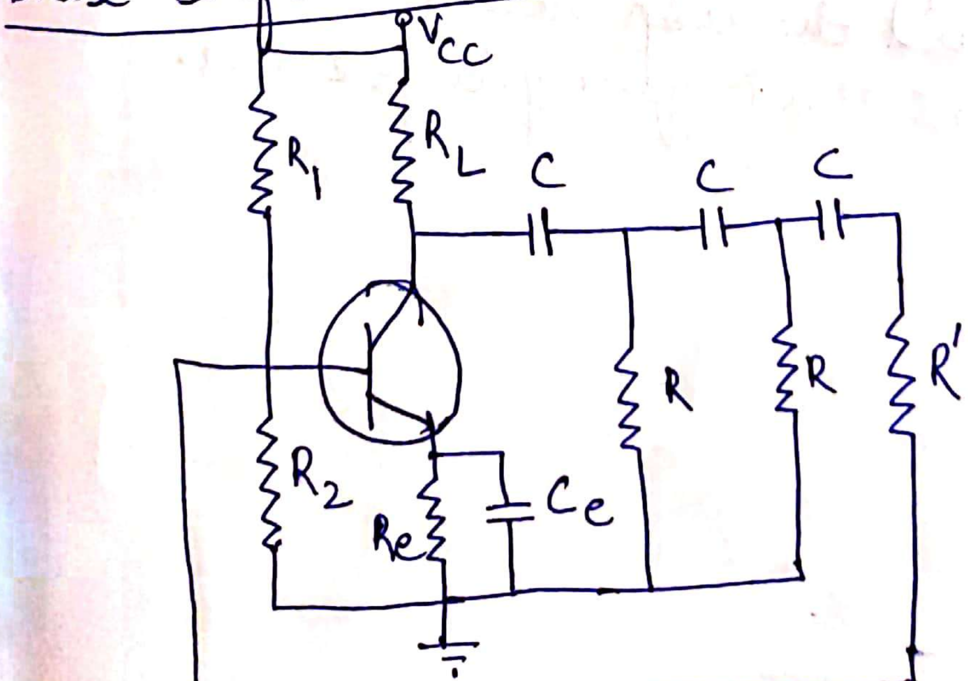
*Therefore, points 1 and 2 are 180° out of phase.

A further phase shift of 180° is produced by the transistor.

*In this way, feedback is properly phased to produce continuous undamped oscillations.

*In other words, energy is supplied to the tank circuit in phase with the oscillations and if Aβ is greater than one, oscillations are sustained in the circuit.

Phase-shift oscillator



*$R_1 - R_2$ provides dc emitter base bias. R_L is the load which controls the collector voltage.

*$R_e - C_e$ combination provides temperature stability and prevents ac signal degeneration.

*The output of the amplifier goes to a feedback network which consists of three identical R-C sections.

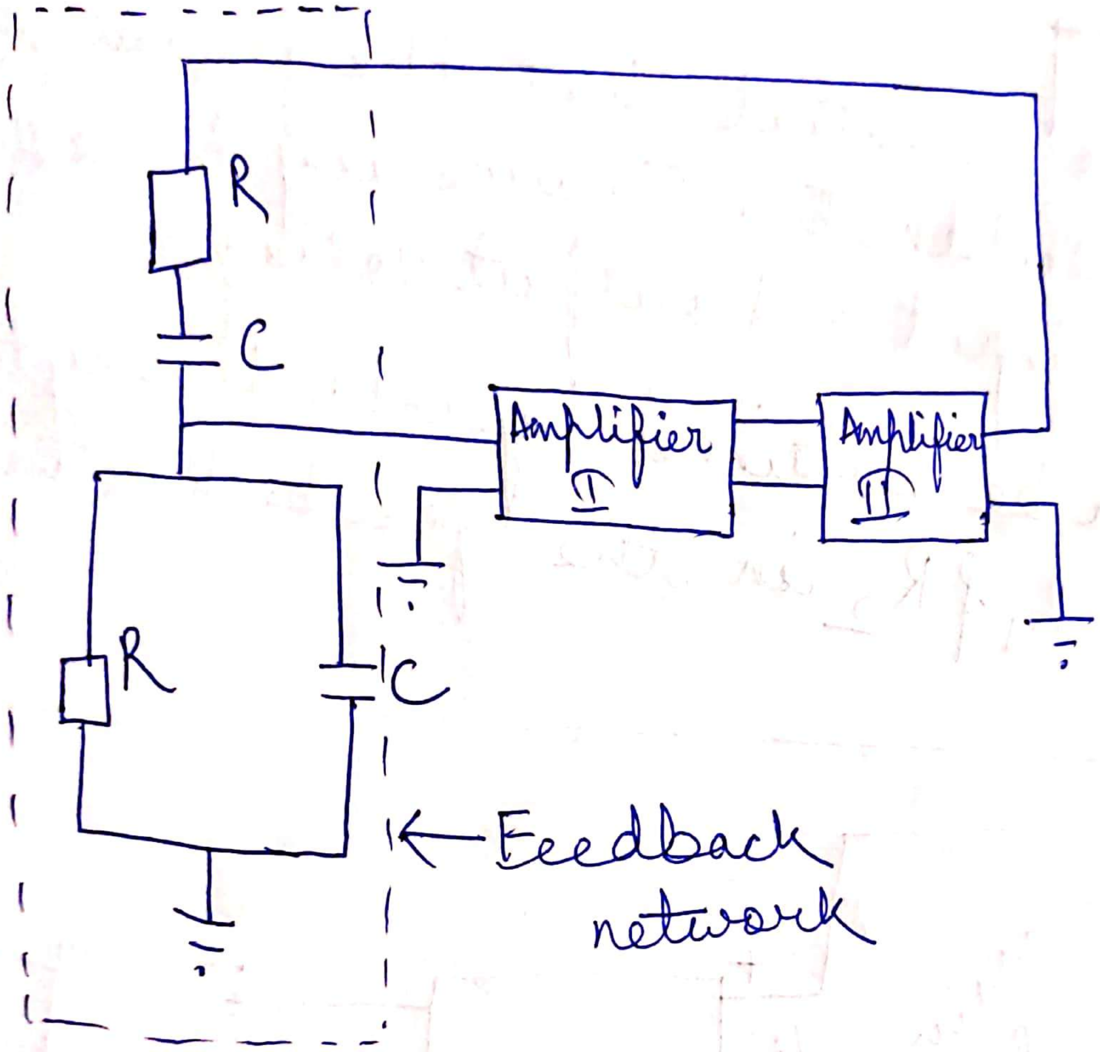
Working

* Here R-C network produces a phase shift of 180° between input and output voltages. Since C-E amplifier produces a phase of 180°, the total phase change becomes 360° or 0° which is the essential requirement of sustained oscillations

*The RC phase shift networks serve as frequency determining circuit.

* Since, Only at a single frequency the net phase shift around the loop will be 360°, a sinusoidal waveform at this frequency is generated.

Wein - Bridge Oscillator



(fig-1)

* The oscillator consists of two stages of R-C coupled amplifier and a feedback network.

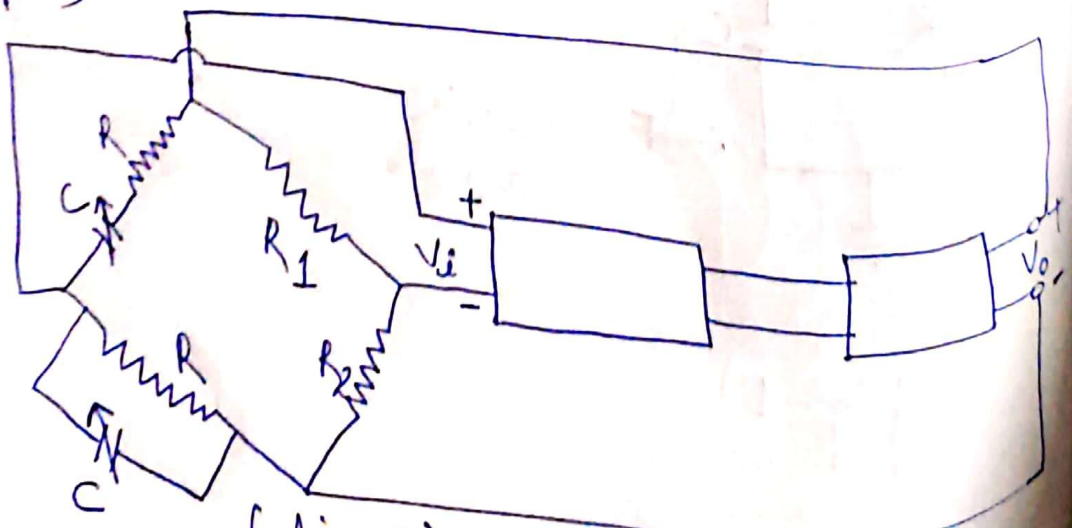
* The voltage across the parallel combination of R and C is fed to the input of amplifier I.

* The output of amplifier II is not fed to amplifier I because amplifier I will amplify signals over a wide range of frequencies and hence the direct coupling would result in poor frequency stability.

~~* By adding~~

* It is now essential that the feedback network shouldnot introduce any phase shift between its input and output voltages.

* This can be obtained by introducing two resistances R_1 & R_2 in the feedback network (fig-2)



(fig-2)

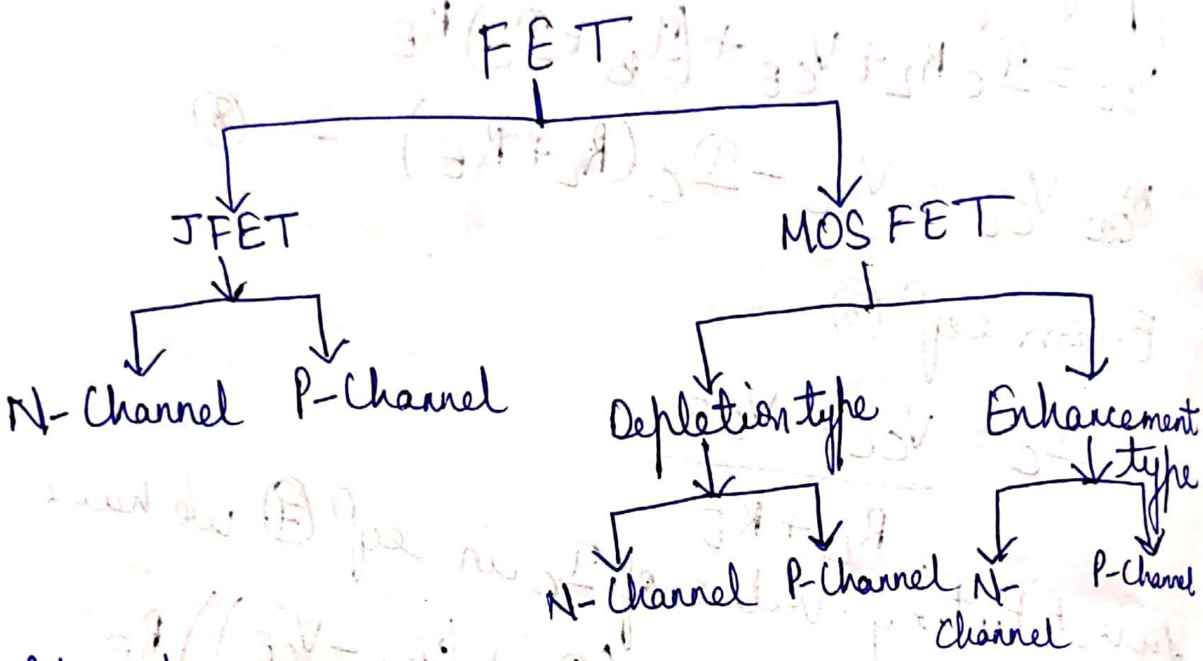
* We can vary the frequency of this oscillator by varying the two capacitors simultaneously.

* The range of the frequency of the oscillator can be changed by using different values of resistors R.

Field effect transistors

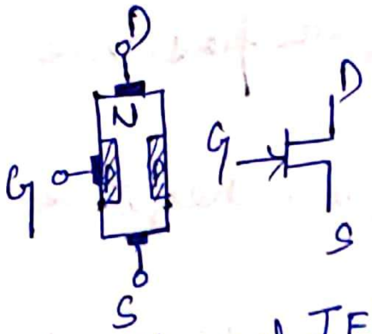
* FET is a three terminal unipolar semiconductor device in which current is controlled by an electric field.

* Classification of FET

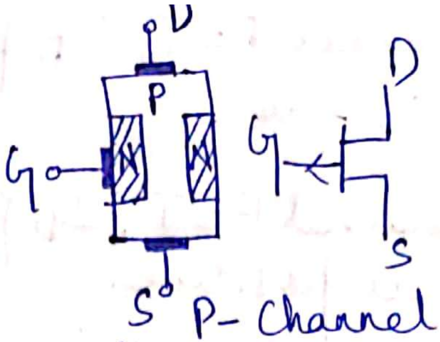


Advantages of JFET over BJT

JFET	BJT
1) Unipolar device (current conduction is only due to one type of carrier either electron or hole).	1) Bipolar device (current conduction by both types of carriers i.e electron & hole).
2) Voltage driven device	2) current driven device
3) Low noise level	3) high noise level
4) High input impedance	4) low input impedance
5) Gain is characterised by transconductance	5) Gain is characterised by voltage gain.
6) Better thermal stability	6) Less thermal stability.



N-Channel JFET



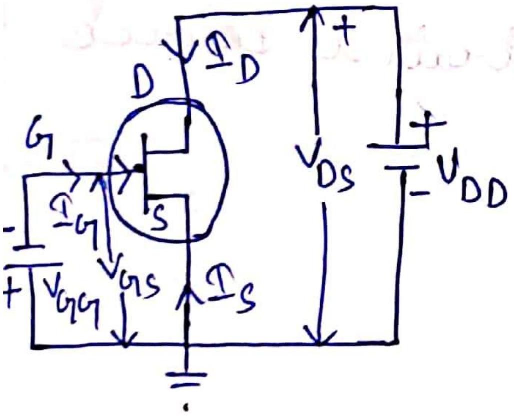
P-Channel JFET

Source - The Source S is a terminal through which the majority carriers enter the bar.

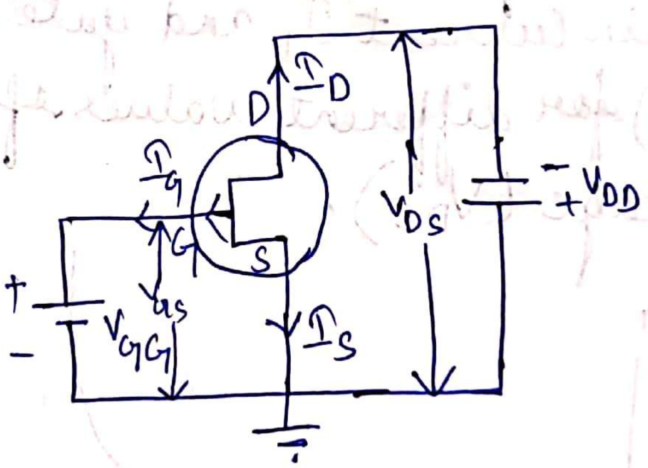
Drain - The drain D is a terminal through which the majority carriers leave the bar.

Gate - These are two internally connected heavily doped impurity regions which form two P-N junctions

Channel - The space between two gates through which majority carriers pass.



N-Channel



* Assumed positive directions of I_S, I_G & I_D are into the FET

* The direction of arrow at the gate indicates the direction in which the gate current flows when gate junction is forward biased.

* For N-Channel FET, I_D & V_{DS} are positive while V_{GS} is -ve.

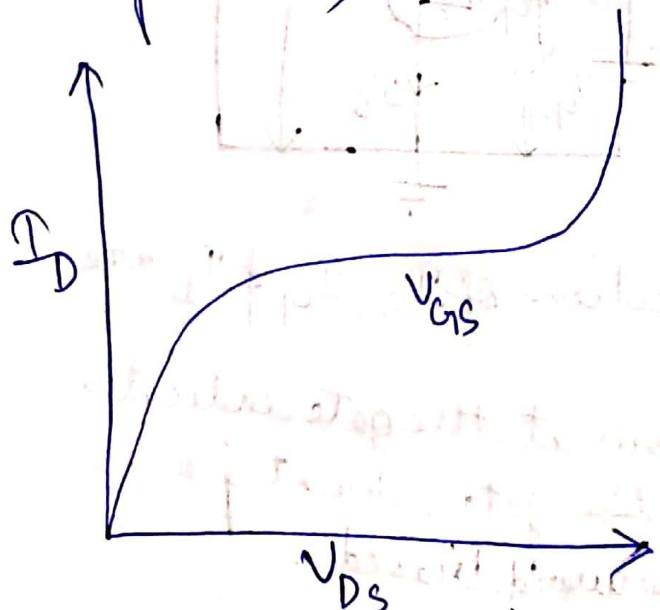
* For P-Channel FET, I_D & V_{DS} are negative while V_{GS} is positive.

* The source, gate and drain of FET correspond to emitter, base and collector of a bipolar transistor.

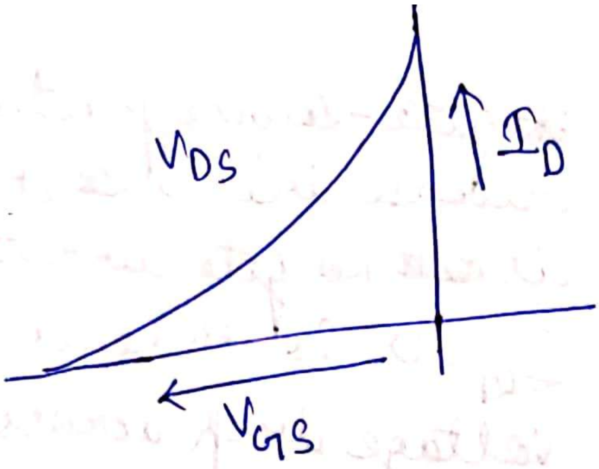
Characteristics of JFET

* **Drain Characteristics** → The curves between drain current (I_D) and drain to source Voltage (V_{DS}) for different values of gate to source voltage (V_{GS}).

* **Transfer Characteristics** → The curve between drain current I_D and gate to source voltage (V_{GS}) for different values of drain to source voltage (V_{DS}).



Drain Characteristic



FET parameters

* D.C drain resistance (R_{DS})

$$\boxed{R_{DS} = \frac{V_{DS}}{I_D}}$$

* A.C drain resistance (r_d)

$$\boxed{r_d = \left(\frac{\Delta V_{DS}}{\Delta I_D}\right)_{V_{GS}=\text{constant}}}$$

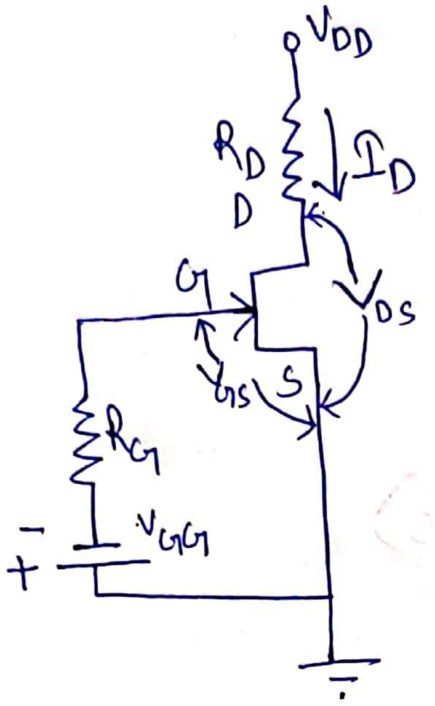
* Transconductance

$$\boxed{g_{fs} = \left(\frac{\Delta I_D}{\Delta V_{GS}}\right)_{V_{DS}=\text{Constant}}}$$

Biasing of FET circuits

1) Fixed-bias
2) Self bias
3) Current-source
4) Voltage-divider

Fixed bias



* gate-source junction is reverse biased so there is no gate current I_G $I_G = 0$. So, there is no voltage drop across R_G

Applying KVL to the i/p circuit we have

$$V_{GG} + V_{GS} = 0$$

$$V_{GS} = -V_{GG}$$

The drain current is given by

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_p}\right)^2$$

I_{DSS} - Drain current when gate is shorted to source.

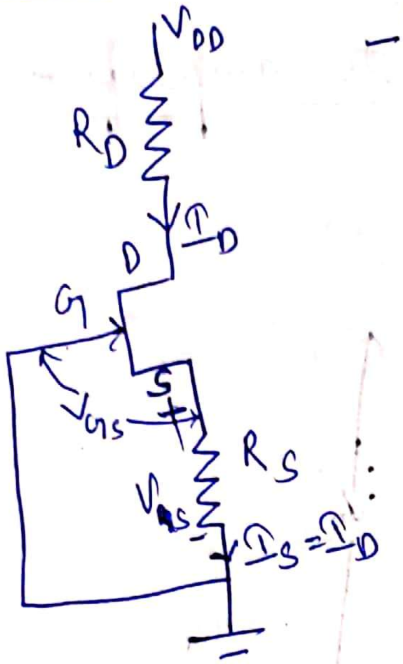
V_p = Pinch-off voltage.

Applying KVL to o/p ckt

$$V_{DD} = I_D R_D + V_{DS}$$

$$\Rightarrow \boxed{V_{DS} = V_{DD} - I_D R_D}$$

Self bias



~~$-V_{GS} - V_{RS} = 0$~~ $V_S = I_D R_S$

~~$V_{GS} = -V_{RS}$~~

~~$V_{GS} = -I_D R_S$~~

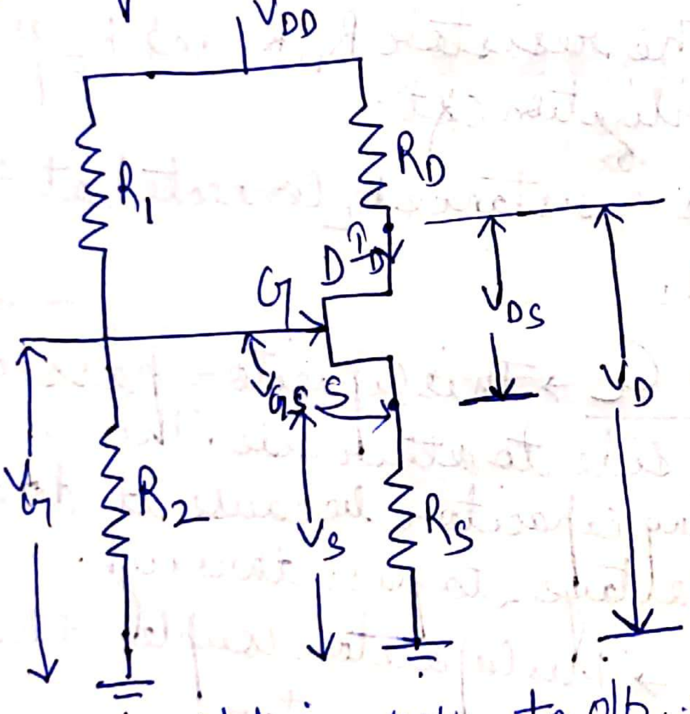
$V_G = I_G R_G = 0$

~~$V_{GS} = V_G - V_S = 0 - I_D R_S$~~

$V_S = V_G - V_{GS}$

$V_{GS} = V_G - V_S = 0 - I_D R_S$

Voltage divider bias



$V_G = \left(\frac{V_{DD}}{R_1 + R_2}\right) R_2$ —①

$V_S = V_G - V_G S$

$I_D R_S = V_G - V_{GS}$

$V_{GS} = V_G - I_D R_S$ —②

$$\boxed{I_D = \frac{V_S}{R_S} = \frac{V_G - V_{GS}}{R_S}}$$

Applying KVL to o/p side

~~$V_{DD} = I_D R_D + V_{DS} + I_D R_S$~~

~~$= V_{DS} +$~~

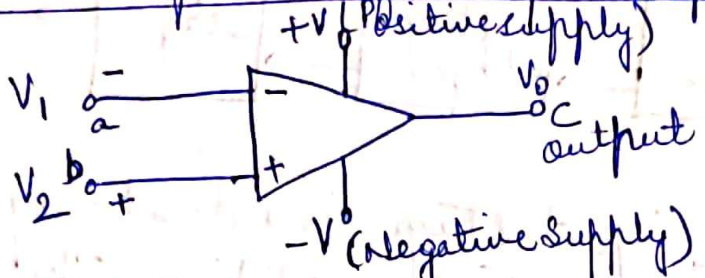
$V_{DD} = I_D R_D + V_{DS} + I_D R_S$

$$\boxed{V_{DS} = V_{DD} - I_D (R_D + R_S)}$$

Operational Amplifiers

*The operational amplifier is a direct-coupled, high gain, negative feedback amplifier.

circuit symbol of an op-amp



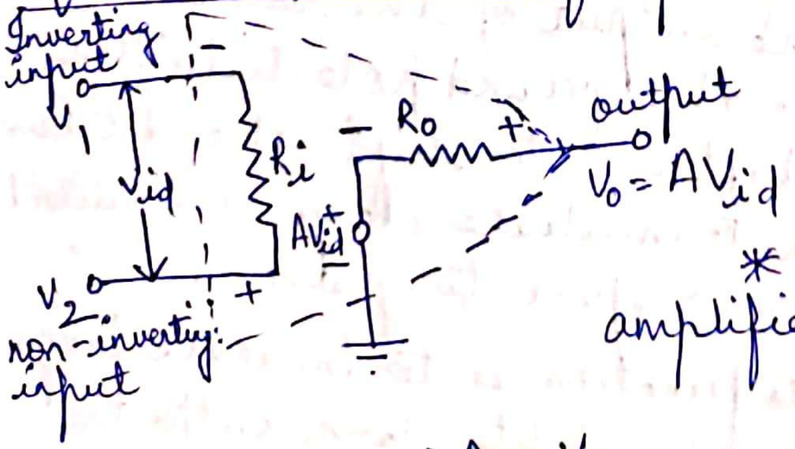
* OP-Amp has two input terminals and a single output terminal.

*Terminal a is the inverting terminal which indicates that a signal applied at the terminal a will appear amplified but phase inverted at terminal c

* Terminal b is called as non-inverting terminal which indicates that a signal applied at the terminal b will appear amplified but in phase at terminal c.

*The two d.c sources, named as +V & −V are required for biasing of op-amp. These voltages are equal in magnitude with opposite polarities.

Equivalent circuit of op-amp



*The difference i/p voltage

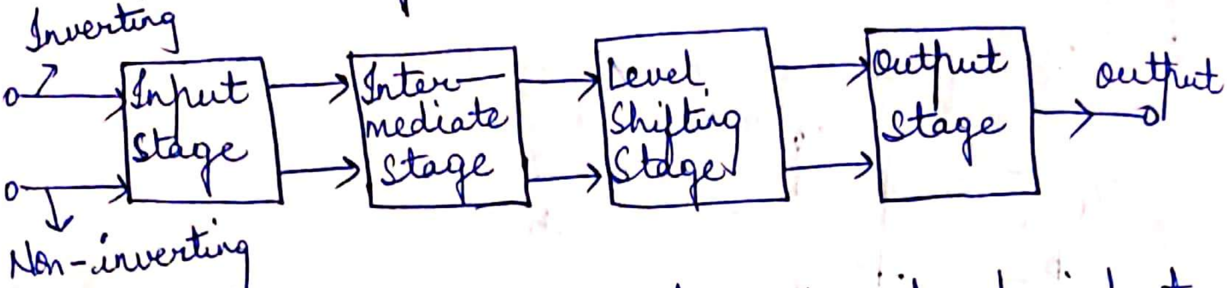
$V_{id} = V_2 - V_1$

* The gain of the amplifier $A = \frac{\text{output}}{\text{difference between two i/p signals}}$

$\Rightarrow A = \frac{V_o}{V_2 - V_1}$

$\Rightarrow A = \frac{V_o}{V_{id}}$ $\Rightarrow \boxed{V_o = A V_{id}}$

* OP-AMP stages



→ <u>Input Stage</u> → The input stage is a dual-input, balanced output differential amplifier. The function of differential amplifier is to provide most of the voltage gain to OP-AMP. The differential amplifier in the input stage rejects the common noise signals present at the input terminals and amplifies only the difference between the input signals.

→ <u>Intermediate stage</u> → It is a dual input, unbalanced output differential amplifier. This is driven by output of first stage and is used to provide some additional gain. There is a direct coupling between the first two stages.

→ <u>Level shifting stage</u> → As direct coupling is used, the d.c at the output of the intermediate stage is well above the ground potential. The function of level shifter is to shift the d.c level at the output of intermediate stage downwards to zero volt with respect to ground.

<u>output stage</u> → Its function is to increase large output voltage swing capability, large output

current swing capability of the amplifier and to provide low output resistance.

* Open-loop OP-AMP configurations

→ when there exists no connection between the output and input terminals of OP-AMP, then it is known as open loop OP-AMP.

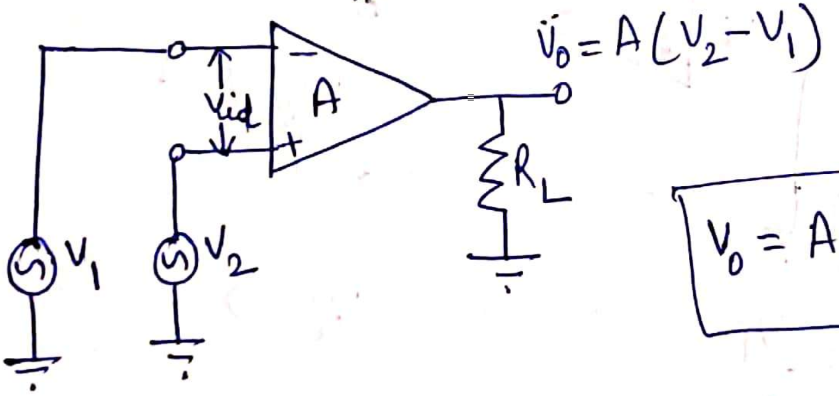
There are 3 open-loop configurations

a) Differential amplifier b) Inverting amplifier

c) Non-inverting amplifier.

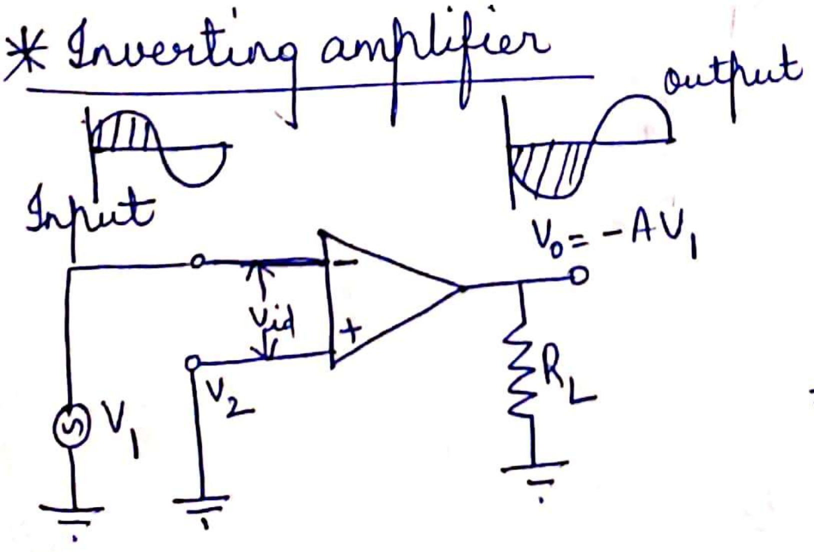
* Differential amplifier

→ As the OP-AMP amplifies the difference between two input signals and hence this configuration is called as differential amplifier.



$$\boxed{V_0 = AV_{id} = A(V_2 - V_1}$$

* Inverting amplifier

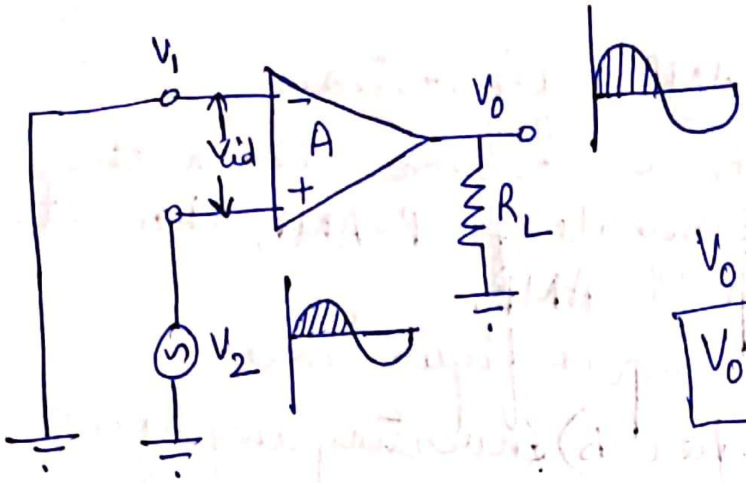


$V_2 = 0$

$V_0 = AV_{id} = A(V_2 - V_1)$

$$\Rightarrow \boxed{V_0 = -AV_1}$$

* Non-inverting

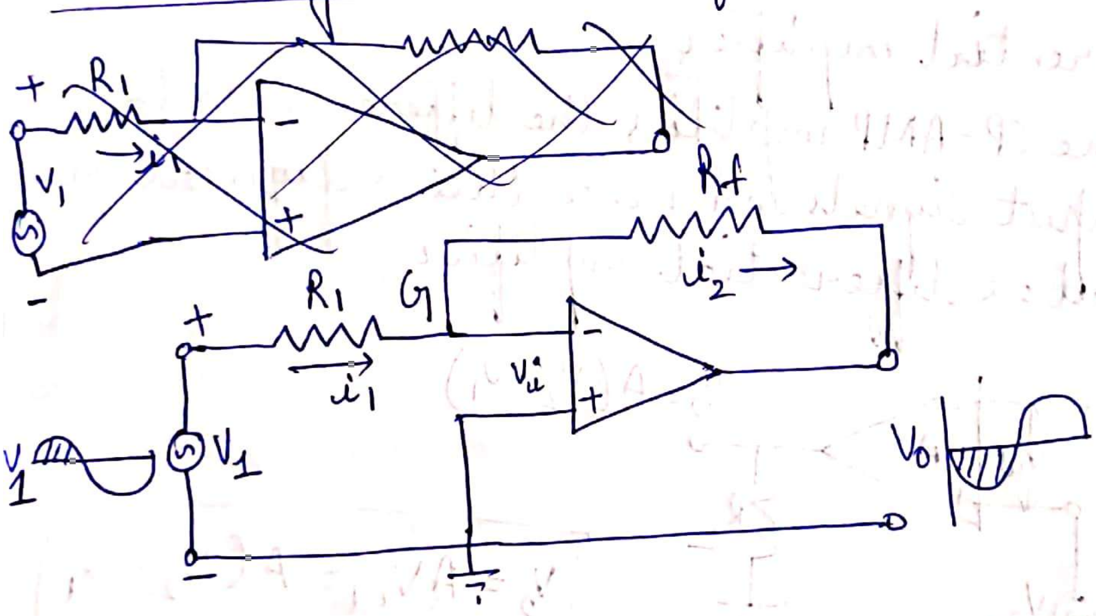


$V_1 = 0$

$V_0 = AV_{id} = A(V_2 - V_1)$

$$\boxed{V_0 = AV_2}$$

* Inverting OP-AMP with feedback



$$i_1 = \frac{V_1 - V_i}{R_1} = \frac{V_1}{R_1}$$

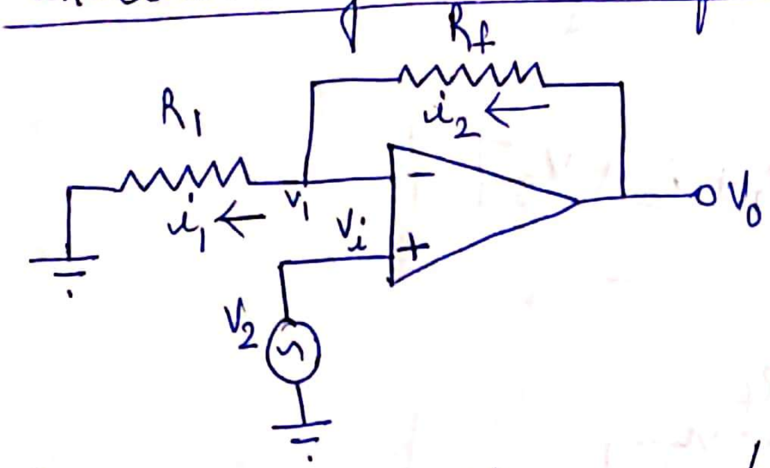
$V_i = 0$

$$i_2 = \frac{V_i - V_0}{R_f} = \frac{-V_0}{R_f}$$

$$\frac{V_1}{R_1} = -\frac{V_0}{R_f}$$

Voltage Gain $\boxed{A_V = \frac{V_0}{V_1} = -\frac{R_f}{R_1}}$

Non-inverting OP-AMP with feedback

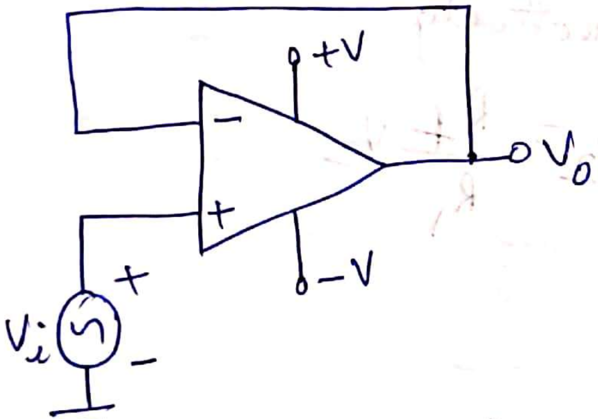


$$i_1 = \frac{V_2}{R_1},\ i_2 = \frac{V_0 - V_2}{R_f},\ A_V = \left(1 + \frac{R_f}{R_1}\right)$$

Voltage follower / Buffer

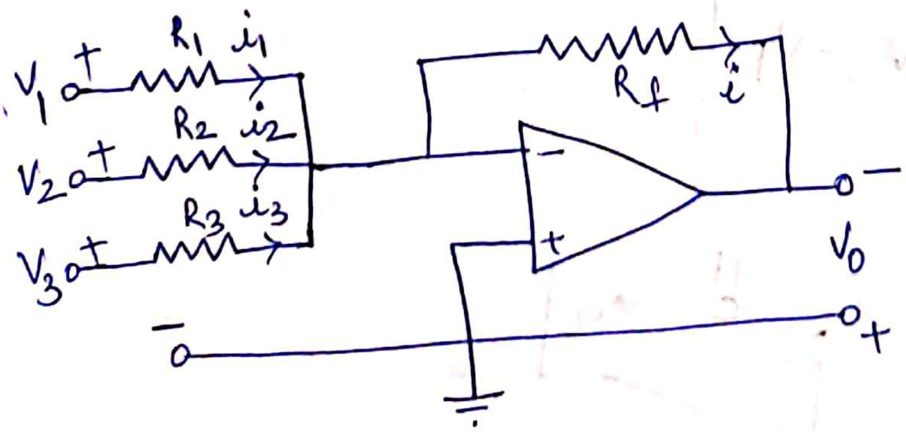
$A_V = 1$

$V_0 = V_2 = V_i$



* The output voltage is equal and in-phase with the input i.e OP-AMP circuit acts as a voltage follower

Adder or summing amplifier



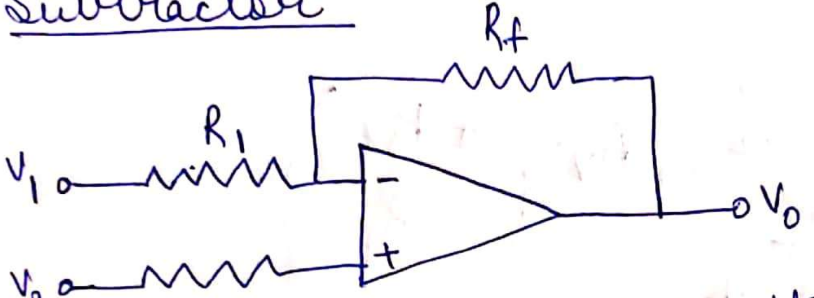
$$i_1 = \frac{V_1}{R_1},\ i_2 = \frac{V_2}{R_2},\ i_3 = \frac{V_3}{R_3}\quad i = \frac{V_0}{R_f}$$

$$\boxed{V_0 = -[V_1 + V_2 + V_3]}$$

if $R_f = R/3$ then

$$\boxed{V_0 = -1/3\,[V_1 + V_2 + V_3]}$$

Subtractor



Let $(V_0)_1$ & $(V_0)_2$ be the output voltages produced by input voltages V_1 & V_2 respectively

$$(V_0)_1 = -\frac{R_f}{R_1} V_1 \quad , (V_0)_2 = \frac{R_f}{R_1} V_2$$

$$V_0 = (V_0)_1 + (V_0)_2$$

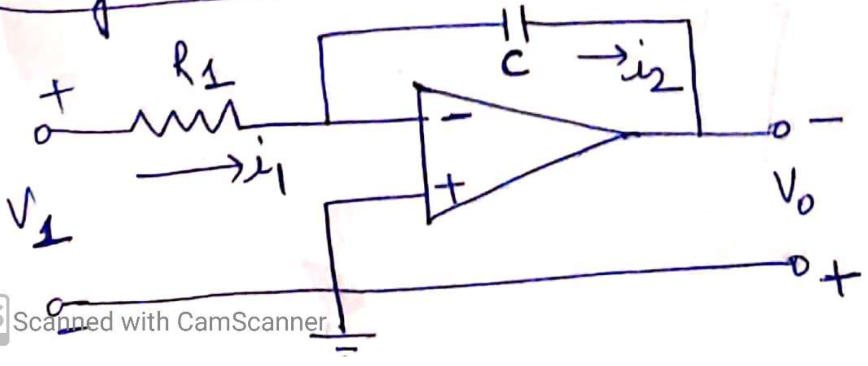
$$V_0 = -\frac{R_f}{R_1} V_1 + \frac{R_f}{R_1} V_2$$

$$V_0 = \frac{R_f}{R_1}(V_2 - V_1) = K(V_2 - V_1)$$

if $R_f = R_1$

$$\boxed{V_0 = V_2 - V_1}$$

Integrator



The capacitive impedance X_C can be expressed as

$$X_C = \frac{1}{j\omega C} = \frac{1}{sC} \qquad s = j\omega$$

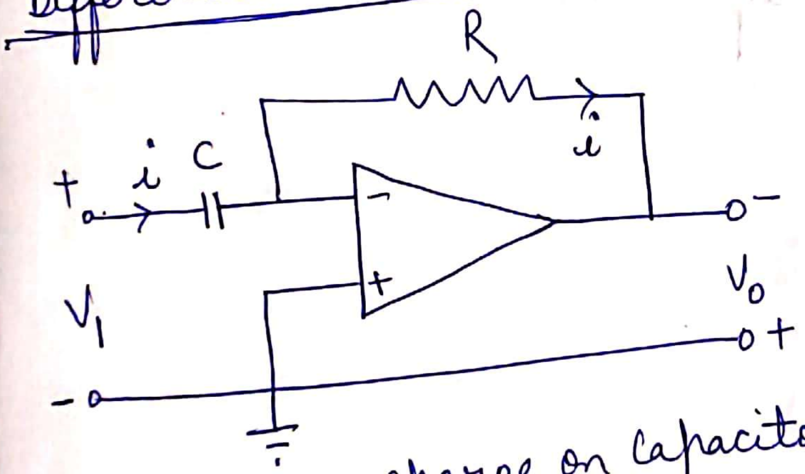
$$i_1 = \frac{V_1}{R_1} \;;\; i_2 = -\frac{V_0}{X_C} = -sCV_0$$

$$\Rightarrow \frac{V_1}{R_1} = -sCV_0 \Rightarrow \frac{V_0}{V_1} = \frac{-1}{sCR_1} \quad \text{— ①}$$

eqⁿ① can be rewritten in time domain as

$$\boxed{V_0(t) = -\frac{1}{R_1 C}\int V_1(t)\,dt}$$

Differentiator



$$V_1 = \frac{q}{C} \;,\; q = \text{charge on capacitor} \quad \text{— ①}$$

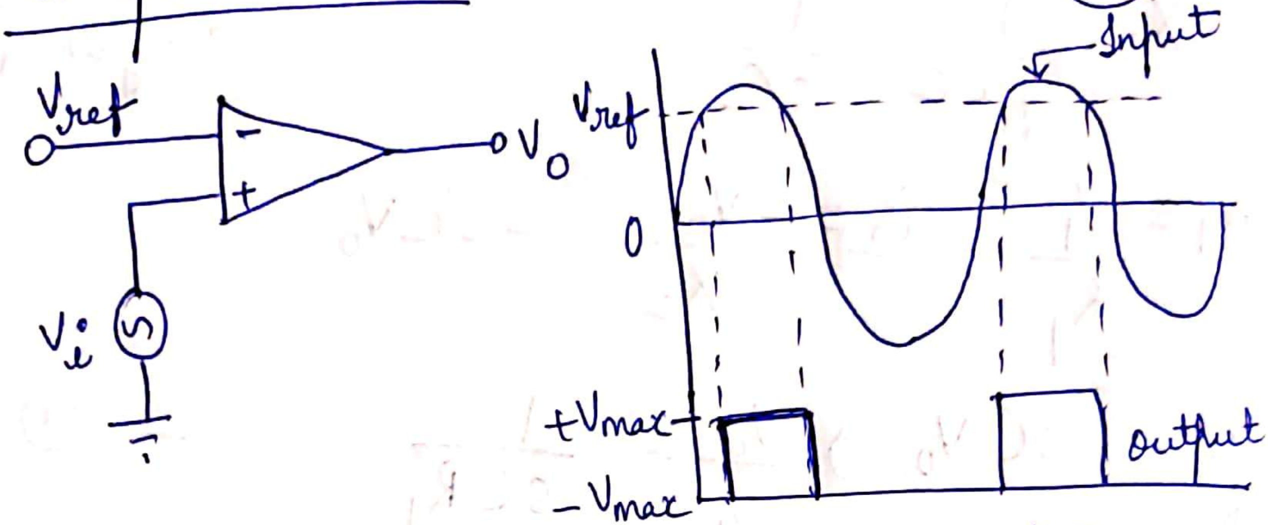
$$\frac{dV_1}{dt} = \frac{1}{C}\frac{dq}{dt} = \frac{i}{C} \;,\; \text{where } \frac{dq}{dt} = i \quad \text{— ②}$$

$$V_0 = -iR \quad \text{— ③}$$

Substituting the value of i from eqⁿ② in eqⁿ③

$$\boxed{V_0 = -CR\frac{dV_1}{dt}}$$

Comparator



* Comparator is a circuit which compares two voltages and provides an output that indicates the relationship between them.

Hence, comparator may be used to compare:

a) two changing voltages like two sine waves

b) a changing voltage with a set d.c reference voltage.

Chapter - I ..: MEASURING INSTRUMENTS :-

Instrument :- An instrument is a device for determining indicating, measuring & recording Physical quantities the value or magnitude of a quantity known as instrument.
(device - A tool or ~~equiment~~ piece of equipment made for a particular purpose).

Measurement :- It is the process of comparision b/w an unknown quantity (area) with a predefined quantity. (meter in(m))

→ It is a process by which we convert physical parameters into numerical values.

→ measurement is done by connecting a measuring instrument into a system under consideration & observing the response on the instrument.

Application :- - For recording or observing the o/p of a process.

- To control a process of operation
- For analysis purpose.

Methods of measurement :-

It can be broadly classified into two catagories

(1) Direct method	(11) Indirect method.
→ It includes comparision with standard fundamental quantities finding the unknown magnitude.	→ In this method the unknown quantity is indirectly compared against a standard & the result is expressed as numerical.
→ Mass, length, time etc. Elect current, Temp., Amt of substance (mole), Luminous intensity	→ most preferred method. → Power, Area

Some Important Terminologies :-

① **Accuracy** :- The degree of closeness of an instrument reading b/w the true value & measured value.

→ In other words accuracy means the rightness.

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Precision:- It is defined as the measure of consistency or repeatability of a measurement.
i.e- For a given i/p, how many times the o/p of the instrument remains same.

→ Precision means exactness, ~~word~~ term precision comes from 'Precise' which means 'clearly or sharply defined.'

E.g:- An ammeter doesn't give 100% accurate value of current, but whenever the same ~~[illegible]~~ current is measured it gives the same reading. The ammeter is said to be precision ammeter though it is not perfectly accurate.

Resolution or Discrimination:-

→ The smallest change in the measured quantity to which the measurement will respond.

Sensitivity:- The ratio of change in o/p to the change in i/p of the instrument.

$$\text{Sensitivity} = \frac{\text{change in o/p}}{\text{Change in i/p}}$$

$$S = \frac{\text{Torque}}{\text{weight in pan}} \text{ ratio}$$

Error:- measurement is done to check whether the measured quantity is equal to the true value or the predefined standard. whenever the measured value is not equal to true value an error is produced.

→ Error is defined as the deviation or difference of true value from measured value.

Mathematically $e = Y_n - X_n$

where e = absolute error

Y_n = true value

X_n = Measured value.

$$\% \text{ Error} = \frac{\text{Absolute value}}{\text{True value}} \times 100$$

$$\Rightarrow \% E = \frac{e}{Y_n} \times 100$$

$$\Rightarrow \boxed{\% E = \frac{Y_n - X_n}{Y_n} \times 100}$$

Types of Error:

① Gross Error ② Systematic Error ③ Random Error

① Gross Error:

→ Gross error occurs largely due to human mistakes i.e. misreading of instrument, ~~[illegible]~~ at the time of calculating the measurement results, incorrect adjustment, improper application of instrument, mishandling, computational mistake etc.

→ The gross error can't be eliminated completely but can only be minimized.

→ One of the frequently occurred gross error is due to improper use of an instrument, it can be minimized by taking proper care in reading

& reloding measurement auantity.

② Systematic errorer

→ Systematic error ~~occures~~ ~~due~~ to divided into 3 catagories (I) Instrumental Error
(II) Environmental Error.
(III) Observational error.

→ Systematic error occures due to Shortcomings (defect/fault)/weakness of the instruments; such as due to defective parts of the instrument, effect of environment on the instrument or due to user.

(I) Instrumental error are due to the mechanical structure of the instrumente. It ~~causes~~ covers such as mechanical error, constructional error, error due to damage etc.

(II) Environmental error are due to enternal weather condition of the instrument & the observer. The factores include temp., pressure, humidity, magnetic or electrostatic field etc.

(III) Observational error due to observer or person taking reading. These error such as parallax error or vision error, faulty reading of meter scale etc.

⑧ Random errors :

→ All other known are unknown causes of error are called Random errors. These error includes lack of knowledge, Poore design, poore maintenance etc.

Classification of Measuring Instruments

- Electrical Instrument
  - Absolute Instrument (measure deflection or direction)
    - E.g :- Tangent galvanometer, Thermometer
  - Secondary Instrument (measure magnitude)
    - Indicating Instrument
      - E.g :- Ammeter, voltmeter, wattmeter
    - Recording Instrument
      - E.g :- Sesmograph (Earthquake msmnt)
    - Integrating Instrument
      - Eg :- ① Energy mtr ② A-h mtr (Am-hr)

Absolute Instrument :-

→ These instruments give the measured value in terms of instrument constant & It's deflection.

→ This type of Instrument doesn't give direct readings

→ Such types of instruments don't requaire comparision with any other standard.

Eg :- Tangent Galvanometer

Let meter constant = 3

reading = 2×3 = 6

→ Tangent galvanometer which gives the value of the current to be measured in terms of tangent of the angle of deflection produced.

→ These types of instruments are rarely used in labratories for standardisation purpose.

Secondary Instruments :-

→ These instruments gives direct reading.

→ These instruments are so constructed that the deflection of such instruments gives the magnitude of the electrical quantity to be measured directly.

→ These instruments are required to be calibrated by comparision with either an absolute instrument or with anothere secondary instrument, which has already been calibrated before the use.

Secondary Instruments furthere classifed as;

(I) Indicating Instrument
(II) Integrating Instrument
(III) Recording Instrument

① Indicating Instrument :-

→ These instrument are gives the value of the quantity to be measured by the deflection of the pointer.

→ These instruments indicates the magnitude of an electrical quantity at the time when it is being measured. The indication are given by a pointer moving over a calibrated scale.

→ It has scale & pointer mechanism

E.g :- Ammeter, Voltmeter, Wattmeter, Frequencymeter, Powerfactormeter etc.

(ii) Intregreating Instrument:-

→ These instruments integreate ore summerise an event over a specific period of time & gives the o/p result.

→ The summation given by such an instrument is the product of time & an electrical quantity under measurement   T X Electrical

Eg:- Energymeter, Ampere-haure meter.   1 × 1000W

1000 kW = 1 unit

(iii) Recording Instrument:-

→ These instruments keeps a continuous record of the variation of the magnitude of an ~~ea~~ electrical quantity to be observed by an observer over a definite period of time.

→ In such Instrument moving system carries a light weight pen which touches lightly over a sheet of graph paper for recording purpose.

Eg:- Recording voltmeter, Recording wattmeter, (use in power house)

Sesmograph etc., ECG M/C (Electrocardiography M/C)

Types of forces required for the indicating Instrument:-

→ There are 3-types of forces are required for the satisfy operation of any indicating Instrument.

They are :-
1. Deflecting ~~Torque~~ force.
2. Controlling Force.
3. Damping Force.

① Deflecting Force:-

→ Deflecting force is also called as operating force.

→ This force helps in rotating the instrument movement from zero position

→ The system producing the deflecting force is called as deflecting system or moving system.

→ So the deflecting system converts the electrical quantity i.e current or voltage into mechanical force.

→ The torque produced by the deflecting force is called as deflecting torque. (T_d)

→ 'T_d's value depend upon the electrical signal to be measured.

② Controlling force:-

→ The act of this force is opposite to the deflecting force.

→ The force opposes the deflecting force & increase with the deflecting force of a moving system is called as controlling force.

→ The torque produce by the controlling force is known as controlling torque (T_c).

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→ This torque opposes the deflecting torque & increases with the deflection of the moving system.

→ The pointer is brought to rest at a position when the deflecting torque & controlling torque are equal in magnitude.
i.e: $\boxed{T_d = T_c}$ is known as definite position/ final steady state position/ equilibrium/ rest.

→ The system which produce controlling torque is called controlling system.

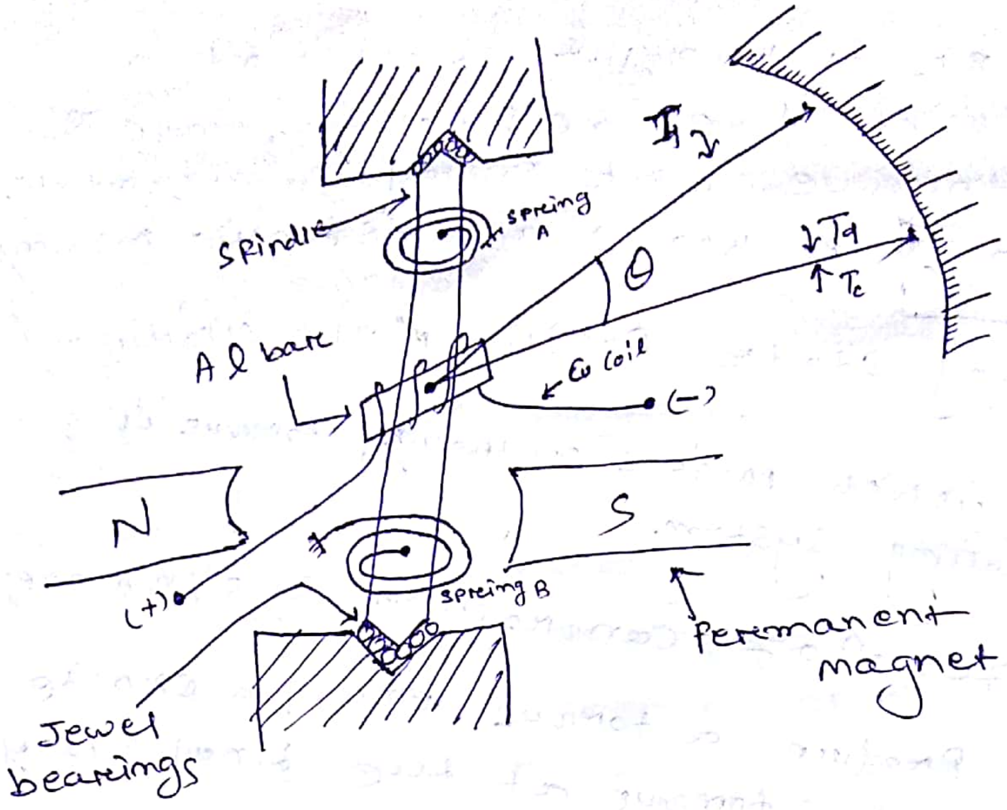
The func^n of controlling system are;

→ To produce a torque equal & opposite to the deflecting torque at the final steady position of the pointer in order to make definite the deflection of the pointer for a particular magnitude of current.

→ To bring back moving system to it's zero position when the force causing the instrument moving system to deflect is remove

→ The controlling or balancing torque in indicating instrument is obtained by
(i) Spring control (ii) Gravity control.

① Spring Control :-



→ Two Spiral spring usually of Phosphere-Bronze are wound in opposite direction on the Spindle or moving System, which is used for controlling in indicating instruments purpose.

→ when moving system deflects, one of the spring is open & another close in opposite direction. i.e- the spring get twisted in opposite direction which produce controlling torque (T_c)

→ Here, Tc ∝ angle of deflection of the pointer (θ)

i.e $T_c \propto \theta$ where K_s = spring const.

$$\Rightarrow \boxed{T_c = K_s\theta}$$

& $T_d \propto$ current flowing through the instrument (I)

i.e $T_d \propto I$

$$\boxed{T_d = KI}$$

So at final steady state position :-

$$\boxed{T_d = T_c}$$

$$\Rightarrow KI = K_s \theta$$

$$\Rightarrow \theta = \left(\frac{K}{K_s}\right) I$$

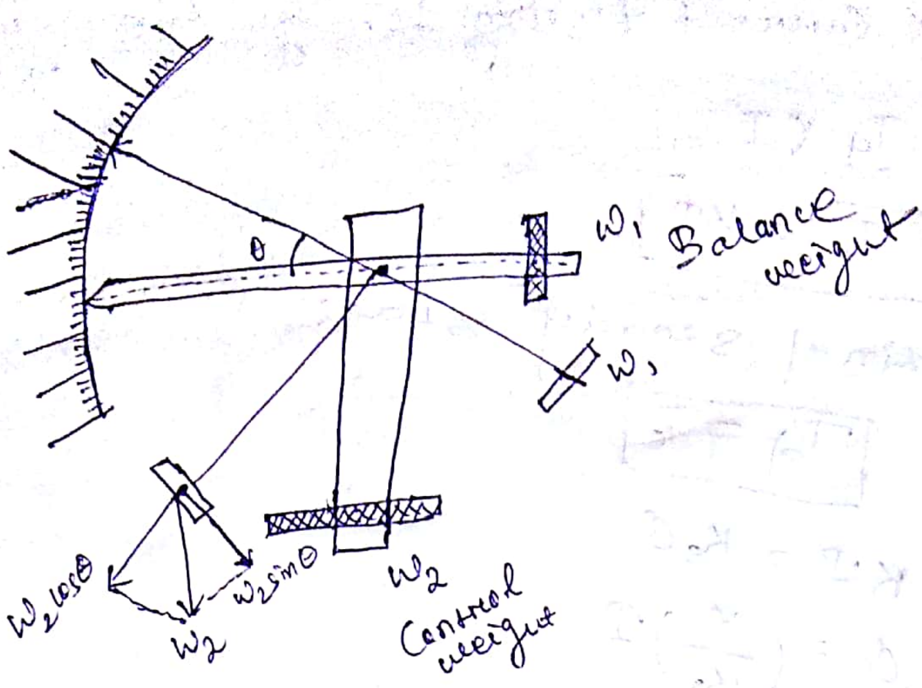
$\therefore \theta \propto I$

or $\boxed{\theta = KI}$ i.e- The scale is uniform or linear

Advantages	Disadvantages
→ Linear or uniform scale	→ Complex construction than gravity control.
→ It can be mounted for both horizontally as well as vertically.	→ Accidental stress may damage the spring.
	→ Change in temp. effect the spring length & hence T_c.

(ii) Gravity control method :-

→ In gravity control instrument, a small weight is attached to the moving system in such a way that it produces a restoring are controlling force when the system is deflected.



→ Here two weights w_1 & w_2 are attached to the spindle.

→ The func^n of w_1 is to balance the weight of the pointer & w_2 provides the controlling torque.

→ When the pointer is at zero, w_2 hangs vertically downwards.

→ Here the deflected position of w_2 can be converted into two component when pointer is deflected through angle 'θ'. i.e- $w_2 \sin\theta$ & $w_2 \cos\theta$.

→ Only $w_2 \sin\theta$ will provide controlling torque (T_c)

$$T_c \propto w_2 \sin\theta$$

$$\& \quad T_d \propto I$$

→ At initial steadystate position. $T_d = T_c$

$$\Rightarrow I = w_2 \sin\theta$$

$$\Rightarrow \boxed{I \propto \sin\theta}$$

→ Therefore gravity control instrument have non-uniform scale.

Advantages	Disadvantages
- No temperature effect	→ Non-uniform scale.
→ Cheaper than the spring controlled instrument	→ Instrument has to kep in vertical position.
	→ Because of gravity the pointer will make (while coming to steady state.

* Notes:- Spring control instrument can be placed in any direction & gives linear scales, Hence it is used in all instrument

Comparision b/w Gravity control & Spring control

Gravity Control	Spring Control
→ Independent of temperature.	→ Variation of temp. causes an Error in the instrument.
→ It has non-uniform scale	→ ~~unifor~~ It has uniform scale.
→ It can be used only in vertical position	→ It can be used ~~only~~ in any position (i.e- either vertical or horizontal).
→ It is cheaper than spring control	→ It is costlier than gravity control.

Damping force:-

→ Damping force is the force by which the moving system comes to its equillibrium position rapidly & smoothly without any oscillation.

→ The Torque produced by the damping force is called as damping torque.

→ Damping torque enable to prevent oscillation of the moving system & makes the pointer to reach to it's final position quickly & smoothly.

→ Due to inertia of the moving system subjected to deflecting & restoring torques a no. of vibration will be produced before coming finally to rest.

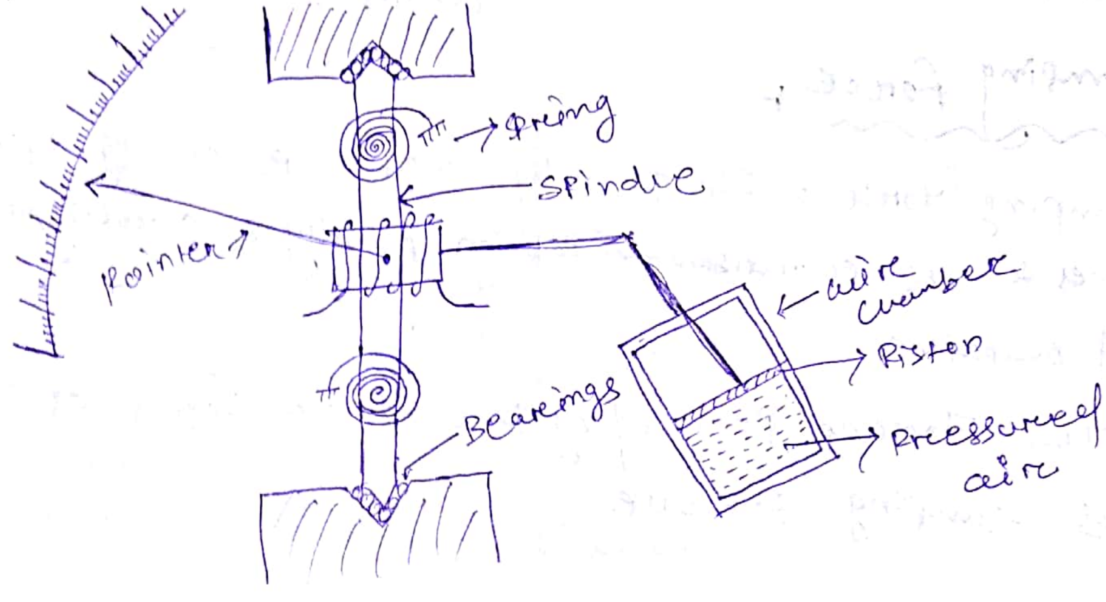
→ To avoide this, a damping torque is required which opposes the motion & moves the pointer comes to rest.

→ The D Td is necessary to bring the pointer to rest position quickly, otherwise due to inertia of the moving system the pointer will oscillates about its final steady state position.

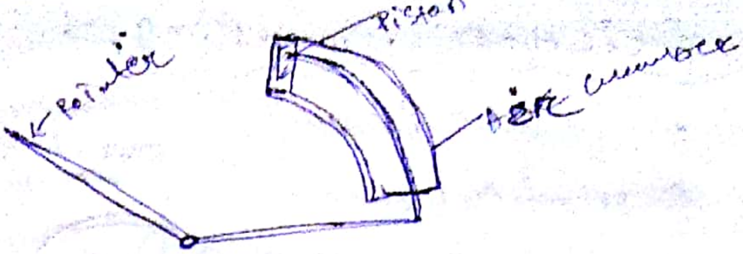
The damping torque can be produced by 3 ways :

ⓐ Air friction damping. ⓓ Electromagnetic damping.
ⓑ Fluid friction damping.
ⓒ Eddy current damping.

ⓐ Air friction damping



~~→ It consist~~



→ It works on the principle of air pressure & friction

→ It consist of a eight aluminium piston which is attached to the moving system.

→ The piston is place inside an air chamber.

→ When there is an oscillation on the ~~Piston~~ pointer, then the piston will move upwards & downward in the air chamber.

→ The oscillatⁿ of moving system is damped by the action of air in the chamber.

→ When the pointer moves upward or downward in the air pressure inside the chamber in either direction created & damp the moving part

→ When piston moves downward, the pressurized air are compressed, which oppose the movement of pointer & hence oscillation of the system is reduced.

Advantages :-

→ Very simple & cheap method of damping

→ It doesn't requireed any permanent magnet

→ Low maintainance.

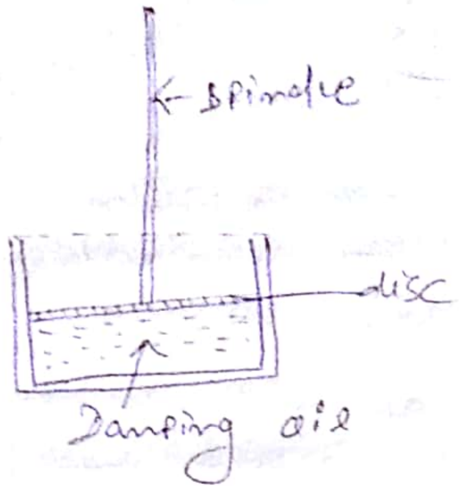
→ Can be mounted horizontally & vertically

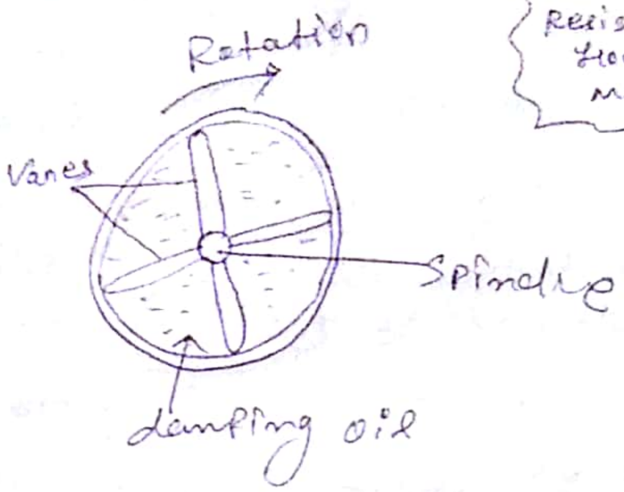
Note
* This method is suitable for the instrument having weak magnetic field.

E.g :- MI instrument, Electrodynamometer, wattmeter

Fluid friction Damping

Viscosity - physical property of fluid. Resistance to flow, how much sticky





→ In this type of damping, oil is used in place of air & as the viscocity of oil is greater the damping force is also correspondingly greater.

→ Here the damping force is produced due to liquid substances.

→ Here the vanes are attached to the spindle of the moving system, which are submerged in oil

→ The vanes are dipped into a pot of damping oil & are completely submerged by the oil.

→ The motion of the moving system is also opposed by the friction of the damping of oil on the vanes.

→ The damping force, thus created always increases with the increase in velocity of vanes.

→ Due to friction of the fluid a force is produced so that ossilations are reduces accordingly.

→ There is no damping force when the vanes are stationary.

→ The damping oil must have following properties

(i) must be a good insulator.

(ii) should be non evaporating.

(iii) should not have corrosive action upon the metal.

(iv) The viscosity of the oil should not change with the temperature

Disadvantages:-

→ These instruments must be placed in vertically only.

→ more maintenance is required.

Note:- This method is suitable for ~~having~~ instrument having low deflecting torque.

E.g:- Electrostatic Voltmeter

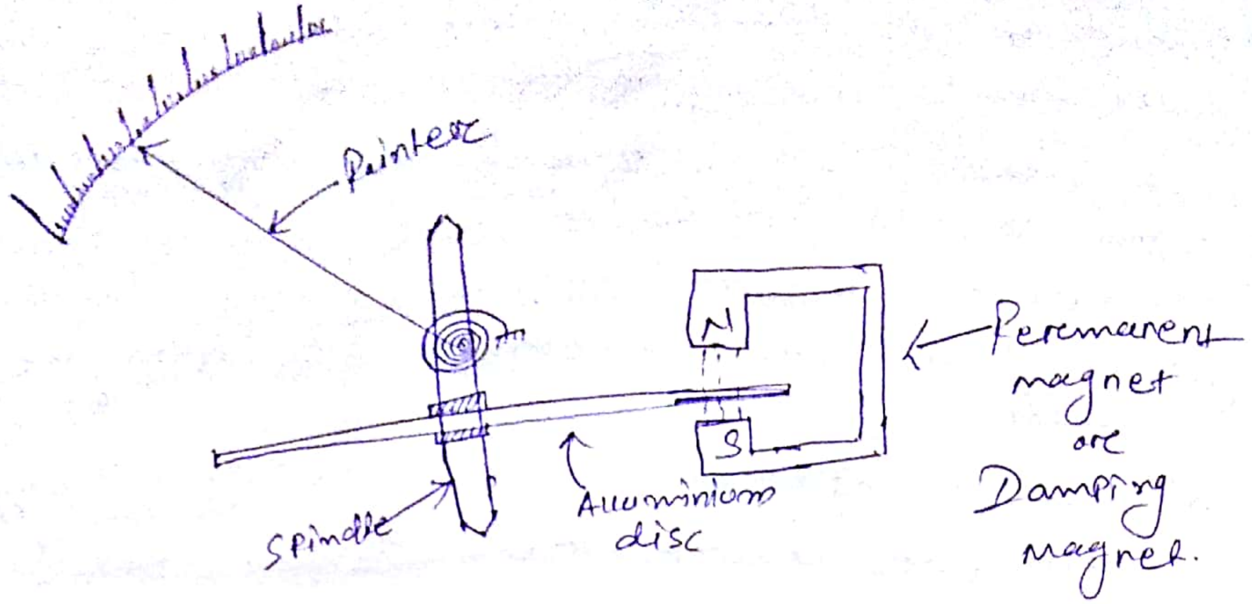
(C) Eddy current damping

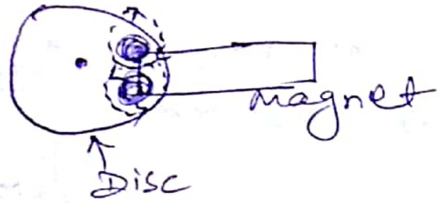
→ This method of damping is based on the principle that when a ~~current carrying~~ conducting material ~~conductor~~ but non-magnetic ~~material~~ moved in a magnetic field, an emf is induced in it which causes a current called eddy current.

→ Due to this eddy current a force exists b/w them & the field.

→ Acc^n to Lenz's law this force is always in opposition to the force causing rotation of the conducting material, thus it provides the necessary of damping.

Scanned with CamScanner





→ Here a Cu or Al disc carried by spindle is moved b/w the poles of a permanent magnet

→ If the disc moves clockwise, the emf is induced in the disc & circulate eddy current as shown in dotted lines.

→ It follows from Lenz's law that these current exerts a force opposing the motion producing them & hence provides damping.

Calibration of Instrument

→ Calibration is a comparision b/w the known measurement & the measurement using measuring instrument.

→ The calibration of measuring instrument has ~~two objects~~;

~~as~~ to check the accuracy of the instrument

(b) It determine the history of locations & applicatn of the instrument

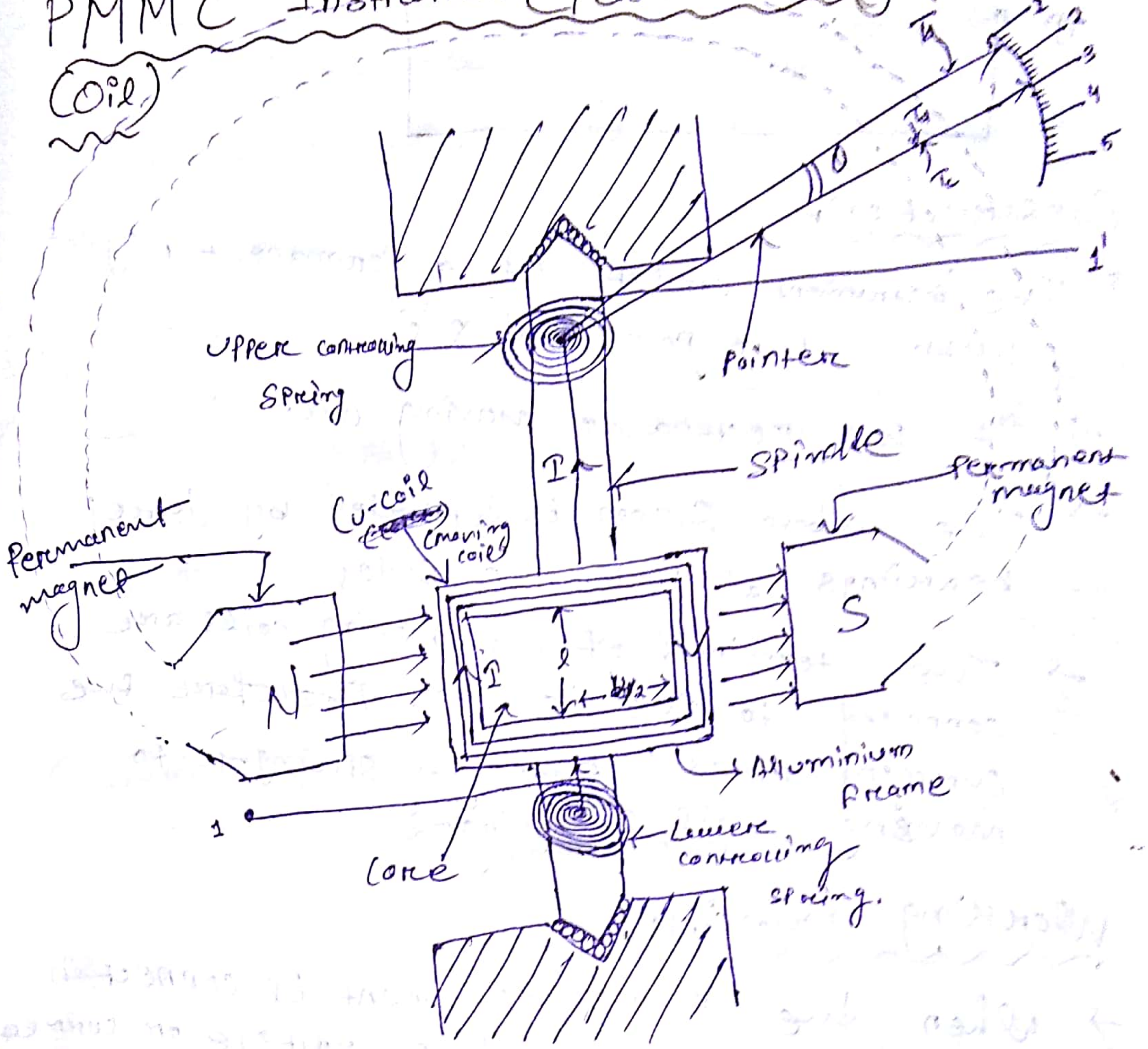
* Why calibration is important?

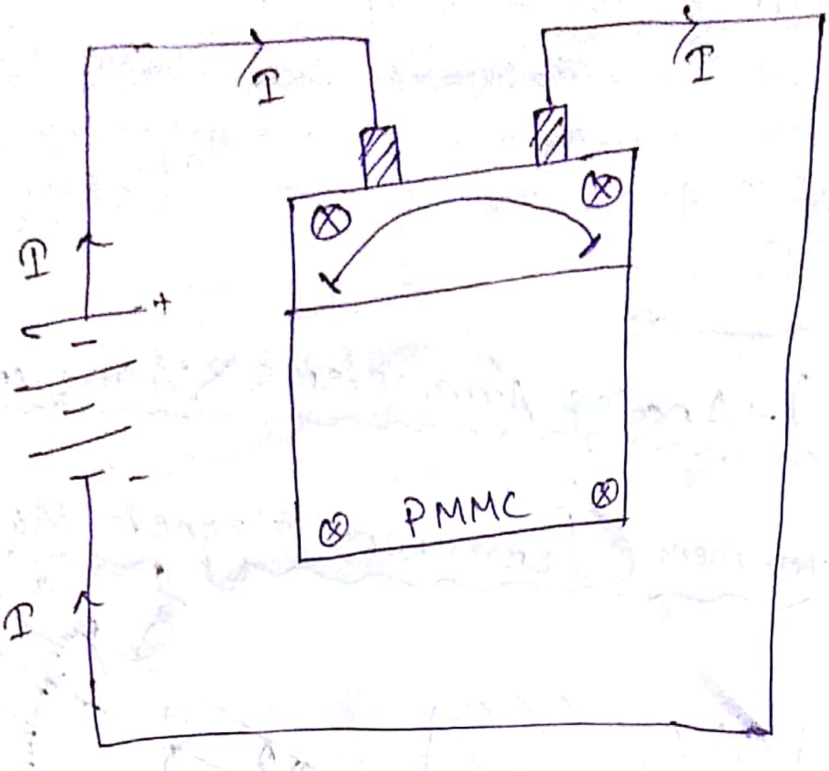
→ The accuracy of all measuring instrument degrades over time, So the calibration of the instrument is important because it gives the opportunity to check the error & accuracy.

—*—

(Chapter-2) - Analog Ammeters & Voltmeters :

PMMC Instrument (Permanent Magnet Moving Coil)





Construction:

→ The instrument consist of a permanent magnet with two poles 'N' & 'S'.

→ It has rectangular moving coil.

→ The above system is supported by jewel bearings at both the sides.

→ The terminals of the moving coils are connected to the springs. Therefore the current flows through spring-1 to moving coil & spring-2.

Working Principle:

→ When the PMMC instrument is connect in the ckt to measure the voltage or current, then the current carrying coil is placed in a magnetic field of the permanent magnet.

→ Acc^n to the Lorentz's force a mechanical force is developed in the Alluminium bar.

As a result a mechanical torque acts on it. So that the Pointer attached to the moving system moves in the clock-wise direction over the scale to indicate the value of current or voltage to be measured.

→ Deflecting Torque (T_d)

If a current 'I' amp is flows in the coil then the force acting on each side of the coil is;

$F = BIl\cancel{(A)}$ Newton $F = BIL \sin\theta$ ($\because \theta = 90°$)

T_d = Force × ⊥^r distance

where

$= BIl\cancel{N} \times b$ for n no. of turns

B = flux density (web/m²)

$= B\cancel{IN}(l \times b)$

I = current (A)

l = length of the coil

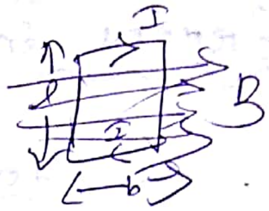
$= BI\cancel{N}(A)$ ($\because A = l \times b$)

b = breadth of the coil.

N = No. of turs of of the coil.

$\boxed{T_d = BI\cancel{N}A}$ ✓ or $\boxed{T_d = NBIA}$

$\boxed{T_d \propto I}$ or $\boxed{T_d = nBIA}$



~~Td~~ ve

Controlling Torque

Due to Spring control $T_c = K_c\theta$

At final steady state position or at equillibrium Point

$$T_c = T_d$$

$$K_c\theta = NBIA \Rightarrow \theta = \frac{NBIA}{K_c}$$

→ $\theta \propto I$ → The Scale is uniform or linear

$T_d \propto I \Rightarrow T_d \propto +ve$

$T_d \propto I \Rightarrow T_d \propto -ve$

$T_{davg} \simeq T_{net} \simeq 0$ ✓

Advantages of PMMC:-

1. Uniform Scale
2. Eddy current damping is effective
3. High efficieny.
4. Required less power for operation.
5. No hysteresis as magnetic field is const.
6. Very reliable & accurate

Disadvantages:-

→ It can't be used for AC measurement.

→ More expensive, than the moving Iron Instrument.

→ Errors occurs due to control spring (i.e. due to ageing effect.

Errors in PMMC Instrument

① Due to magnetic field density:-

→ magnetic field density decreases with weakening of permanent magnet due to ageing effect, which tends to decrease the deflection of niddle of instrument.

② Due to spring control:-

→ The value of spring const decreases with weakening of spring due to ageing &

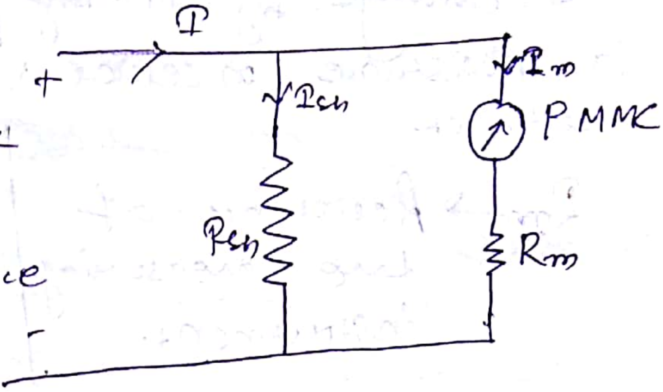
temp. effect, which will increases the deflection of the pointer & magnetic flux density.

⑤ Error due to moving coil :-

→ When the increase in resistance of moving coil is increases with temp, then the current flowing through the coil ~~increase~~ decreases accordingly.

Extension of Range of PMMC Instrument :-

ⓐ As an Ammeter :-



→ Since the shunt resistance in parallel with the meter then the votage drop across the shunt resistance & voltage drop across the meter must be same.

⇒ R_m = Internal Resistance of the meter

R_{sh} = Shunt Resistance in Ω.

I_{sh} = Shunt Current

I = Current to be measured.

$I_m = I_{fs}$ = full scale deflection current.

from the above ckt

$$\boxed{V_{sh} = V_m}$$

$$\Rightarrow I_{sh} R_{sh} = I_m R_m$$

$$\Rightarrow (I - I_m) R_{sh} = I_m R_m \quad [\because I_{sh} = I - I_m]$$

$$\Rightarrow R_{sh} = \frac{I_m R_m}{I - I_m}$$

$$\Rightarrow R_{sh} = \frac{R_m}{\left(\frac{I}{I_m} - 1\right)}$$

Let $\frac{I}{I_m} = m$ i.e. multiplying factor

I = New range

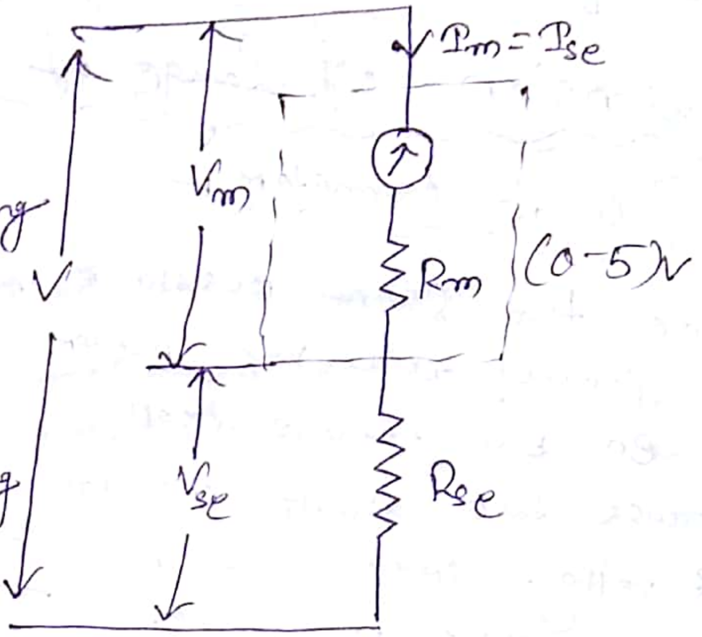
I_m = old range

$$\Rightarrow \boxed{R_{sh} = \frac{R_m}{m-1}}$$

[$R_{sh} << R_m$ as we need more current]

(b) PMMC instr. as a voltmeter:-

→ The Range of the PMMC instrument can be change by connecting a resistance in series with it.



R_m → Resistance of the measuring instrument

R_{se} → multiplier series resistance

V_m → ~~At~~ Voltage across the meter.

V_{se} → voltage across the series resistance.

→ From the above ckt

$$I_m = I_{se}$$

$$\frac{V_m}{R_m} = \frac{V_{se}}{R_{se}} = \frac{V - V_m}{R_{se}}$$

$$\Rightarrow R_{se} = \left(\frac{V - V_m}{V_m}\right) R_m$$

$$\Rightarrow R_{se} = \left(\frac{V - V_m}{V_m}\right) R_m$$

$$\Rightarrow R_{se} = R_m\left(\frac{V}{V_m} - 1\right)$$

$$\Rightarrow \boxed{R_{se} = R_m(m-1)}$$

$$\left[\because \frac{\overset{\text{new range}}{V}}{\underset{\text{old range}}{V_m}} = m = \text{multiplying factor}\right]$$

Moving Iron Instrument (MI Instrument)

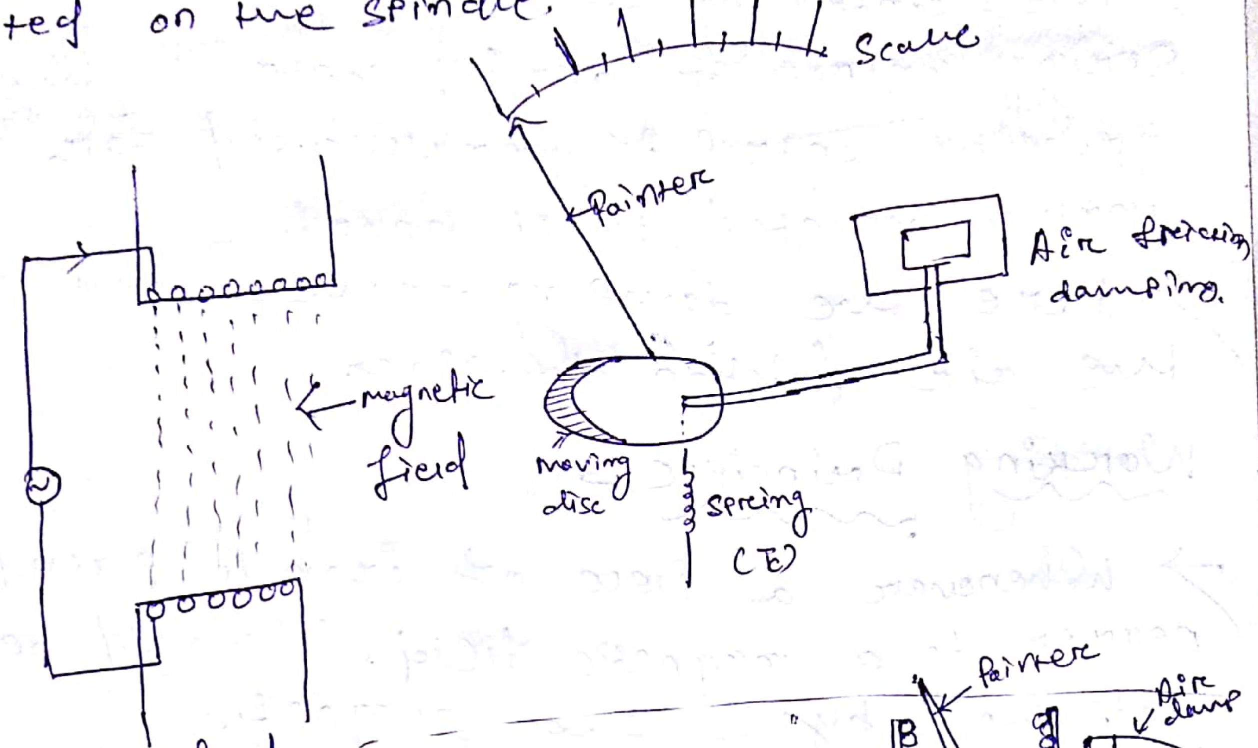
(having MI disc & having Electromagnet)

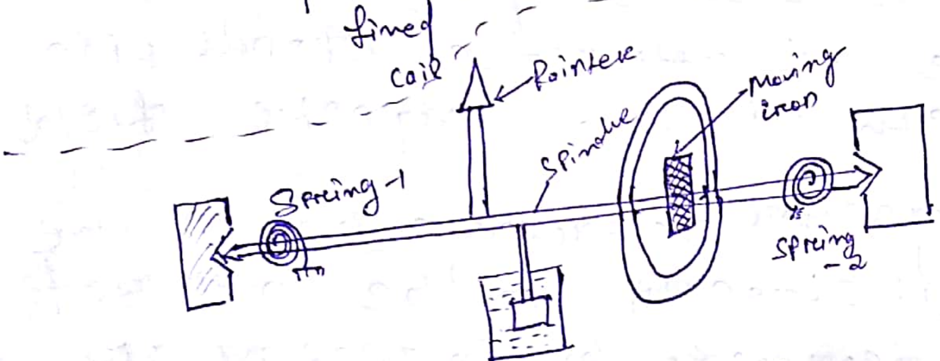
→ mainly two type ! they are

① Attraction type:-

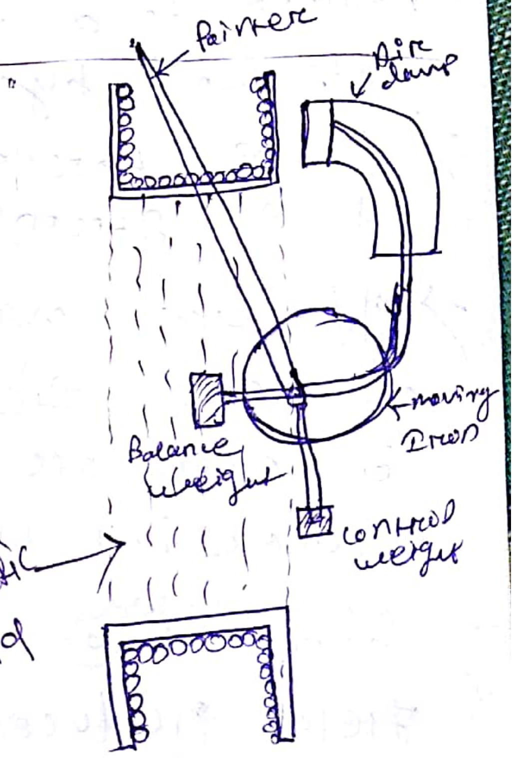
Construction:-

→ It consist of a fixed coil & moving ~~coil~~ iron piece. The moving iron is a flat disc which mounted on the spindle.





Air friction damping.



Construction-

→ It consists of a fixed coil & moving iron piece. The moving iron is a flat disc which is mounted on spindle. A pointer is moves over a graduate scale.

→ The no. of turns of the fixed coil depends upon the range of the instrument.

→ The controlling torque is provided by either spring control or gravity control & the gravity control is generally used for the vertical mounted panel board.

→ Here the damping torque is provided by the air friction damping.

Working Principle-

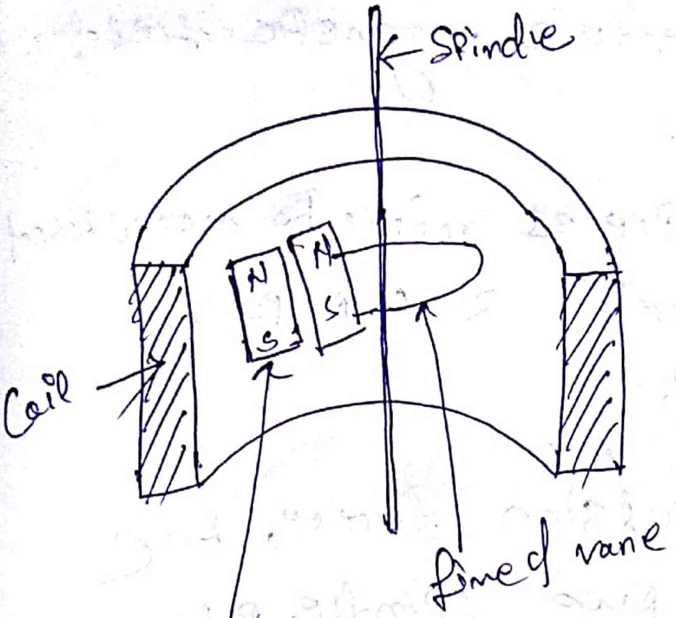
→ Whenever a piece of iron is placed nearer to a magnetic field, it would be attached by the magnet.

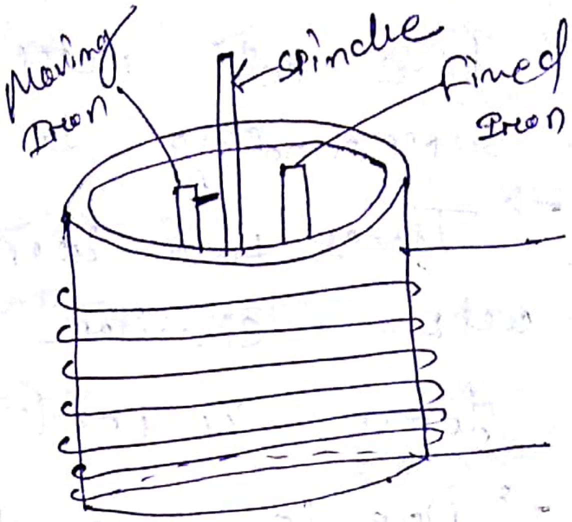
→ The Force of attraction depends upon the strength of the magnetic field.

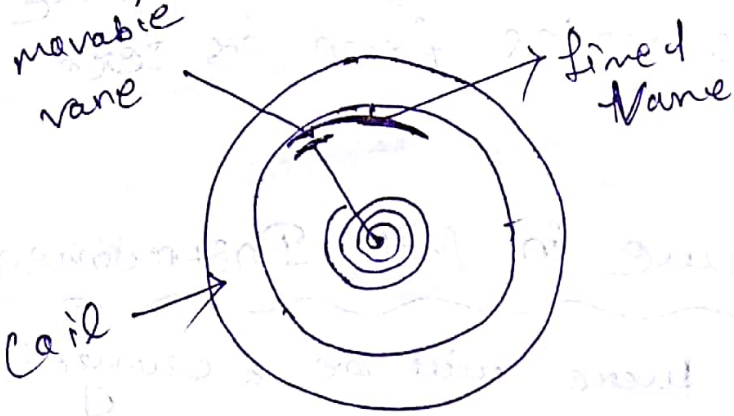
→ If the ~~magnetic~~ electromagnet then the magnetic field strength can be ~~is increased~~ increases or decreases by increasing or decreasing the current through the coil.

→ When the supply is given & magnetic field produced then the moving ~~&~~ iron moves from weak field to strong magnetic field & the pointer moves from one position to Othere position.

② Repulsion Type MI Instrument







Construction :-

→ It consist of a hollow cylinder which hil carry the operating current.

→ The core consist of two iron pieces

(i) ~~Fix~~ one is fixed iron piece which is attach to the hollow cylinder.

(ii) Othere is Movable iron piece which is attach to the spindle.

Working Principle :-

→ When the instrument is connected to the supply current will flows in the fixed coil & the coil will produce magnetic field surrounding to it.

→ Thus two iron pieces will be magnetised with similar polarity & a repulsion force is produced.

→ Due to the repulsion force, the movable iron moves the spindle & the pointer ~~starts~~ moves from its zero position.

Deflecting Torque in MI Instrument :-

→ In MI instrument there will be a change in energy stored in the magnetic field due to chang in inductance of the fixed coil.

→ this is because the Iron disc always try to occupies the position of minimum reluctance (∵ Inductance is inversely proportional to the reluctance $L \alpha \frac{1}{S}$)

Let emf Induce ~~on the~~ the coil

$$V = \frac{d}{dt} LI$$

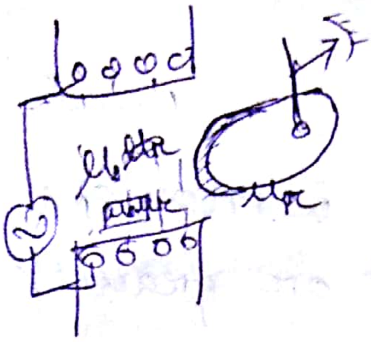
The medium of magnetic field two coil is air & relative P. = μ_0

→ The medium
→ when the disc enter to the magnetic field now reach the medium (~~two~~ of m-field is not completely air there is Iron too.

μ_0 changes to $\mu_0 \mu_r$

where μ_0 = ~~Relative~~ Relative Permiability of free space or air
$= 4\pi \times 10^{-7}$

μ_r = change in Relative Permiability
(1 in free space or vaccumes)



when Relative permiability of coil changes changes Inductance because Inductance depend upon relative permiability.

$$\boxed{L \propto \mu_0 \mu_r}$$

$$\boxed{L = \frac{\mu_0 \mu_r N^2 A}{l}}$$ → Inductance of a coil
N = no. of turns.

Inductance changes when position of moving Iron changes, ~~then~~ i.e when θ changes
then L changes. θ changes → L changes

$$\boxed{L \propto \theta}$$

so the Torque is given by $\boxed{T = \frac{dU}{d\theta}}$
↳ Potential/Stored Energy.

We know ~~the~~

Energy Stored in an Inductor is

~~$\varnothing$~~ $$\boxed{\frac{1}{2} L I^2 = U = \text{Potential energy}}$$

We know torque changes due to change in θ & L.

~~$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$~~ $T_d = U = \frac{1}{2} L I^2$

Differentiating 'U' w.r.t θ

$T_d = \left(\frac{dU}{d\theta} = \frac{1}{2} I^2 \frac{dL}{d\theta}\right)$

$\Rightarrow \boxed{T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}}$

So $\boxed{T_d \propto I^2}$ - / AC & DC $\boxed{T_d \propto V^2}$

Controlling torque

Hence controlling torque is provided by either spring control or gravity control

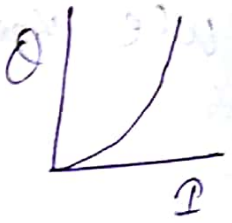
$$\boxed{T_c \propto \theta}$$

$\Rightarrow \boxed{T_c = K_c \theta}$ K_c = spring const.

for steady state $T_d = T_c$

$\Rightarrow \frac{1}{2} I^2 \frac{dL}{d\theta} = K_c \theta \Big| \Rightarrow \theta = \frac{1}{2K} I^2 \frac{dL}{d\theta}$

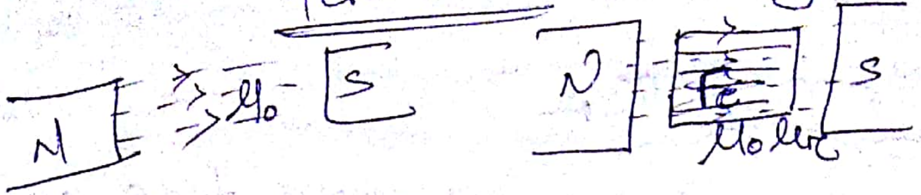
$\Rightarrow \boxed{\theta \propto I^2}$



(Non-linear ~~relation~~ Scale)

* All indicating inst. works for AC as well & D except PMMC

Permiability – Ability to permit flow magnetic flux.



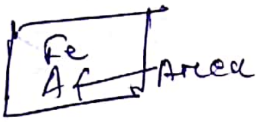
B = M-field density

H = M. field strength

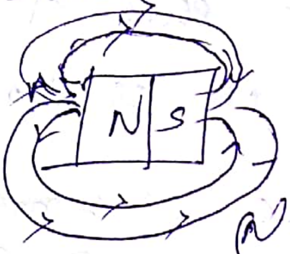
$\mu = \frac{B}{H}$ = Absolute (H/m) Permiability

μ = Permiability is the relative increase or decrease in the resultant magnetic field inside a material compared with the magnetizing field in which the given material is located.

$B_0 = \mu_0 H$ (μ_0 = P. of space = $4\pi \times 10^{-7}$ Tm/A)



$\boxed{B_i = \frac{N}{A}}$ → Induced flux density



(N webers)

$B = B_0 + B_i$

$= \mu_0 H + \frac{N}{A}$

$= \mu_r \cdot \mu_0 H = \mu_r B_0$

$\mu_r = \frac{B}{B_0} = \frac{B \text{ (material)}}{B_0 \text{ (vaccum)}}$

μ_r = not const., changes with

$\mu_r = 1$ (Air), 5 (wall)

→ position of material with r.e.t magnetic field

→ frequency of the field

→ Temp.

→ any other factors.

μ_r = Relative Permiability of a material is the ratio b/w the flux density produced in the material & the flux density produced in a vaccum by the same magnetising force.

~~Advantages~~

MI as ammeter:-

→ When MI Instrument used to measure the current in the ckt it should be always connected in series with the ckt & carries the current to be measured.

→ The current flowing through the coil produces the desired deflecting forcance.

→ It should have Low resistance coil as it is to be connected in series.

MI as Voltmeter:-

→ When MI inst. used to measure voltage ~~across~~ b/w two points in a ckt it should be always connected in parallel

→ Current flowing through the operating coil of the meter produces deflecting forcance.

→ It should have high resistance coil, thus a high resistance of order of kilo-ohms is connected in series with the coil of the instrument.

Extension Range of Ammetere & voltmeter

MI type Instrument

→ For a given M.I instrument the Amp-turns necessary to produce full scale deflection are const

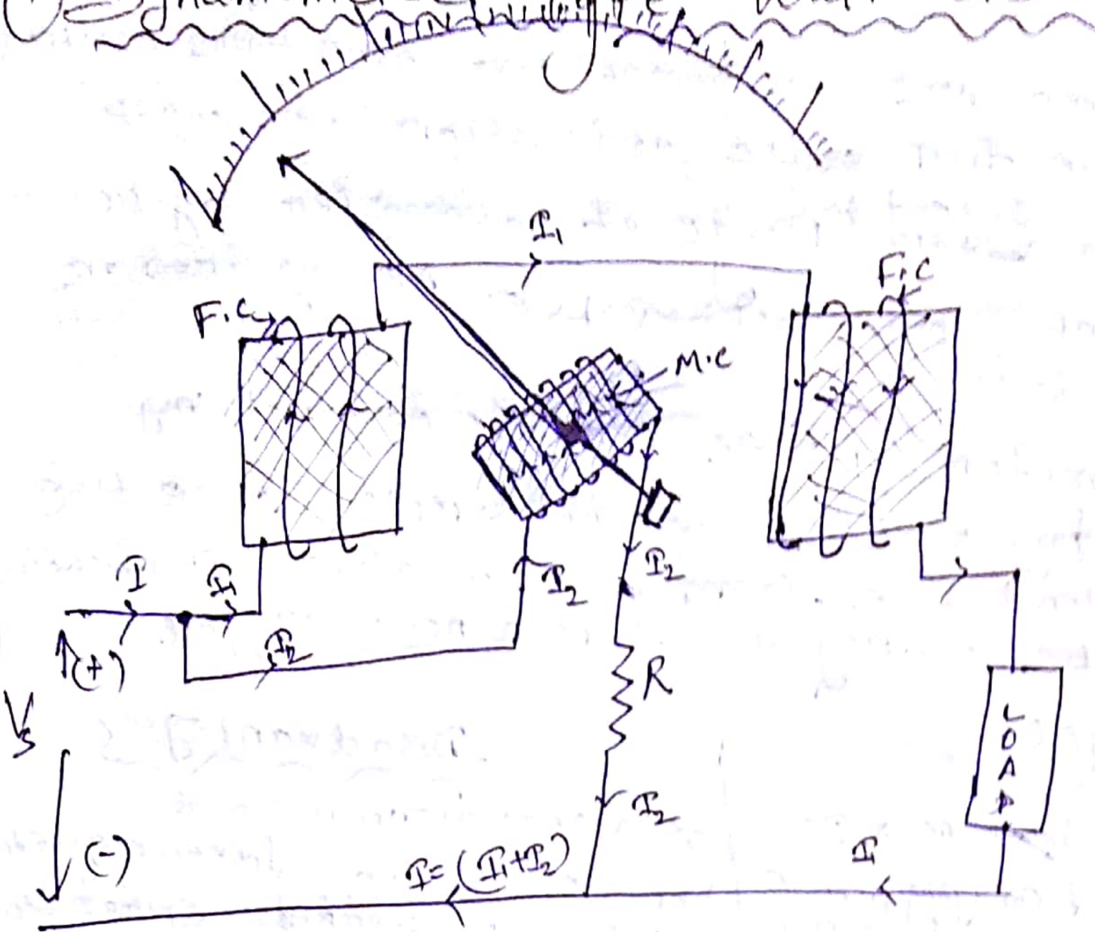
→ One can Extend ~~Extend~~ the range of ammeter by providing a shunt coil either the Moving iron are moving coil.

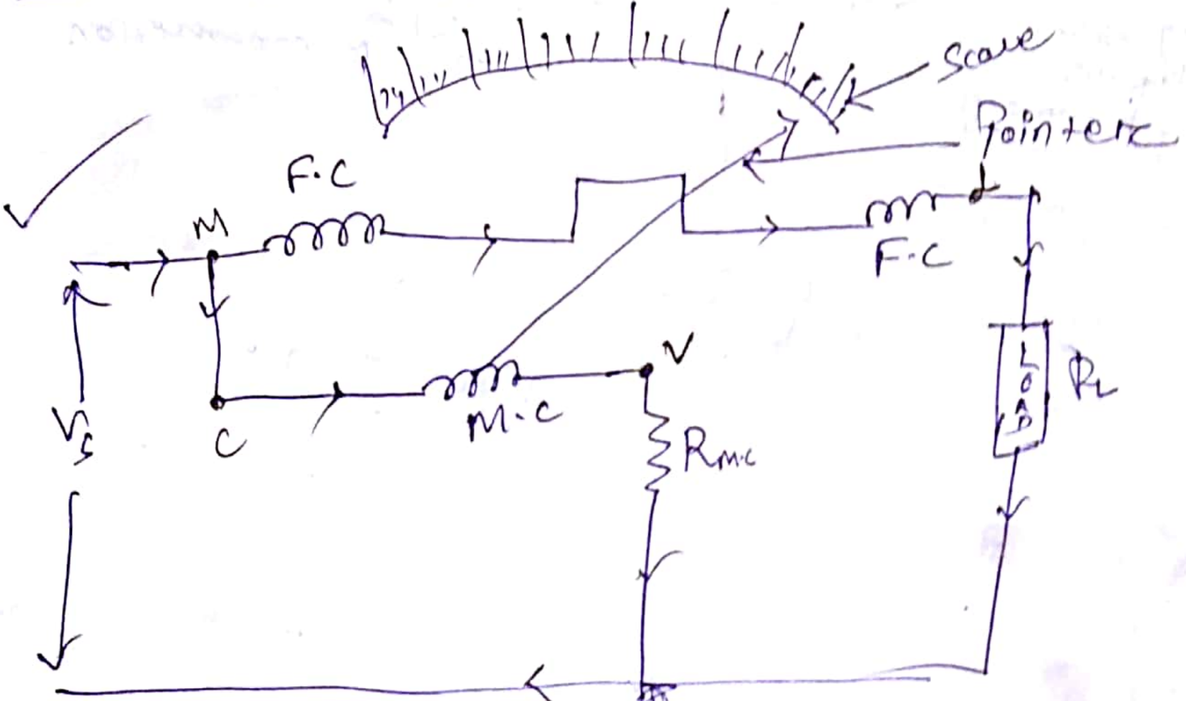
→ Voltmeter range can be extend by connecting a resistance in series with the coil, Hence the same coil winding specification may be employed for a no. of ranges.

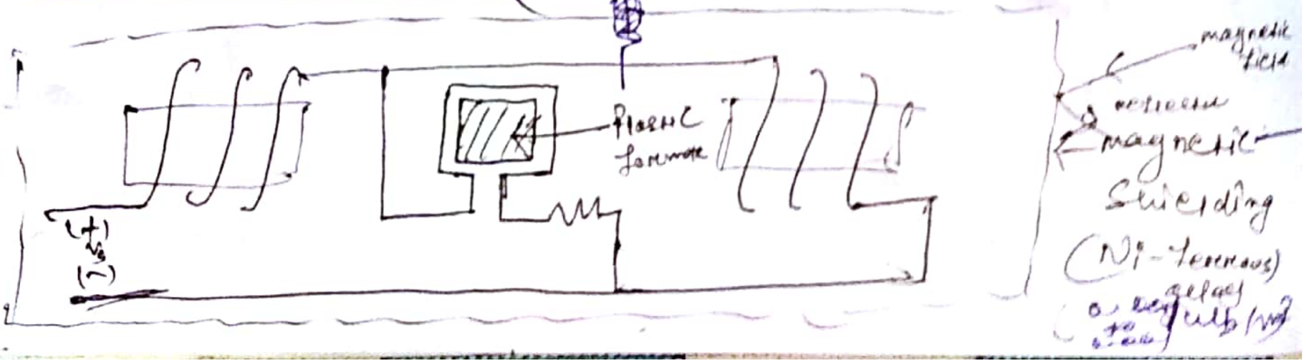
Advantages	Disadvantages
→ used for both AC & DC.	→ Non-uniform scale
→ No current carrying path in moving system hence inst reliable.	→ Errors due to freq. magnetic field, hysteresis error etc
→ Good accuracy	→ High power consumption

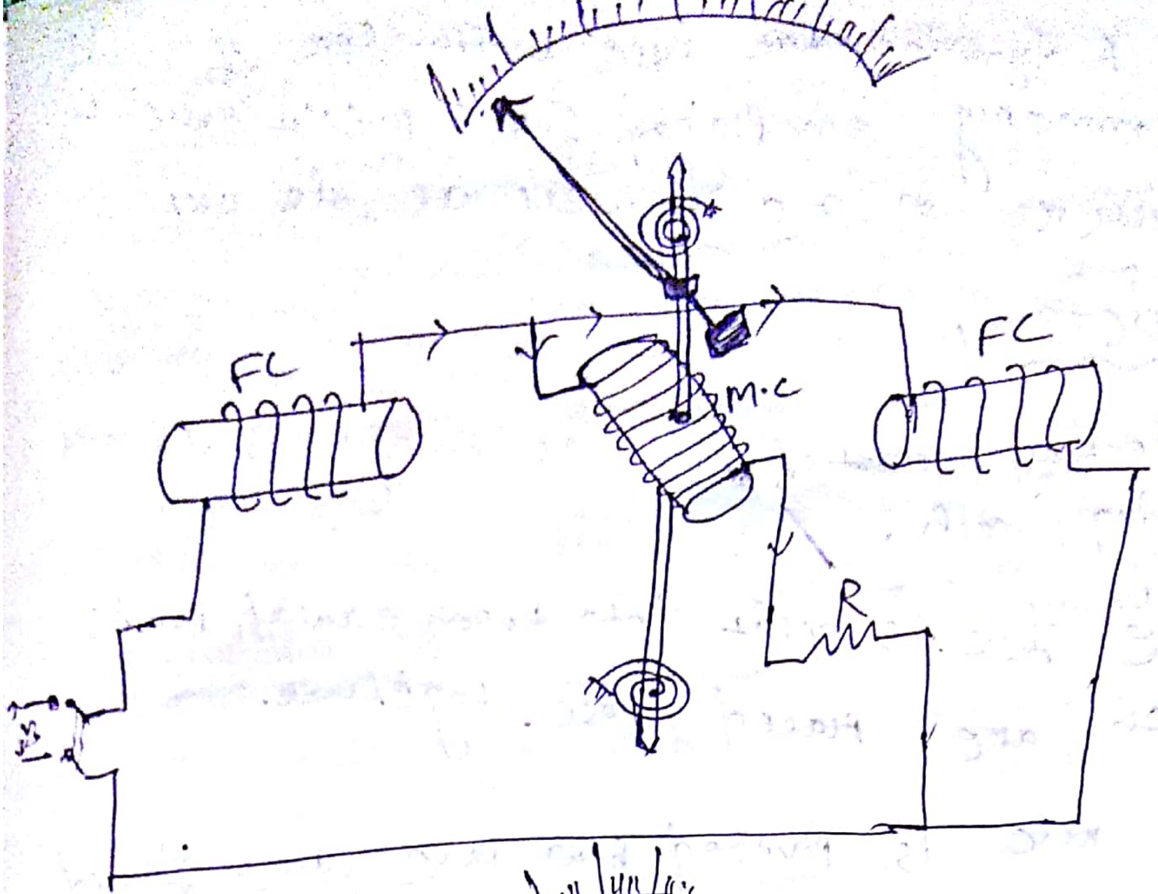
DYNAMOMETER TYPE INSTRUMENT.

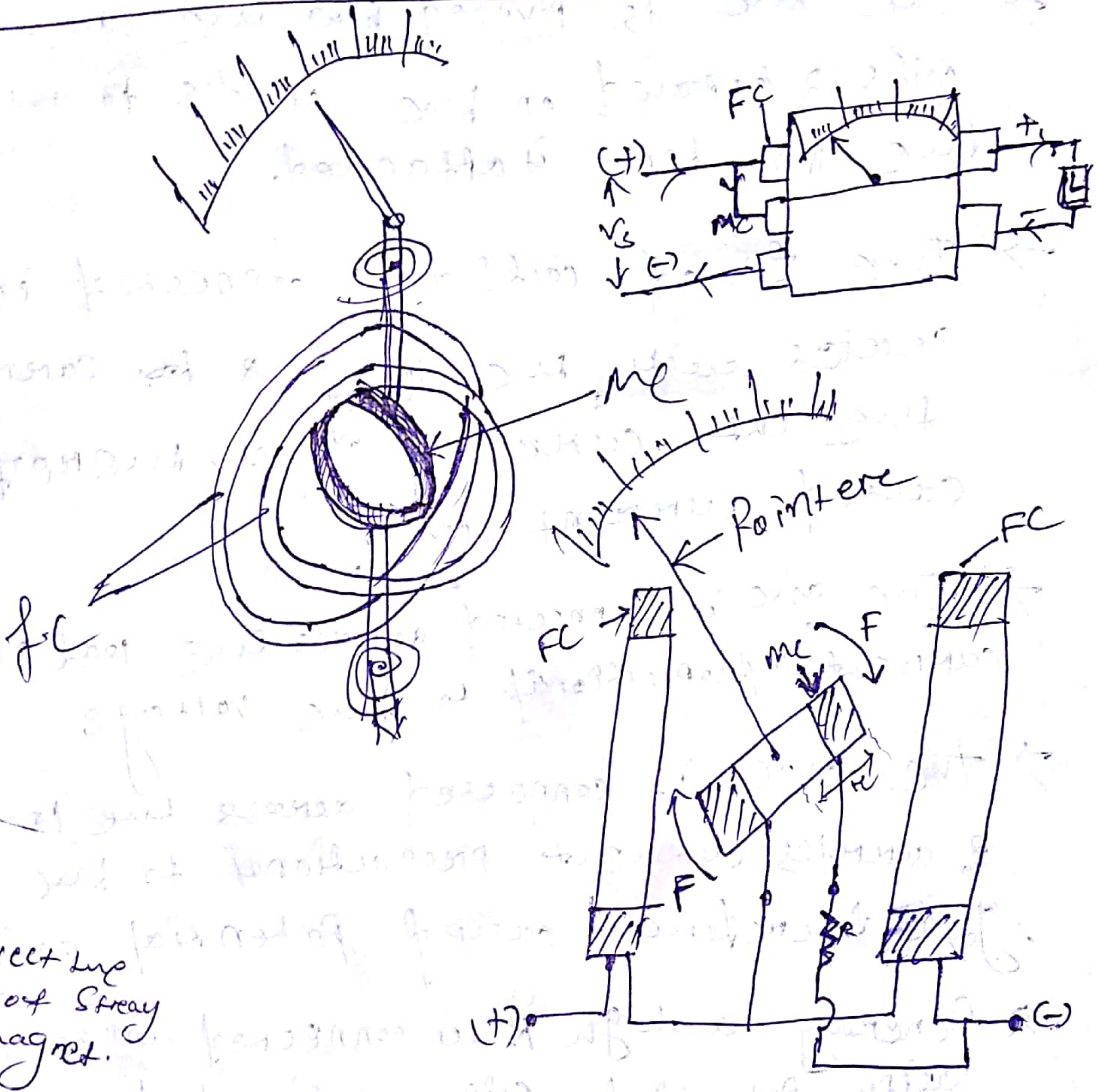
① Dynamometer Type Wattmeter Instrument.











→ to neglect the effect of Streay magnet.

Defin^n^ - A dynamometer type wattmeter is most commonly employed for measurement of power in a.c as well as dc ckt

CONSTRUCTION -

→ It essentially consist of two coils, namely fixed coil & moving coil.

→ The f.c is split into two equal parts which are placed close together.

→ The m.c is pivoted b/w the two fixed coils & is placed on the spindle to which the pointer is attached.

→ The fixed coils are connected in series with the load & ~~too~~ carry the ckt current. It is, therefore called current coil.

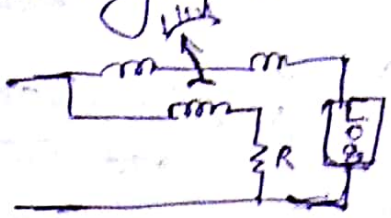
→ The m.c is connected across the load & carries current proportional to the voltage

→ The m.c is connected across the load & carries current proportional to the voltage. It is therefore called potential coil

→ Generally a high R is connected in series with potential coil to limit the current through it.

- The controlling torque is Provided by spring (which also serve the additional purpose of reading current into out of the moving coil).
- In ED type inst. plastic frame is used instead of Al frame to reduce Eddy loss.
- Aire friction damping is employed in such instruments.

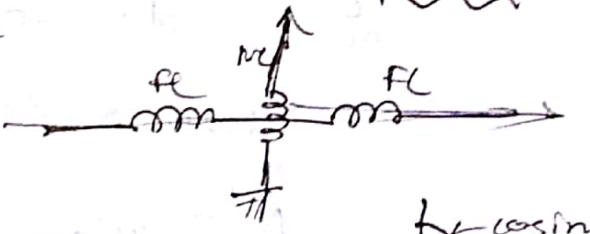
WORKING PRINCIPPLE



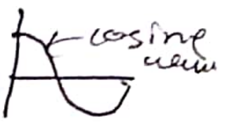
- The CC is connected in series with load so that it is carries the ckt current
- The P.C/V.C is connected across the load so that it carries current proportional to the voltage
- Due to the current in the coils, mechanical force exists b/w them. The result is that the moving coil, moves the pointer over the scale.
- The pointer comes to rest at a position where deflecting torque is equal to the controlling torque. $(T_d = T_c$

TORQUE IN DYNAMOMETER TYPE W-METER Inst.

① Deflecting Torque



- when M.C moving ~~far~~ far further from F.C then magnetic field starts to reduce.

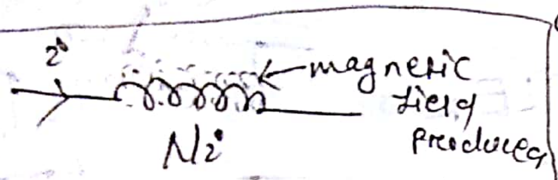


Then the deflecting torque produced in M.C is directly proportional to current through F.C & current through M.C

i.e- ✓ $T_d \propto I_{mc} I_{fe}$.

✓ $T_d = I_{FC} I_{mc} \frac{dm}{d\theta}$ where $\frac{dM}{d\theta}$ = Const

m = mutual inductance

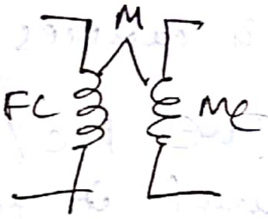


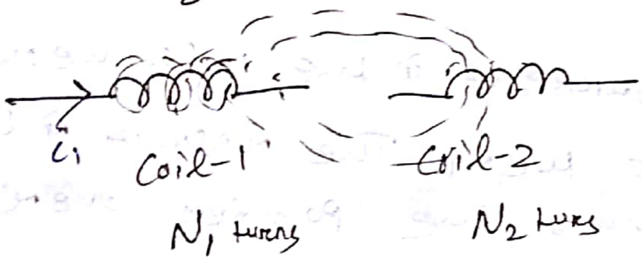
N = no. of turns

$N\phi \propto i$

$N\phi = Li$ L = self inductance

$L = \frac{N\phi}{i}$





$N_2\phi_{21} \propto i_1$

ϕ_{21} = flux in coil-2 due to coil-1 current i_1

$N_2\phi_{21} = Mi_1$

$M = N_2\phi_{21}$

$m = M_{max}\cos\psi$

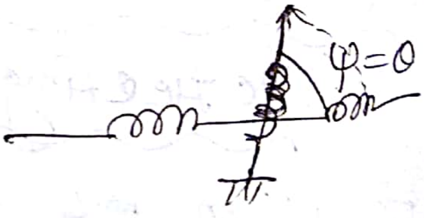
ψ = angle b/w f.C & M.C

i.e $T_d = I_{FC} I_{mc} \frac{dm}{d\theta}$

Now make $\frac{dm}{d\theta}$ const.

$M = m_{max}\cos\psi$

$\psi = \theta$

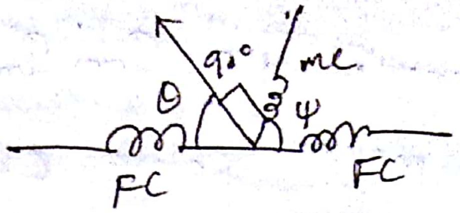


θ = angle b/w Pointer & FC

ψ = angle b/w MC & FC

$m = M_{mm} \cos\theta$ ✓

$\frac{dm}{d\theta} = M_m \sin\theta \neq \text{const.}$



✓ If Pointer placed 90° from moving coil.

$\theta + 90 + \psi = 180°$

$\psi = 90 - \theta$

$M = M_m \cos\psi$

$= M_m \cos(90 - \theta)$

$$\boxed{\Rightarrow M = M_m \sin\theta}$$

$$\boxed{\frac{dm}{d\theta} = M_m = \text{const.}}$$

we know
$\sin\theta \simeq \theta$ ✓

$\sin\frac{\pi}{6} = 0.5$

$\Rightarrow \frac{\pi}{6} = 0.52 \simeq \sin\pi/6$

→ In ED type Inst. Pointer is placed 90° from the moving coil.

$$\boxed{T_d = I_{FC} + I_{mc} \frac{dm}{d\theta}}$$

→ ED works on ac as well dc

→ in case of dc, $I_{mc} = I_1$, $I_{FC} = I_2$ } avg. value are const. val

✓

$$\boxed{T_d = I_1 I_2 \frac{dm}{d\theta}}$$

In case of AC $I_{mc} = I_{m1} \sin\omega t$

✓ $I_{fc} = I_{m2} \sin(\omega t - \phi)$

$T_{instantaneous}$ $T_d = I_{m1} I_{m2} \sin\omega t \sin(\omega t-\phi)\frac{dm}{d\theta}$

To make same calibration for AC as well as DC take average value

$$T_{avg} = \frac{1}{2\pi}\int_0^{4\pi} T_{inst.}\ d\omega t$$

$$\Rightarrow T_{avg} = \frac{I_{m1}I_{m2}}{2\pi}\frac{1}{2}\int_0^{2\pi}\left(\cos(2\omega t-\phi)+\cos\phi\right)d\omega t$$

$$= \frac{I_{m1}I_{m2}}{4\pi}\left[\frac{\sin 2\omega t-\phi}{2}\right]_0^{2\pi} + \cos\phi\cdot\left[\omega t\right]_0^{2\pi}$$

$$= \frac{I_{m1}I_{m2}}{4\pi}\left[\cancel{\left(\frac{\overset{-\sin\phi}{\sin(4\pi-\phi)}}{2}\right)} - \cancel{\frac{\overset{+\sin\phi}{\sin(-\phi)}}{2}}\right] + (\cos\phi)[2\pi-0]$$

$$= \frac{I_{m1}I_{m2}}{\cancel{4\pi}2}\times(\cos\phi)\cancel{(2\pi)}$$

$\sin A\cos B = \frac{\cos(A+B) - \cos(A-B)}{2}$

$\sin\omega t\sin(\omega t-\phi) = \frac{\cos(2\omega t-\phi)+\cos\phi}{2}$

$$T_{avg} = \frac{I_{m1}}{\sqrt{2}}\times\frac{I_{m2}}{\sqrt{2}}\cos\phi\frac{dm}{d\theta}$$

$$T_{avg} = (I_{fc})_{rms}\times(I_{mc})_{rms}\cos\phi\frac{dm}{d\theta}$$

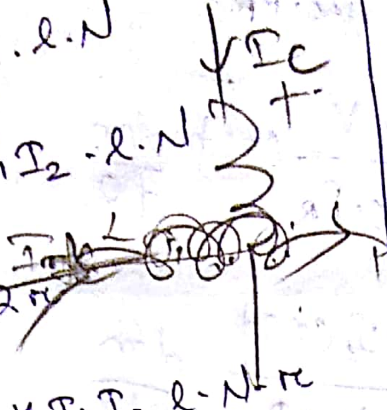
$$\therefore \boxed{T_d = I_{fc}\, I_{mc}\cos\phi\cdot\frac{dm}{d\theta}}$$

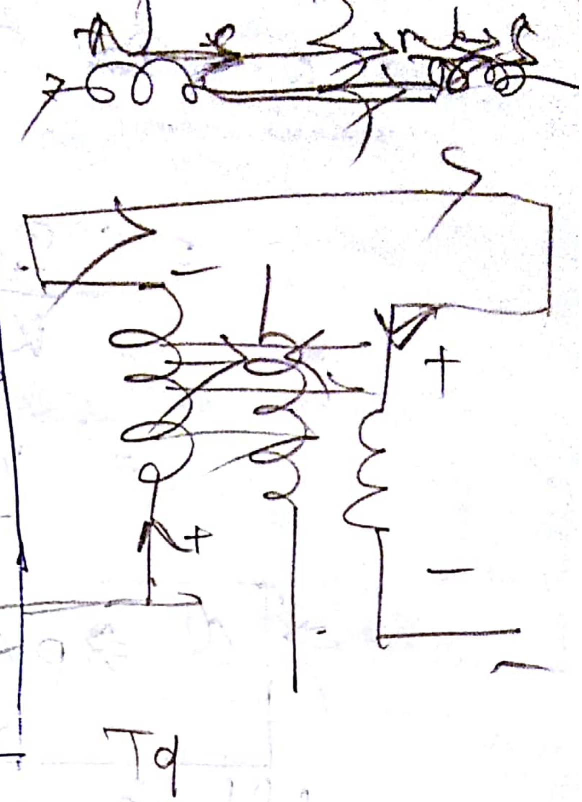
ϕ = angle b/w m.c I & f.c I

→ E.D type inst. alway read RMS value

~~In case~~

$$\boxed{\begin{aligned} B &= K I_1 \\ F &= B I_2 \cdot l \cdot N \\ F &= K I_1 I_2 \cdot l \cdot N \\ T_d &= F \cdot 2r \\ \Rightarrow T_d &= K I_1 I_2\, l \cdot N \cdot r \\ &\boxed{T_d \propto I_1 I_2} \end{aligned}}$$





② Controlling Torque

→ The controlling torque is produced due to spring.

i.e $\boxed{T_c \propto K_c \theta}$

K_c = Spring const.

θ = angle of deflection.

$T_c = K_c \theta$

At equilibrium

$T_d = T_c$

For DC

$\Rightarrow I_1 I_2 \frac{dM}{d\theta} = K_c \theta$

$\Rightarrow \theta = \frac{I_1 I_2}{K_c} \frac{dM}{d\theta}$

$\theta \propto I_1 I_2$

For AC

$T_d = T_c$

$\Rightarrow I_{fc} I_{mc} \cos\phi \frac{dm}{d\theta} = K_c \theta$

$$\boxed{\Rightarrow \theta = \frac{I_{fc} I_{mc} \cos\phi \frac{dm}{d\theta}}{K_c}}$$

We know that $I_{mc} = \frac{V}{R_{mc}}$

$$\Rightarrow \theta = \frac{I_{fc} \cdot V}{K_c \cdot R_{mc}} \cos\phi \frac{dm}{d\theta}$$

$$= \frac{I_f \cdot V}{K_c \cdot R_R} \cos\phi \frac{dm}{d\theta} \quad \left(I_{fc} = I \right) \left(I_{mc} = \frac{V}{R_{mc}} \right)$$

$$= \frac{VI_{fc}\cos\phi}{K_c \cdot R_{mc}} \frac{dm}{d\theta}$$

$$\Rightarrow \boxed{\theta \propto P\left(\frac{1}{K_c \cdot R_{mc}} \frac{dm}{d\theta}\right)}$$

where p = avg. power being measured

Advantages:-

→ Used for both AC & dc operation

→ Uniform scale

→ Light weight due to air core.

→ Less power consumption.

→ Range of the instrument can be easily change

→ Can be measured in vertical & horizontal position

→ Accuracy is more.

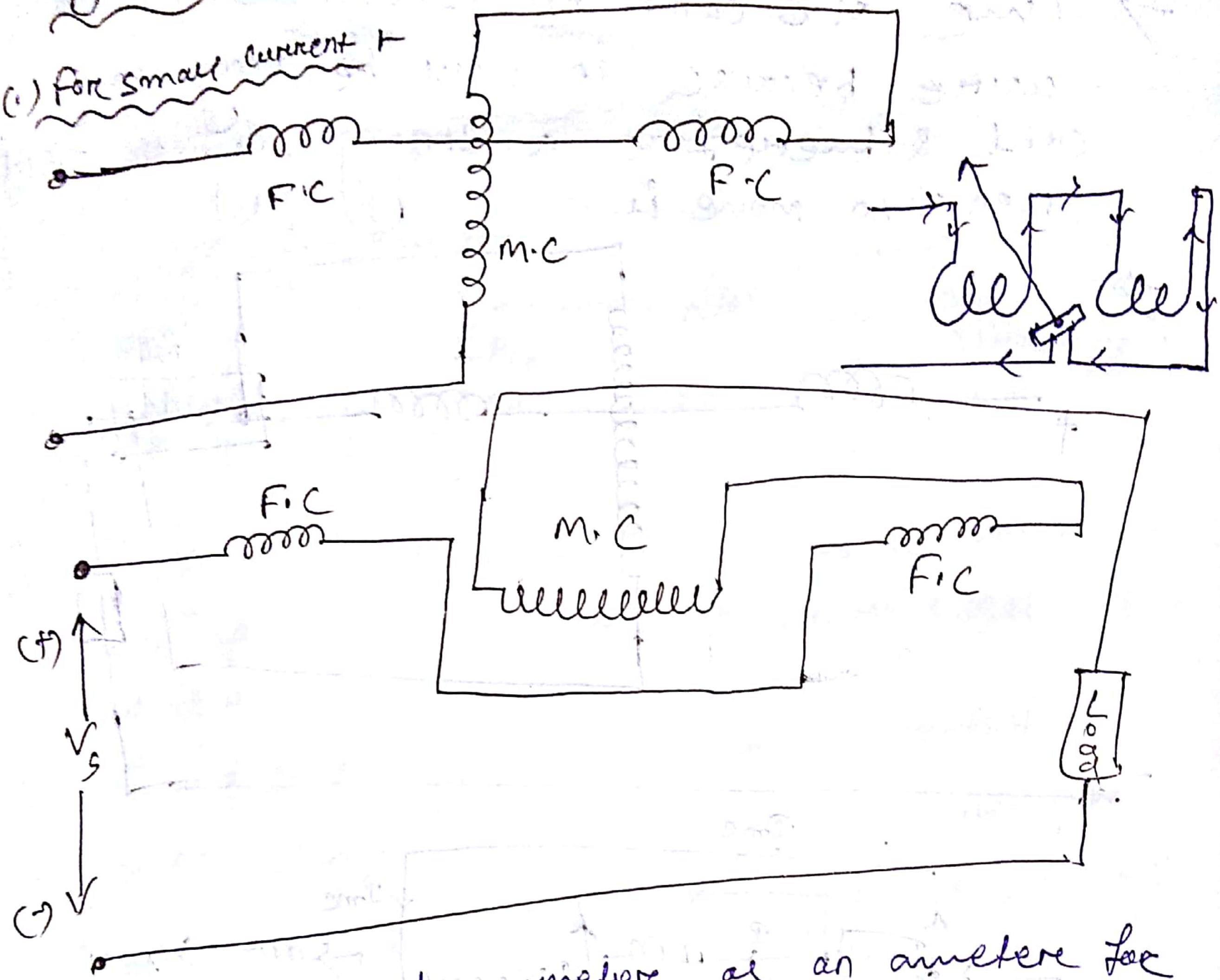
Disadvantages:-

→ Readings can be affected by stray magnetic field, therefore extra magnetic shielding is required.

→ Errore occures due to the inductance of the M.C or P.C or pressure coil at low power factor is vary.

1) Dynameter type Instrument as ammeter →

(i) For small current →



→ To use the dynamometer as an ametere for a measurement of small current the moving coil & fixed coil are connected in series. ~~as sto~~ → In this case current in fixed coil caual to the current in moving coil.

$$I_{fc} = I_{mc}$$

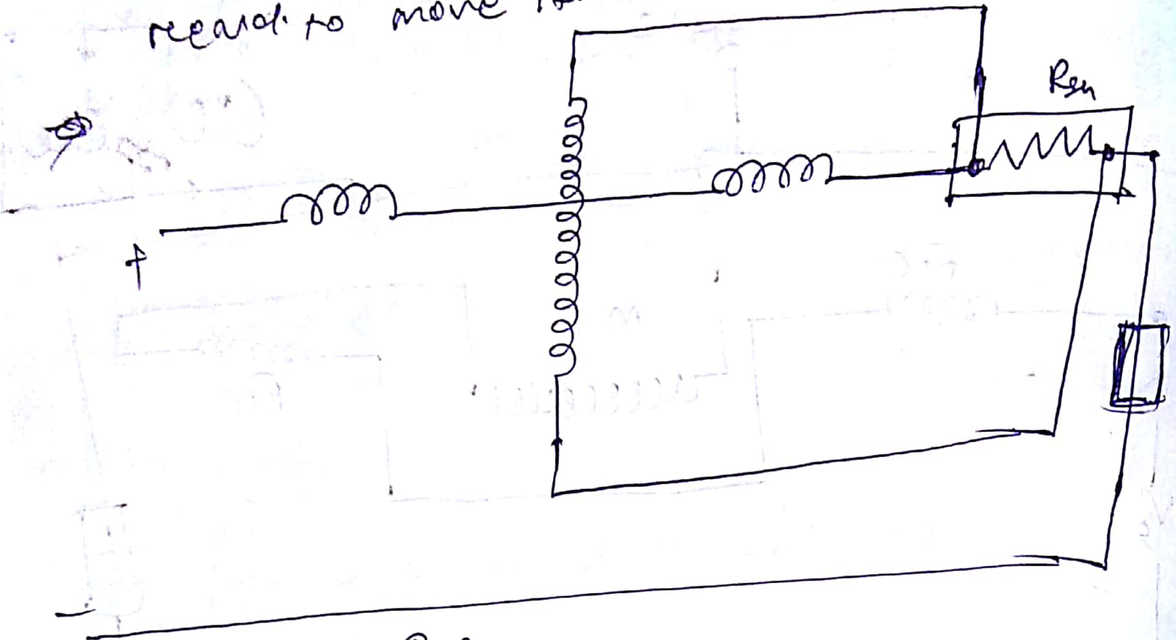
when $T_d = T_c$

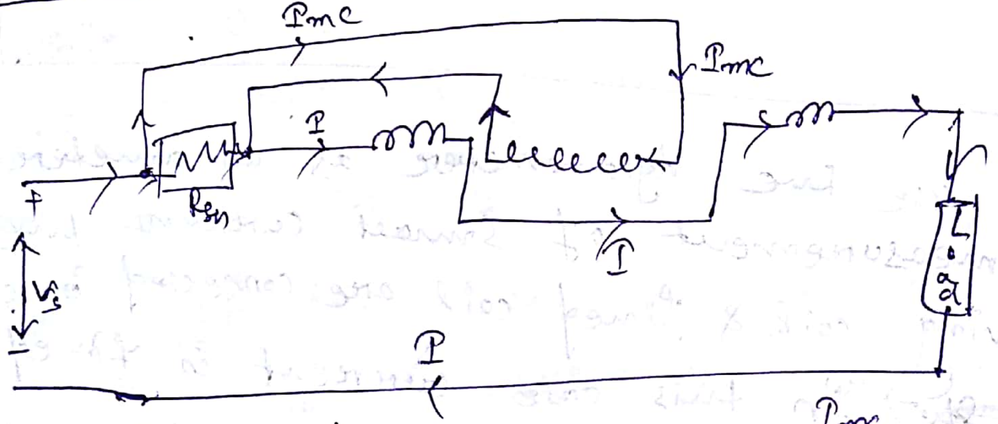
$\theta \propto I_{fc} I_m$ or $\boxed{\theta \propto I^2}$

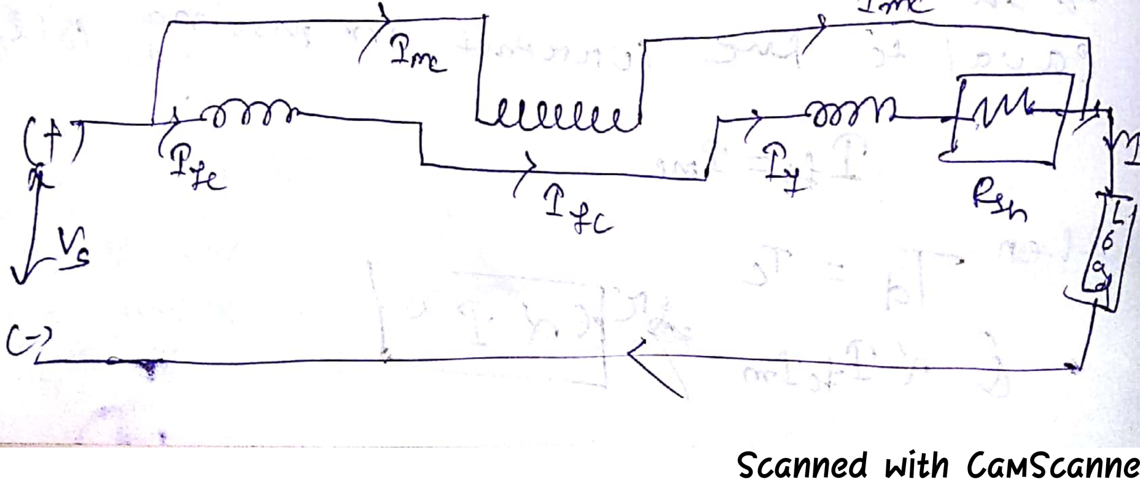
(ii) For high current

→ When the DM is ~~used~~ to be used for measurement of higher currents, the F.C are wound with thick wire.

→ The M.C can't be wound with thick wire because it will became ~~be~~ very heavy coil & therefore a strong magnetic field need to move it.



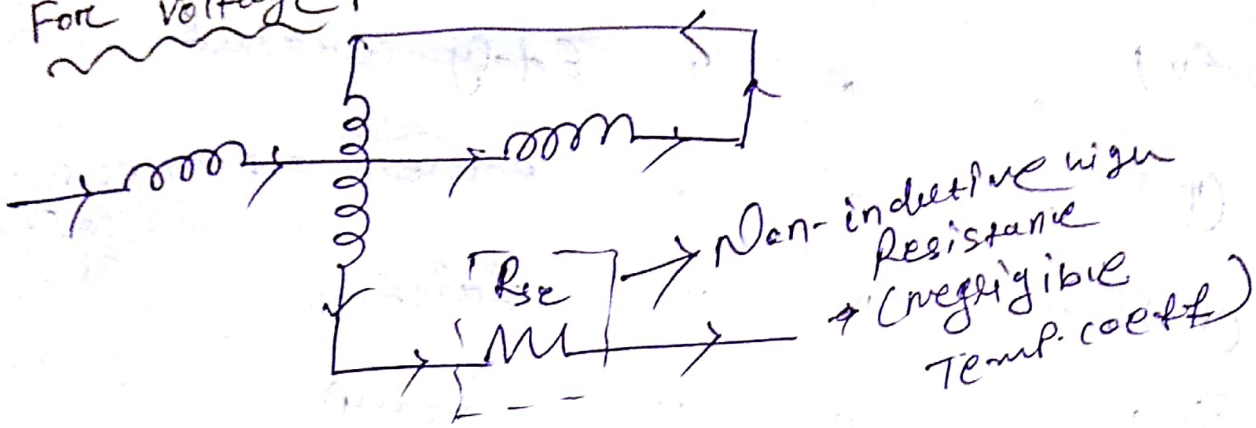




→ The difficulty is overcame by canneating the moving coil terminals of a shunt resistance R_{sh} or one terminal of M.C & one terminal of f.c can be connected across ~~to~~ shunt resistance. For measurement of higuere current.

→ ~~Thus the Rsh limits the current in MC &~~

(iii) For voltage t



→ When DM is to be used as a voltmeter the coils are wound with high resistance

→ Fixed & moving coils are connected in series along with a high Non-inductive resistance Rse which have negligible temp. coeff.

→ In this case same current flows through both of the fixed & moving coils.

$$T_d \propto V^2$$

$$T_d = T_c$$

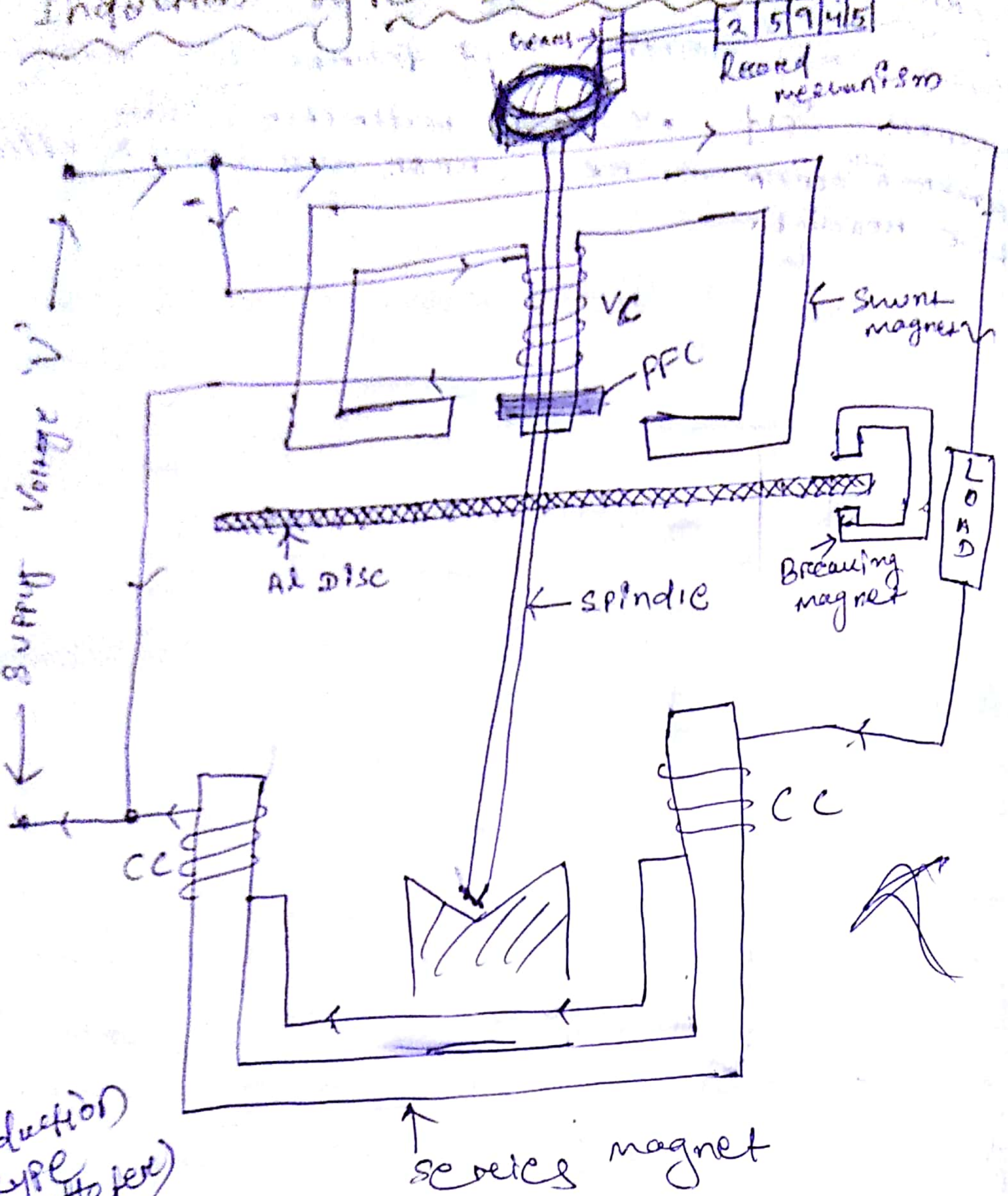
$$\theta \propto V^2$$

Errors in dynamometer type Instruments

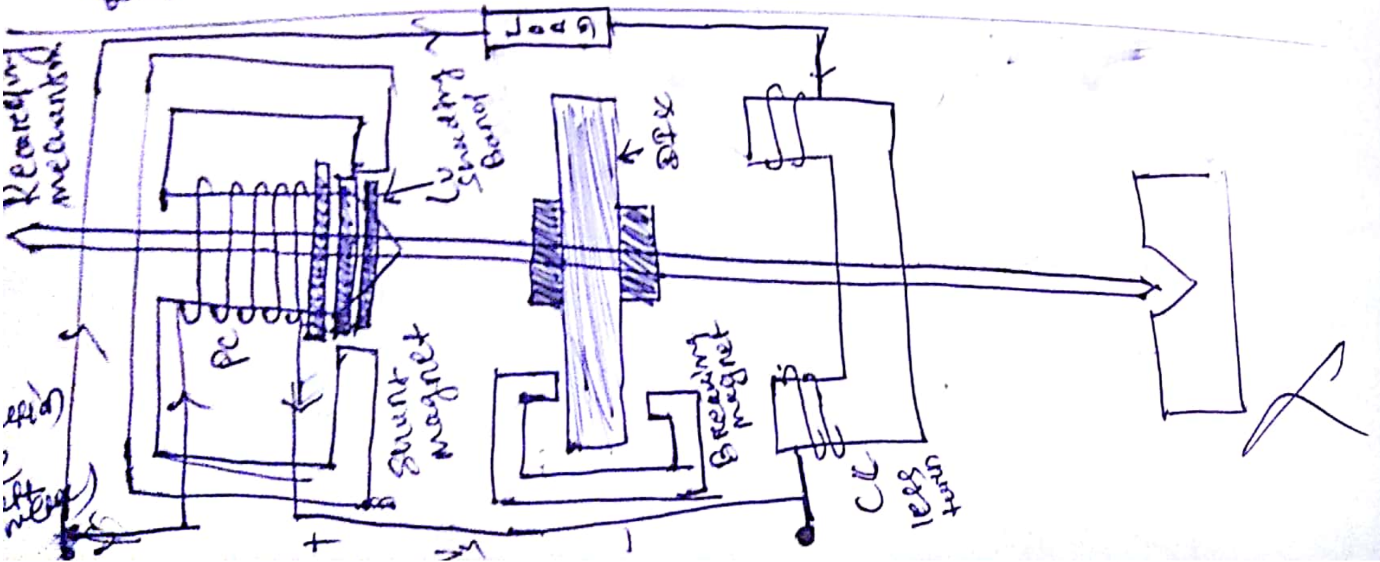
→ The various types of errors in DM-type instruments are:

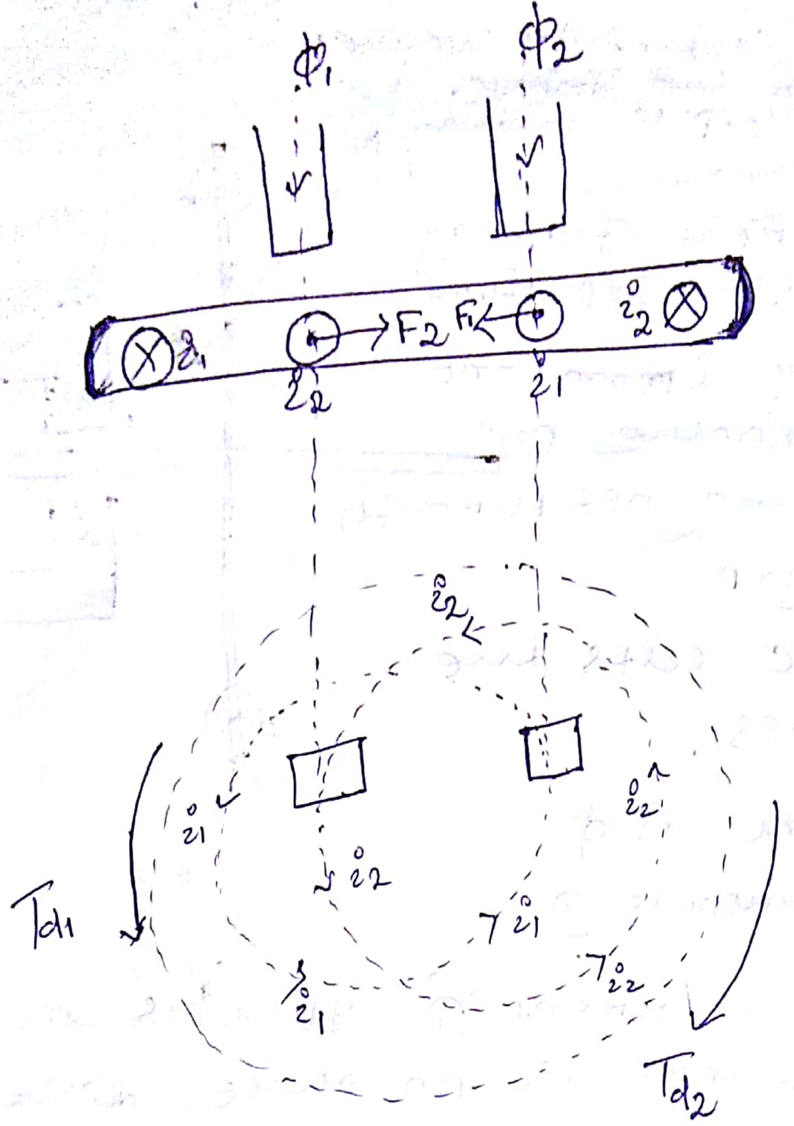
(I) Error due to M.C or pressure coil Inductance
(II) " " " M.C or P.C Capacitance
(III) " " " Eddy current
(IV) " " " power loss in Pressure coil or M.C
(V) " " " friction
(VI) " " " temp.
(VII) " " " Stray magnetic field

Induction type Instrument



Induction type (wattmeter)





Construction :-

→ It consist of one electromagnet ~~consist of~~ having some coils in the magnet.

→ An Aluminium disc or a highy resistive metalic disc placed b/w the electromagnet

→ ~~The disc can be~~

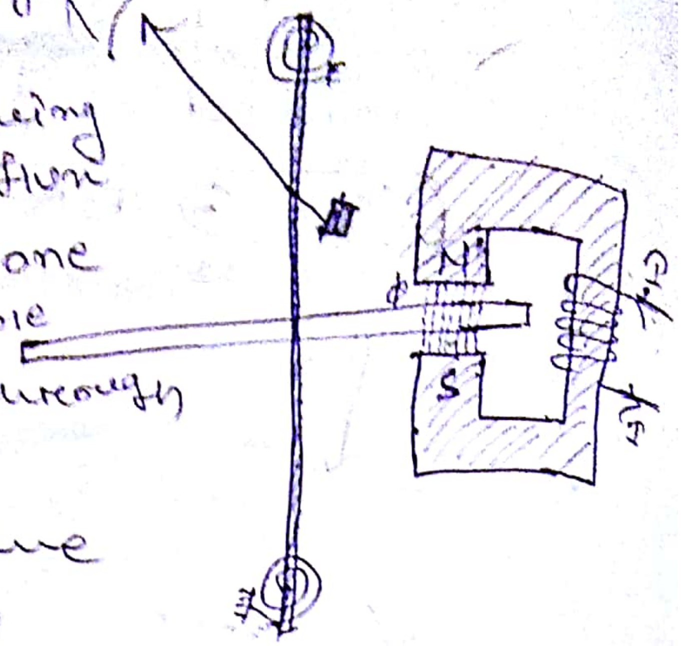
→ A spindle is introuded with the disc so that the disc can rotate about ~~the~~ this spindle.

→ The disc is placed in b/w two poles of the electromagnet.

→ A Pointer is attached to the spindle.

→ The ~~springs~~ controlling torque provided by two springs.

Working principle

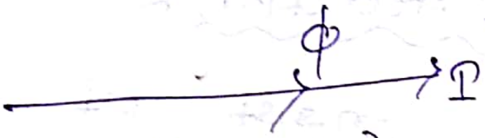


→ when Current flowing through the coil flux lines coming from one pole to another pole of electromagnet through the air gap

→ The disc cuts the flux lines.

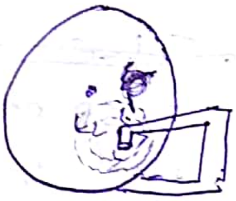
→ Let flux is ϕ
current is I

→ Due to current I flux ϕ is created So the there is no phase difference b/w I & ϕ

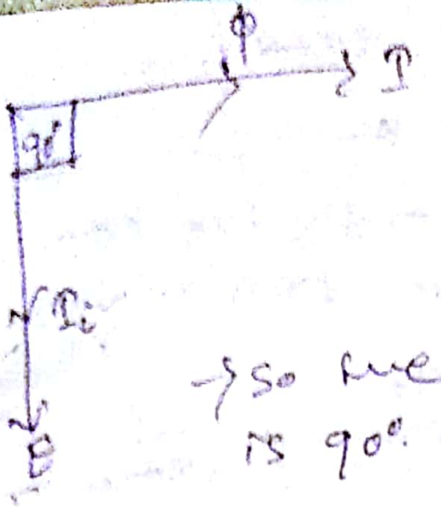


→ when Al. disc cuts the flux lines there will be a circulating eddy current induced in ~~the~~ the disc.

→ The eddy current (I_e) induced due to emf which has been induced due to induction of the flux at that disc



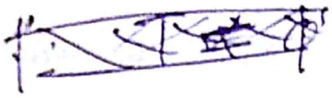
→ The emf (E) lags the flux 'ϕ' by 90° ~~due to~~ because the disc is fully resistive.



→ The eddy current I_i has no phase diff. with induced emf 'E'.

→ So the phase diff. b/w φ & I_i is 90°.

→ ~~Therefore~~ Torque will be produced due the φ of the electromagnet & the eddy current 'I_2'.



→ Therefore the Torque is directly proportional to the value of φ & I_2 & as well as cosine angle b/w φ & I_2.

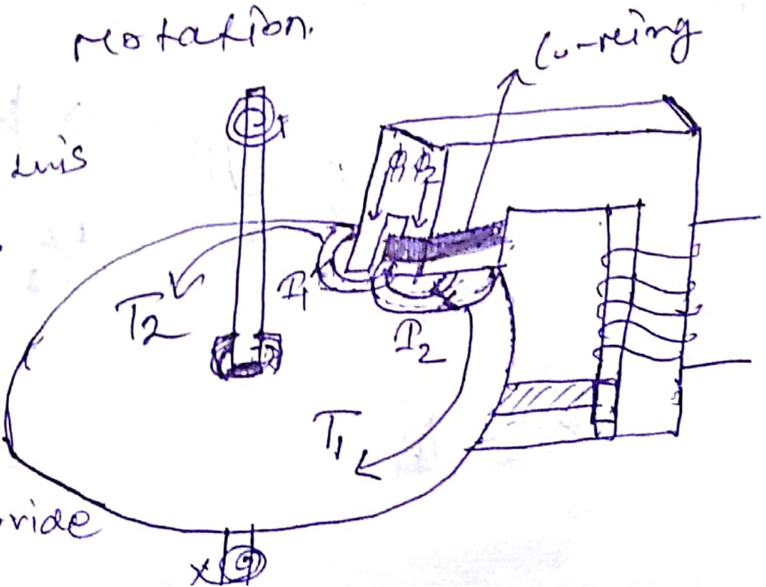
$$\therefore \quad T = K \phi I_2 \cos 90^\circ$$

T = value of torque acting on the disc. (K = proportionality const.)

$$\boxed{\therefore \; T = 0}$$

There is no torque acting on the this neither rotation.

→ To overcome this a groove piece is cut from one pole face of the electromagnet & a Cu ring is provide



to a ~~[illegible]~~ grooved pole face.

→ Now there will be flux from induce of, one through the copper winding ϕ_1 & another flux through the electromagnet ϕ_2

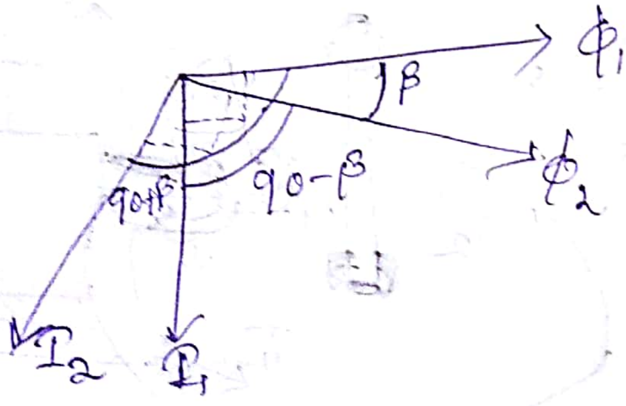
→ ~~The~~ Due to main flux 'ϕ' ~~due to~~ of 'em', one current will Induce in 'C' ring & that current will produce another flux which will ~~produce another~~ ~~[illegible]~~ opposite of the main flux.

→ Because of the opposition of new flux & main flux a resultant flux ϕ_2 is produce.

→ ϕ_1 is in phase with main flux ϕ

→ Due to opposition of main flux ϕ_2 is induced there ~~main flux~~ is some phase diff. b/w ϕ_1 & ϕ_2. is 'β'.

→ I_1 eddy current induced due to ϕ_1 Similarly I_2 due to ϕ_2



→ Now there will be a torque acting on disc due to interaction of ϕ_2 & I_1

(No torque due to interacⁿ of ϕ_1 & I_1 & also ϕ_2 & I_2.)

Let the torque 'T_1'

$$\therefore T_1 = K_1 I_1 \phi_2 \cos(90^\circ - \beta)$$

$K_1 \equiv$ prop. const.

But $I_1 \propto \phi_1 \Rightarrow \boxed{I_1 = K_0 \phi_1}$

~~$I_2 \propto \phi_2$~~ & $\cos(90^\circ - \beta) = \sin\beta$

So we can write

$$\boxed{T_1 = K \phi_1 \phi_2 \sin\beta}$$

where K = prop. const. of ϕ_1 & I_1 & K_1

$$\boxed{K = K_1 K_0}$$

Similarly due to interaction of ϕ_1 & I_2 another torque acting..

$$\therefore T_2 = K_2 I_2 \phi_1 \cos(90 + \beta)$$

~~T_2~~ $I_2 \propto \phi_2 = K_0 \phi_2$

$\cos(90 + \beta) = -\sin\beta$

$$\therefore \boxed{T_2 = -K \phi_1 \phi_2 \sin\beta}$$

→ Because of two torques T_1 & T_2 there will be a resultant torque that will deflect the disc & hence we can write

$$T_d = T_1 - T_2$$

$$= K_1 \phi_1 \phi_2 \sin\beta - (-K\phi_1\phi_2 \sin\beta)$$

$$= K\phi_1\phi_2 \sin\beta + K\phi_1\phi_2 \sin\beta$$

$$\boxed{T_d = 2K\phi_1 \phi_2 \sin\beta.}$$

$$\therefore \boxed{T_d \propto \phi_1 \phi_2}$$

The actual cause of ϕ_1 & ϕ_2 is main current 'I' entering through the coil

So $\phi_1 \propto I$ ✓

$\phi_2 \propto I$ ✓

$$\therefore \boxed{T_d \propto I^2}$$

→ The controlling torque provided by the spring

$$T_c \propto \theta$$

At steady state

$$T_d = T_c$$

$\Rightarrow 2k\phi_1\phi_2 \sin\beta = K_C \theta$

$$\Rightarrow \theta = \frac{2k\phi_1\phi_2\sin\beta}{K_C}$$

$$\boxed{\theta \propto \phi_1\phi_2}$$ ✓

Advantages :-

- Less expensive as compared to MI instrument
- It has high torque to weight ratio as compared to other instruments.
- Accuracy is good.

Disadvantages :-

- Can use for AC measurements only.
- Non linear scale
- consume more power as comp. to other instruments.
- Errors are caused due to temp, waveform & frequency changes.

Rectifier Type Instrument

Rectifier → AC signal to DC signal

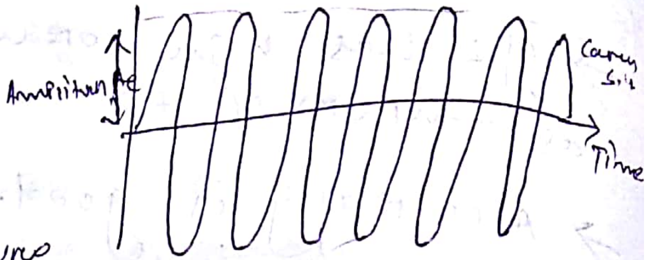
→ For diff. signals we use diff instr.

For AC signal → RMS value should measure

DC signal → Avg. value should measure

→ Some AC-signals can't be measured by AC-inst. like communication signals i.e. wireless signal.

→ communication signals are Low volt. & high freq. signal



→ MI, dynamometer, & Induction typemeter are the inst. can measure AC-signal but can't measure this type of signal

→ This insts. can only measure those AC-signal which have only power frequency (i.e. 50 to 60 Hz)

↳ At which freq we can generate & transmit.

→ only PMMC (DC) type indicating instrument can measure communication signal (AC)

→ PMMC inst. can only measure DC, so it need some extra arrangement to measure high freq. signal.

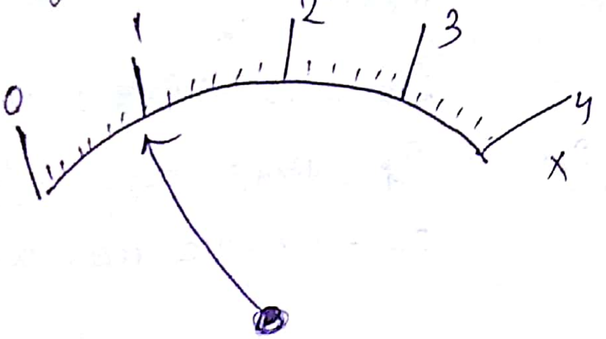
→ A rectifier ckt arrangement with the PMMC inst, so that it can measure this type ~~the Average value~~ of signal.

AC → $\boxed{\text{Rectifier}}$ → DC → Avg value × Form Factor

$$\Rightarrow \text{Avg. value} \times \frac{\text{RMS}}{\text{Avg value}}$$

$$= \text{RMS} = \text{AC value.}$$

→ i.e. $\boxed{\text{Reading of rectifier type inst} = \text{PMMC meter reading} \times \text{Form factor}}$



× F.F. = Reading of rectifier type inst.

→ ~~The~~ After rectification of signal PMMC instrument measure ~~the~~ Avg. value of DC component & then the Avg. value multiply with form factor so that user get desired measured RMS value ~~which is~~ which is AC ~~quantity~~ value.

→ Instead of repeatedly multiplying ~~repeatedly with form~~ measured value with ~~form~~ FF ~~factor~~ the scale is replaced by another the scale which is ~~already multiplied~~ ~~calibrated~~ scale so calibrated that it is already ~~with ff.~~ multiply with. F.F.

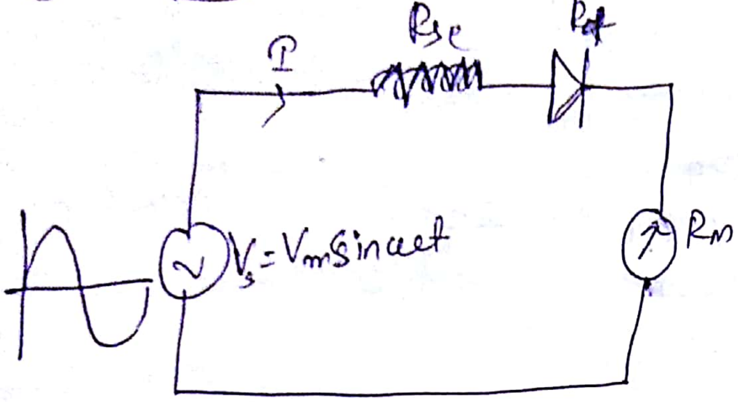
→ There is ~~some~~ a limitation of rect. type instrument :-

(1) while measuring ~~a~~ a signal the nature of the signal shouldn't be changed i.e. if it's sinusoidal then only for sinusoidal calibrated inst. used otherwise it will give error at O/P.

→ Basically rectifire type inst. are two types.

① Half wave Rectifier.
② Full wave Rectifier.

① Half wave Rectifier type:



where

R_{se} = series Resistance
R_d = diode resistance
R_m = meter resistance

Ideal Diode = $R = 0 \rightarrow$ F.B
$R = \infty \rightarrow$ R.B

practical " $R = R_d \rightarrow$ F.B
$R = \infty \rightarrow$ R.B.

→ In this ckt a rectifying element is connected in series with the sinusoidal volt. source, PMMC inst. & a series multiplier resistance (R_{se})

→ The func of the Resistance is to limit the current drawn by PMMC instrument

→ The given ckt is a voltmeter, so

R_{eq} or $R_v = R_{se} + R_d + R_m$

$V_s = V_m \sin\omega t$

$I_{avg} = \frac{I_m}{\pi}$ & $I_m = \frac{V_m}{R_{eq}}$, $\boxed{\begin{array}{l} V_m = \sqrt{2}\, V_{rms} \\ V_m = \pi\, V_{avg} \end{array}}$ & $V_{avg} = \frac{V_m}{\pi}$

I_m = meter current

$$\therefore I_{avg} = \frac{V_m}{\pi (R_{ew})} = \frac{V_m}{\pi (R_{se} + R_d + R_m)} = \frac{\sqrt{2} \times V_{rms}}{\pi (R_s + R_d + R_m)}$$

$$= \frac{V_{avg}}{R_{ew}}$$

$$\boxed{I_{avg} = \frac{0.45\, V_{rms}}{R_{ew}}}$$

$$\boxed{V_{avg} = 0.45\, V_{rms}}$$

or

$$\boxed{I_{avg} = \frac{V_{avg}}{R_{ew}}}$$

$$\left(\because V_{avg} = 0.45\, V_{rms}\right)$$

$$V_{avg} = \frac{V_{max}}{\pi}$$

$$V_{rms} = \frac{V_{max}}{\sqrt{2}}$$

$$V_{rms} = ~~2.77~~ \times V_{avg} \Big)$$

$$FF = \frac{V_{rms}}{V_{avg}} \Rightarrow \boxed{V_{rms} \text{ or } V_{fsd} = F.F\, V_{avg}}$$

$$= \frac{\frac{V_m}{\sqrt{2}}}{\frac{V_m}{\pi}} = \frac{\pi}{\sqrt{2}} \Rightarrow V_{rms} = 1.11\, V_{avg}$$

$$\% \text{ Error} = \left(\frac{V_{rms} - V_{true}}{V_{true}}\right)_{rms} \times 100$$

$$= \left(\frac{1.11\, V_{avg} - FF \cdot V_{avg}}{FF\, V_{avg}}\right) \times 100$$

→ Hence sensitivity of half wave rectifier instrument with ac is 0.45 times its sensitivity with dc.

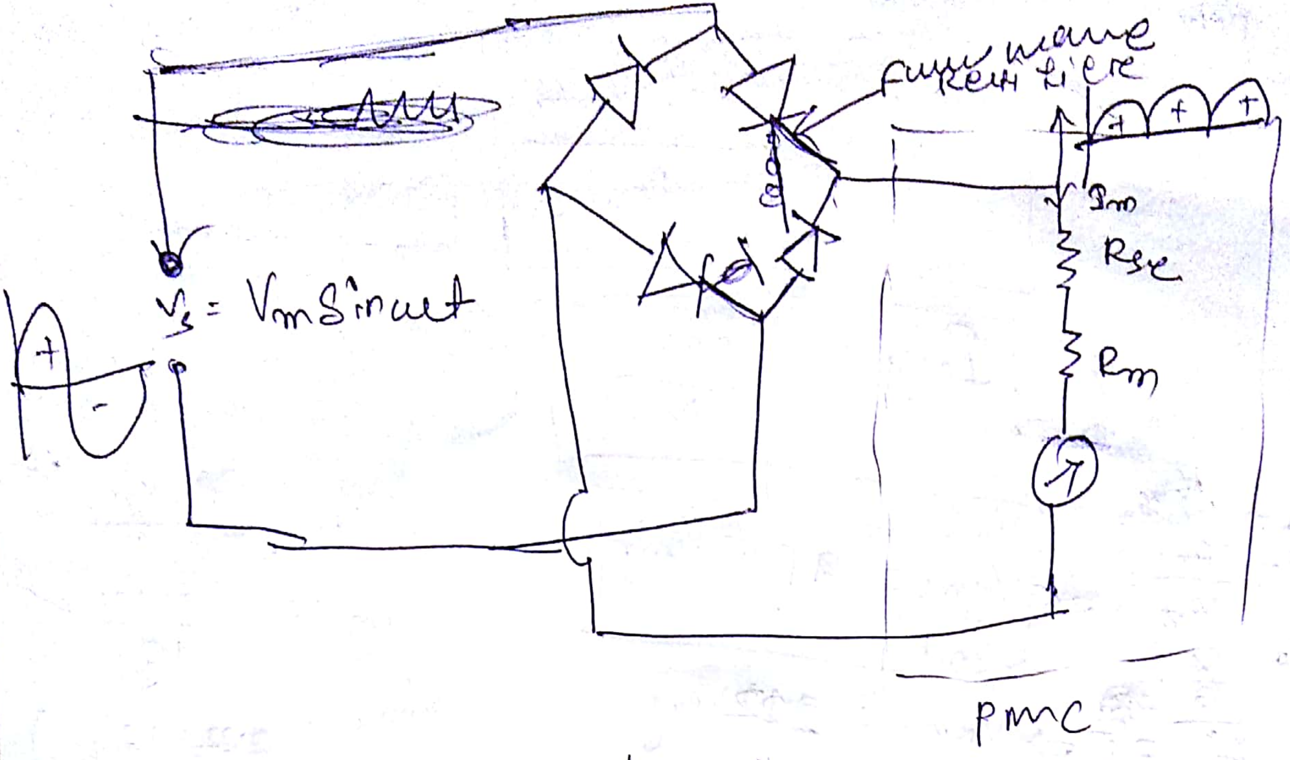
$$\boxed{V_{FSD} = 1.11\, R_{ew}\, I_{mFSD}}$$

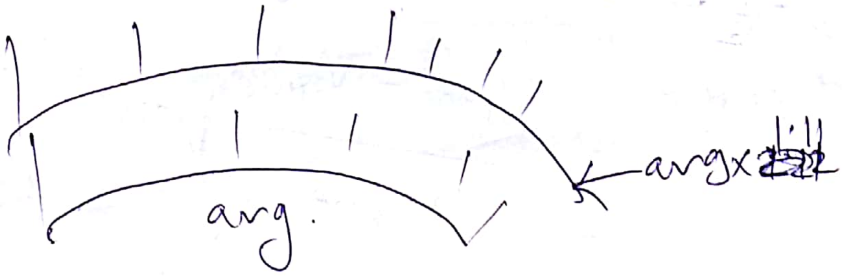
$$R_v = \frac{1}{1.11} \times \frac{1}{I_{mfsd}} \times V_{fsd}$$

$$\frac{R_v}{V_{fsd}} = \boxed{0.90\, S_{dc}} = S_{ac}$$

$$\boxed{S_{ac} = 0.45\, S_{dc}}$$

② Full wave Rectifier type





→ In this ckt a full wave bridge rectifier is connected ~~in se~~ across a pmmc instrument & a series multiplier resistance & a voltage source

$$R_{ea} \text{ or } R_v = R_s + R_m + 2R_d$$

($2R_d$ → because only two diodes will ~~only~~ conduct at at times)

$I_{avg} = \frac{2I_m}{\pi}$, $V_s = V_m \sin\omega t$

$V_m = \sqrt{2} V_{rms}$ | $V_{rms} = \frac{V_m}{\sqrt{2}}$

$V_m = \frac{\pi}{2} V_{avg}$ | $V_{avg} = \frac{2V_m}{\pi}$

$$= \frac{2}{\pi}\left(\frac{V_m}{R_s+R_m+2R_d}\right) = \frac{2}{\pi}\left(\frac{\sqrt{2}\,V_{rms}}{R_s+R_m+2R_d}\right) =$$

$$\boxed{I_{avg} = \frac{0.9\,V_{rms}}{R_V}}$$

2.22

~~$V_{avg} = 0.9\,V_{rms}$~~

$$V_{avg} = \frac{2V_m}{\pi}$$

$$\boxed{V_{rms} = 1.11\,V_{avg}}$$

In dc case

$$I_m = \frac{V_s}{R_{eq} \text{ or } R_V} = \frac{V_s}{R_V} \qquad (V_s \Leftrightarrow V_{rms})$$

$$(I_m)_{ac} = \frac{0.9\,V_{rms}}{R_V} = 0.9(I_m)_{dc}$$

$$\boxed{(I_m)_{ac} = 0.9\,(I_m)_{dc}}$$

$$\boxed{V_{FSD} = 1.11 \times R_V \times I_{mFSD}}$$

$\theta \propto I \rightarrow \theta_{ac} = (0.9) \times \theta_{dc}$

θ = angle of deflection.

Sensitivity

$$S = \frac{\theta}{V} \qquad S \propto \theta, \ \propto \frac{1}{V}$$

$V_{FSD} =$

$$\boxed{S_{ac} = 0.9\,S_{dc}}$$ ✓

Form factor = $\frac{RMS}{Avg}$

FF = rms/avg

FWR

$V_{avg} = \frac{2V_m}{\pi}$

$V_{rms} = \frac{V_m}{\sqrt{2}}$

FWR FF = $\frac{\frac{V_m}{\sqrt{2}}}{\frac{2V_m}{\pi}} = \frac{\pi}{2\sqrt{2}} = 1.11$

~~HWR F.f = V_m~~

HWR

$V_{avg} = \frac{V_m}{\pi}$ $\frac{\pi}{\sqrt{2}}$

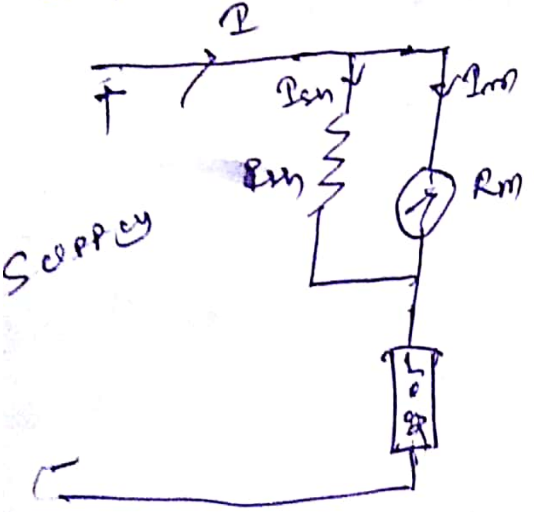
$V_{rms} = \frac{V_m}{\sqrt{2}}$

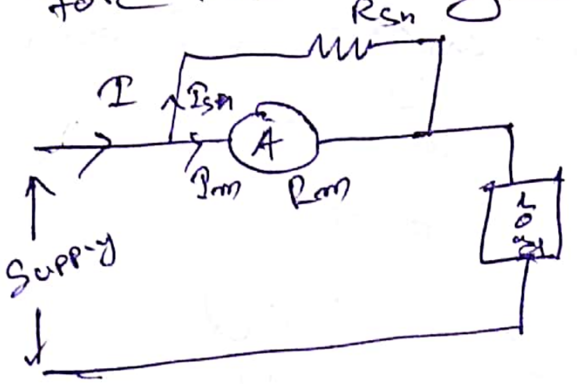
HWR F.f = $\frac{\frac{V_m}{\sqrt{2}}}{\frac{V_m}{\pi}} = 2.22$

Extend the Range of instruments by Shunts & multipliers

SHUNT:- A Shunt is a low-value resistance having minimum temp. coeff. & is connected parallel with the coil of the measuring instrument to extend the range.

-> Shunts are used for the range extension of ammeters.





Let I = Current of the ckt to be measured

I_m = " Passing through the instrument or ammeter.

I_{sh} = Current passing through the shunt.

R_{sh} = Resistance of the shunt.

R_m = Resistance of the meter/ammeter

Thus, $I = I_m + I_{sh}$ —①

Also since the voltage drop across the shunt & the instrument is same.→

$\therefore$ $I_{sh} R_{sh} = I_m R_m$ or $R_{sh} = \frac{I_m}{I_{sh}} R_m$

Substituting, $I_{sh} = I - I_m$ from eqn-①, we get

$$R_{sh} = \frac{I_m}{(I - I_m)} \cdot R_m$$

or $$\boxed{R_{sh} = \frac{R_m}{\left(\frac{I}{I_m} - 1\right)}} \quad —⑪$$

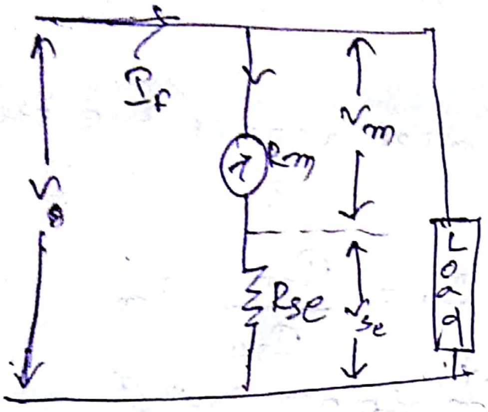
→ The ratio of $\frac{I}{I_m}$ is known as "multiplying factor of the shunt. The ratio $\frac{I}{I_m}$ denoting by N, wee have

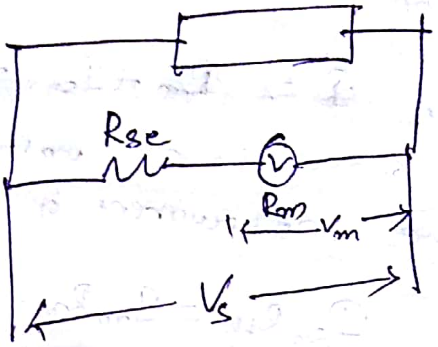
$$\boxed{R_{sh} = \frac{R_m}{N-1}}$$

→ The shunts are made of a material such as; ~~&~~ manganin (Cu, ~~Mg~~ manganese & Ni), which has a negligible temp. coeff. of resistance

Multipliers:- It is a highly non-inductive resistance connected in series with the instrument to extend the range of the meter.

→ Multipliers are used for the range extension of voltmeters.





Let I_f = full scale deflectⁿ current of voltmeter

R_m = Internal resistance of the instrument or voltmeter

V = Voltage of the ckt to be measured

V_m = Voltage drop across R_m

V_{se} = " " " R_{se}.

The V-drop across the internal resistance ~~of the~~ & external series resistance R_m R_{se} are directly proportional to their resistance values, since the same current (I_f) passing through them, i.e,

$$V_{se} = I_f R_{se} \quad \& \quad V_m = I_f R_m$$

or, $$\frac{V_{se}}{V_m} = \frac{\cancel{I_f} R_{se}}{\cancel{I_f} R_m} = \frac{R_{se}}{R_m}$$

or $$\frac{V_{se}}{V_m} + 1 = \frac{R_s}{R_m} + 1$$

$$\Rightarrow \frac{V_{se} + V_m}{V_m} = \frac{R_{se} + R_m}{R_m}$$

$$\Rightarrow \boxed{\frac{V}{V_m} = \frac{R_s + R_m}{R_m}} \quad (\because V = V_{se} + V_m)$$

The ratio of the voltage across the entire ckt to the voltage across the instrument $(\frac{V}{V_m})$ is called the multiplying power or multiplication factor or multiplier (m).

$$\therefore \boxed{m = \frac{R_{se} + R_m}{R_m}} \quad (\because m = \frac{V}{V_m})$$

$$\Rightarrow \boxed{R_{se} = R_m (m-1)}$$

i.e- For measuring 'm' times the voltage, range of the instrument, the resistance of series multiplier resistance is equal (m-1) times the internal resistance of the instrument

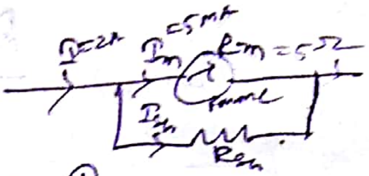
Numericals

① A PMMC inst. gives full scale deflection with 5 mA & has a resistance of 5Ω calculate the resistance of the necessary components in order that instruments may be used as:

(i) 2A & 5A ammeters (ii) 10 V & 100V voltmeters

Solⁿ :-

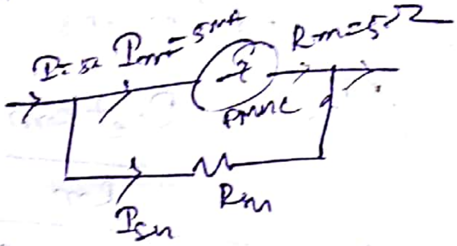
(1) For $I = 2A$.



multiplication factor $N = \frac{I}{I_m} = \frac{2A}{5\times10^{-3}A} = 400$

Thus $R_{sh} = \frac{R_m}{N-1} = \frac{5}{400-1} = 0.0125\Omega$

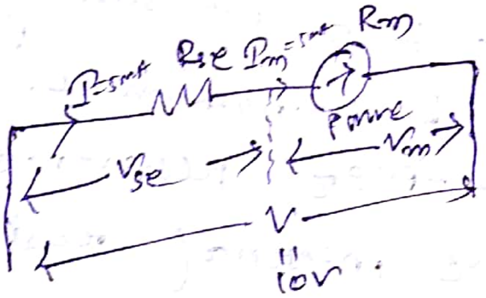
For $I = 5A$.



$N = \frac{I}{I_m} = \frac{5}{5\times10^{-3}} = 1000$

$R_{sh} = \frac{R_m}{N-1} = \frac{5}{1000-1} = \frac{5}{999} = 5\times10^{-3}\Omega$

(ii) For $V = 10V$



meter volt. drop:

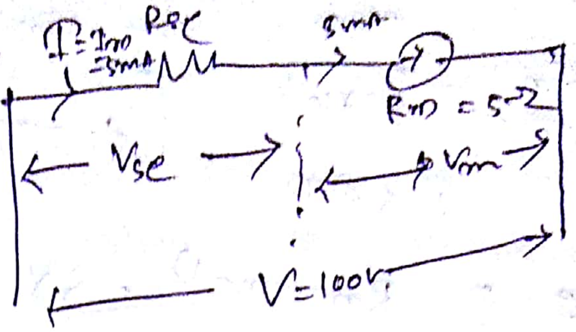
$V_m = I_m R_m$

$= 5\times10^{-3}\times5$

$= 25mV$

Multiplicⁿ factor : $m = \frac{V}{V_m} = \frac{10}{25\times10^{-3}} = 400$

$R_{se} = R_m(m-1) = 5(400-1) = 1995$



For V=100V

$V_m = 25mV$

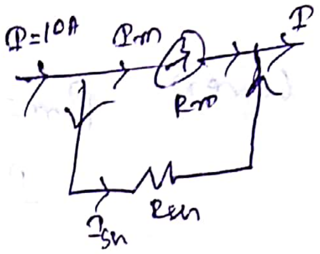
$m = \frac{V}{V_m} = \frac{1\cancel{0}0^4}{\cancel{25}\times10^{-3}} = 4000$

$R_{se} = R_m(m-1) = 5(4000-1) = 19995\Omega$

② How will you use a PMMC inst. which gives FSD at 50mV P.diff & 10mA current as;
(i) Ammeter 0-10A (ii) Voltmeter 0-250V range.

Sol^n Given V-drop across meter $V_m = 50mV$

FSD : $I_m = 10mA$



(i) As ammeter 0-10A range

Meter resistance : $R_m = \frac{V_m}{I_m} = \frac{50\times10^{-3}}{10\times10^{-3}} = 5\Omega$

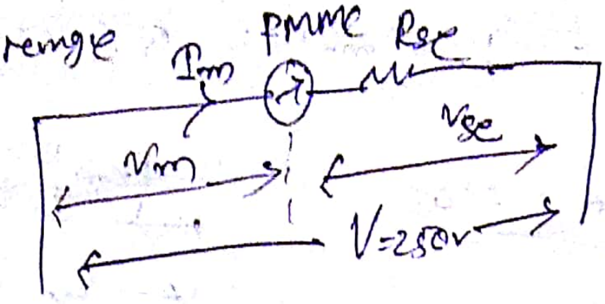
$R_m = 5\Omega$

$\cancel{m} = \frac{I}{I_m} = \frac{10}{10\times10^{-3}} = 1000$

$R_{sh} = \frac{R_m \cancel{(m-1)}}{(m-1)} = \cancel{5(1000-1)}\ \frac{5}{(1000-1)}$

$= 5.005\times10^{-3}\Omega$

(ii) Voltmeter 0-250V range



$$M = \frac{V}{V_m} = \frac{250}{50\times10^{-3}}$$

$$= 5000$$

$$R_{se} = R_m(m-1) = 5\times(5000-1) = 24995\Omega$$

③ A moving coil insti having a reesistance of 50Ω has a FSD of 1mA, calculate

(i) Rsh to convert in Ammeter of 2A range

(ii) Net resistance of meter.

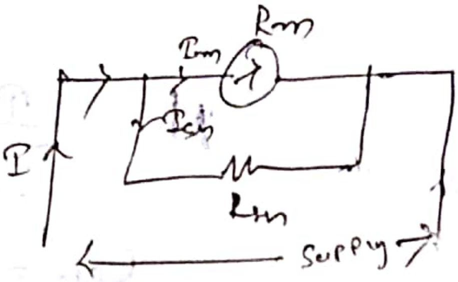
Solⁿ:- Given $R_m = 50\Omega$, $I_m = 1mA = 1\times10^{-3}A$

$I = 2A$

$$m = \frac{I}{I_m} = \frac{2}{1\times10^{-3}} = 2000$$

(i) $$R_{sh} = \frac{50}{m-1}$$

$$= \frac{50}{2000-1} = \frac{50}{1999} = 0.025\Omega$$



(ii) $$R_{net} = R_m || R_{sh}$$

$$= 50 || 0.025$$

$$= \frac{50\times0.025}{50+0.025} = 0.02498\Omega.$$

) A moving coil inst. has a 'R' of 2Ω, it reads upto 250V when a 'R' of 5000Ω is connected in series with it. Find the current range of Inst. when it is used as an ammeter with the coil connected across a shunt Resistance of 2mΩ.

Sol^n

$R_m = 2\Omega$ $\quad V_m = ?$ $\quad I_{se} = ?$

$V = 250$ $\quad I_m = ?$

$R_{se} = 5000\Omega$ $\quad I = ?$

$$\boxed{R_{se} = \frac{R_m}{\frac{I}{I_m} - 1} \qquad R_{sh} = \frac{V - V_m}{I_m}}$$

$V = I_m (R + R_m) \Rightarrow 250 = I_m (5000 + 2)$

$\Rightarrow I_m = 49.98 mA$

$V_m = \frac{I_m}{R_m} = \frac{49.98 \times 10^{-3}}{2} =$

$R_{sh} = 2 m\Omega = 2 \times 10^{-3} \Omega$

$I_{sh} = \frac{I_m R_m}{R_{sh}} = \frac{49.98 \times \cancel{10^{-3}} \times \cancel{2}}{\cancel{2} \times \cancel{10^{-3}}}$

$= 49.98 A$

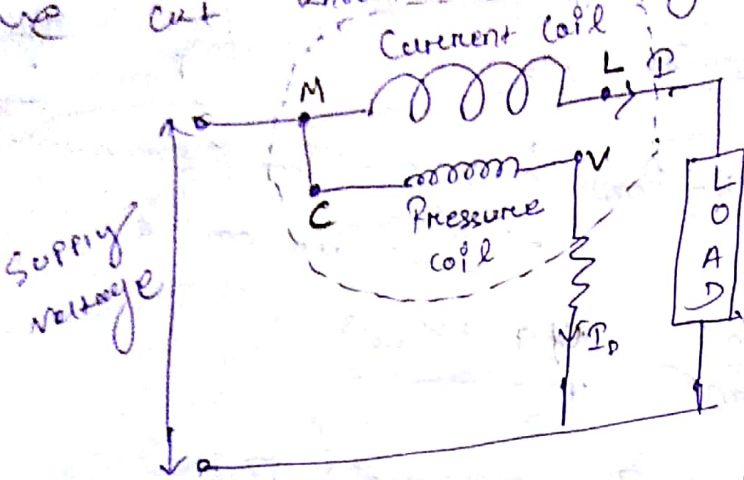
$\underset{\hookrightarrow \text{range.}}{I} = I_m + I_{sh} = 49.98 \times 10^{-3} + 49.98$

$= 50.02 A$

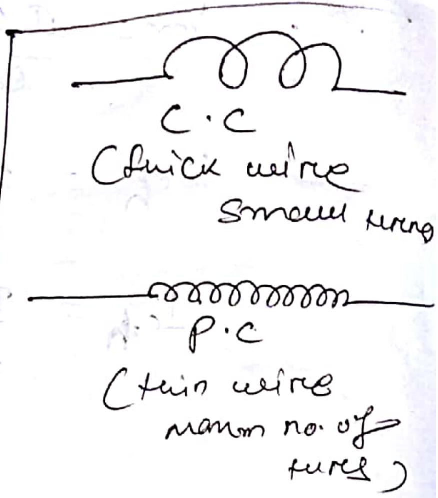
CHAPTER-3: WATTMETERS & MEASUREMEN {OF POWER}

WATTMETER:- The wattmeter is an instr for measurin the electric power in watts of any given ckt.

→ The ~~watt~~ inst. consist of two coils, one known as current coil is in series with the ckt coil & the other ~~one~~ coil connected in parallel with the ckt known as voltage coil.



M= main supply
L= Load
C= common
V= voltage.



→ The given ckt diagram is basic construcn of any wattmeter.

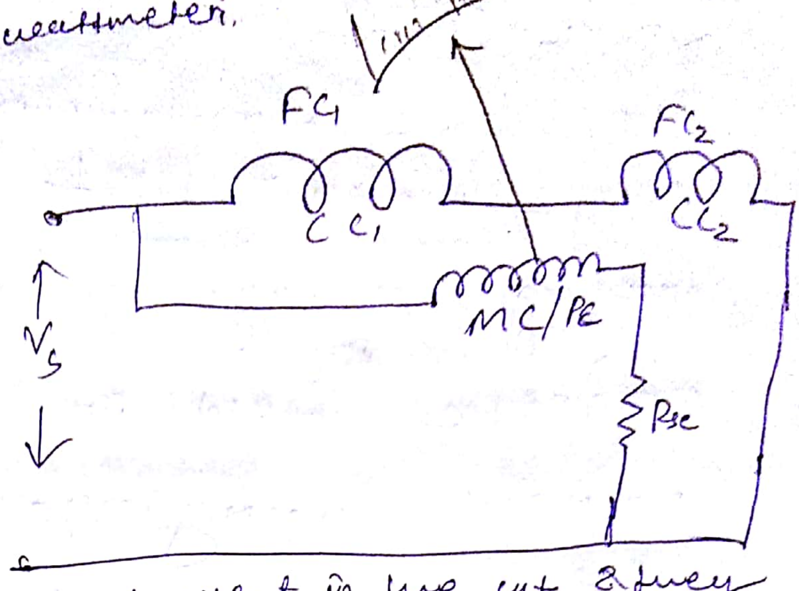
ELECTRODYNAMOMETER TYPE WATTMETER:-

→ These insts. are similar in design & construcn to electrodynamometer type ammeters & voltmeters

→ It consist of two coils are connected in diff. ckt arrangement to measure the power.

→ The fixed coils or field coils are connected in series with the load & so carry the current in the ckt, therefore the fixed coils form current coil or CC in wattmeter

→ The moving coil is connected in parallel with the load & carries a current proportional to voltage ~~so~~ it is called the pressure coil or voltage coil or P.C ~~of~~ of the wattmeter.



Construction :-

→ It consist of two coils, one ~~is~~ is fixed coil & other one is moving coil.

→ The FCs carries the current in the ckt & they are divided into two halves FC1 & FC2

→ The fixed coils ~~can be made~~ can be made to carry considerable current so that ~~they~~ no problem will occur of leading the current in cr out.

→ The fixed coils are wound with heavy wires & less no. of turns.

→ The moving coil is mounted on a pivoted spindle & is embraced by the fixed current coils.

→ A high non-inductive ~~or a high resistive~~ resistance is connected in with the moving coil to limit the current to a small value, since the MC carries a current proportional to the voltage

→ Both FC & MC are air cored in electrodynamometer type instrument

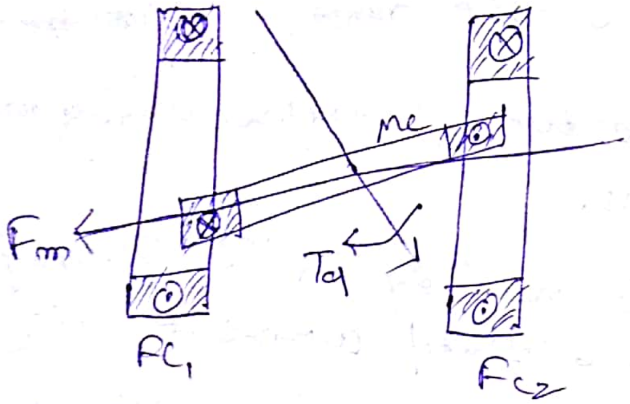
→ Spring control is used for the instrument

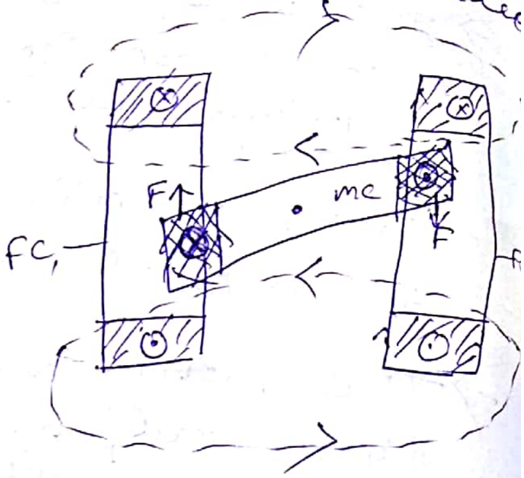
→ Air friction damping is used in ~~too~~ for damping ~~force~~ torque,

→ It equipped with mirror type scales & knife edge pointers to remove reading errors due to parallax

Working Principle:-

-> The basic dynamometer type W-meter working principle is that when a current carrying moving coil is placed in the magnetic field produced by the current carrying fixed coil, a force is exerted on the coil sides of the mc & deflection takes plac





-> In other words when the field produced by the current carrying moving coil tries to come in line with the field produced by the current carrying fixed coil, a deflecting torque is exerted on the moving system & deflection takes place

- when power is to be measured in a ckt, the wattmeter is connected in the ckt.

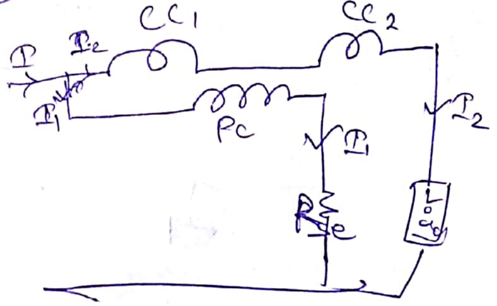
- The CC is connected in series with the load, carries the load current & the P.C connected in parallel with the load carries the current proportional to the voltage across the load.

- The FC produces a main field flux & MC " a rotating field flux.

- The flux produced by MC (i.e rotating field flux) tries to come in line with the main field flux, which produces a deflecting torque on moving coil.

- Thus, the pointer attached to the spindle of the MC deflects. The deflection is controlled by controlling torque produced by the springs.

TORQUE EXPRESSIONS IN DYNAMOMETER TYPE WATTMETER



- We know that instantaneous torque in ED type inst. is directly proportional to the product of instantaneous values of current flowing through both the coils & the rate of change of flux linked with the ckt.

Let 'I_1' & 'I_2' be the instantaneous values of current in PC & CC.

$$\therefore \quad T_{inst} = I_1 I_2 \frac{dM}{d\theta}$$

where θ is the angle

Now Let the applied value of voltage across a PC be

$$V_{inst} = V_{max} \sin\omega t$$

Assuming the P.C ckt has a very high resistance, so it can be treated as purely resistive

Therefore current in PC is in phase with the voltage & it's instantaneous value can be written as

$$I_R = \frac{V_{inst}}{R_{se}+R_m} = \frac{V_{inst}}{R_p}$$

where R_p is the resistance of P.C ckt.

$$I_1 = \frac{V_m \sin\omega t}{R_p} = I_{m_1} \sin\omega t$$

If the current in the C.C lags the voltage by an angle ϕ then instantaneous value of current in C.C is

$$I_2 = I_{max}(\sin(\omega t - \phi))$$

$$\therefore \; T_{inst} = I_{m}\sin\omega t \; I_m(\sin(\omega t - \phi)) \cdot \frac{dM}{d\theta}$$

$$T_{inst} = \frac{V_m \sin\omega t}{R_p} \cdot I_m\,(\sin(\omega t - \phi))\,\frac{dM}{d\theta}$$

$$\boxed{T_{inst} = \frac{V_m I_m}{R_p} \sin\omega t \cdot \sin(\omega t - \phi)\,\frac{dM}{d\theta}}$$

$$\cancel{\frac{V_m I_m}{R_p}\left(\frac{\cos(\omega t - \omega t + \phi) - \cos(\omega t + \omega t - \phi)}{2}\right)}$$

$$= \frac{V_m I_m}{R_p}\,\frac{\cos\phi}{2} = \frac{\frac{V_m}{\sqrt{2}}\,\frac{I_m}{\sqrt{2}}}{R_p}\cos\phi$$

$$= \frac{P}{R_p}\cos\phi$$

$$= \frac{V_{rms} I_{rms}}{R_p}\cos\phi$$

$$T_{inst} = \frac{P}{R_p}$$

$$\boxed{T_{inst} = \frac{V_m I_m}{R_p}\left(\cos(\phi) - \cos(2\omega t - \phi)\right)\frac{dM}{d\theta}}$$

Average deflecting torque can be obtained by integrating $T_{inst.}$ from time 0 to T, where T is the time period of cycle

$$T_d = \frac{1}{T}\int_0^T T_{inst.}\, d\omega t$$

$$= \frac{1}{T}\int_0^T \left[\frac{V_m I_m}{R_p}(\sin\omega t)(\sin(\omega t-\phi))\left(\frac{dM}{d\theta}\right)\right] d\omega t$$

$$T_d = \frac{1}{T}\,\frac{V_m I_m}{R_p}\,\frac{dM}{d\theta}\int_0^T\left[\cos\phi - \cos(2\omega t-\phi)\right] d\omega t$$

$$= \frac{1}{2}\,\frac{V_m I_m}{R_p}\,\frac{dM}{d\theta}\cos\phi$$

$$= \frac{V_m}{\sqrt{2}}\,\frac{I_m}{\sqrt{2}} \times \frac{1}{R_p}\cos\phi\,\frac{dM}{d\theta}$$

$$= V_{rms} I_{rms} \times \frac{1}{R_p}\cos\phi\,\frac{dM}{d\theta} = VI\cos\phi\frac{dM}{d\theta}$$

$$\boxed{T_{d\,avg} = \frac{P}{R_p}\,\frac{dM}{d\theta} = \frac{VI}{R_p}\cos\phi\,\frac{dM}{d\theta}}$$

controlling torque is given by $T_c = K_c\theta$

θ = angle of deflection.

At steady State condition

$$\therefore T_d = T_c$$

$$\Rightarrow \frac{VI\cos\phi}{R_p}\frac{dM}{d\theta} = K_c\theta$$

$$\Rightarrow \boxed{\theta = \frac{P}{R_p K_c}\frac{dM}{d\theta}}$$

$$\Rightarrow \boxed{\theta = K P \frac{dM}{d\theta}}$$

where P = Power being measured

$$K = \frac{1}{R_p K_c}$$

Errors in Dynamometer type wattmeters methods of their Correction:-

→ The various types of errors in DM type wattmeter are:-

(i) Error due to Pressure coil inductance

(ii) " " " " " capacitance

(iii) " " " Eddy current

(iv) " " " Power loss in PC.

(v) " " " friction.

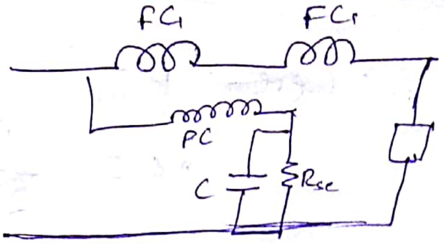
(vi) " " " temperature

(vii) " " " Stray magnetic field

(i) Error due to PC Inductance:-

→ In ideal DM-type w-meter the current i in phase with supply voltage. But practically when the PC inductance the current will lags behind the applied voltage.

→ Inductance of the PC will be reduced by means of capacitor connected in parallel with the portion of resistor.



(ii) Error due to PC Capacitance:-

→ The PC ~~ma~~ ckt may have capacitance as well as inductance, so due to high value of capacitance the effect of capacitor tends to leads the current by the applied voltage.

→ If the capacitive reactance is equal to the inductive reactance then their will be no errors.

(iii) Errore due to Eddy current:-

→ Eddy current errors are induced in the solid metal parts, by the alternating magnetic field produced by the current coil. It alter the magnitude & phase of this field & so produce an Error. → The EC induces in the coil creats its own magnetic field. This field affects the main current flows through the coil & Errors occurs.

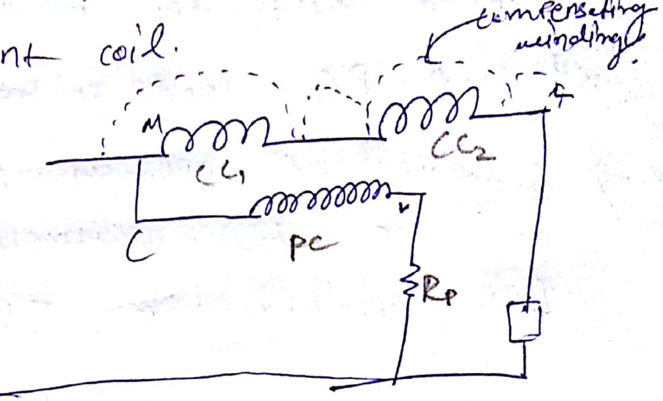
(iv) Errore due to power loss in P Conect:-

→ These errors are due to alternative wattmeter connection.

→ In General the wattmeter having M-C Short Ckt. If L-C points are short then the CC carry more current so more flux produced.

→ So to eleminating the error, a compensating coil is used with the currerrent coil.

$$\phi = (\phi_L + \phi_p - \phi_p) = \phi_L$$



(v) errores due to friction:–

→ friction error occures due to the weight of the MC.

→ So to redue the frictional error, it becomes necessary that the weight of the moving system should be reduced to minimum possible value.

wattmeter Types:–

→ Generally there are two types of wattmeter

i.e (a) LPF (Low PF wattmeter)

(b) UPF (unit PF wattmeter)

(i) LPF Electro-dynamometer type wattmeter

→ The instrument that measures the power of the ckt having low value of power ~~fact~~ factor is known as Low power factor wattmeter

→ measurement of power in the circuits having Low power factor (< 0.5) by ordinary e-dynamometer wattmeter is difficult & inaccurate, because:–

(i) The deflecting torque on the moving system is small even when the CC & PC are fully excited.

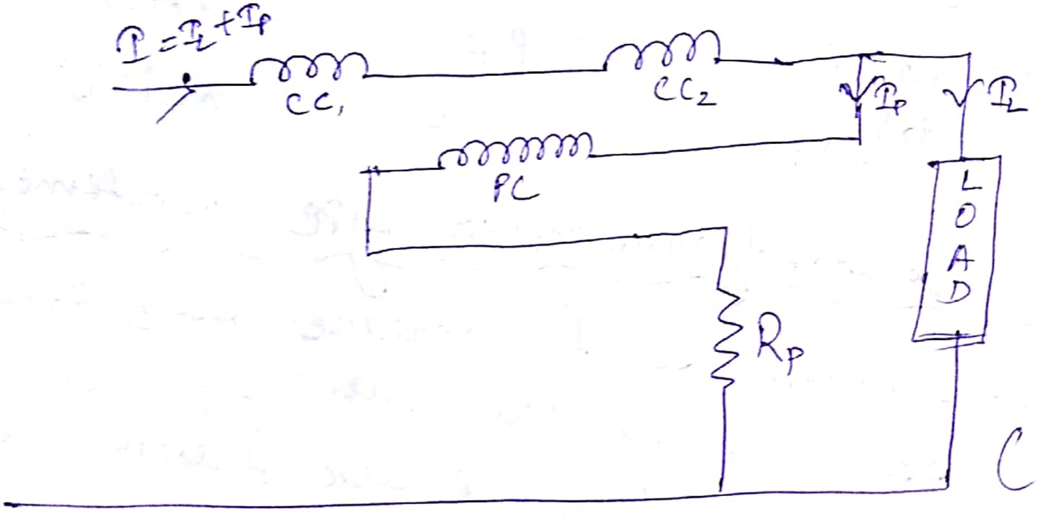
(ii) Error introduced because of the inductance of the PC tends to be large at LPF.

→ Therefore, special modifications are carried out in ED - wattmeter to convert it in to LPF wattmeter, These are :-

(i) Pressure coil current :-

The PC ckt is designed for having a low value of resistance so that the high value of current passes through it. This current produces the deflecting torque on the MC.

(ii) compensation for PC ~~of Inductance of PC~~ :-



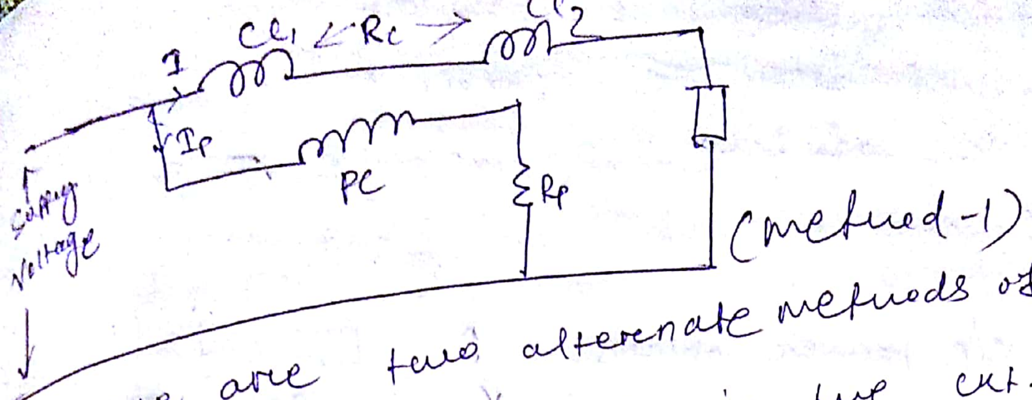
(method-2)

→ ~~In this method~~ the ckt arrangement is different

$P = VI\cos\phi$

$P \propto \frac{I}{V}$

$I \propto \frac{1}{V}$



→ There are two alternate methods of connecting the wattmeter in the ckt.

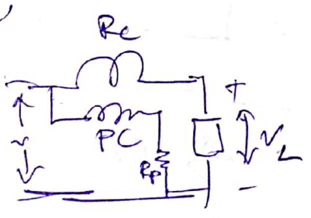
method-1 :- → The PC is parallel connected to supply voltage & the cc is connected in series with the supply voltage.

→ The magnitude of ~~supply~~ voltage across the PC is equal to the supplied voltage,

i.e $V = V_{pc}$

→ The total power measured by the PC is equal to the sum of the power loss in the load & the power loss in the cc.

Let dc supply given in this method



Current coil reading = I

Rc = internal resistance of CC

potential coil " = $I R_c + V$

wattmeter reading = $VI + I^2 R_c$

True value = VI

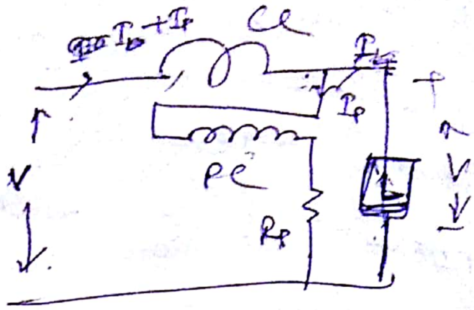
Error = measure value − TV

= $VI + I^2 R_c - VI = I^2 R_c$

(If P&V const) → $I \propto \frac{1}{\cos\phi}$, Low current high p-f

→ So this method is used for high p.f or unit power factor & low current

Method -2 :- The PC is not connected in parallel with the load. So the magnitude of the PC voltage ≠ supplied voltage



→ The o/p power obtains from the ckt is equal to the sum of the load power loss & the power loss of the PC

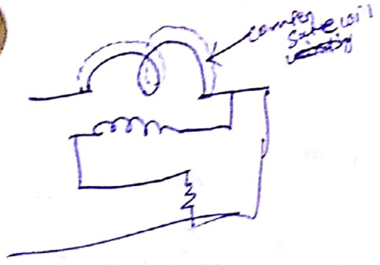
Reading of CC $= I_0 + I_p$

" " PC $= V$

wattmeter reading $= VI_0 + VI_p$

(where $I_p = \frac{V}{R_p}$) $= VI_0 + \frac{V^2}{R_p}$

True value of power $= VI$



$$\text{Error} = VI + \frac{V^2}{R_p} - VI$$

$$\text{Error} = \frac{V^2}{R_p}$$

→ So this is used for High current & Low power factor.

→ The high value of current causes the error in the wattmeter reading. For reducing the error, the compensation coil is used in the ckt.

→ The compensating coil compensates the error in the ckt which induces because of Low p.f.

(iii) Compensation for Inductance of PC :-

→ The small amount of inductances is present in the PC. This inductance cause the error in reading.

→ The error caused by the PC inductance is given by :- $VI\sin\phi \tan\beta$

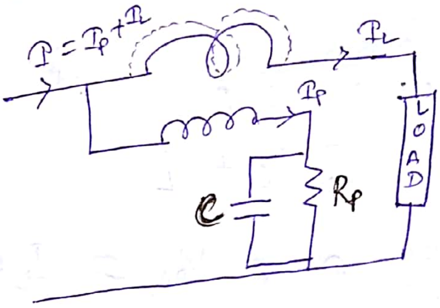
where ϕ = angle b/w voltage & current of the CC.

β = angle b/w voltage & current of the P.C.

→ With low p.f the value of ϕ is large & therefore the error is corresponding large.

→ Hence in LPF wattmeter Error must have to be ~~we~~ compensated induced in it.

→ This is done by connecting a capacitor across in ~~the~~ parallel with a part of series resistance in the PC.



(iv) Small controlling torque :-

→ LPF wattmeters are designed with to have a small controlling torque so that they give FSD for low power factor.

(b) UPF Type wattmeter →

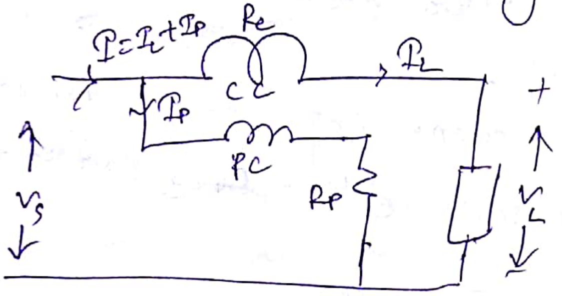
→ The instrument that measures the power of the ckt having ~~low~~ high value of power factor (>0.5) or close to unity value of p.f known as UPF type wattmeter

→ The ckt arrange connection is same as ~~an~~ ordinary wattmeter connection.

→ The PC is connected to supply voltage & the CC is connected in series with the supply voltage, so $|V_S| = |V_{PC}|$

~~→ Where~~ where V_S = supply voltage

V_{PC} = Voltage across PC



R_c = internal resistance of CC

I_L = current flowing through CC to Load

I_P = current flowing through PC.

Voltage drop across CC

$= I_L R_c + V_L$

" " across PC $= V_{PC} = I_L R_c + V_L$

i.e $= V_{CC} = V_{PC}$

~~wattmeter reading~~

Current across CC $= I_L$

voltage " PC $= V_{PC} = I_L R_c + V_L$

wattmeter reading = $V_L I_L + I_L$

$= VI + I^2 R_c$

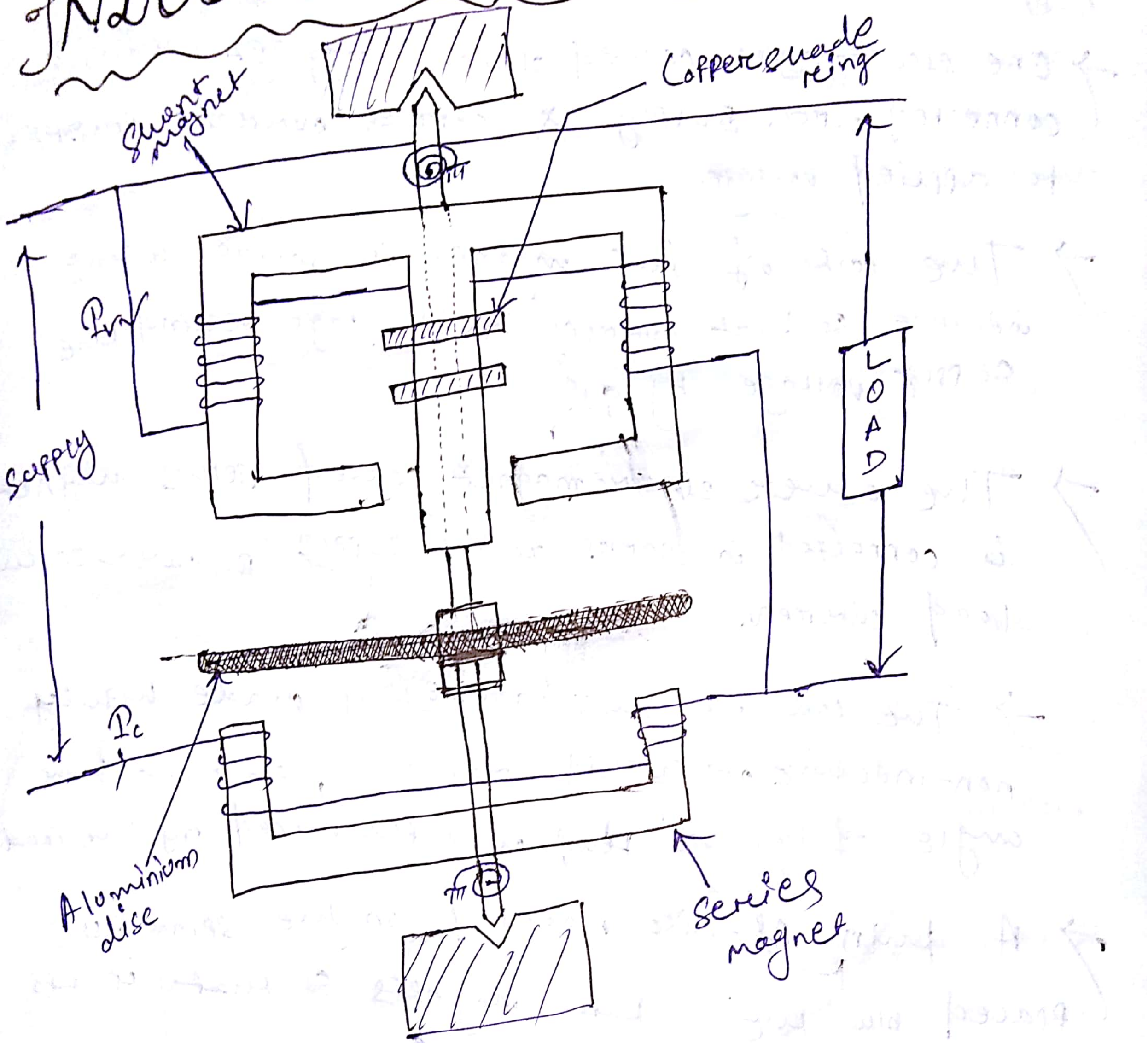
~~Errors~~ True value $= VI$

Error " $= I^2 R_c$.

If. P & 'V' const $I \propto \frac{1}{\cos\phi}$

so this arrangement is used for low current & high p.f.

INDUCTION TYPE WATTMETER



→ Induction type wattmeter belongs to the family of induction type measuring instrument.

→ These types of watt-meters operate on the same working principle on which the induction type ammeter & voltmeter operates.

→ The Induction type wattmeter is used to measure ac power supply only. Due to phase difference it can't be used for dc supply.

Construction :-

→ It consists of two laminated electromagnets.

→ One electromagnet called shunt magnet which is connected across supply & carries current proportional to applied voltage.

→ The coil of this magnet is made highly inductive so that current in it lags behind the supply voltage by 90°.

→ The other electromagnet called series magnet is connected in series with supply & carries the load current.

→ The coil of this magnet is made highly non-inductive or highly resistive, so that the angle of lag or lead is determined by the load.

→ A thin Al-disc mounted on the spindle is placed b/w the two magnets so that it cuts the fluxes of both the magnets.

→ The controlling torque is provided by two spiral springs.

→ Two or more adjustable copper ~~ring~~ shading ring are provided on the central limb of the shunt magnet to make the phase angle displacement b/w magnetic field set up by shunt magnet & ~~series magnet~~ supply voltage is approx. 90°.

→ The damping torque in induction type instrument is provided by the eddy current produced in the rotating disc.

Working Principle

→ The principle of operation of an Induc^n wattmeter is same as that of induc^n ammeter & voltmeters, i.e- induc^n principle.

→ But Induc^n type wattmeter is having different arrangement from Induc^n type voltmeter & ammeter.

→ In this type of instrument two separate coils are used to produce rotating flux, in place of one coil ~~one electromagnet~~ with split phase arrange as in Induc^n type voltmeter & ammeter.

→ When the wattmeter is connected in the ckt to measure a.c power, the shunt magnet carries current proportional to the supply voltage & the series magnet carries the load current.

→ The two fluxes produces two eddy current in the aluminium disc.

→ Due to the interaction b/w the two fluxes & two eddy currents, the deflecting torque is produced in the aluminium disc, which cause

The pointer connected to the moving system to move over the scale.

Torque Expression In Induc^n wattmeter.

Let V = Applied voltage

I_c = Load current carried by the series magnet or Current magnet

I_v = current carries by the shunt magnet or voltage magnet

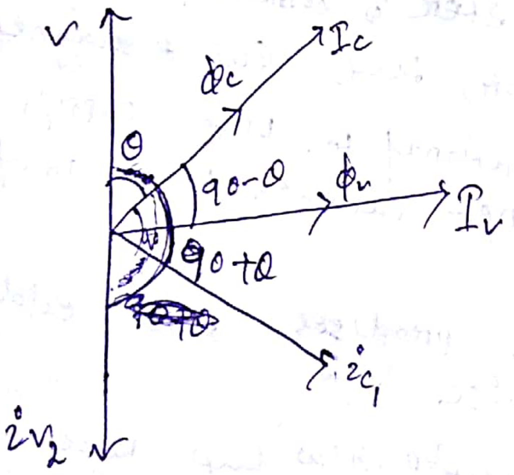
$\cos\phi$ = power factor of the load.

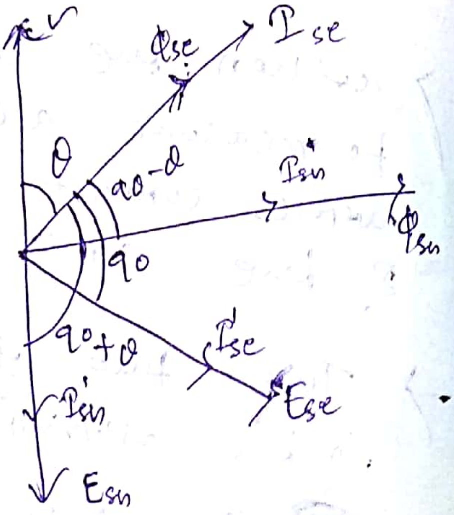
ϕ_c = flux produced ~~on the disc~~ due to current I_c

ϕ_v = flux produced ~~on the disc~~ due to current I_v.

i_{c_1} = Eddy current ~~produced~~ induced on the disc due to ϕ_c

i_{v_2} = Eddy current induced on the disc due to ϕ_v.





→ The current I_v in the shunt magnet lags the applied voltage 'V' by 90° & ~~so the~~ due to this flux ϕ_v is produced by it.

→ The current I_c in the series magnet is the load current & hence lags behind the applied voltage 'V' by an angle 'θ'.

→ The flux ϕ_c produced by current I_c is in phase with it.

→ Therefore I_v & I_c having a phase diff. of $(90°-\theta)$ apart from each other & as well as the fluxes ϕ_v & ϕ_c also apart ~~from~~ $(90°-\theta)$ from each other.

→ Due to flux ϕ_v the eddy current i_{v_2} induces in the Al-disc.

→ Similarly due to flux ϕ_c eddy current i_{c_1} induces in the disc.

→ i_{c_1} lags behind the flux ϕ_c by an angle 90° & also i_{v_2} lags ϕ_v by angle 90°.

→ Therefore two torque developed on the dis, T_1 due to interaction of ϕ_c & i_{v_2} & T_2 due to " of ϕ_v & i_{c_1}

Resultant deflecting Torque

$$T_d = T_1 - T_2$$

$$T_d = K \phi_c \phi_v \sin(90-\theta)$$

$$\therefore T_d \propto \phi_c \phi_v \sin(90-\theta)$$

$$T_d \propto VI\cos\phi \quad (\because \phi_v \propto V,\ \phi_c \propto I)$$

$T_d \propto$ AC Power $\boxed{T_d = K VI \cos\phi}$

Hence in this instrument it has uniform scale

Since controlling torque provided by the springs

$$T_c \propto \theta$$

$$T_c = K_c \theta$$

At final steady state condition

$$T_d = T_c$$

$$\Rightarrow K VI \cos\phi = K_c \theta$$

$$\Rightarrow \boxed{\theta = K_1 VI \cos\phi} \quad \left(\because K_1 = \frac{K}{K_c}\right)$$

$$\theta \propto VI$$

Measurement of Power in 3-ϕ System

→ There are 3 methods are used for measurement of power in 3-ϕ ckt.

(I) 3-wattmeter method.

(II) 2-wattmeter method

(III) Single wattmeter m/d.

* Generally 2-wattmeter methods are used for measurement of power both balanced & unbalanced load.

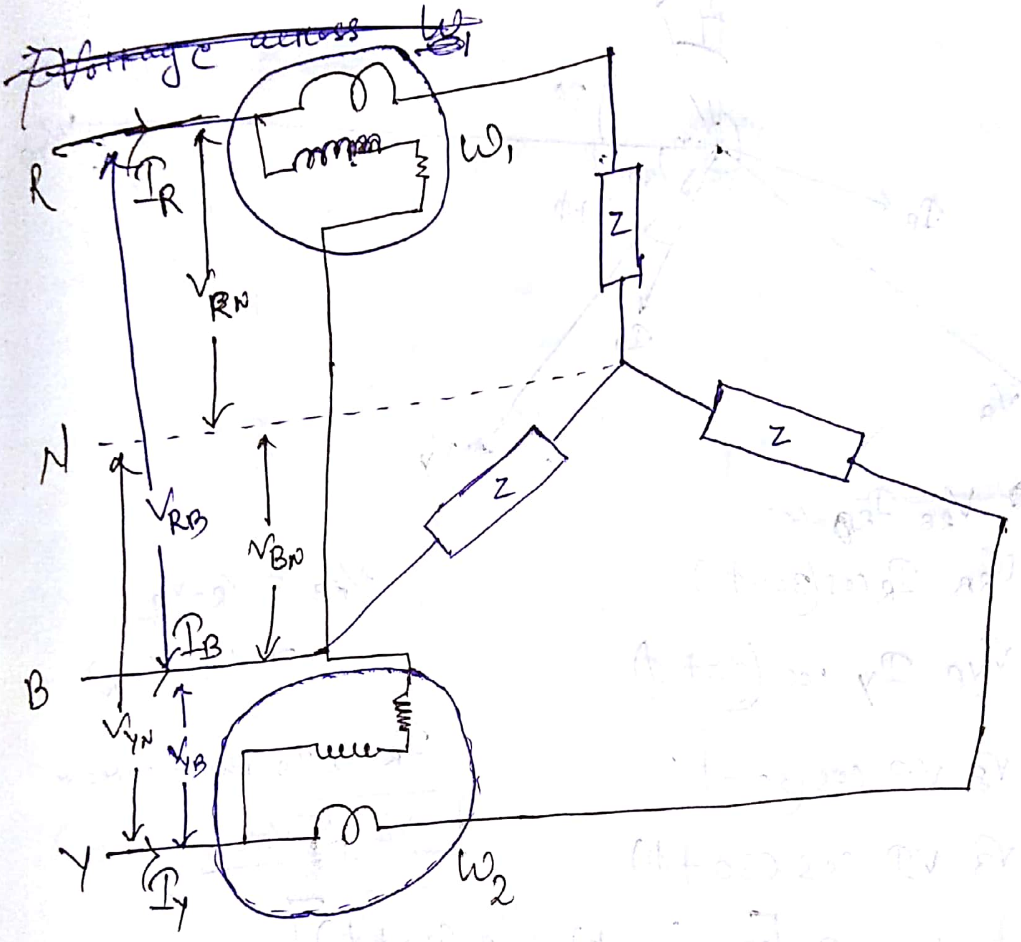
(ii) 2-wattmeter method

let, I_R, I_Y & I_B be the RMS value of phase current, i.e- $I_R = I_Y = I_B = I_L = I_{Ph}$

V_R, V_Y & V_B be the RMS value of phase voltage, i.e- $V_{RN} = V_{YN} = V_{BN} = V_{Ph}$

$V_{RY} = V_{YB} = V_{RB} = V_L$

$$\boxed{V_L = \sqrt{3}\, V_{Ph}}$$



for unbalanced load

$w_1 = V_{RB} I_R$

$w_2 = V_{YB} I_Y$

$I_R + I_Y + I_B = 0 \Rightarrow (I_R + I_Y = -I_B)$

$w_1 + w_2 = V_{RB}\, I_R + V_{YB}\, I_Y$

$= (V_R - V_B) I_R + (V_Y - V_B) I_Y$

$= I_R V_R + I_Y V_Y - V_B(-I_B)$

$$\boxed{w_1 + w_2 = I_R V_R + I_Y V_Y + I_B V_B} \checkmark$$

for balanced

~~[illegible] V_{RB} cos~~

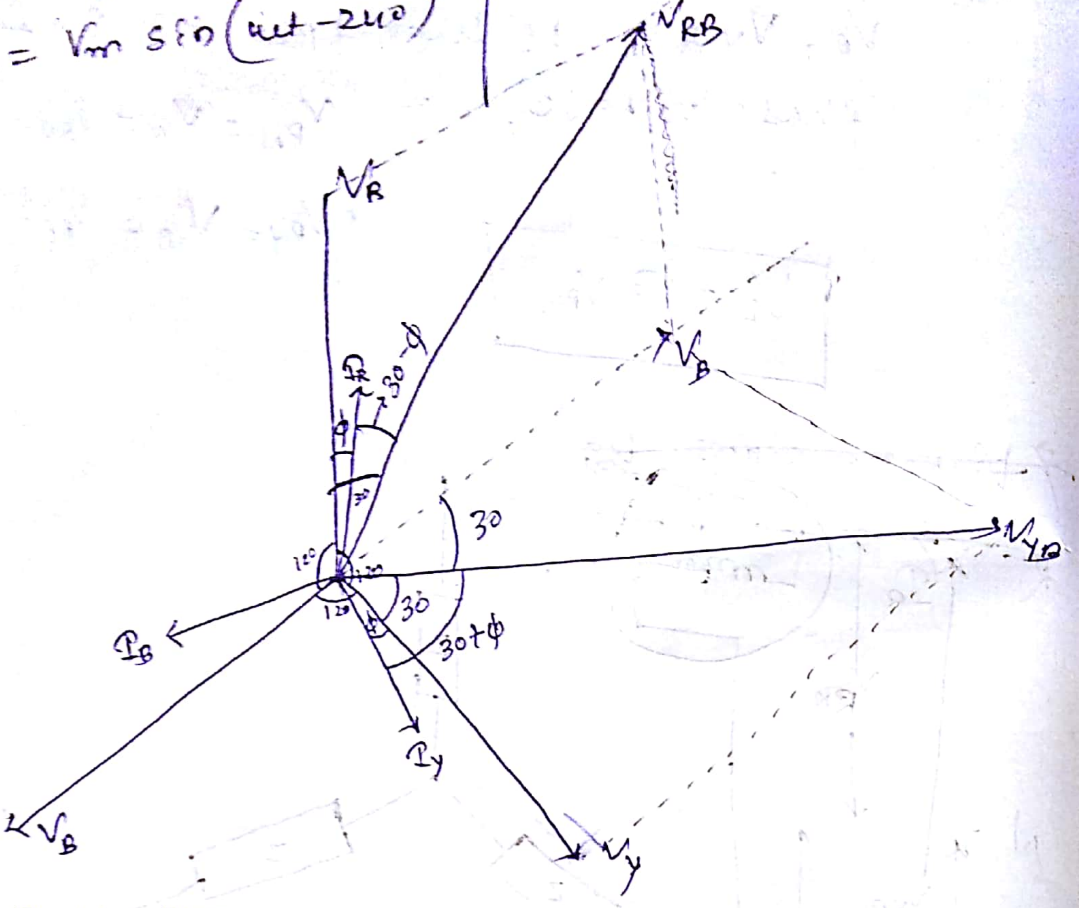
$V_R = V_m \sin \omega t$

$V_Y = V_m \sin(\omega t - 120)$

$V_B = V_m \sin(\omega t - 240)$

$W_1 = I_R V_{RB} \cos \begin{smallmatrix} I_R \\ V_{RB} \end{smallmatrix}$

$W_2 = I_Y V_{YB} \cos \begin{smallmatrix} I_Y \\ V_{YB} \end{smallmatrix}$



~~W_1 = V_{RB} I_{RB} cos~~

$W_1 = V_{RB} I_R \cos(30-\phi)$

$W_2 = V_{YB} I_Y \cos(30+\phi)$

$V_{RB} = V_R - V_B$

or $V_R + (-V_B)$

I_R, I_Y, I_B Phase current

$\boxed{V_L = \sqrt{3}\, V_{ph}}$

or $W_1 = \sqrt{3}\, VI \cos(30-\phi)$

$W_2 = \sqrt{3}\, VI \cos(30+\phi)$

$W_1 + W_2 = \sqrt{3}\, VI [\cos(30-\phi) + \cos(30+\phi)]$

$= \sqrt{3}\, VI [\cos 30 \cos\phi + \cancel{\sin 30 \sin\phi} + \cos 30 \cos\phi - \cancel{\sin 30 \sin\phi}]$

$= \sqrt{3}\, VI (2 \cos 30 \cos\phi)$

$= \sqrt{3}\, VI\, \cancel{2} \times \frac{\sqrt{3}}{\cancel{2}} \cos\phi$

$$\Rightarrow \boxed{W_1 + W_2 = 3\,VI\cos\phi} \rightarrow 3\phi \text{ Active power} \quad ①$$

For reactive power

$$W_1 - W_2 = \sqrt{3}\,VI\,[\cos(30-\phi) - \cos(30+\phi)]$$

$$\boxed{W_1 - W_2 = \sqrt{3}\,VI\sin\phi} \quad ②$$

or

$$\boxed{\sqrt{3}(W_1 - W_2) = 3\,VI\sin\phi} \rightarrow 3\phi \text{ Reactive power}$$

For power factor

eqn ② ÷ eqn ①

$$\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2} = \frac{\cancel{\sqrt{3}}\,\cancel{V}\cancel{I}\sin\phi}{\cancel{3}\,\cancel{V}\cancel{I}\cos\phi} = \tan\phi$$

$$\Rightarrow \frac{\sqrt{3}\,W_1 - W_2}{W_1 + W_2} = \tan\phi$$

$$\Rightarrow \phi = \tan^{-1}\left(\frac{(W_1 - W_2)\sqrt{3}}{W_1 + W_2}\right)$$

$$\therefore \boxed{\cos\phi = \cos\left[\tan^{-1}\left\{\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right\}\right]}$$

Special case

Case-I :- If p.f is unity

$$\cos\phi = 1$$

$$\phi = 0$$

$$W_1 = \sqrt{3}\,VI\cos(30-\phi) = \frac{3VI}{2}$$

$$W_2 = \sqrt{3}\,VI\cos(30+\phi) = \frac{3VI}{2}$$

$$\boxed{W_1 = W_2}$$

∴ At UPF both w-mtr read same

If P.f asked in exam both W-mtr read same then what is the P.f ?

$$\phi = \tan^{-1}\left(\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right)$$

$$W_1 = W_2 = W_2$$

$$\therefore \phi = \tan^{-1}\left(\frac{\sqrt{3}(W - W)}{2W}\right) = 0$$

$$\boxed{\phi = 0,\ \cos\phi = 1}$$

case - II If P.f is 0.866

$\cos\phi = 0.866$ then $\boxed{W_1 = \sqrt{3}VI \quad W_2 = \frac{\sqrt{3}VI}{2}}$

$\phi = 30°$

$$\boxed{W_1 = \frac{W_2}{2}}$$

$\therefore$ If P.f is 0.866 one of the W-mtr read half of the other.

$$\phi = \tan^{-1}\left[\frac{\sqrt{3}\left(\frac{W_2}{2} - W_2\right)}{\frac{W_2}{2} + W_2}\right] = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = -30°$$

(lagging)

case - III If P.f is 0.5

$\cos\phi = 0.5$ then $\boxed{W_1 = \frac{3VI}{2} \quad W_2 = 0}$

$\phi = 60°$

$\therefore$ At 0.5 P.f one of the W-mtr reads '0'.

Let $W_2 = 0$

$$\phi = \tan^{-1}\left(\frac{\sqrt{3}(W_1 - 0)}{(W_1 + 0)}\right) = \tan^{-1}\sqrt{3} = 60$$

$$\cos\phi = 0.5$$

Case - IV

If pf is < 0.5

$\cos\phi < 0.5$ so $\phi > 60°$

~~$\phi > 60$~~.

Let ~~ϕ~~ $\phi = 70°$

$W_1 = \sqrt{3}\, V I \cos 40$ = +ve value

$W_2 = \sqrt{3}\, V I \cos(100)$ = -ve value

A < 0.5 p.f one of the wt. mt. reads -ve value

Q) A 3-ϕ, 440V motor load has a p.f of 0.6. Two wattmeter connected to measure the power i.e 25kW. Find the reading of each inst.

Solⁿ: Given $W_1 + W_2 = 25$ kW

$W_1 = ?$

$W_2 = ?$

$V_L = 440V$

$\cos\phi = 0.6$

$\phi = \cos^{-1} 0.6 = 53.13$

We know that

$$\tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

$$\Rightarrow \tan(53.13) = \frac{\sqrt{3}(W_1 - W_2)}{25}$$

$$\Rightarrow \frac{1.33 \times 25}{\sqrt{3}} = W_1 - W_2$$

$\Rightarrow W_1 - W_2 = 19.42$ kW

$W_1 - \cancel{W_2} = 19.42$

$W_1 + \cancel{W_2} = 25$

$2W_1 = 19.42 + 25$

$$\Rightarrow W_1 = \frac{19.42 + 25}{2}$$

$= 22.12$ kW

$W_2 = 2.88$ kW (Ans)

Chapter-4 ENERGYMETERS & MEASUREMENT OF ENERGY

Energy :- Energy is the total Power delivered or Consumed over a time interval, i.e

$$\text{Energy} = \text{Power} \times \text{Time}$$

$$E = \int (\text{power}) \times dt$$

Kwh meter - AC supp

Amph meter - DC sup

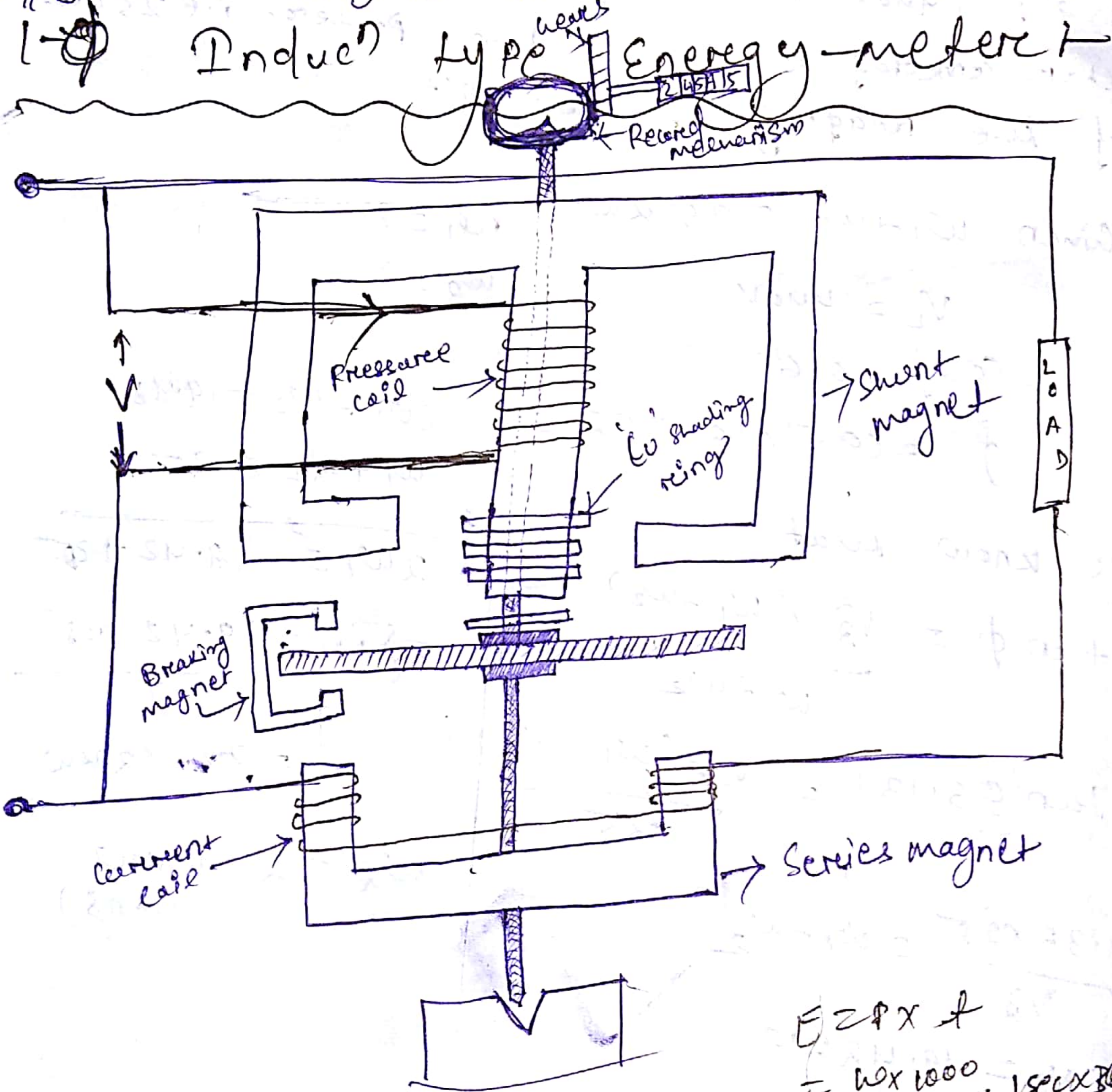
→ It is integrating type ins

Acronym = Power multiplied by hour = Energy

P × h = E

→ It works only on AC-supply.

1-Φ Induc^n type Energy-meter :-



$E = P \times t$

$= \frac{W \times 1000}{1000} \times \frac{1sec \times 3600}{3600}$

$\boxed{E = \frac{KW}{1000} \times \frac{t}{3600}}$ Kwh.

→ It operates in induction principle. (1 kWh = 1 unit)
→ It is integrating type instrument which consume power commulatively over a period of time.

Construction ⊢

→ There are '4'-main part of the operating mechanism
(i) Driving System (iii) Braking system
(ii) Moving system (iv) Registering or Recording system.

(i) Driving System ⊢

→ The driving system consist of shunt magnet & series magnet
→ The shunt magnet which is M-shaped carries the current proportional to the supply voltage. which is having many no. of turns of thin wire.

→ The series magnet which is U-shaped carries the current proportional to the load current, which is having less no. of turns of thick wire.

$$T_d \propto \phi_{se}\,\phi_{sh}\sin(\Delta-\phi) \quad (\Delta \simeq 90)$$

(ii) ~~At~~ MOving System ⊢

→ A thin Al-disc is placed b/w two magnet.
→ A deflecting torque produced in the disc due to the interaction of the two eddy current.
→ Due to the interaction b/w the two fluxes & two eddy currents the deflecting torque is produced in the aluminium disc, which cause the pointer to move over the scale.

(iii) Braking system ⊢

→ A C-shaped permanent magnet is placed near the Al-disc which is also known as braking magnet.

→ The eddy current induced in the aluminium disc produced a braking torque, which opposes the rotation of disc. $\boxed{T_b \propto N}$

(iv) Registering or Recording mechanism:-

→ ~~This System is used to record or register the no. of~~

→ This System used a record mechanism which is used to register or record the no. of rotation of the Al-disc, which is proportional to the energy consumed in kWh.

Working Principle:-

→ The working principle of 1-ϕ Induction type energy meter is same as Induction type ammeter, voltmeter & wattmeter.

→ In Induction type energy there is an extra recording mechanism.

→ When the energy meter is connected in ckt the CC carries the load current & PC carries the current proportional to the supply voltage

→ The ~~flux p~~ magnetic field produced by ~~shunt magnet~~ series magnet in phase with the line current.

→ The magnetic field produced by shunt magnet is in quadrature (to the power (eg) e.g = 24°) with the applied voltage, ~~thus a phase diff. exists~~

→ Thus, a phase diff. exists b/w the fluxes produced by the two coils.

→ Therefore a rotating magnetic field is setup which interacts with disc & a deflecting torque (T_d) is produce.

→ Due deflecting torque the disc starts to rotating

→ the no. of revolution made by the disc depend upon the energy passing through the meter.

→ The spindle attached to a recording mechanism so that energy consumed in the ckt is directly recorded in kwh.

→ The speed of the disc is adjusted by adjusting the position of breaking magnet.

Compensation of Error :-

① Friction or No Load compensation :-

→ The friction error are serious at light load condition. So it is necessary to overcome the friction at the bearings & recording mechanism.

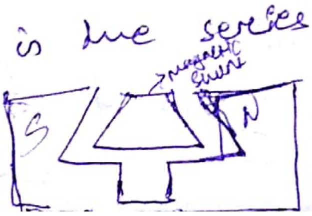
(ie shading)

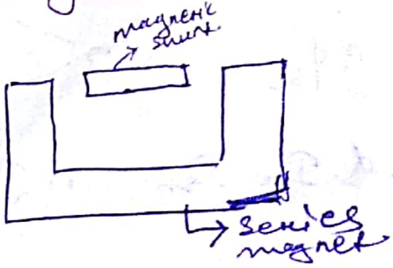
→ This is usually done by placing a small shading loop in the air gap of the shunt magnet.

② Overload compensation :-

→ Through the majority of breaking action is provided by the breaking magnet, the shunt magnet & series magnet also exert some amount of breaking torque. Since the fluxes are cut by the rotating disc.

→ So to compensate this error, a magnetic shunt is provided in the series magnet.





③ Compensation for creeping

→ In same meters a slow but a continuous rotation of disc is obtained even at no load when the potential coil is excited. This is known as creeping.

→ This may be due to the overcompensation of friction, stray magnetic field or excess of supply voltage than normal.

→ Such creeping is prevented by cutting two holes or slots in the disc on opposite sides of the spindle.

④ Temperature Error Compensation

→ By changing the temperature, the parameter of the coils change slightly which introduce a small error in meter. However, this error negligible small & there is no need to prevent any means to eliminate the error.

⑤ Frequency Error Compensation

→ Since the energy meter are used normally at fixed frequency, therefore, they are designed & adjusted to have minimum error declared supply frequency which is normally 50 Hz in India.

Torque expresⁿ

$T_d \propto \phi_{se} \phi_{sh} \sin \angle^{I_{se}}_{I_{sh}}$

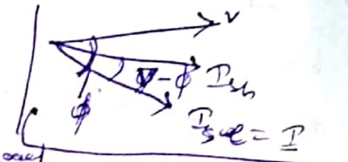
$T_d \propto I_{se} I_{sh} \sin \angle^{I_{se}}_{I_{sh}}$

$T_b \propto N$

when

$T_d = T_c$

$\boxed{P \propto N}$ → pwr consumed by load



$T_d \propto \frac{VI}{Z} \sin(\Delta - \phi)$ (Δ = shunt field angle)

If Δ = 90°

$T_d \propto \frac{VI}{Z} \cos\phi$

$\boxed{T_d \propto P}$ (If P.C of EM is highly inductive)

Energy meter Testing

→ The testing of energy meter is done by compensation with the revolution of the standard & the test meter.

→ The Error of the meter under test is found by counting the no. of revolutions & comparing with the no. of revolutions of the substandard.

So the Error at any load =

$$E = \frac{n_2K_1 - n_1K_2}{n_1K_2} \times 100$$

where n_1 = revolution shown on substandard.

n_2 = " " " test meter

K_1 = Constant of the substandard in revolution per kwh

K_2 = constant of test meter in revolution per kwh.

meter const

$E \propto N$

$N = KE$

$K = \frac{N}{E}$ → mtre const.

mtre const = $\left(\frac{\text{No. of rev}}{\text{kwh}}\right)$

Eg $\frac{1200}{\text{kwh}}$

Chapter 5 } + Measurement of speed, frequency & power factor +

Tachometer

→ Tachometer is a speed measurement device whereas Tacho is related to speed & meter is related to to measurement.

→ It converts a ~~mechan~~ mechanical deviation to electrical signal when voltage is induced & measured by the voltmeter connected to it.

→ There are 3-types of tachometers are used:-

(1) AC Tachometer Generator

(2) DC Tachometer Generator

(3) Eddy current Tachometer or Drag cup Tachometer

(2) DC Tachometer Generator:-

→ It is a small dc generator whose i/p is mechanical (i.e speed of the shaft) & o/p is the induced voltage at the armature terminals.

→ Here emf depends upon two factors

(i) Field Excitation

(ii) speed of the shaft.

Construction & working:-

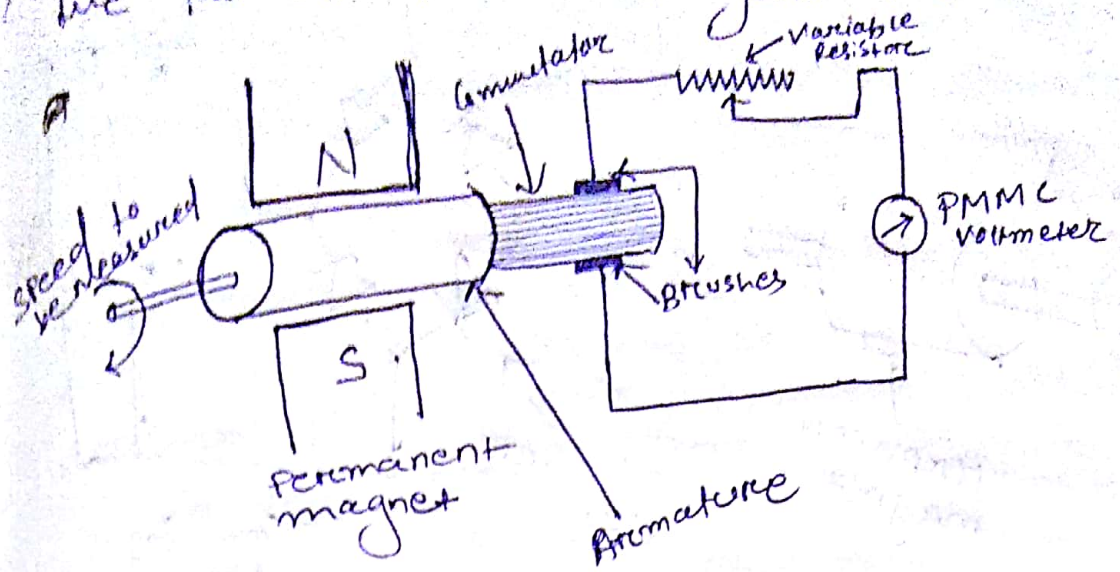
→ Here a permanent magnet is used to provide the magnetic field.

→ The generated voltage proportional to the product of flux & speed of the shaft.

→ Since the flux of the permanent magnet is constant, the voltage generated is proportional to the speed.

→ This emf is measured with the help of a moving coil voltmeter having a uniform scale & calibrated directly in terms of speed.

→ A Series resistance is used in the ckt to limit the current from the generator.



Advantages :-

→ Direction of rotation is directly indicated by the Polarity of o/p Voltage.

→ o/p Voltage is typically 10mv/rpm & can be measured with conventional type dc voltmeter.

Disadvantage :-

→ commutation & brushes required Periodic maintainance.

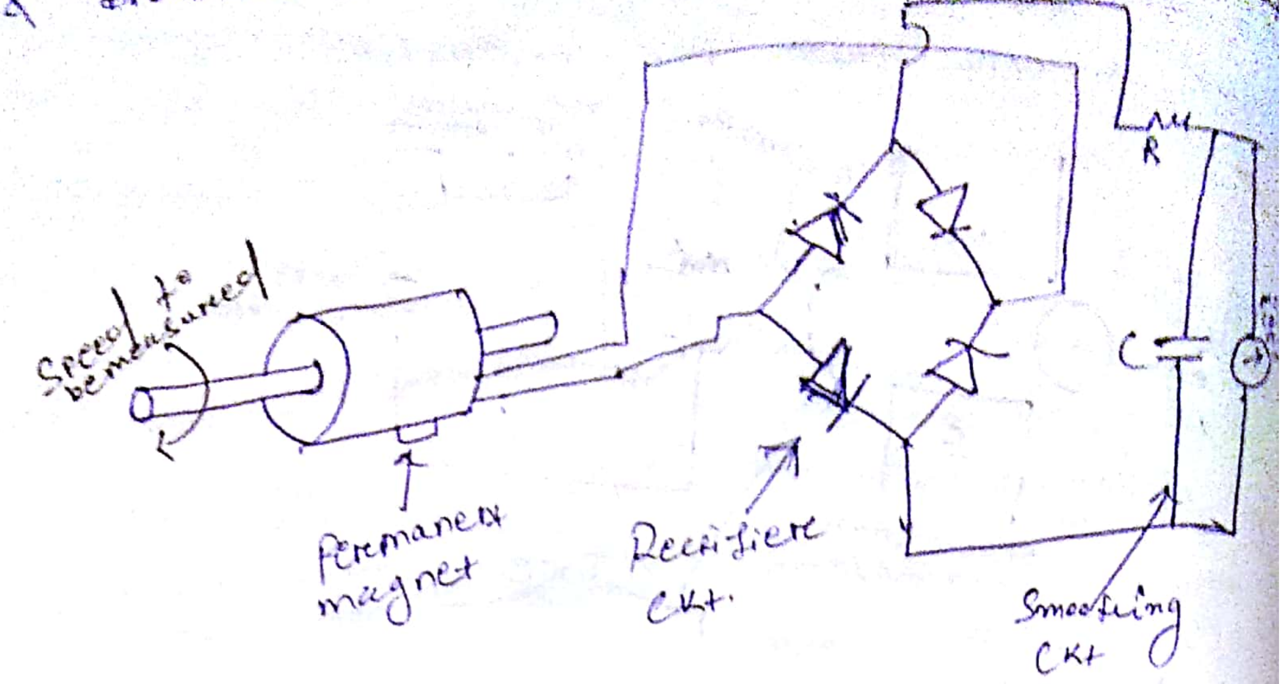
① AC Tachometer

→ The DC-tachometer generator uses the commutator & brushes which have many disadvantages

→ The AC-tachometer generator designed for reducing the problem.

→ The AC-tachometer has stationary armature & rotating magnetic field. Thus the commutation

& brushes are absent in AC-tachometer gener



Construction & working :-

→ When the magnetic field rotates an emf will induced in the stationary coil of ~~the~~ the stator.

→ Then the current will flow through the rectifier ckt which ~~rectify~~ rectifies it

→ The Resistance 'R' will protect the device by limiting the current generated.

→ A smoothing ckt is used where a filter capacitor is used to smooth the o/p.

→ Then the emf will be measured with the help of the voltmeter having uniform scale & calibrated directly in terms of speed.

Advantages:-

→ Cost of generation is less as compared to the DC generator.

Disadvantages:-

→ The non-linear relationship obtains b/w the o/p voltage & i/p voltage when the rotor rotates at high speed.

Frequency meter:-

→ Frequency meters are classified into ~~two~~ various types

ⓐ ~~Electrical~~ mechanical Resonance type

ⓑ Electrical Resonance type.

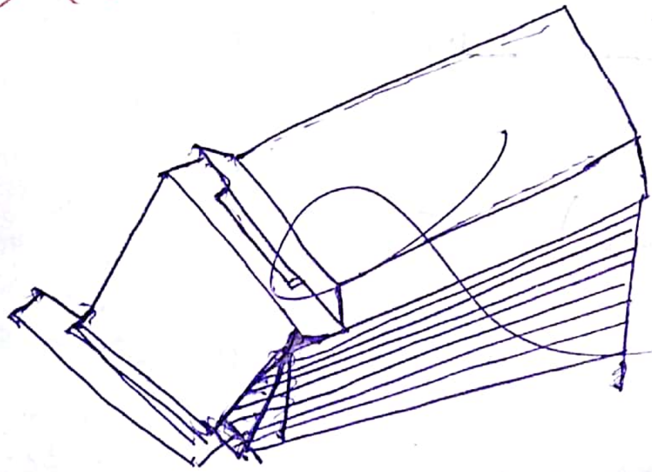
(c) Electrodynamometer type.

(d) Weston type.

(e) Ratiometer type.

(f) Saturable core type

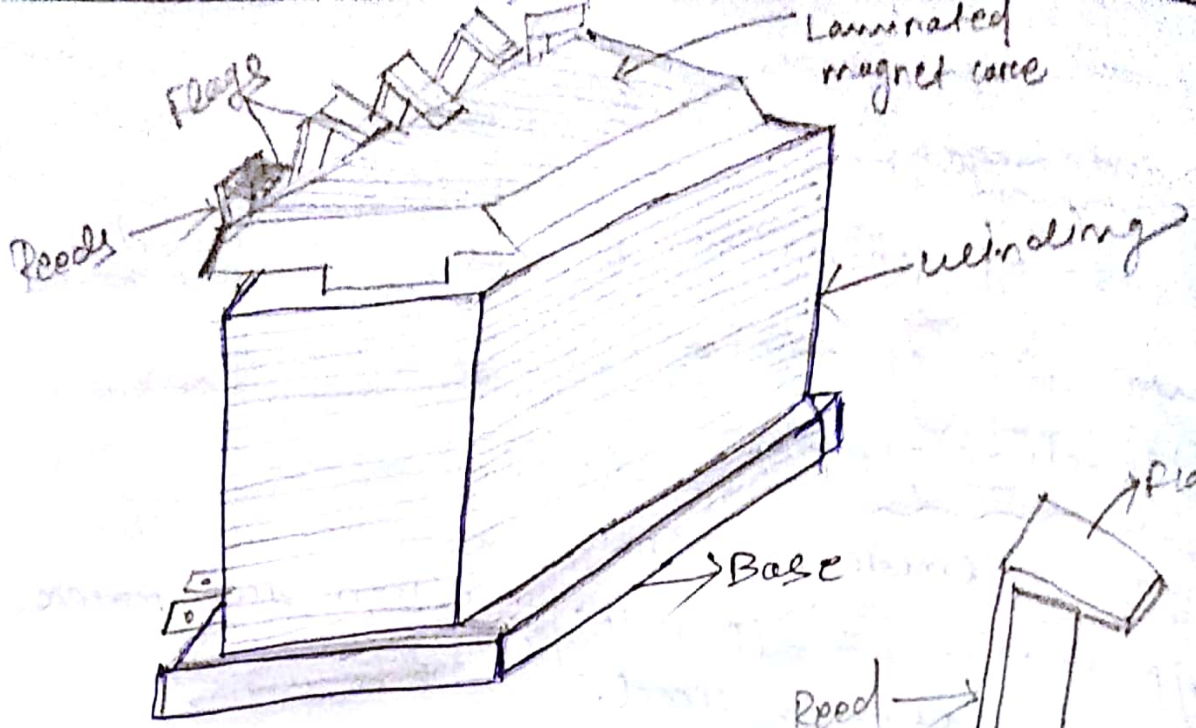
ⓐ Mechanical Resonance type (Vibrating Reed type):-

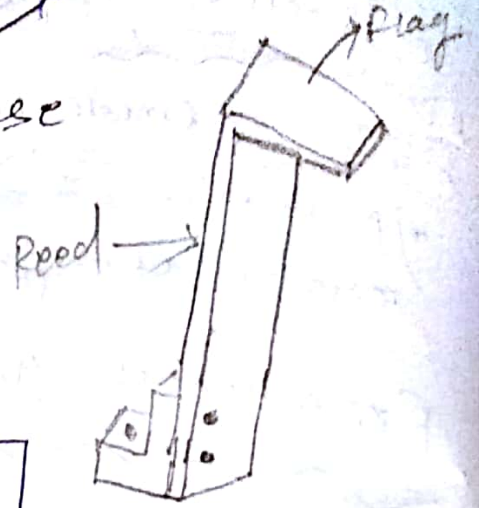


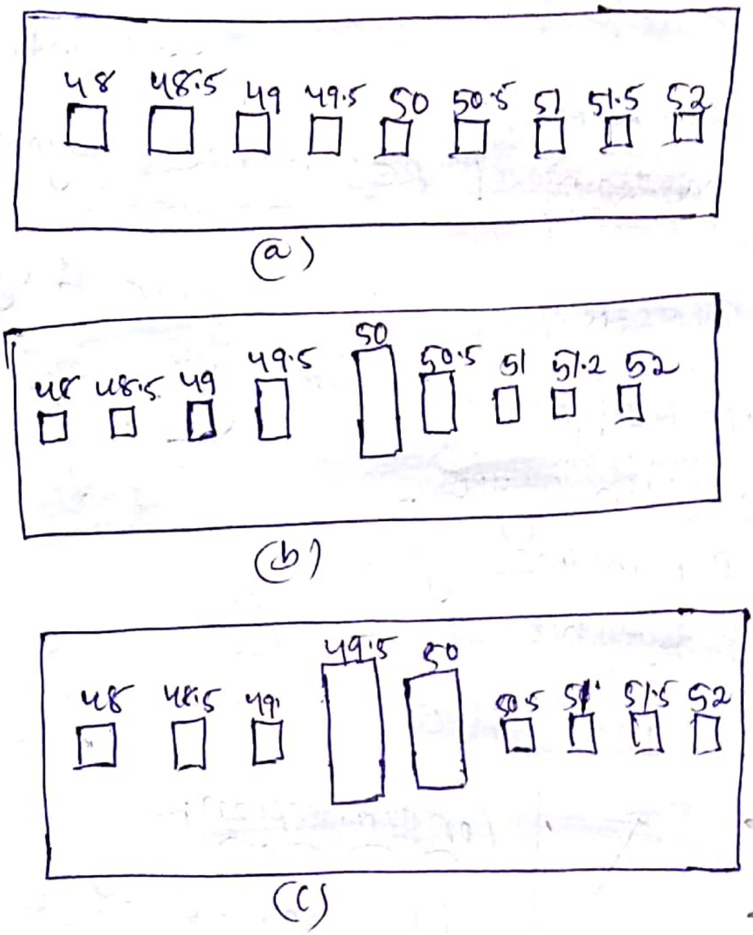
Construction:-

→ It consists of a no. of thin steel strips called reeds.

→ These reeds are placed in a rows alongside & close to an electromagnet.





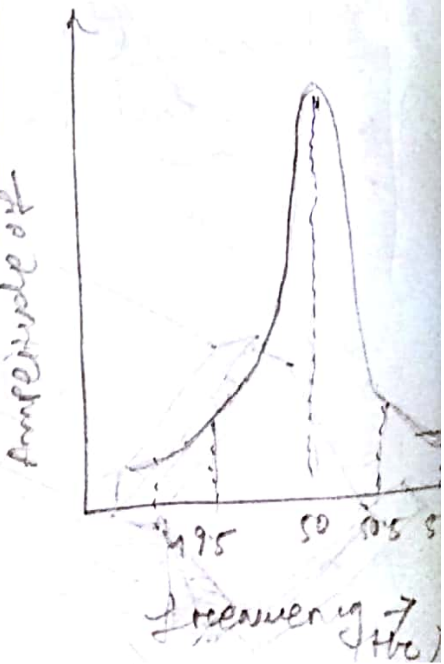


(a)

(b)

(c)

(Indications from vibrating reeds)



→ The electromagnet has a connected iron core & its coil is connected in series with a resistance across the supply whose frequency is to be measured.

→ Each reed is approximately about 4mm wide & 0.5mm thick. All the reeds are not exactly similar to each other. The reeds are not exactly similar to each other.

Working :-

→ When the frequency meter is connected across the supply whose frequency is to be measured the coil of ~~ee~~ electromagnet carries a current 'i' which alternates at the supply frequency.

→ The force of attraction b/w the reeds & the electromagnet is proportional to 'i^2' & therefore the force varries at twice the supply frequency.

→ This force exerted on the varies every half cycle.

→ All the reeds will tend to vibrate, but the reeds whose natural frequency is equal to twice the supply frequency.

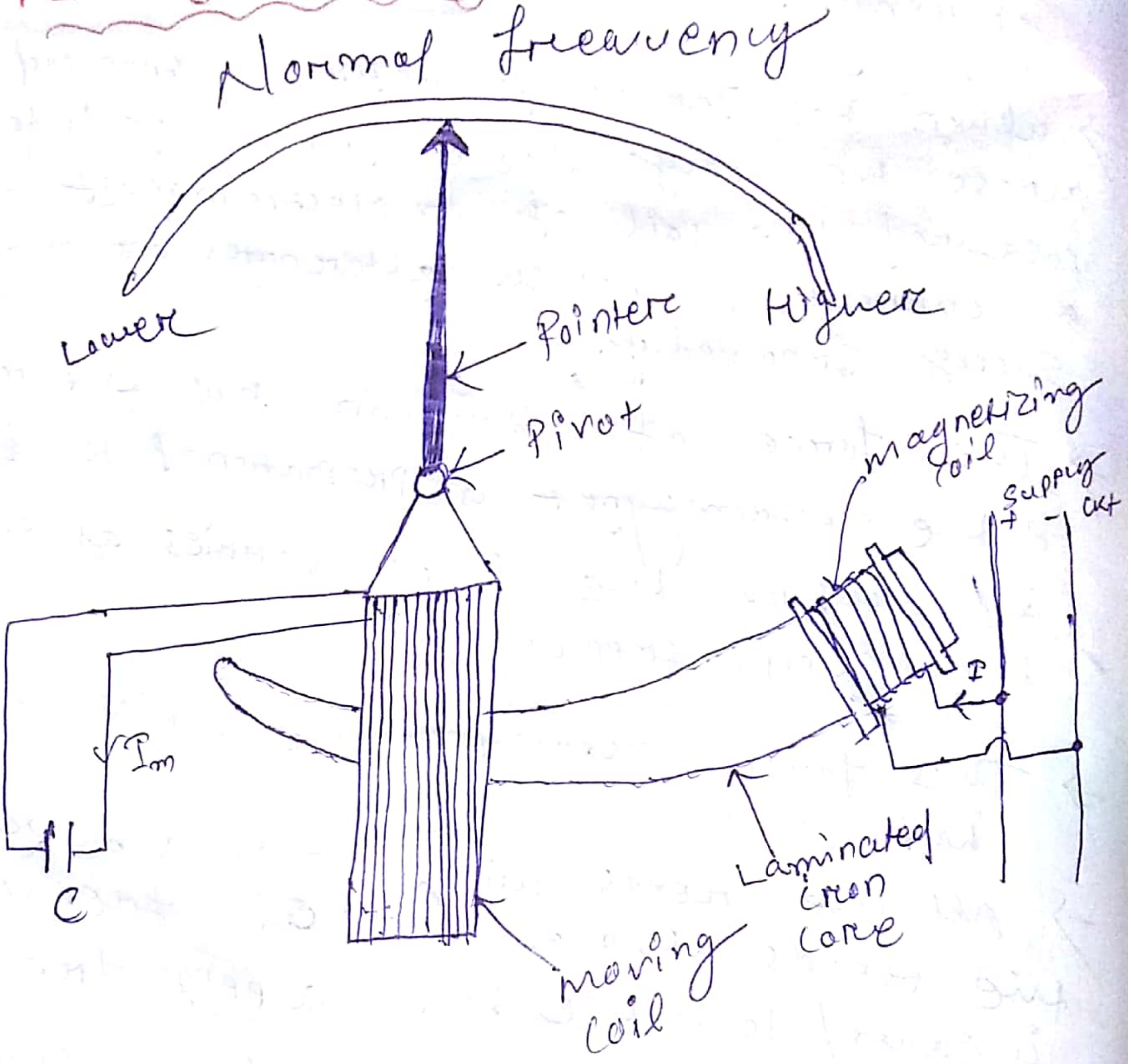
→ All the reeds will tend to vibreate, but the reeds whose natural ~~frequency~~

is equal to twice the supply frequency ~~is equal to~~ will be in resonance & vibrate mostly.

→ Normally the vibration of other reed so slight as to be unobservable.

② Electrical Resonance type Frequency meter :-

ⓐ Ferrodynamic Type :-



Construction:-

→ It consist of a fixed coil which is connected across the supply whose frequency is to be measured. This coil is called magnetizing coil.

→ The magnetizing coil is mounted on a laminated iron core.

→ The iron core has a cross-section which varies gradually over the length being max^m near the end.

→ At the near end side of iron core the magnetizing coil is mounted & minimum at the other end.

→ A pointer is attached to the moving coil.

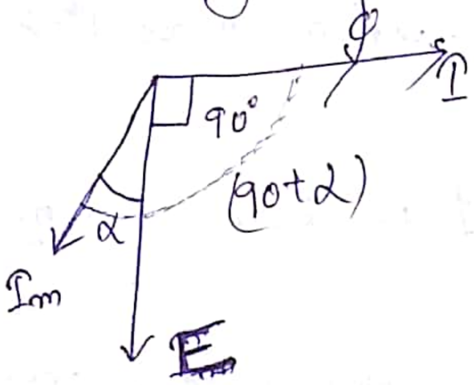
→ The pointer of the moving coil are connected to a suitable capacitor 'C'.

Working

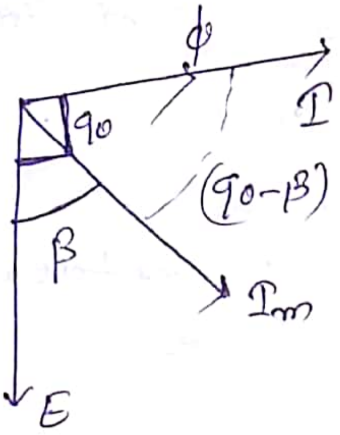
→ The magnetizing coil carries a current ~~ϕ~~ 'I' ~~&~~ produces a flux 'ϕ'. If we neglect resistance of the coil & the iron losses in the core, Then the flux 'ϕ' is in phase with current 'I'.

→ The flux 'φ' being alternating in nature induces an emf (E) in the moving coil. This emf lags the flux by an angle 90°.

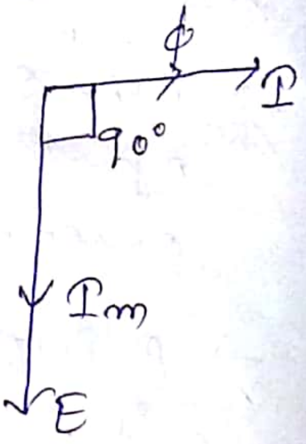
→ The emf induced circulates a current 'Im' in the moving coil. The Phase of the 'I' & current 'Im' depend upon the inductance 'L' & capacitance 'C' of the moving coil.



(a) (Inductive) (X_L)



(b) (X_C) (capacitive)



(c) (Resonance) ($X_L = X_C$)

(a) Let the moving coil is assumed to be inductive then torque acting on the moving coil is

$$T_d \propto \phi I_m \cos(90+\alpha) = T_d \propto I_m \cos(90+\alpha)$$

(b) If the moving coil is assumed to be capacitive then the torque acting on the moving coil is

$$T_d \propto \phi I_m \cos(90-\beta) = T_d \propto I_m \cos(90-\beta)$$

→ (c) If the inductive reactance is equal to the capacitive reactance then the ckt is in resonance condition. Therefore the ckt is purely resistive & 'Im' is in phase with 'E' & the deflecting torque :- $T_d \propto I_m \cos 90°$

$$\Rightarrow T_d = K I_m \cos 90$$

$$\Rightarrow T_d = 0 \quad (\because \cos 90 = 0)$$

(Rest condition of pointer)
or
(Steady state condition)

So there is no requirement for controlling force arrangement in this type of instrument.

→ For a fixed frequency the capacitive reactance is constant but the inductive reactance for the moving coil is not constant. This is because the inductance of the moving coil is depend upon the position which the moving coil occupies on the iron core.

→ If the inductive reactance is greater than the capacitive reactance ($X_L > X_C$) then the torque must move the coil to a position where

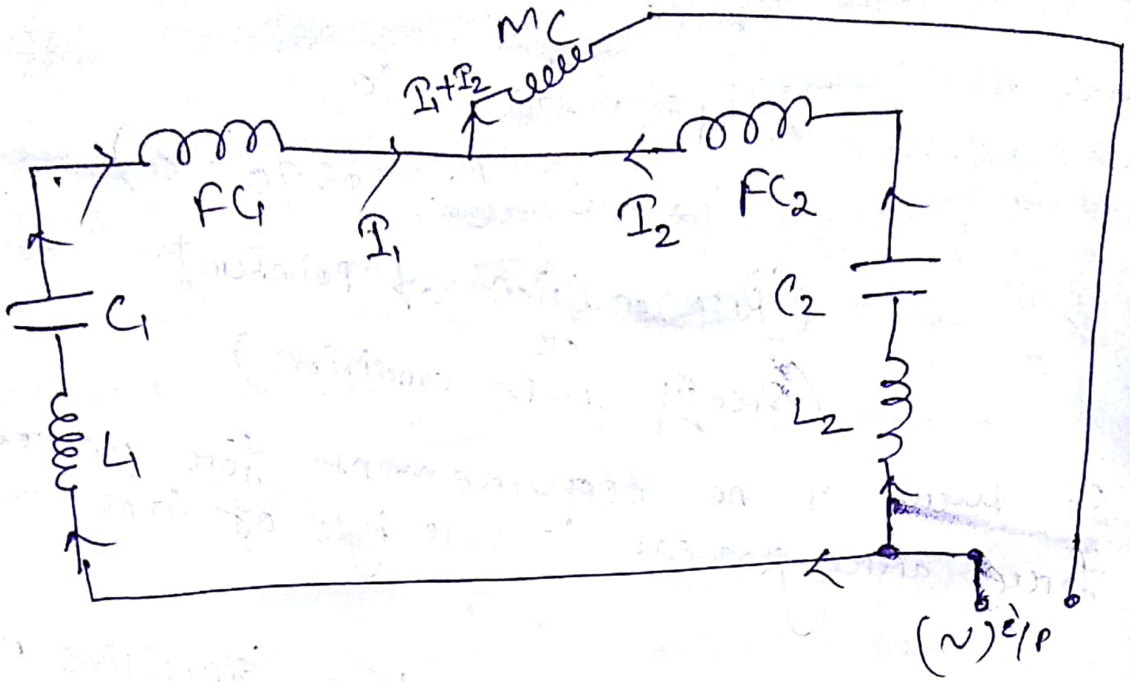
$$\boxed{X_L = X_C}$$

→ A decreased inductive reactance is obtained if the moving coil moves away from the magnetizing coil

→ The coil will comes to rest when

$$\boxed{X_L = X_C}$$

(b) Dynamometer type frequency meter



→ The f.c is devided into two parts FC_1 & FC_2.

- The two part of the f.c form two separate resonant ckt.

→ The torque on the m.c is proportional to the current through the M.C.

→ FC-1 is in series with an inductance L_1 & a capacitance C_1 forming a resonant ckt, the frequency of this ckt 'f_1' slightly below the lower end of the instrument scale.

→ FC-2 is is series with inductance L_2

& capacitance C_2 forming a resonance ckt, which frequency f_2 slightly ~~below the lower~~ end higher than the upper end of the instrument scale.

→ For the applied frequency (which is to be measured) the fC-1 is operate above the resonant frequency ($X_{L_1} > X_{C_1}$) with current 'i_1' & the fC-2 is operate below the resonant frequency ($X_{C_2} > X_{L_2}$) with current 'i_2'.

→ One fixed coil circuit is inductive & other is capacitive in nature

→ Therefore the torque produced by the two currents 'i_1' & 'i_2' & the torque is the resultant torque between the two torque.

→ Hence the meter scale can be calibrated in terms of frequency.

Power factor meters:-

→ The instrument which is used for the measurement of power factor is known as power factor meter.

→ There are two types of power factor meters:- (1) Electrodynamometer type
(2) Moving iron type

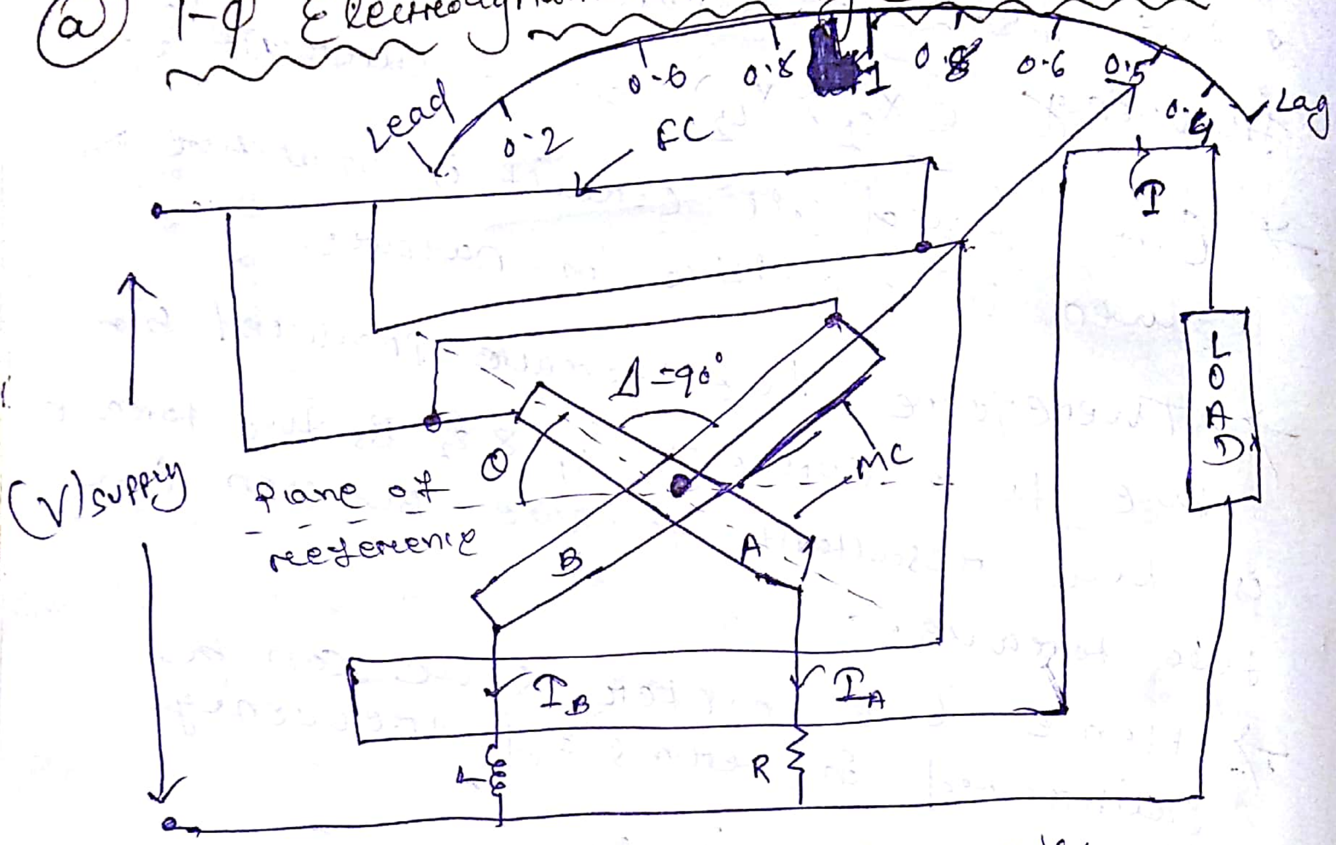
① Dynammometer type Power factor meter

→ Acc^n to Phase distribution of electrical Power supply it is further divided into two types

i.e- ⓐ 1-ϕ Electrodynamometer type p.f mtr

ⓑ 3-ϕ Electrodynamometer type p.f mtr

ⓐ 1-ϕ Electrodynamometer type p.f meter :-



→ It consists of a fixed coil which acts as a current coil. This coil is splited into two parts & carries the current of the ckt. Therefore magnetic field produced by the ckt is proportional to the supply current.

→ Two identical pressure coil 'A' & 'B' pivoted on a spindle constitute the moving system.

→ Pressure coil 'A' has a non-inductive resistance 'R' connected in series with it & coil 'B' has a highly inductive choke coil 'L' connected in series with it.

Operation ↦

→ Let us assume that current through 'coil-B' lags the voltage by an angle 90° & the angle b/w two moving coil is 90°

→ Now there will be two deflecting torque T_A & T_B acting on the moving coil.

$$T_A = KVI\, M_{max} \cos\phi \sin\theta$$

$$T_B = KVI\, M_{max} \cos(90-\phi) \sin(90+\theta)$$

$$= KVI\, M_{max} \sin\phi \cos\theta$$

Here M_{max} = maximum value of mutual inductance b/w two coil.

So at steady state position

$$T_A = T_B$$

$$\Rightarrow \cancel{KVI\, M_{max}} \cos\phi \sin\theta = \cancel{KVI\, M_{max}} \sin\phi \cos\theta$$

$$\Rightarrow \frac{\sin\theta}{\cos\theta} = \frac{\sin\phi}{\cos\phi}$$

$$\Rightarrow \tan\theta = \tan\phi$$ (∵ ϕ = Phase angle of meter

$$\Rightarrow \boxed{\theta = \phi}$$ θ = angle of deflection)

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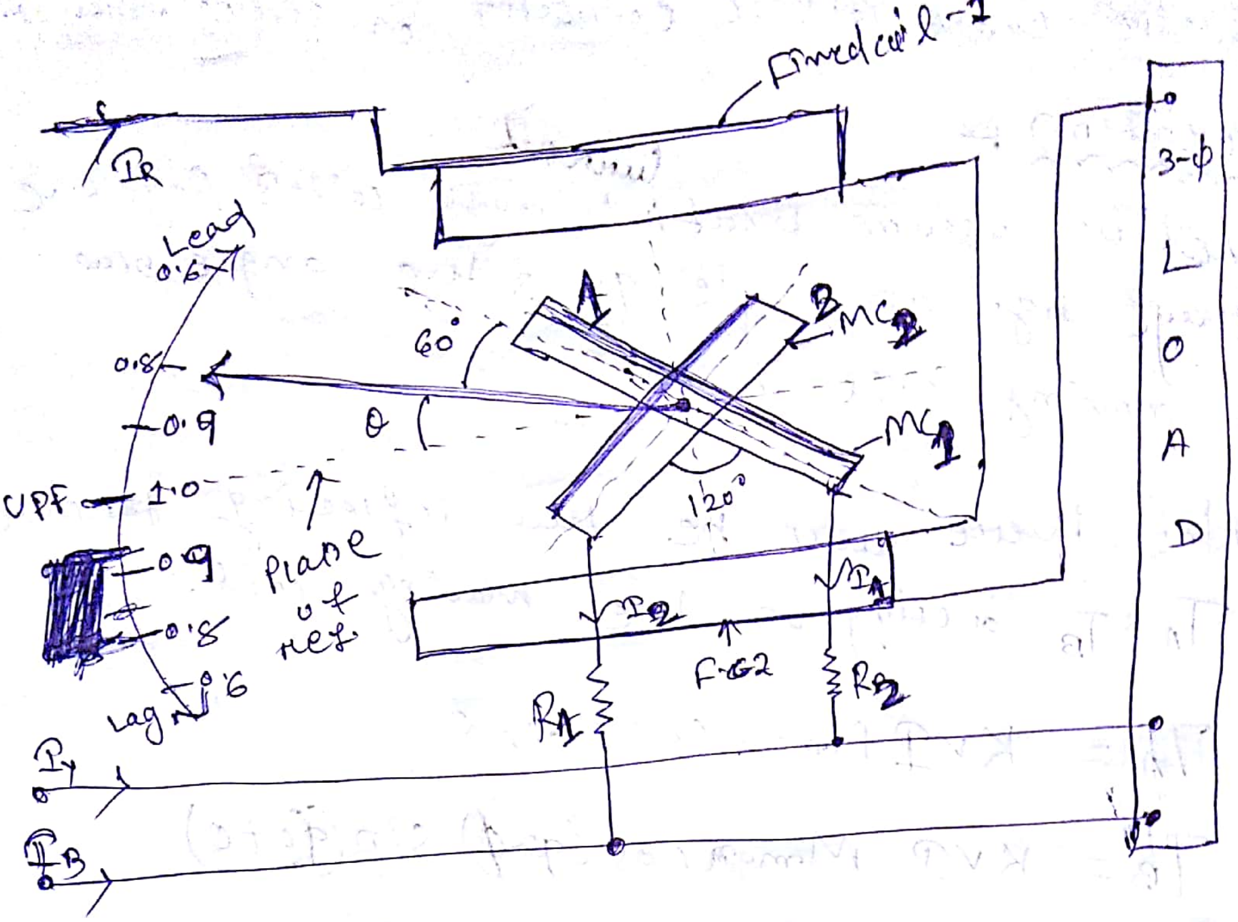
(b) 3-ϕ Dynamometer type P.f meter.



Construction

→ It consists of two fixed coil connected in series in one of the phase & carries the line current as shown in above figure.

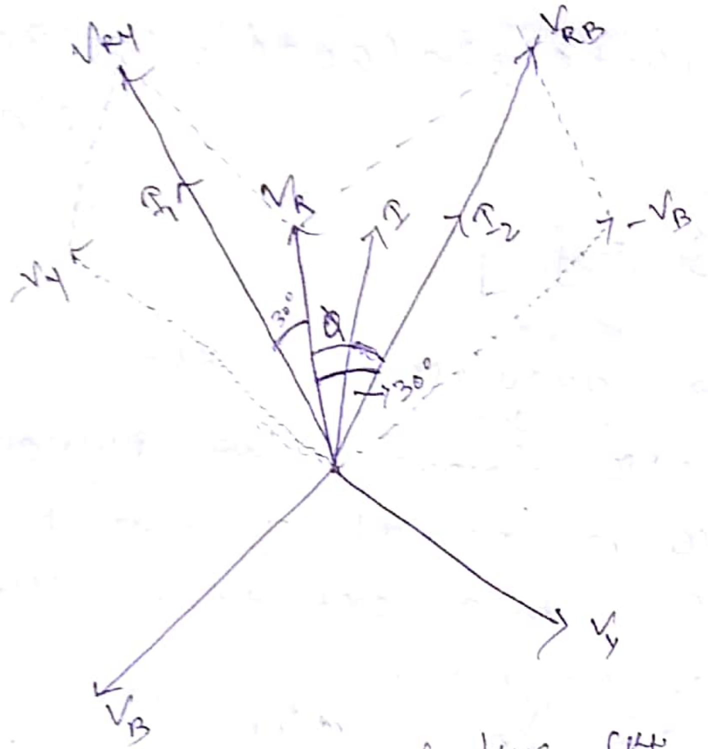
→ The two identical moving coils i.e. MC_1 & MC_2 ~~A & B~~ are fixed with their planes by an angle 120° apart & connected across two remaining phases through the resistances.

Working :-

→ When 3-ϕ P.f meter is connected in the ckt under balanced load conditions the angle through which the pointer is deflected from the unity power factor position is equal to the phase angle of the ckt, because the two moving coils are fixed by 120° apart

→ The deflection in 3-ϕ power factor meter are independent of frequency & wave form, since the current in the two moving coils are both affected in the same way by any change of frequency. ✱↓

CHAPTER-6 :- MEASUREMENT OF RESISTANCE, INDUCTANCE & CAPACITANCE :



Let ϕ = Phase angle of the ckt

θ = angular deflection from the plane of reference.

Torque acting on coil -1

$T_1 = K V_{RY} I_{RB} M_{max} \cos(30+\phi) \sin(60° + [illegible]$

$T_1 = \sqrt{3} K V_{RY} I_{RB} M_{max} \cos(30+\phi) \sin(60 + [illegible]$

Torque acting on coil "2" is

$$T_2 = K V_{RB} I M_{max} \cos(30-\phi) \sin(120+\theta)$$

$$T = \sqrt{3} K V I M_{max} \cos(30-\phi) \sin(120+\theta)$$

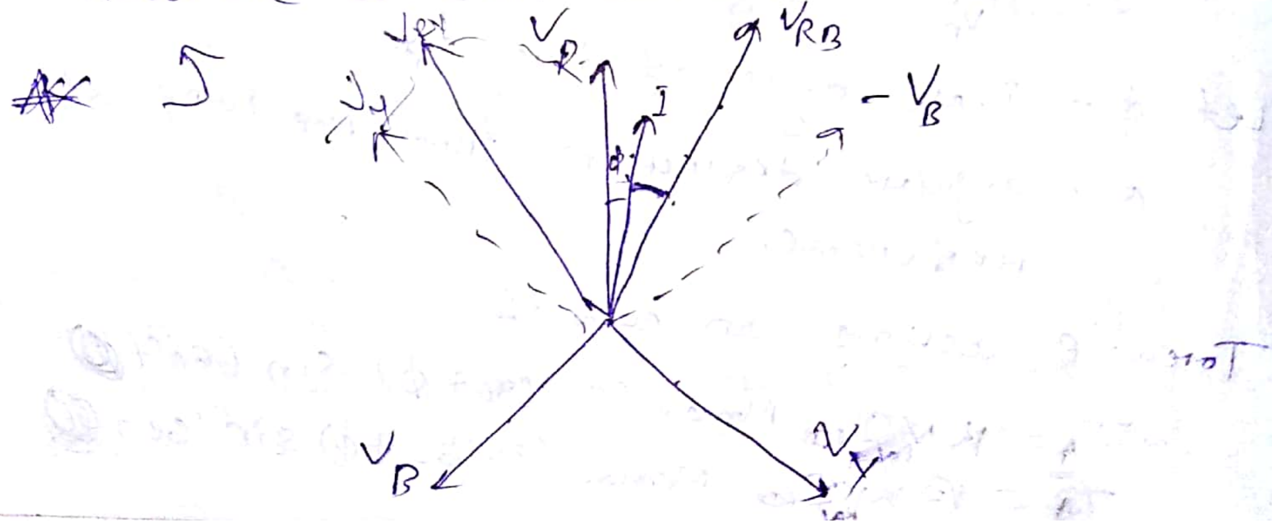
→ Torque T_1 & T_2 act in the opposite directions & the moving ~~coil~~ system takes up a position where

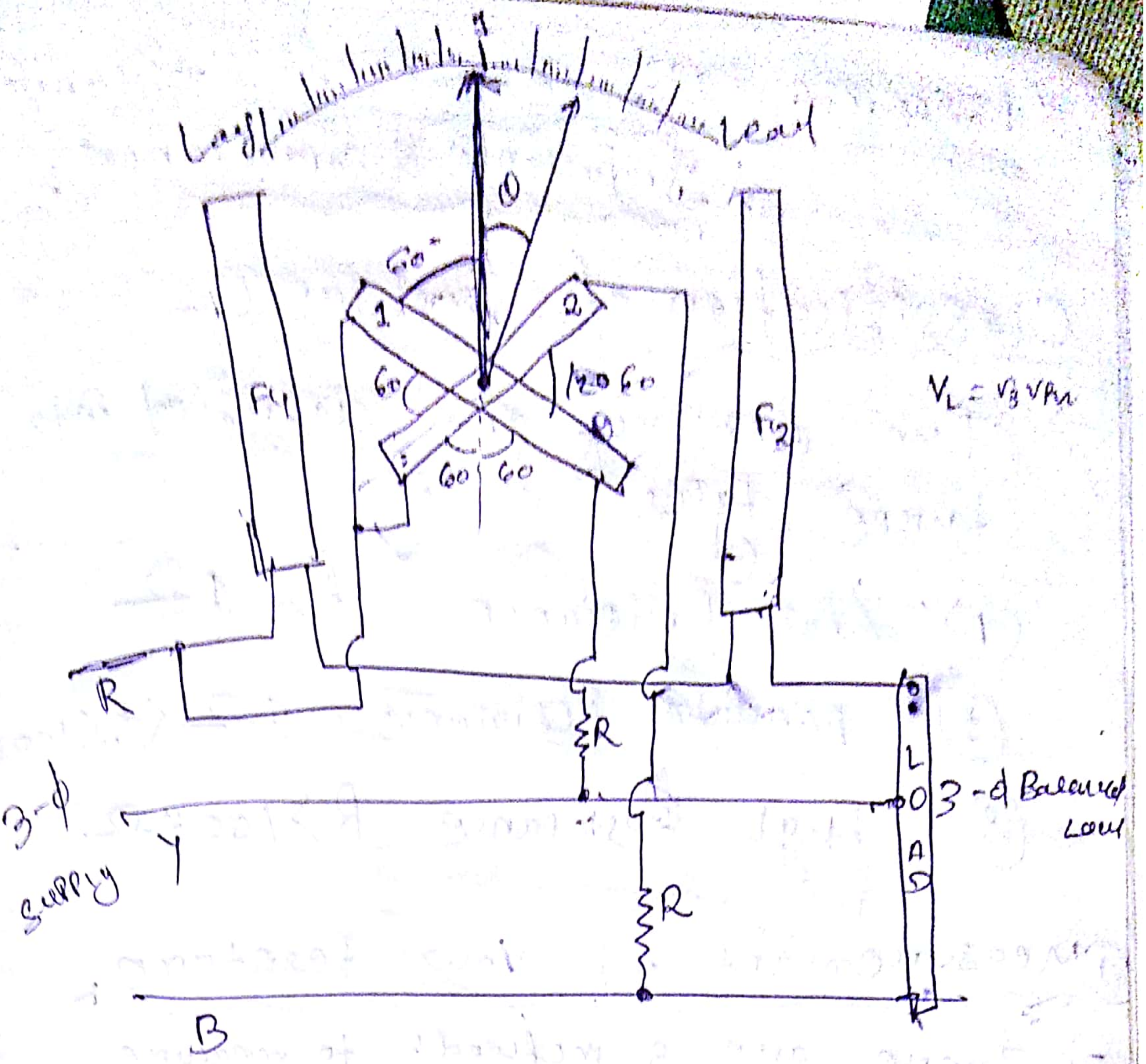
$$T_1 = T_2$$

$$\therefore \cos(30+\phi) \sin(60+\theta) = \cos(30-\phi) \sin(120+\theta)$$

$$\boxed{\theta = \phi}$$

Thus the angular deflection of the pointer from the plane of reference is equal to the phase angle of the cut to which the meter is connected.





$V_L = \sqrt{3} V_{Ph}$

$$T_1 = K M_{max} V_{RY} I \cos(30+\phi) . \sin(60+\theta)$$
$\sqrt{2}$

$$T_2 = K M_{max} V_{RY} I \cos(30 \pm \phi) . \sin(120+\theta)$$

$$T_1 = T_2$$

$$\Rightarrow \sqrt{3}K \cos(30+\phi) . \sin(60.+\theta) = \cos(30 \pm \phi) . \sin(120+\theta)$$

$$\Rightarrow \cancel{\frac{\sin(120+\theta)}{\cos(30+\phi)}}$$

$$\Rightarrow \frac{\cos(30+\phi)}{\cos(30-\phi)} = \frac{\sin(\overset{\overset{120}{\cancel{60}}}{\cancel{120}}+\theta)}{\sin(120+\theta)}$$

$$\Rightarrow \frac{\sqrt{3}}{2}\cos(\theta) - \frac{1}{2}\sin\theta \Big/ \sqrt{3}/2 \cos\theta + \frac{1}{2}\sin\theta$$

Chapter-6 Measurement of Resistance, Inductance & Capacitance

Classification of Resistance

→ The resistance are classified into three types.

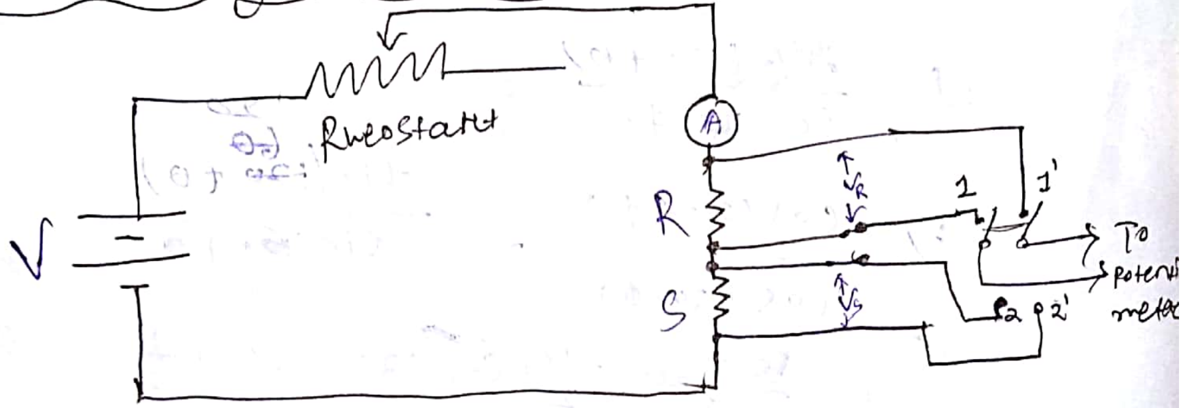
1. Low Resistance $R < 1\Omega$
2. medium Resistance $1\Omega < R < 100k\Omega$
3. High Resistance $R > 100k\Omega$.

① Measurement of Low Resistance

→ There are 3-methods to measure Low resistance, i.e-

- (i) Kelvin double bridge method
- (ii) Potentiometer method.
- (iii) Ammeter-voltmeter method (or voltage drop method.)

(ii) Measurement of Low ~~resis~~ resistance by Potentiometer method



→ The ckt of measurement of resistance with a potentiometer is shown in above fig.

→ The unknown resistor (R) is connected in series with the standard known resistor (S).

→ The current through the circuit is controlled with the help of a rheostat

→ Here a two pole double throw switch is used, when the switch is in position 1 & 1', the unknown resistance R' is connected to the potentiometer.

→ Let the reading of the potentiometer is 'V_R'

$$\boxed{V_R = I \cdot R} \text{ —— ① } \qquad I = \frac{V_R}{R}$$

→ Now the switch is in position 2 & 2' then the standard resistor (S) is connected to the potentiometer.

→ Let the reading of the potentiometer is 'V_s'.

$$\boxed{V_s = I \cdot S} \text{ —— ② } \Rightarrow I = \frac{V_s}{S}$$

By dividing eqn ① & ② ~~for~~

$$\frac{V_R}{V_s} = \frac{\cancel{I} \cdot R}{\cancel{I} \cdot S}$$

$$\Rightarrow \boxed{R = S \cdot \frac{V_R}{V_s}}$$

from eqn-① & ②

$$\frac{V_R}{R} = \frac{V_s}{S}$$

$$\Rightarrow \boxed{R = \frac{V_R}{V_s} \times S}$$

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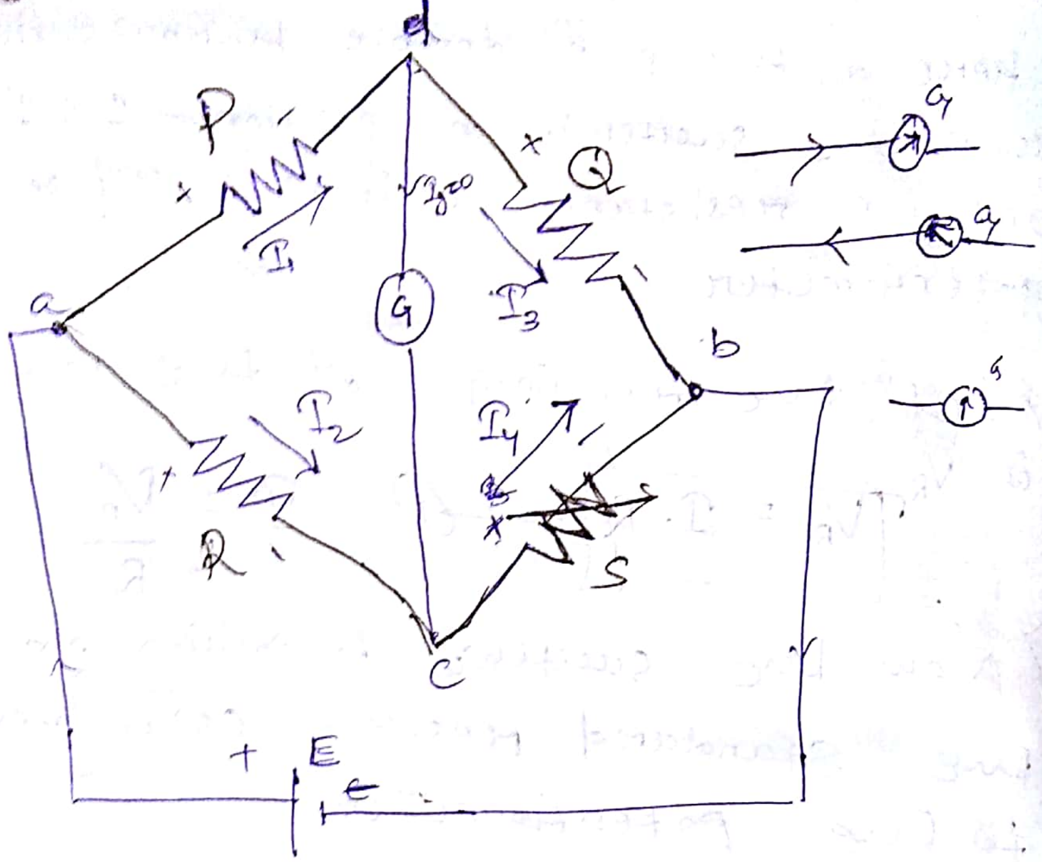
→ Since the value of the Standard resistor (S) is accurately known then the value of the 'R' can also be known accurately

(2) Measurement of medium Resistance by wheat-stone Bridge method



(Wheatstone Bridge)

→ Wheatstone bridge is the very ~~wheatstone~~ ~~bridge~~ important device which is used in the measurement of medium resistance

→ This is the simples & the most basic bridge cut used in measurement studies.

→ It mainly consists of four arm of resistance 'P', 'Q', 'R' & 'S'. where 'R' is the unknown resistance which is to be measured, while 'S' is a Standard variable resistance & 'P' & 'Q' are known as the ratio arms.

- An 'emf' source ~~⊘~~ 'E' is connected b/w points 'a' & 'b' while a galvanometer is connected b/w points 'c' & 'd'.

- A bridge ckt always works on the principle of null indication or null detector, i.e- we vary a parameter until the detector shows zero & then use a mathematical relation to determine the varying parameter & other constants.

- The standard resistance, 'S' is varied in order to obtain null deflection in the galvanometer (G).

- This null deflection implies no current flows from point 'c' to 'd', which means potential of point 'c' & 'd' is same. i.e- the bridge is in balanced condition.

Hence $I_1 P = I_2 R$ —— ①

For galvanometer current to be zero ~~also~~

$$I_1 = I_3 = \frac{E}{(P+Q)} \quad \text{—— ②}$$

&

$$I_2 = I_4 = \frac{E}{(R+S)} \quad \text{—— ③}$$

① & ②③ can

Combining the above two equations we get the ~~, we obtain~~

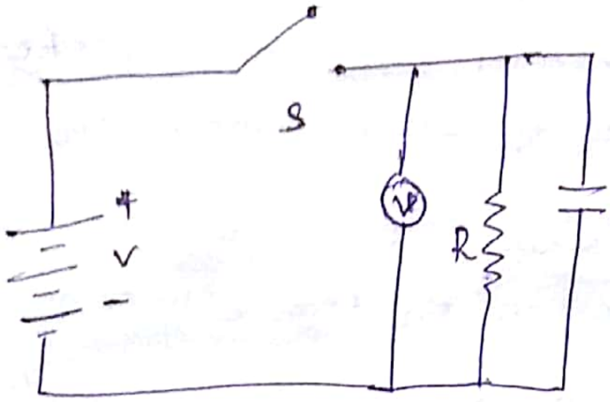
$$\boxed{\frac{P}{Q} = \frac{R}{S}}$$

$$\Rightarrow \boxed{R = \frac{P}{Q} \times S}$$

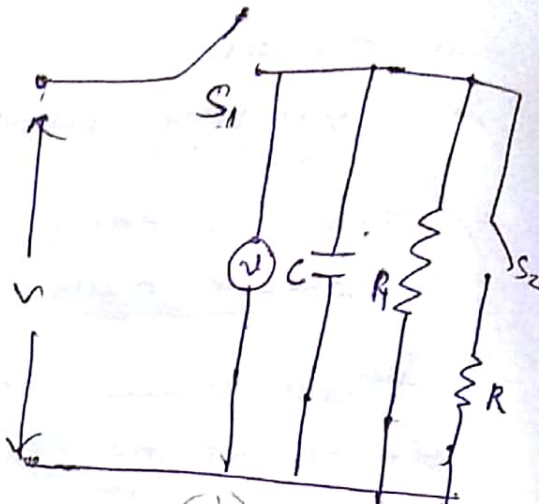
③ Measurement of high resistance by loss of Charge method :-

~~→ There are few methods used for~~

→ In this method we utilize the curve of voltage across a discharging capacitor to find the value of unknown resistance 'R'.



(a)



(b)

→ In this method the unknown resistance is 'R' connected in parallel with a capacitor 'C' & a electrostatic voltmeter.

→ The electrostatic voltmeter measure the voltage across the resistance 'R' & through the voltage & current we can findout the unknown resistance.

→ The Capacitor 'C' is allowed to charge through a ~~battery~~ voltage i.e a battery is connected across it by switch 'S'.

→ After that the Capacitor 'C' is charged upto some voltage, the battery is disconnected by switch 'S' & the capacitor is allowed to discharge through the unknown resistance 'R'.

→ The relationship of the discharge or the loss of charge in ~~through~~ the capacitor 'C' through that we can calculate the unknown resistance 'R'. That is why it is called loss of charge method.

→ The capacitor is initially charged to some suitable voltage by means of a battery of voltage 'V' & then allowed to discharge through the unknown resistance.

→ The charging & discharging of capacitor can be expressed in the form of an expression i.e

→ The terminal voltage is observed during discharge → $\boxed{V = v\, e^{(-t/cR)}}$

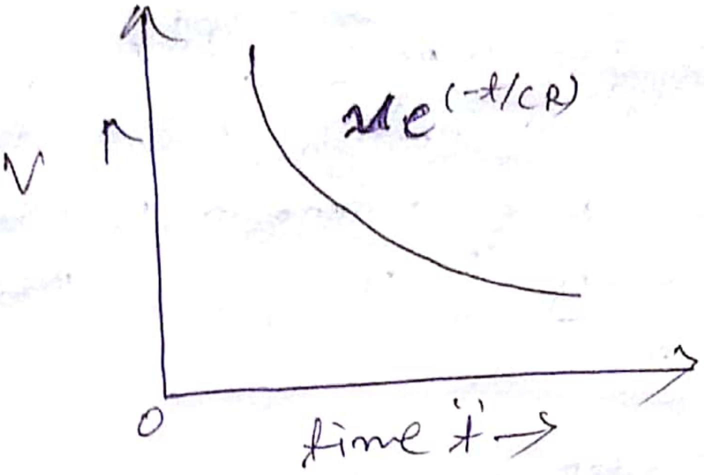
V = emf of batter.

v = voltmeter reading.

$$\boxed{\frac{V}{v} = e^{(-t/cR)}}$$

t = time taken to full discharge of capacitor.

→ The discharging of capacitor is in the form of exponential or the capacitor discharging exponentially



From the above expression now we can findout **R** high unknown resistance 'R'.

~~$R = \frac{t}{C\log_e v}$~~

$$\boxed{R = \frac{t}{C\log_e\left(\frac{V}{v}\right)}}$$

$$\boxed{R = 0.4343\frac{t}{C\log_{10} V/v}}$$

$\left(\log_e \rightarrow \log_{10} = 0.4343\log_{10}\right)$

→ If resistance 'R' is very ~~high~~ large then the process becomes time consuming ~~therefore~~ therefore there are some factors which could occur error.

→ So Instead of measuring voltage across capacitor, ~~we measure~~ the diff. b/w voltage ~~@~~ battery 'V' & voltage across voltmeter 'v' is calculated.

i.e $\boxed{V - v = e}$

so $$\boxed{R = \frac{0.4343\, t}{C \log_{10} \frac{V}{V-e}}}$$

where e = small difference b/w '$V-v$'

- In this method measures high resistance but it rearcires a capacitor of very high leakage resistance as compared to the unknown resistance R, so that no leakage current are produce.

- So we have to consider the leakage resistance of capacitor also. & the ~~[illegible]~~ ckt became as shown is fig (b)

Let R_1 is the leakage resistance of the capacitor

R' is the equv. resistance of R & R_1

$$\boxed{R' = \frac{R \times R_1}{R + R_1}}$$

Then discharge eqn will become when switch S_1 & S_2 closed 'C' discharg across equv. Resistance R'.

$$R' = \frac{0.4343\, t}{\left(C \log_{10} V/v\right)}$$

Now when S_1 = open & S_2 also open

then $$\boxed{R_1 = 0.4343\, t / \left(C \log_{10} V/v\right)}$$

MEGGER (Ohmmeter ~~Ohmmeter~~)

→ " is a special type of ohmmeter used to measure the electrical resistance of ~~insulators~~ insulation. Insulating components i.e. cable jackets, winding resistance of x-mer, must be tested for ~~[illegible]~~ their insulation strength at the time of commission & as part of maintenance of high voltage electrical equipment & installations.

→ megger is adapted to application in portable instruments measuring insulation resistance. This ~~[illegible]~~ principle of ~~[illegible]~~ insulation testing instrument known as megger

→ ~~[illegible]~~ why is megger testing done?

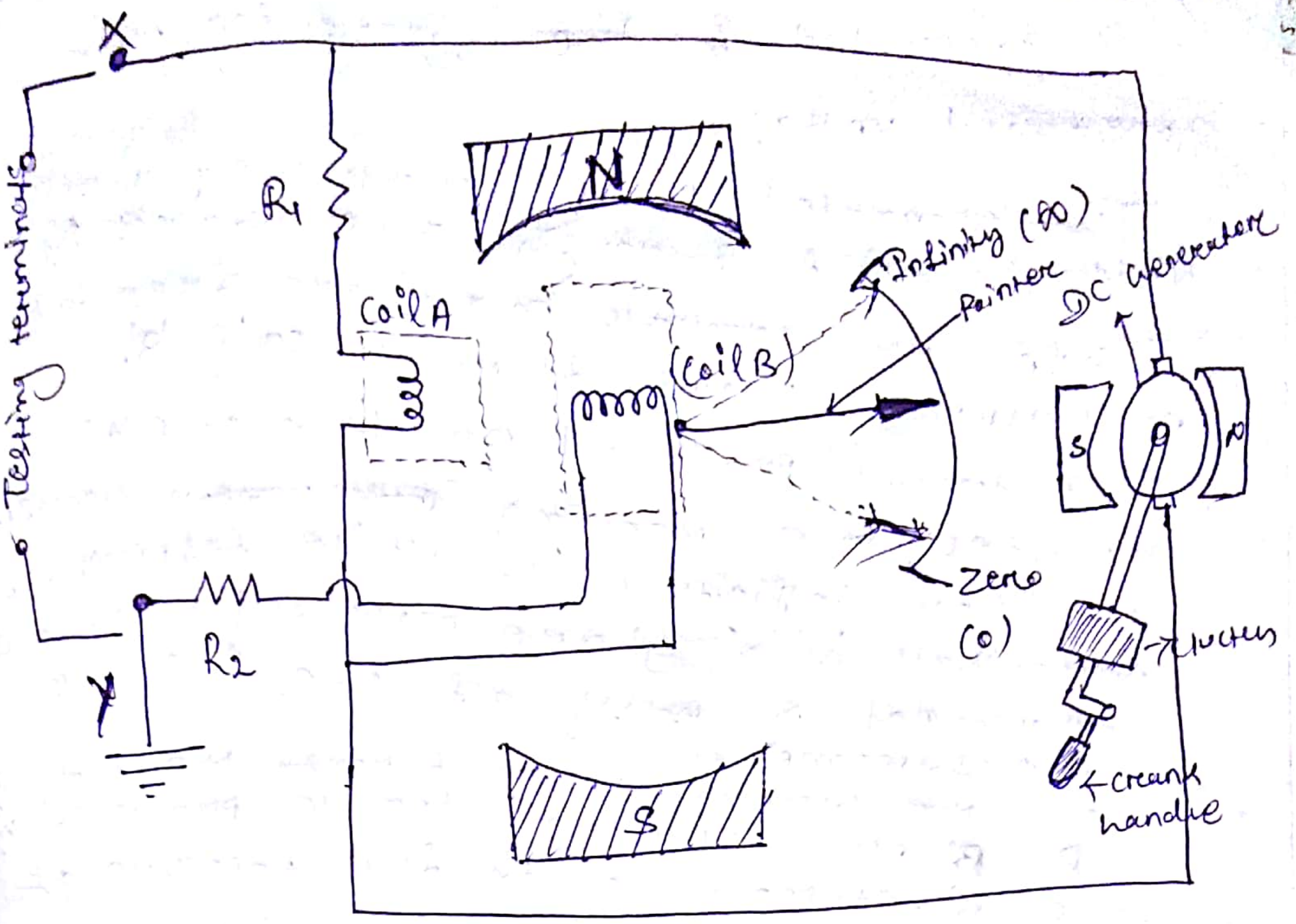
→ The Isulatn resistance needs to be tested to check the insulation quality (puncture in insulation) of the electrical system & to avoid any major or minor electrical shocks to operators.

~~Construction~~

→ The parts of megger are shown in the fig-1.

→ The armature of the generator is rotated by the hand driven crank lever.

→ The clutch mechanism is designed to slip at a predetermined speed. This facilitates



(fig-1)

the generator to maintain a constant speed & hence the constant voltage while testing

-> The two coils 'A' & 'B' constitute a M.C voltmeter & an ammeter. Both are combined to form one instrument.

-> coil A is voltage coil & coil 'B' is M.C as in PMMC instrument

-> The 'Hot' terminal of the equipment whose insulation resistance has to be measured is connected to the testing terminal 'X'.

-> The terminal 'Y' is connected to the body of the equipment, which is generally grounded

→ When the crank handle is rotated, a voltage is generated in the generator. ~~the~~ ~~generated voltage~~

→ The generated voltage is applied across the voltage coil A through a resistance R_1.

→ When the terminals 'x' & 'y' are free initially no current flows through coil 'B'.

→ The torque produced by the coil 'A' rotates the moving ~~element~~ element to show infinity (∞), while testing the terminals 'x' & 'y' are connected across the terminal & body of the M/C for measurement.

→ Now the current passes through the deflecting coil 'B'. The deflecting torque produced by coil 'B' interacts with the torque of coil 'A' & rotates the moving element to indicate the resistance value.

→ Voltage generated by this instrument is around 500 volts. Meggers are available to generate 1KV, 2'5KV & 5KV also.

→ High voltage meggers are either motor operated or power operated.

Earth Resistance Measurement

Earth Tester:-

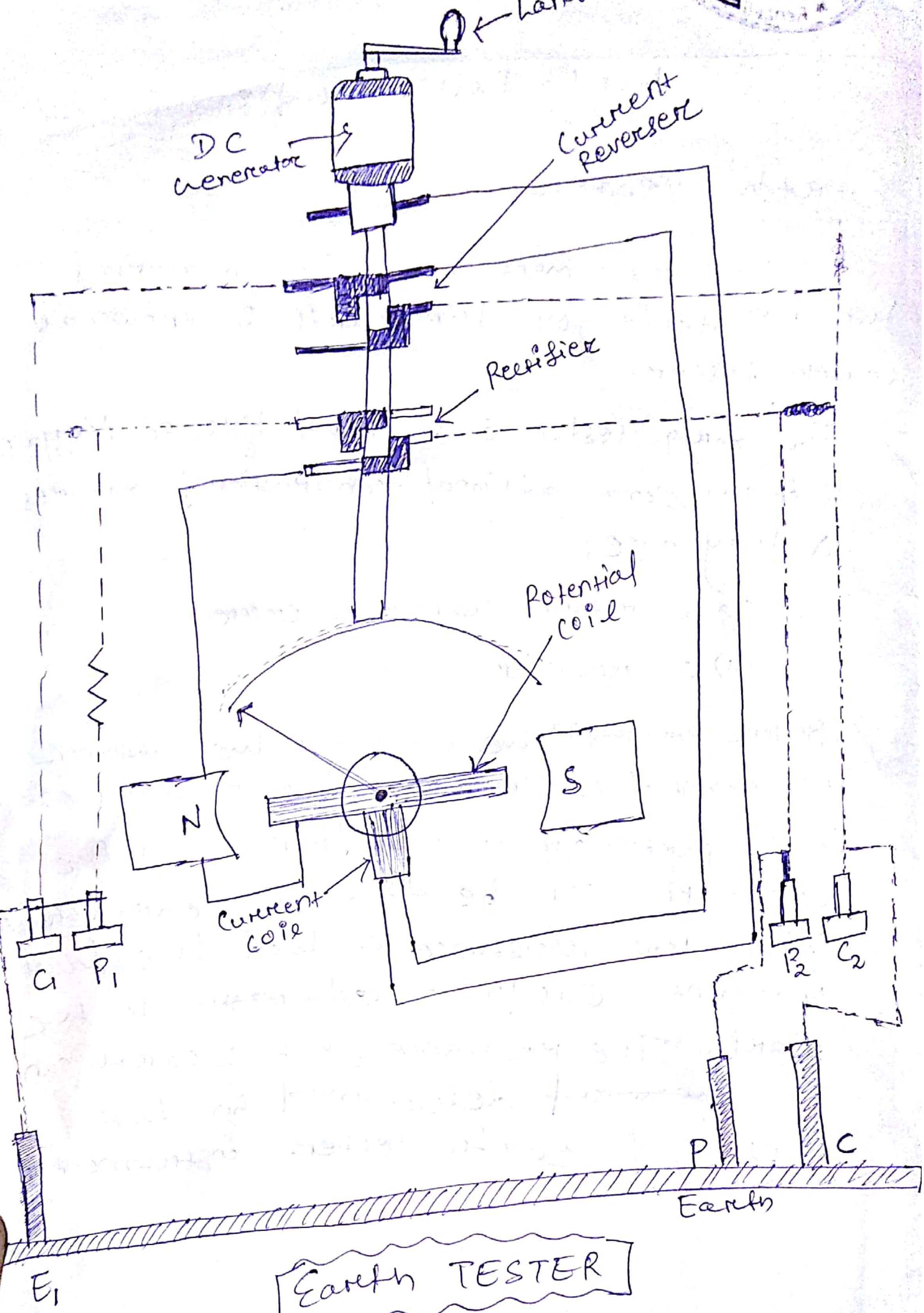
The instrument used for measuring the resistance of the earth is known as earth tester.

→ The Earth Tester is a special type of Meggar, & it has some additional constructional features & they are;

(I) a rotating current reverser
(II) a rectifier.

→ Before providing the earthing to the equipment it is essential to determine the resistance of that particular area from where the earth pit can be dug. The earth should have low resistance so that the fault current easily passes ~~through~~ to the earth. The resistance of the earth can be ~~measured~~ determined by the help of earth tester instrument.

Construction & Working Principle



Earth TESTER

→ The two additional features of earth tester consistof simple commutators made up of 'L' shaped segments.

→ They are mounted on the shaft of hand driven generator.

→ Each commutator has four fixed brushes. one pair of each set of brushes is so positioned that they make contact alternately with one segment & then with other as the commutator rotates.

→ The second pair of ~~B~~ each of set of brushes is so positioned on the commutator so that continuous contact is made with one segment whatever the position of the commutator.

→ The earth Tester ~~has four terminals~~ consists of two pressure coils & two current coils. These are four of earth testere P_1, P_2 ~~of~~ terminals & C_1, C_2.

→ Two terminals P_1 & C_1 are shorted to form a common point to be connected to the earth electrode. The other two terminals P_2 & C_2 are connected to auxiliary electrodes 'P' & 'C' respectively.

→ The deflection of its pointer indicates the resistance earth directly. The deflection of the pointer depends upon the ratio of the voltage of P. C ~~to~~ the

Current of the C.C.

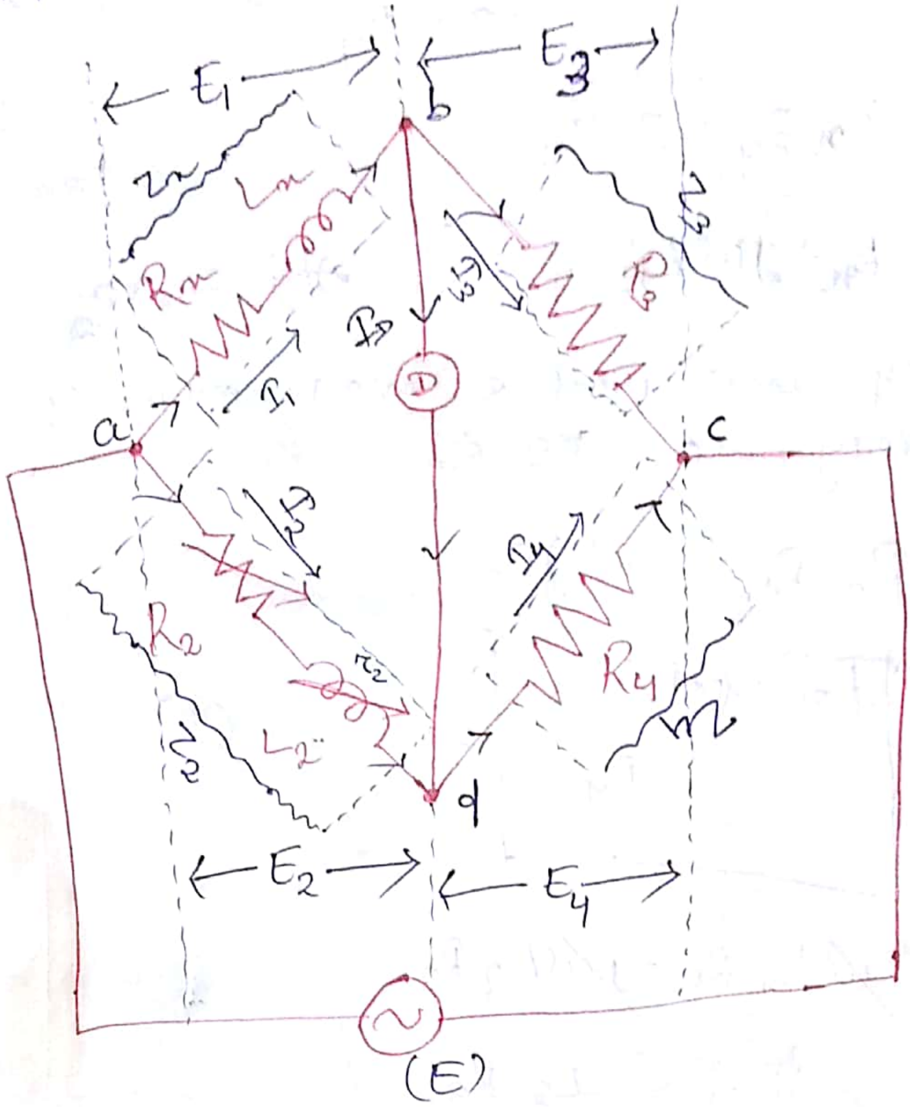
→ Although the earth tester which is a PMMC instrument & can operate on d.c only, yet by including the reverser & the rectifying device it is possible to make measurements with a.c flowing in the soil.

→ the short ckt current passes through the equipment to the earth is alternating in nature. Thus, we can say that the Alternating current flows in the soil.

This AC current reduces the unwanted effect of the soil, which occurs because of chemical action or because of the production of back emf.

Measurement of Inductance by Maxwell's Bridge Method :

-> This bridge ckt measures an inductance by comparision with a variable standard self-inductance.



The connection of the bridge as shown in above figure.

Let L_x = unknown inductance of R_x

L_2 = Variable inductance of fixed resistance r_2.

R_2 = variable resistance connected in series with inductor L_2.

R_3 & R_4 = Known non-inductive resistances.

→ A detector 'D' is connected across point 'b' & 'd' to detect the current I_D through it.

Therefore at balanced condition $I_D = 0$

$$E_1 = E_2 \quad \text{or} \quad E_3 = E_4$$

$$Z_x Z_4 = Z_2 Z_3$$

or $$(R_x + j\omega L_x) R_4 = ((R_2+r_2) + j\omega L_2) R_3$$

Equating the real & imaginary parts separately, we have;

$$R_x R_4 = (r_2+R_2) R_3$$

$$\Rightarrow \boxed{R_x = \frac{(r_2+R_2) R_3}{R_4}} \text{ —— ①}$$

and $$\cancel{j\omega} L_x R_4 = \cancel{j\omega} L_2 R_3$$

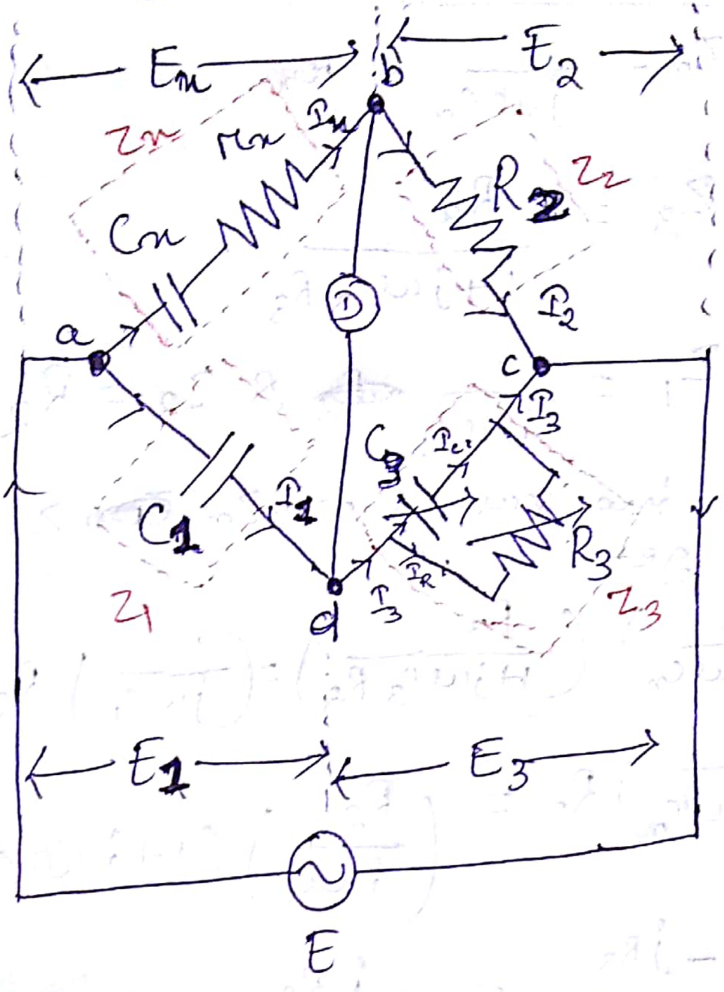
$$\Rightarrow \boxed{L_x = \frac{L_2 R_3}{R_4}} \text{ —— ⑪}$$

Thus, the unknown value of inductance & resistance can be measured by using above expression i.e eqn ① & ⑪ in terms of R_2, R_3, R_4 & L_2.

Measurement of capacitance by Schering Bridge method:-

→ This bridge is widely used for measurement of capacitance & dissipation factor.

→ Let us consider the ckt of Schering bridge as shown in figure below



Here C_x = unknown capacitance whose value is to be determined with series resistance r_x.

r_x = series resistance representing the loss in the capacitor 'C_1'.

C_1 = A standard capacitor

C_3 = A variable capacitor

R_2 = pure non-inductive resistor.

R_3 = variable non-inductive resistor.

in parallel with variable capacitor C_3.

Now the supply is given to ~~the bri~~ the bridge b/w the points 'a' & 'c'. The detector is connected b/w 'b' & 'd'.

Therefore at balanced condition

$$\boxed{Z_x Z_3 = Z_1 Z_2}$$

where $Z_x = \frac{1}{j\omega C_x} + r_x$

$$Z_3 = \frac{R_3}{1+j\omega C_3 R_3}$$

$$Z_1 = \frac{1}{j\omega C_1} \; \& \; Z_2 = R_2$$

substituting the values of Z_x, Z_1, Z_2 & Z_3, we get

$$\left(r_x + \frac{1}{j\omega C_x}\right)\left(\frac{R_3}{1+j\omega C_3 R_3}\right) = \left(\frac{1}{j\omega C_1}\right) R_2$$

$$\left(r_x + \frac{1}{j\omega C_x}\right) R_3 = \left(\frac{R_2}{j\omega C_1}\right)(1+j\omega C_3 R_3)$$

$$r_x R_3 - \frac{jR_3}{\omega C_x} = \frac{-jR_2}{\omega C_1} + \frac{R_2 R_3 C_3}{C_1}$$

Equating the real & imaginary parts, we get;

$$\boxed{r_x = \frac{R_2 C_3}{C_1}} \text{ — ①}$$

$$\boxed{C_x = C_1 \frac{R_3}{R_2}} \text{ — ⑪}$$

Dissipation factor:-

$$\boxed{\begin{aligned} D_1 &= \tan\delta = \omega C_x r_x \\ &= \omega\left(C_1 \frac{R_3}{R_2}\right) \times \left(\frac{R_2 C_3}{C_1}\right) = \omega C_3 R_3 \end{aligned}}$$

Digital Multimeter :

→ It is an instrument which measures a.c & d.c voltages, ac & d.c currents & resistances over a wide range.

Digital
↓
Indicates that the device has a digital or LCD output.

Multimeter
↓
Indicates that a single device can be used for multiple measurements.

(LCD : Liquid crystal Display)

Parts of Digital Multimeter :

① Display screen :- It has illuminated display screen for better visualization.

→ Five digits Display or Sign
- one for sign value
- four ~~one~~ for number representation

	0 to 9	0 to 9	0 to 9	0 to 9
$\bar{1}$	2	3	4	5

② Selection knob : multimeter is used for several voltage, current & resistance.

→ The selection knob allow the user to select the diff. measurement.

③ Port + ~~Two~~ Port

→ There are Two ports
(i) mAVΩ port
(ii) COM port.

→ One is mili-amp, volt & ohm to measure current, voltage & resistances & another is common port.

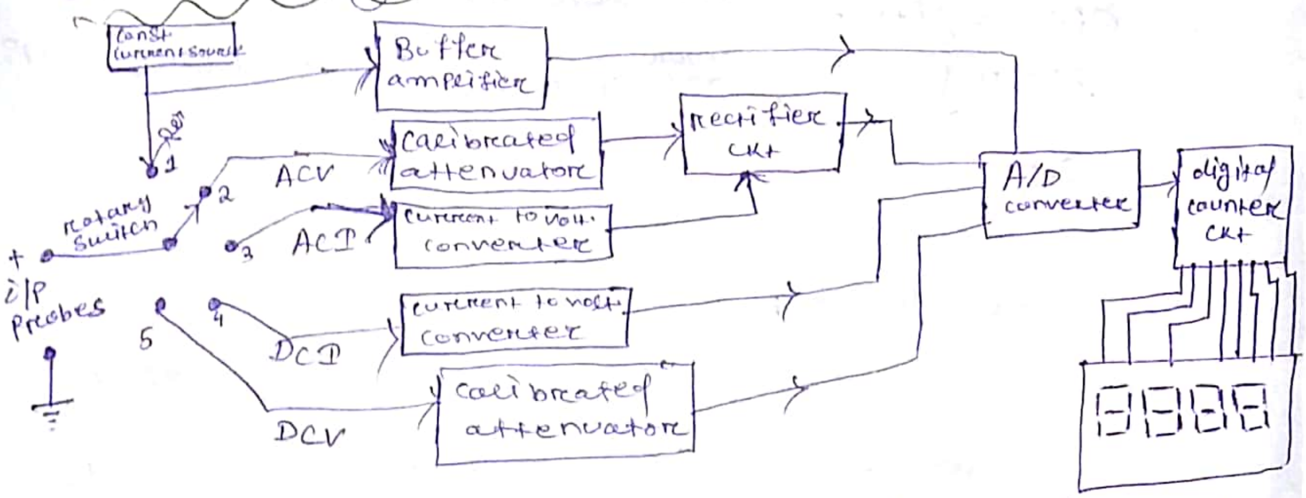
→ In multimeter there having two probes i.e one Red probe (+) & one Black probe (−)

→ Red probe is (+ve) & connected to mAVΩ port

→ Black probe is (−ve) & connected to common port.

→ In this multimeter a '10A' port also available & this ~~port~~ current port can measures large currents.

Block Diagram of Digital Multimeter



1. Resistance
2. ACV (AC voltage)
3. ACI (AC current)
4. DCI - (DC current)
5. DCV - (DC voltage)

→ The current is converted into voltage by passing it through low shunt resistance.

→ The AC quantities & converted into dc-quantities by employing various rectifier & filtering circuits.

→ The resistance measurements consists of a low current source that is applied across an unknown resistance.

Measurement of voltage:-

→ For measurement of A.C voltage, the i/p voltage is fed through a calibrated compensated alternator, to a precision full wave rectifier followed by a ripple reduction filter & then converted by A/D converter to show digital form of voltage on display.

Measurement of Current:-

→ For current measurement, the drop across an internal calibrated shunt is measured directly by the A/D converter in terms of "DC current mode" & after AC to DC conversion in the "ac current mode".

Measurement of Resistance:-

→ Digital multimeter measures the voltage across the externally connected resistance, resulting from a current forced through it from a calibrated current source.

$$V = IR$$

$$R = \frac{V}{I}$$

* Analog Multimeter:

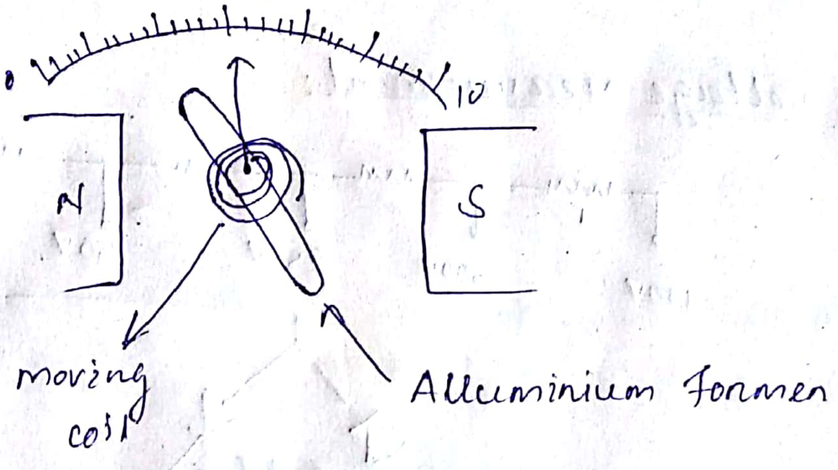
* Construction & working Principle:

→ It is an galvanometer of PMMC type.

→ It consists of a moving coil and a permanent magnet. The moving coil is wound on an alluminium former.

→ The pointer is attached on the moving coil and moves ~~in~~ due to influence of the magnetic field.

→ The pointer is calibrated over the scale



→ Two spiral springs are attached to the coil assembly (at the top and bottom) to provide controlling torque.

→ Galvanometer is converted into a voltmeter, ammeter & ohmmeter with the help of suitable ckts for measuring voltage, current and resistance

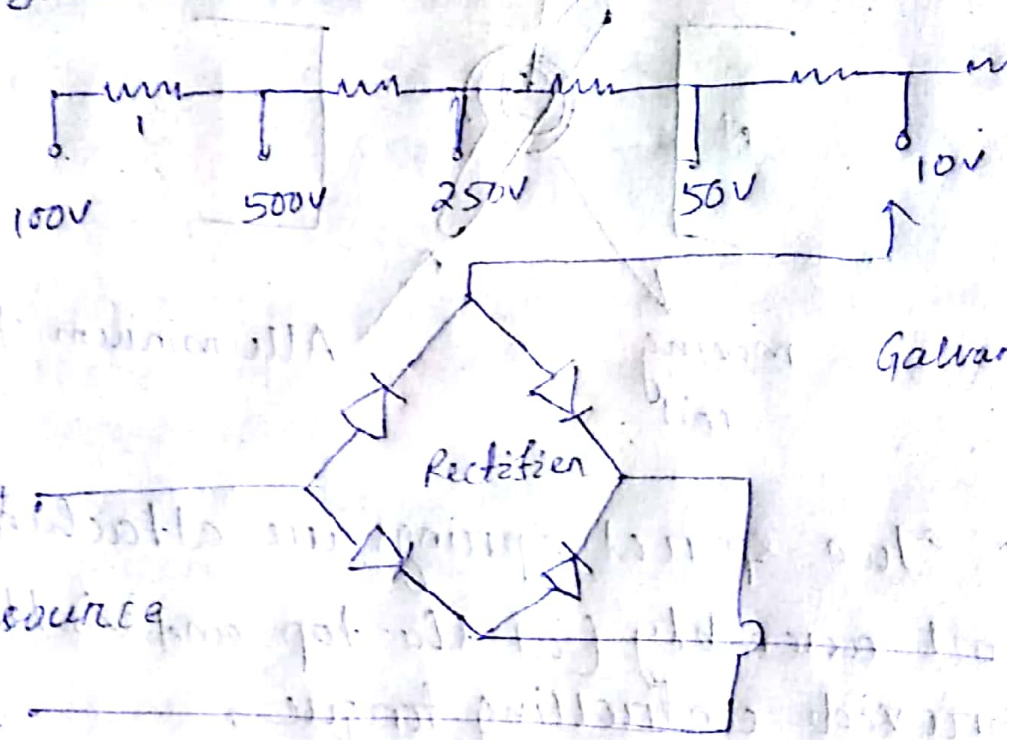
* Voltage measurement by multimeter:

↳ high voltages are measured by connecting resistance in series with galvanometer.

* Multimeter having two lead Red (+ve)
Black (-ve)

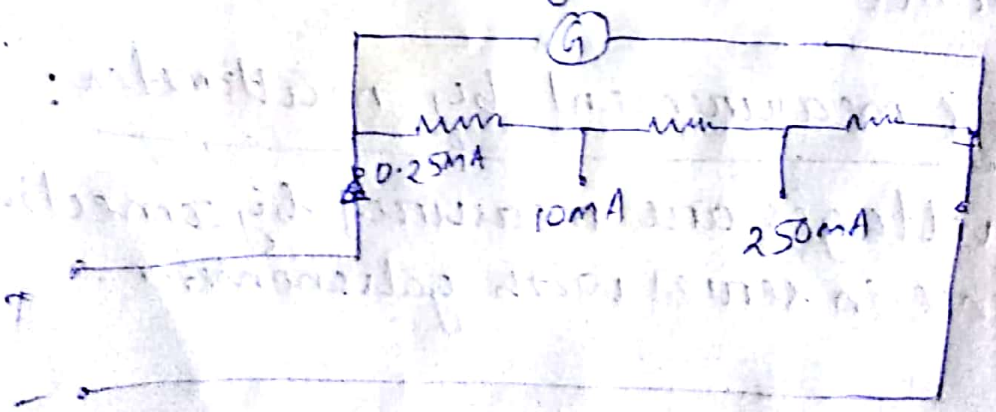
* One lead is connected in voltage range socket
other lead → common socket

AC voltage Measurement:



→ An rectifier is connected during the m
ment of AC voltage source

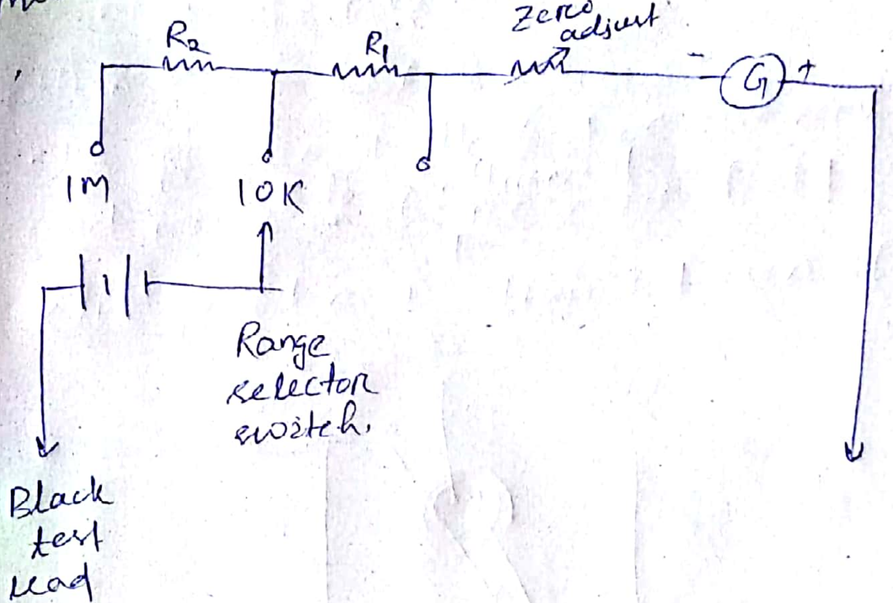
* Current measurement by Multimeter



→ As the value of the current to be measured is increasing the shunt resistance value should be decreased.

• Resistance Measurement by Multimeter:

→ Here the Galvanometer is converted as an ohm meter.



→ Here to measure the resistance value we have to make the voltage and current to be constant

→ The zero adjustment control is valid untill the meter reads zero resistance.

÷ OSCILLOSCOPE :-

→ Oscilloscopes are commonly used to measure shape of a waveform, measure amplitude & frequency of a signal & detect error & noise in a signal.

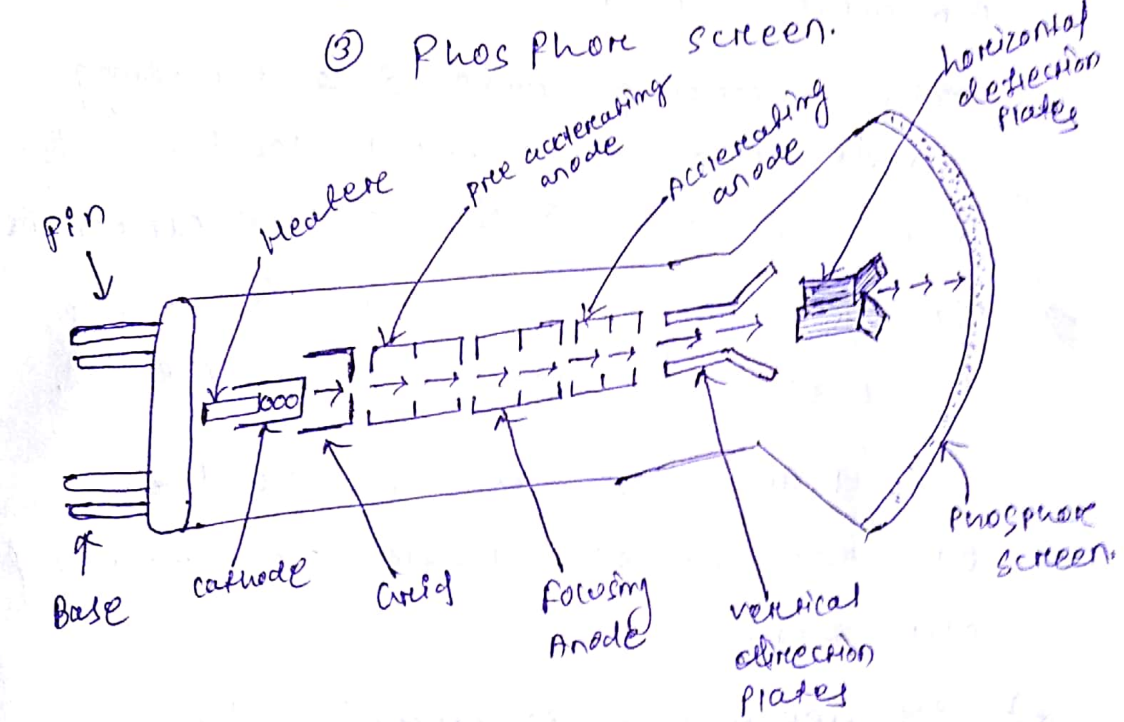
Cathode Ray Tube :-

→ CRT is one of the main parts of CRO

→ The entire CRT is enclosed in an evacuated glass envelope.

→ It consist of 3-main sections

(1) Electron gun Assembly
(2) Deflection plates
(3) Phosphor screen.



→ Electron gun assembly consist of a heater, cathode, Grid, preaccelerating & accelerating anodes, focusing anodes.

→ Cathode is indirectly heated by heater to emitt electrons

→ These electrons then pass through the Grid.

→ The Grid has a centrally located hole co-axial with the axis of tube.

→ The grid focous the emitted electrons produced by the cathode towareds anode.

→ The grid's potential is -ve w.r.t cathode.

→ Then the emitted electrons pass through the accierating anodes.

→ The preaccierating anode is a hollow cylindrical shape & it's potential is more +ve w.r.t cathode.

→ The preaccierating anode has an electric fied to accierate the electrons to a particular direction.

→ The focousing anode & accierating anode provide partical speed to the electrons & focous the electrons.

→ In CRT two verctical direction plates are used also ~~~~ known as Y-plates.

→ The vertical plates moves the electrons either upward or downward direction.

→ If upper plate is more '+ve' as compare to lower plate then electron beam moves upper direction & vice-versa.

→ CRT consists of another two plates known as horizontal plates also known as X-plates.

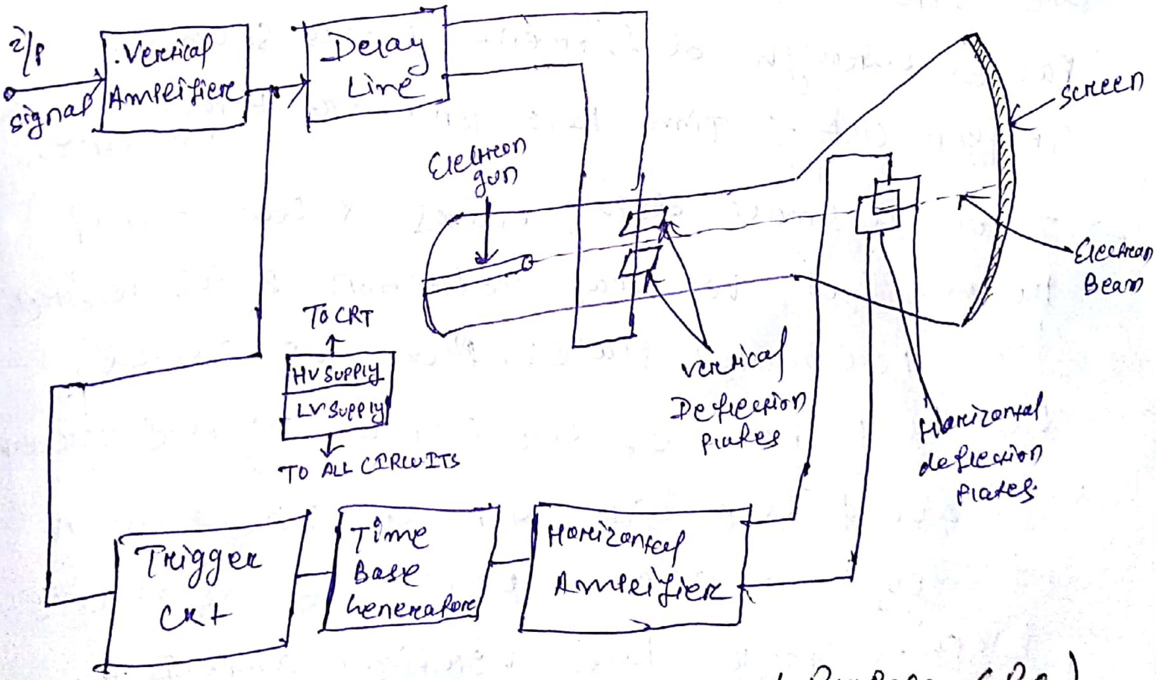
→ The horizontal plates moves the electrons towards right or left side.

→ If backward plate is more '+ve' as compared to lower plate then the electron beam moves towards right direction & vice versa.

→ At the end a phosphore screen is placed. In this way the electron beams strike on the phosphore screen & produce a picture.

→ Phosphore is one type of substance which emits the lights & produce particular colour. The lights produce on the screen are in dotted form.

Principle of Operation of Oscilloscope



[Block diagram of general purpose CRO)

→ CRO widely used ~~a~~ measuring instrument in college laboratories & also well as in industries.

→ It is made of diff. blocks such as: ⓐ Vertical Amplifier, ⓑ Delay Line, ⓒ Trigger ckt, ⓓ Time Base generator, ⓔ Horizontal Amplifier, ⓕ Cathode Ray Tube (CRT) ⓖ Power supply

ⓐ Vertical Amplifier :- ~~The i/p~~

→ It is the 1st block of CRO. The i/p signal to be displayed on screen of the CRO is applied to the vertical amplifier.

→ This amplifier amplifies the weak signal that they produce measurable deflection on the screen

→ It decides the sensitivity & bandwidth of CRO.

→ It o/p is given as i/p to delay line block.

ⓑ Delay line :-

→ The i/p signal is applied to the horizontal as well as vertical deflection plates, but before reaching the horizontal deflection plates the signal passes through different blocks such as:

Trigger ckt → Time base generator → Horizontal amplifier.

→ Thus a small delay occurs & the signal reaches the vertical deflection plates before the horizontal plates, But this causes the distortion of the signal on the screen.

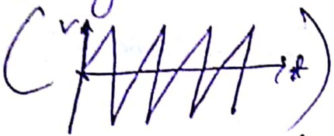
→ To avoid the situation a small amount of delay is added using the delay line block after the vertical amplifier.

ⓒ Trigger ckt -

→ This ckt generates trigger pulses, which keeps the synchronization b/w the i/p signal & the horizontal deflection ckt.

ⓓ Time Base Generator -

→ It generates Sawtooth waveforms &



& applies it b/w the horizontal deflection plates.

→ As the Sawtooth wave varies linearly with time the movement of the spot on the screen takes place at a constant velocity, hence x-axis of the CRO is calibrated in terms of time & i/p can be displayed w.r.t time.

ⓔ Horizontal Amplifier -

→ The ~~sawtooth~~ strength of sawtooth signal is available at the o/p of a Time based generator is not sufficient, thus before applying it to horizontal plates the signal is amplified using a horizontal amplifier.

ⓖ Power Supply -

→ The power supply section of CRO generates two levels of DC voltage..

→ Low voltage used for working of electronic circuits & high voltage used as Anode for CRT

→ The high voltage generated is of the order of 1000 to 1500 volts.

Measurement of voltage, current & frequency by oscilloscope

① Voltage measurement :-

→ The oscilloscope is mainly voltage oriented device or it's a voltage measuring device

→ The simplest way to measure signal is to set the trigger button to auto i.e.- oscilloscope start to measure the voltage signal by identifying the zero voltage point or peak voltage by itself.

→ As any of these two points identified the oscilloscope triggers & measures the range of the voltage signal.

→ vertical & horizontal controls are adjusted so that the displayed image of the sine wave is clear & stable.

→ Now voltage can be measured along the centre vertical line which has the smallest divisions.

→ Reading of the voltage signal is will ~~give~~ be given by vertical control.

② Current measurement

→ Electrical current can't be measured directly by an oscilloscope. However it could be measured indirectly ~~oscilloscope~~ by attaching probes or resistors.

→ Resistor measures the voltage voltage across the points & then substituting the value of voltage & resistance in ohm's law & calculates the value of electric current.

→ To measure current first attach a probe with the resistor to an electrical circuit.

→ Make sure that resistor's power rating ~~sou~~ should be equal or greater than the power o/p of the system

→ Now take the value of resistance & plug into ohm's law to calculate the current.

→ Accⁿ to ohm's law

$$\text{current (I)} = \frac{\text{Voltage (V)}}{\text{Resistance (R)}}$$

③ Method to measure frequency

→ Frequency can be measured on an oscilloscope by investigating the frequency spectrum of a signal on the screen & making small calculation.

→ The maximum frequency of an oscilloscope can measure may vary but it always in the 100's of MegaHz. range.

→ To check the performance of response of signals in a ckt, oscilloscope measures the rise & fall of the wave.

TRANSDUCERS:

In general form, Transducer may be defined as a device, which converts energy from one form to another.

However according to electrical instrumentation, transducer may be defined as a "device which converts a physical quantity or a physical condition into an electrical signal".

Advantages of electrical transducer:-

(1) Electrical amplification and attenuation can be done easily.

(2). The mass-inertia effect are minimized. In fact, when dealing with electrical or electronic signal, the inertia effects are due to electrons which have negligible mass.

(3). The effect of friction are minimized.

(4). The electrical and electronic system can be controlled with a very small power level.

(5) The electrical output can be easily used

(6) It can be used in telemetry.
~~In short~~

Thus Telemetry is used in almost all sophisticated measurement system.

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The entire aerospace research and development is based upon telemetry and remote control.

(viii).

In short, it can be said that the transforming a physical phenomenon into electrical form can be easily used, transmitted and processed for the purpose of measurement.

The transducer consist of two important part: These two part are:-

(1). Sensing element.

(2.) Transduction element.

(1) Sensing element or Detector element:

A detector or a sensing element is that part of a transducer, which respond to a physical phenomenon or a change in physical phenomenon.

(2) Transduction element:

A transduction element transform the output of sensing element to an electrical output.

Classification of transducers:

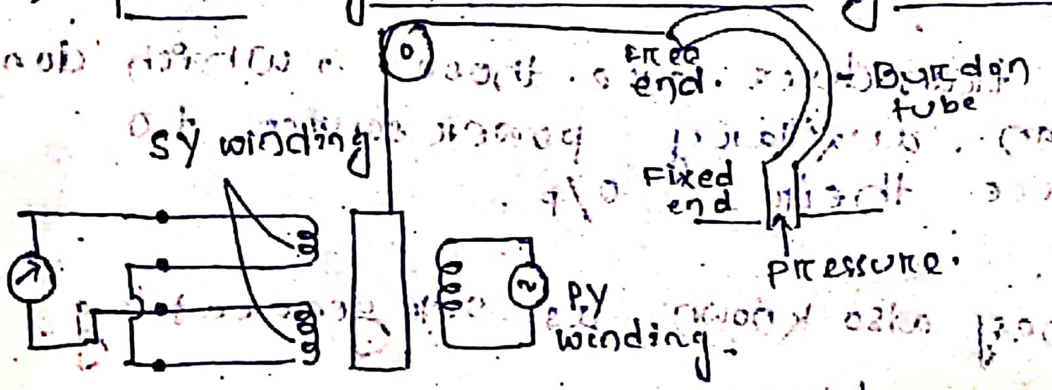
(a) The transducer ~~m~~ can be classified as

(1) on the basis of transduction from used.
(2) as primary and secondary transducers.
(3) as positive and active transducer.
(4) as analog and digital transducer.
(5) as transducers and Inverse transducers.

(1) on the basis of principle of transduction transducers may be (1) Resistive transducer
(2) Inductive transducer
(3) capacitive transducer

Depending upon how they convert the i/p quality into resistance, Inductance and capacitance they can be classified as pte piezo electric, thermoelectric, magneto-restrictive, electro-kinetic and optical.

(2). primary and secondary transformer:



The ~~burd~~ bourdon tube ~~acting~~ a the senses the pressure and converts the pressure into a displacement of its free end. then the displacement of the free end moves the core of a linear variable differential transformer (LVDT), which produce an o/p

Thus there are 2 stages of induction, the 'P' is converted into displacement by Bourdon tube. then the displacement is converted into an analogous voltage by LVDT.

The Burdon tube is called primary transducer, while the L.V.D-T is called a secondary transducer.

(3) passive and active transducers:

Passive transducers derive the power required ~~fro~~ for transduction from an auxillary power source.

They also known as externally powered transducers.

ex:- resistive transducer, inductive transducer, and capacitive transducer.

Active transducer are those, which don't require an auxillary power source to produce their o/p.

They also known as self generating type transducer.

ex:- "accelerometer" ~~is~~ a transdu

accelerometer transducers converts acceleration into electrical 'v' does n't need any auxillary power source to convert a physical phenomenon into electrical o/p.

[4] Analog and digital transducer:

The transducers can be classified on the basis of the o/p which may be a continuous function of time or the output may be discrete ~~type~~ steps.

1. Analog transducer

These transducers convert the i/p quantity into an analog o/p which is a continuous function of time.

ex:- A straingauge, LVDT, thermocouple, are analog transducer.

2. Digital transducer:

These transducers convert the i/p quantity into an electrical o/p which is in the form of pulses. / coded digital signals and its output is represented by 0 and 1

example: digital techometer.

[5] Transducer and Inverse transducer:

Transducer:

A transducer can be defined as a device which converts a non electrical quantity into an electrical quantity.

2. Inverse transducer:

A inverse transducer is defined as a device, which converts a electrical quantity into a non-electrical quantity.

ex:- A 'I' carrying coil moving in a magnetic field is a inverse transducer, because 'I' carried by it is converted into a force which cause rotational displacement.

Resistive transducer:

Thermistors: (thermistor is a type of resistor whose resistance is dependent on tempreture)

Thermistor is a contraction of a term thermal resistor. (short form)

Thermistors is generally
1: composed of semi-conductor material.

2: Although +ve temp. co-efficient of unit are available, most thermistor have -ve temp. co-efficient. i.e resistance decreases with increase in tempreture.

- Thermistor is high sensitivity to tempreture change.

Thermistor is widely used in the applications which involves measurement in the range of -60 - 15°C.

Resistance of thermistor ranges from 0.5Ω -0.75Ω.

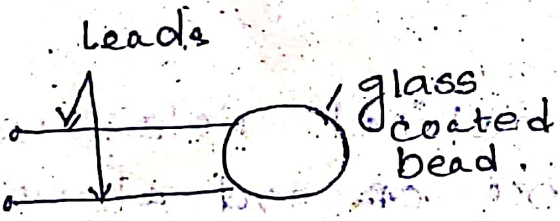
- Thermistor Is highly sensitive device.

- Thermistor exibits a highly non linear characteristics of resistance v's temp.

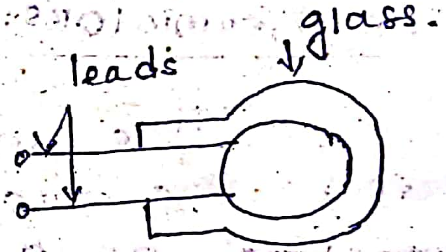
Construction:

Thermistors are composed of mixture of metallic, oxides such as manganese, nickel, cobalt, copper, iron and uranium.
They are available in variety or shapes and sizes..

- Thermistors may be in the form of beads, rods, and discs.

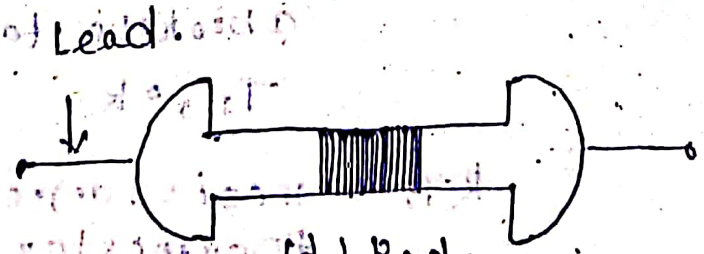


Bead



probe.

Disc.



(d) Rod.

A thermistor in the form of a bead is smallest in size and bead may have a diameter of 0.015 mm to 1.25 mm.

- Beads may be sealed in the tips of solid glass rods to form probes which may be easier to mount than the beads. glass probe have a diameter of about 2.5 mm and length varies from 6 mm — 50 mm.

- Disc are made by pressing material under high pressure into cylindrical flat shape ~~under high pressure~~ with diameter from 2.5 mm — 25 mm.

Resistance - tempreture characteristics of thermistors:

The mathematical relationship between the resistance and absolute tempreture of a thermistor is,

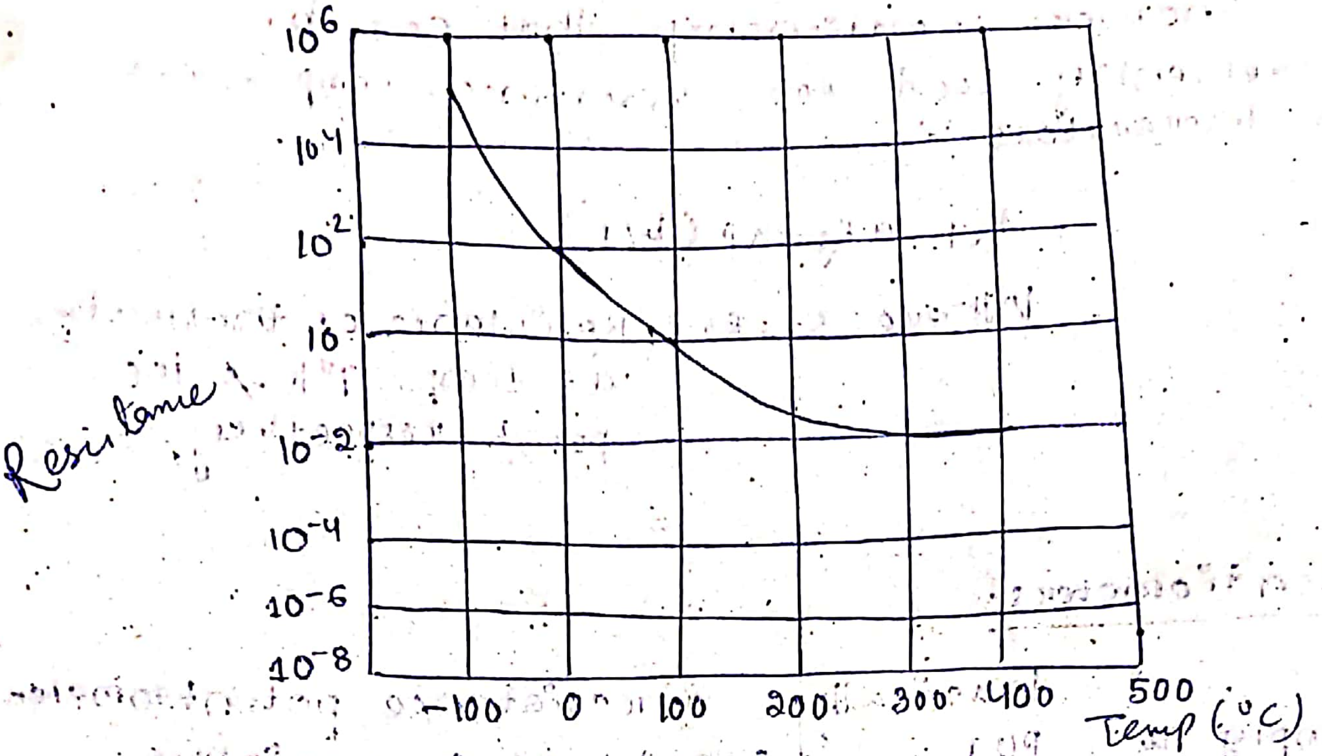
is the temp. of an object on a scale where 0 is taken as absolute.

$$R_{T1} = R_{T2} \exp\left[\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)\right]$$

Where, R_{T1} - resistance of the thermistor at absolute tempreature T_1, °k.

R_{T2} - resistance of the thermistor at absolute tempreture T_2, °k.

β - a constant depending upon the material of thermistor, typicall



[Resistance temprature characteristics of a typical thermistor.]

Figure 4 shows that, a thermistor has a very high negative temprature co-efficient of resistance.

- The ~~char~~ resistance temprature characteristics of a thermistor is ~~not~~ non linear but a linear approximation of the ~~temp.~~ resistance- temp. curve can be obtained over a small range of temp.

Thus for a limited range of temprature, the resistance of a thermister varies as,

$$R_\theta = R_{\theta_0}(1+\alpha_{\theta_0}\Delta\theta)$$

A thermistor exhibits a -ve resistance temp. co-efficient which is typically about 0.05%/°C.

er relationship that can be
ly used for resistance - temp. curve
stors is,

$$R_T = a R_0 \exp(b/T)$$

Where R_T, R_0 = Resistance of thermistor at temp. T°K & ice point respectively.

Platinum resistance thermometer:

The resistance of a conductor changes when its tempreture changed. This property is utilized for the measurement of tempreture.

The variation of resistance R with tempreture T(°K) can be represented by following relationship for most of the metals as,

$$R = R_0(1 + \alpha_1 T + \alpha_2 T^2 + --- + \alpha_n T^n + --)$$

Where, R_0 = resistance at temp. @ $T = 0$
and $\alpha_1, \alpha_2, \alpha_3 -- \alpha_n$ = are constants.

Platinum is especially suited for this purpose, as it can withstand high tempreture.

Resistance thermometers are also called resistance tempreture detectors (RTDs)

The requirements of conductor material to be used in RTD are:-

(i) The change in resistance of material per unit change in tempreture should be as large as possible.

(ii) The material should have high value of resistivity so that minimum volume of material is used for the constructing of RTD.

(iii) The resistance of material should have a stable relationship with temp.

- Gold and silver rarely used for constructing of RTDs on account of their low resistivities.

- Tungsten has relatively high resistivity, but it is reserved for high temprature. & it is difficult to work.

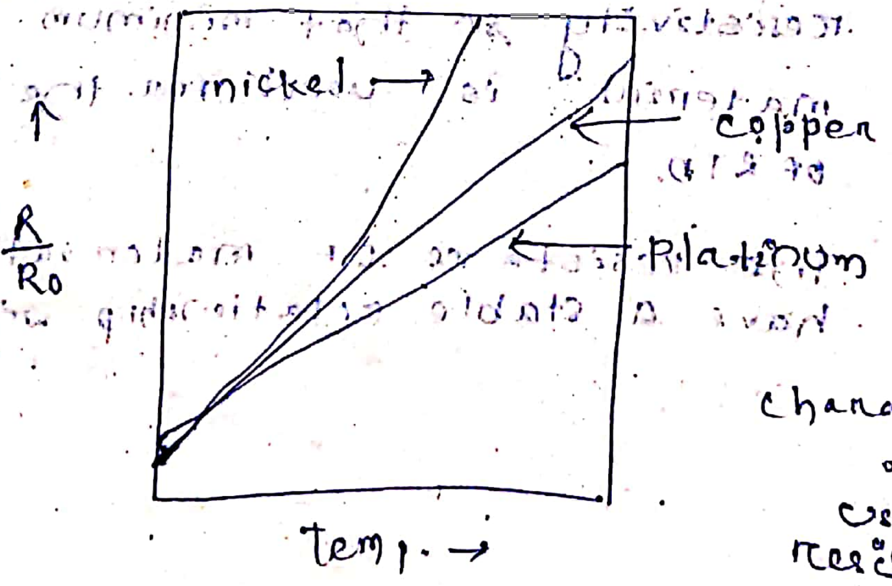
- copper is used occasionally as RTD element.

- The most common RTDs are made of either platinum, nickel or nickel alloys. nickel weres are used over a limited temprature range.

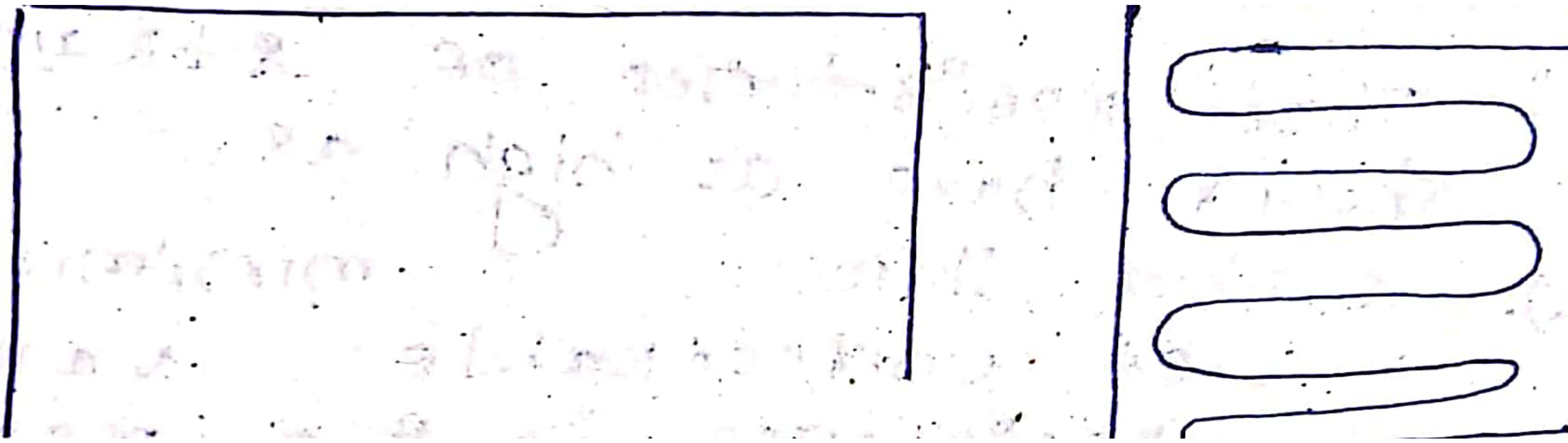
- The common values of resistance for a platinum RTD range from 10 Ω to several thousand ohm.

- The single most common value is 100 Ω at 0°C with a resistance temp. co-efficient of 0.00385/°c

- The more chemically platinum were has a resistance temp. co-efficient of 0.00392/°C.



Characteristics of material used for resistance thermometer



Constructional Features of bonded strain gauge:

1. It consist of a grid of fine resistance wire of about 0.025 mm in diameter or less.

2. The grid is cemented to carrier (base) which may be a thin sheet of paper.

3. The wire is covered with a thin sheet of material in order to protect from mechanical damage.

4. The spreading of the wires permits a uniform distribution of stress.

5. The carrier is bonded with an adheshive material structure, so that it permits a good transfer of strain from carrier to wires.

6. For excellent results, ~~the~~ the bonded strain gauge should have following properties,

(i) It should have high value of gauge factor. (GF)

(ii) The resistance of strain gauge should have as high as possible.

(iii) (since this minimices the effects of undesirable variations of resistance in the measurement ckt.)

(iii) The strain gauge should have a low resistance temp. co-efficient.

(This is essential to minimize error on account of temp. variation, which effect the accuracy of measurement)

15 UNBONDED STRAIN GAUGE

An unbonded strain gauge is consist of a wire streched between 2 points in an insulating medium such as air.

The diameter of the wire is about 25 eem and can be strained depending on the w

The wire may be made of various copper. nickel, chrome nickel or nickel iron alloys.

They are about 0.003 mm in diameter, have a gauge factor of 2-4 and sustain a force 2mN. The length of the wire is 25 mm or less.

The spring element is connected via a rod to diaphragm., the spring which is used for pressure measurement.

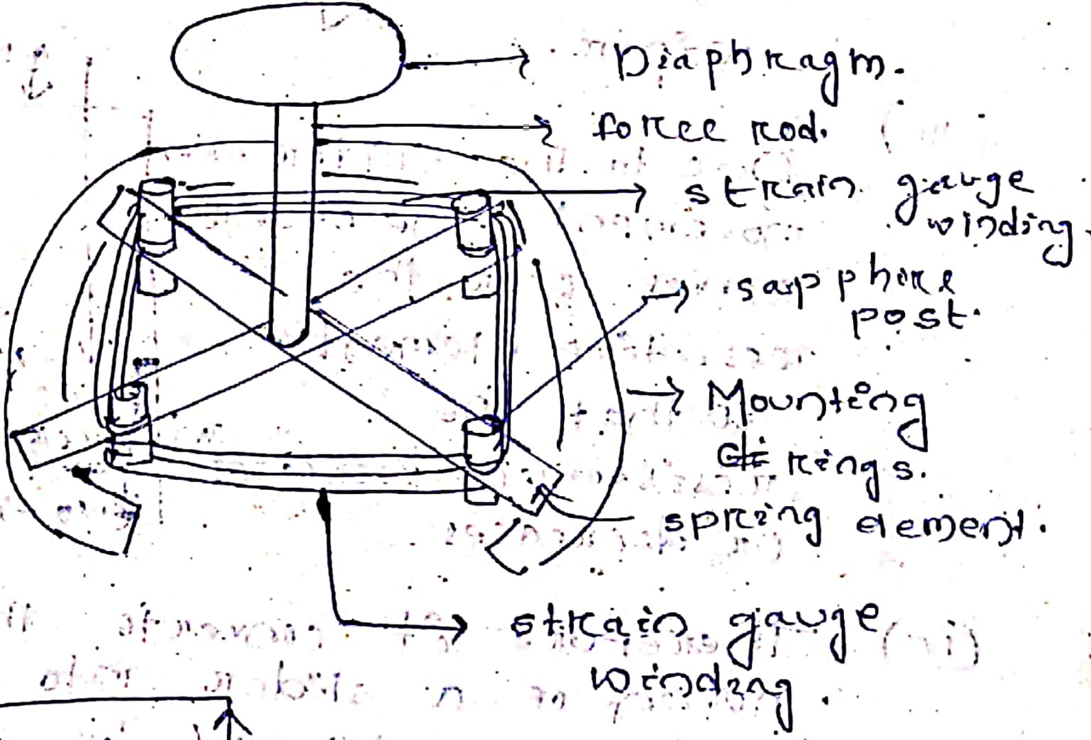
* The unbonded metal wire gauges, used almost exclusively in transducer application, employ preloaded resistance wires connected in a wheatstone bridge, *

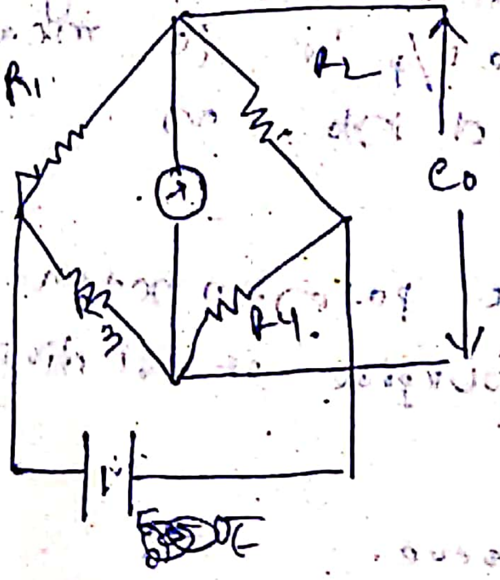
(At initial, the strain & resistance of 4 arms are normally equal ,) with the result the o/p 'v' of the bridge, $e_0 = 0$.

Bj when 'p' is applied, there is a small displacement which is about 0.004mm, the displacement increases tension in 2 wires and decreases it in the other 2.

thereby increasing the resistance in 2 wires which are in tension and decreasing the resistance in the other two.

This causes an unbalance of the bridge producing an o/p 'V'.



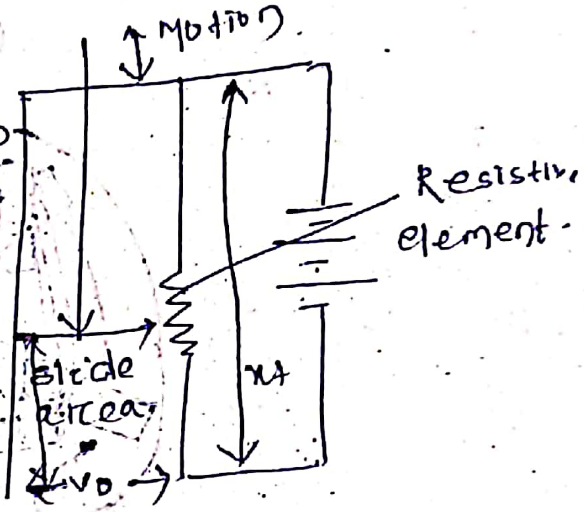


17 Potentiometers: (POT).

(i) It is a passive transducer, so it requires an external power source for it operation.

(ii) POT consist of a resistive element provided with sliding contact. This sliding contact is called wiper.

(iii) Due to the slider arm movement, the slider moves over the resistive element, so that the resistance increases or decreases.



(iv) Therefore it converts the linear motion of a slider into changes in measure resistance, and the o/p 'V' is directly or fed into an amplifier.

(v) Thus, a resistance potentiometer is used for the purpose of 'V' division.

Advantages:—

(1) They are inexpensive.

(2) simple to operate.

(3) very useful for measurement of large amplitude.

(4) electrical efficiency is very high.

12. Disadvantages:

(1) They require a large force to move their sliding contacts.

(2). sliding contact may be contaminated, can wear out, & generate noit.

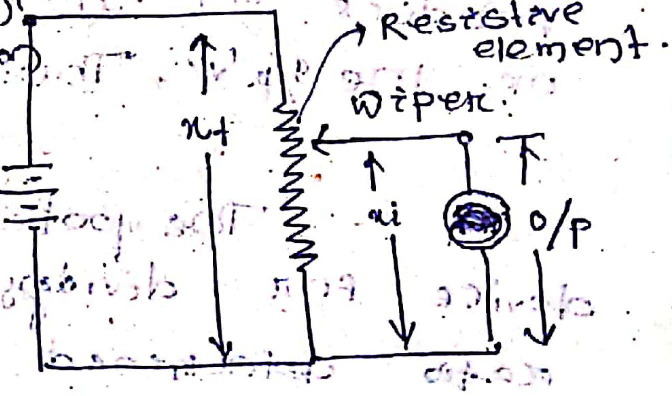
Let,

e_i = input vol~~ta~~tage

e_0 = o/p voltage.

x_t = Total displacement of translatory pot

x_i = Displacement of wiper from its zero position.



R_p = total resistance of potentiometer.

The o/p (v.) ~~under of~~

$$e_0 = \left(\frac{\text{Resistance at o/p terminals}}{\text{Resistance at i/p terminals}}\right) \times \text{i/p (v)}$$

$$= \left[\frac{\left(\frac{R_p}{x_t}\right)\left(\frac{x_i}{\cancel{x_t}}\right)}{R_p}\right] \times e_i$$

$$= \frac{x_i}{x_t} \times e_i$$

Thus o/p 'v' varies linearly with displacement.

Let θi = I/p angular displacement in degree

θt = total travel of wiper in degree

$$o/p\ 'v' = e_o = e_i(\theta i/\theta t)$$

Thus the ckt are called potentiometer dividers since they produce an o/p 'v' which is a fraction of the I/p 'v'. Thus I/p 'v' is devided.

The potential devider is a device for dividing the potential in a ratio determined by the position of sliding contact.

→ The linear variable differential transformer i
la inductive transducer.

→ The "LVDT" use to measure linear motion into an electrical signal

→ construction

→ It consist of one primary winding (P) and two secondary winding S_1 and S_2.

→ A ferromagnetic core of cylindrical shape as attached to the transducer sensing shaft.

→ The sy winding have equal number of turns and are identically placed on another ~~either~~ side of the py winding.
The py winding is connected to an alternating current source.

→ * The core is made of high permeability.

→ The magnetic core is free to move inside the coil and motion being measured ~~and each mechanically~~

→ The 2 secondary S_1 & S_2 have equal no of turns but they are connected in series opposition to that emfs (E_1 & E_2)

→ The primary is energised from a suitable A.c ~~su~~ source.

2) Working:

when the core is in the centre, the induced voltages E1 & E2 are equal and opposite. so, $E1 = E2 \Rightarrow Vo = 0$.

- when the external force applied ~~moved~~, the & when core moved towards the coil S1, E1 increased but E2 decreased in magnitude. so

  $Vo = Es1 - Es2$ and the net 'V' in inphase with ~~pry~~. S1

- similarly when the magnetic core moves towards coil S2, $E2 > E1$. $Vo = Es2 - Es1$ and is in 180° out of ~~E2~~ phase of pry. S1

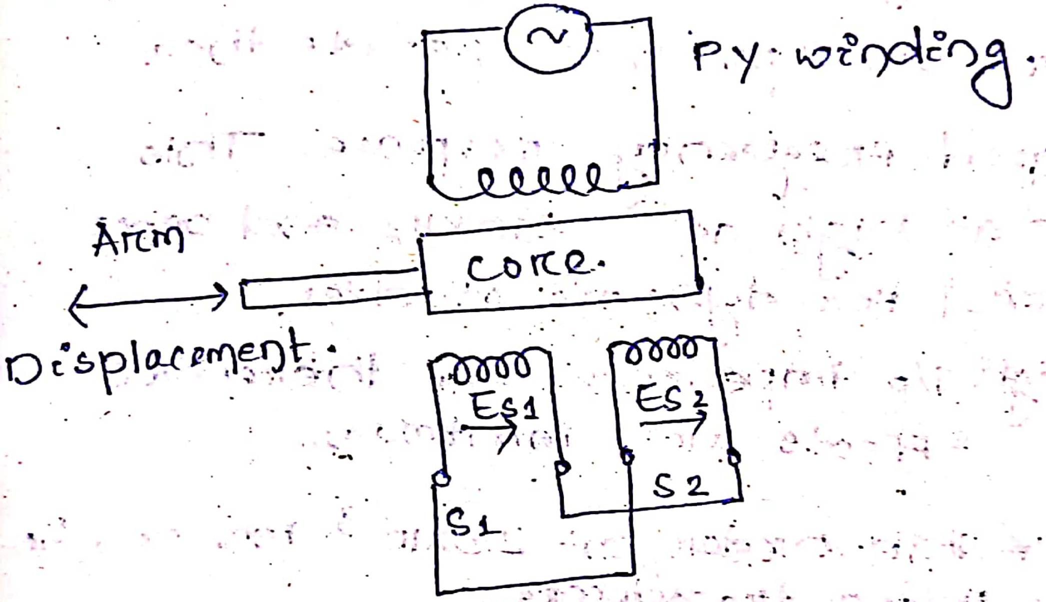
Conclusion :- Thus we find that the magnitude of o/p 'v' is a function of the distance moved by the core & its phase indicates in which direction it has moved.

uses :-

1. LVDT can be used in all application where displacement ranging from ~~few mm~~ fraction of a mm to few cm.
2. Act as a secondary transducer. It can be used as a device to measure force, weight, & pressure etc.

22 → force - load cell
→ Fluid pressure - Bourdon tube.

- use to measurement & control of thickness of a metal sheet.



23. Capacitive transducer:

The principle of operation of capacitive transducers is based on the equation

$$C = \frac{A\varepsilon}{d}$$

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d}$$

Where; A = Overlapping area of plates, m^2
d = distance between 2 plates, m
$\varepsilon = \varepsilon_r \varepsilon_0$ = permittivity of medium, F/m.
ε_r - relative permittivity.
ε_0 = Permittivity of freespace.
= 8.85 × 10^{-12} F/m.

The capacitive transducer works on the principle of change of capacitance which may be caused by;

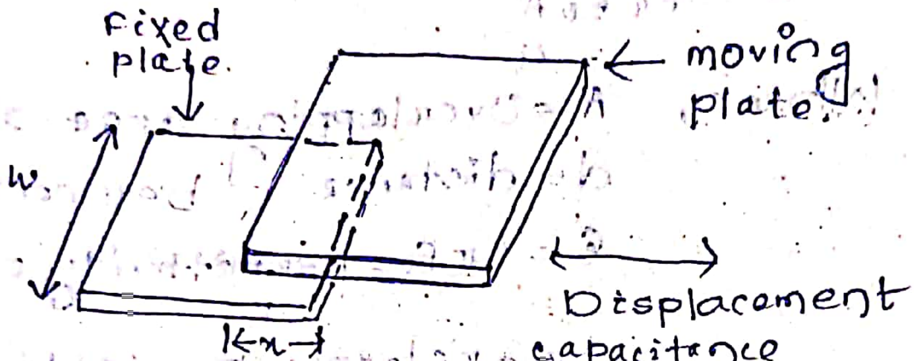
(1) change in overlapping area A,
(2) change in distance 'd' between the plates.
(3). Change in dielectric constant.

Transducer using change in Area of plates (variable area capacitive transducer)

The principle of operation of capacitive transducer is based on the equation of parallel plate capacitor,

$$C = \frac{A\varepsilon}{d}.$$

Where A = overlapping area.
d = distance between 2 plates.
ε = permittivity.



[capacitive transducers working on the principle of change of capacitance with change in Area] → capacitance increases. ← decreases.

If the moving plate is moved right ward then overlapping area will increase such that capacitance will increase and vice

If the moving plate is moved ~~left~~ towards left, the overlapping area will decrease such that capacitance is decrease.

Transducer using change in distance between 2 plates:

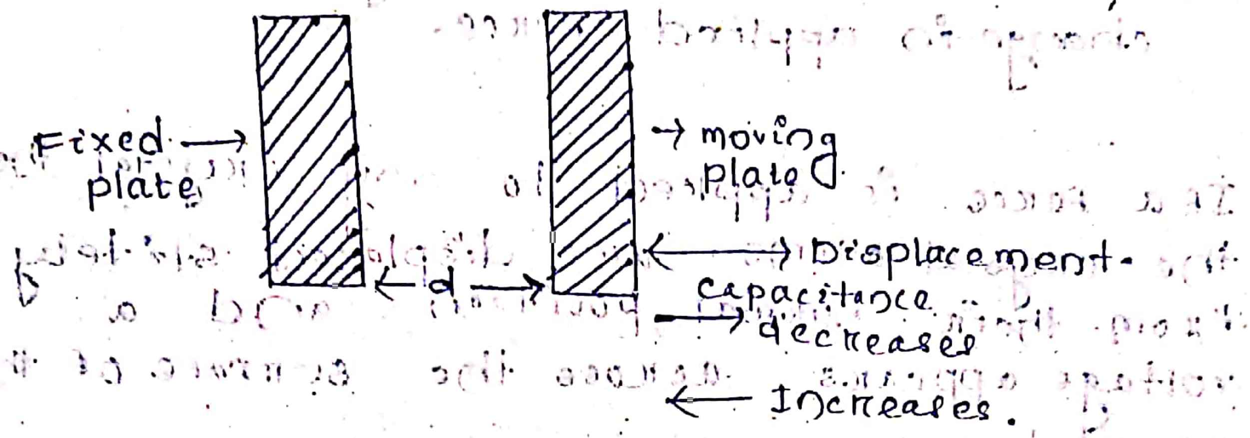
The principle of operation of ~~parcatell~~ ~~parcattel~~ capacitive transducer based on the equation,

$$c = \frac{A\epsilon}{d}.$$

Where, A = overlapping area betn the plate.

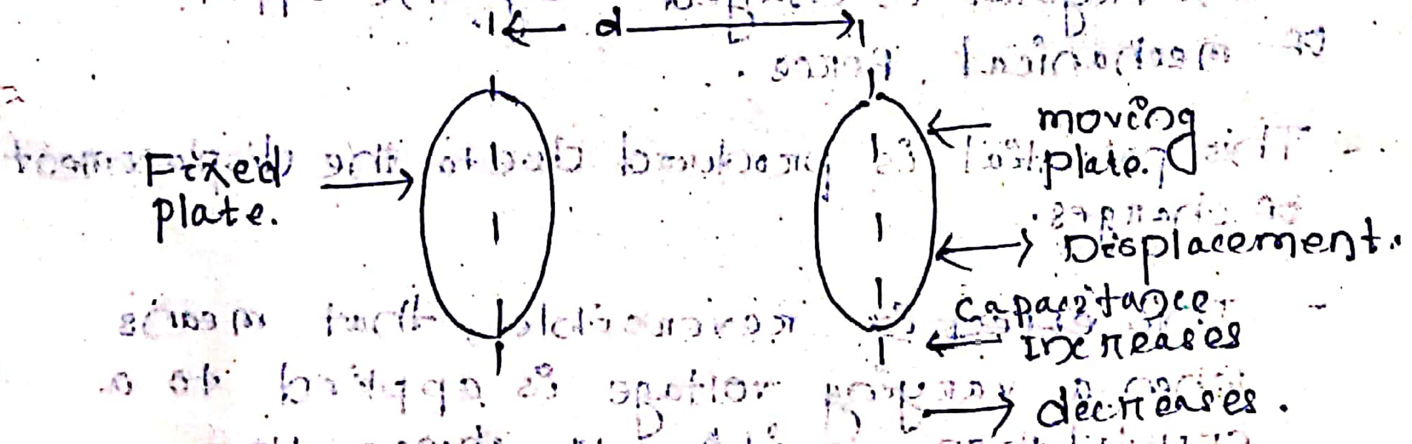
d = distance between the plate

ε = dielectric strength.



If the moving plate is moves towards the right direction, distance increases, Since distance is inverse proportional to capacitance, so
so capacitance decreases.

If the moving plate is moves towards the left, distance between 2 plate decrease.
so capacitance increases.



~~capacitance~~

[capacitive transducer using the principle of change of capacitance with change of distance between plates.]

2.6 Advantages of capacitive transducer:-

(i) They require extremely small force to operate them and hence are very useful for use in small system.

(ii) They are extremely sensitive.

(iii). They require small power to operate them.

(iv) They have good frequency response. This response is as high as 50 KHz and hence they are useful for dynamic studies.

(v) They have a high i/p impedance and therefore loading effects are minimum.

(vi) A resolution of the order of 2.5×10^{-3} mm can be obtained with these transducers.

(vii) The capacitive transducers can be used for applications where stray magnetic fields render the inductive transducers useless.

Disadvantages:-

(i) The metallic parts of the capacitive transducer must be insulated from each other.

(ii) It shows non-linear behaviour many times.

(iii) The o/p impedance of capacitive transducers tends to be high due to small capacitance value.

* Piezo-electric means change due to applied force.

Principle:

A piezoelectric material is one in which an electric potential appears across certain surface of a crystal, if the dimension of the crystal is changed by the application of mechanical force.

- This potential is produced due to the displacemen of charges.
- This effect is reversible, that means when a varying voltage is applied to a crystal then it will change the dimension of the crystal.

This effect is known as piezoelectric effect.

Example of piezoelectric material are :-

Quartz, Lithium sulphate, dipotassium tetrate, potassium dihydrogen phospate, Rochelle salt, and ceramics.

Optoelectronic transducers:

Optoelectronic transducer operates on the principle that, it produces an electrical output response to the light input.

Application:-

~~These are use~~

It is used in.

(1) satellite use in space research;

(2) solar batteries as sources of electric power for rocket

(3) photographic exposure meter.

(4). for counting packeges moving on a conveyor belt.

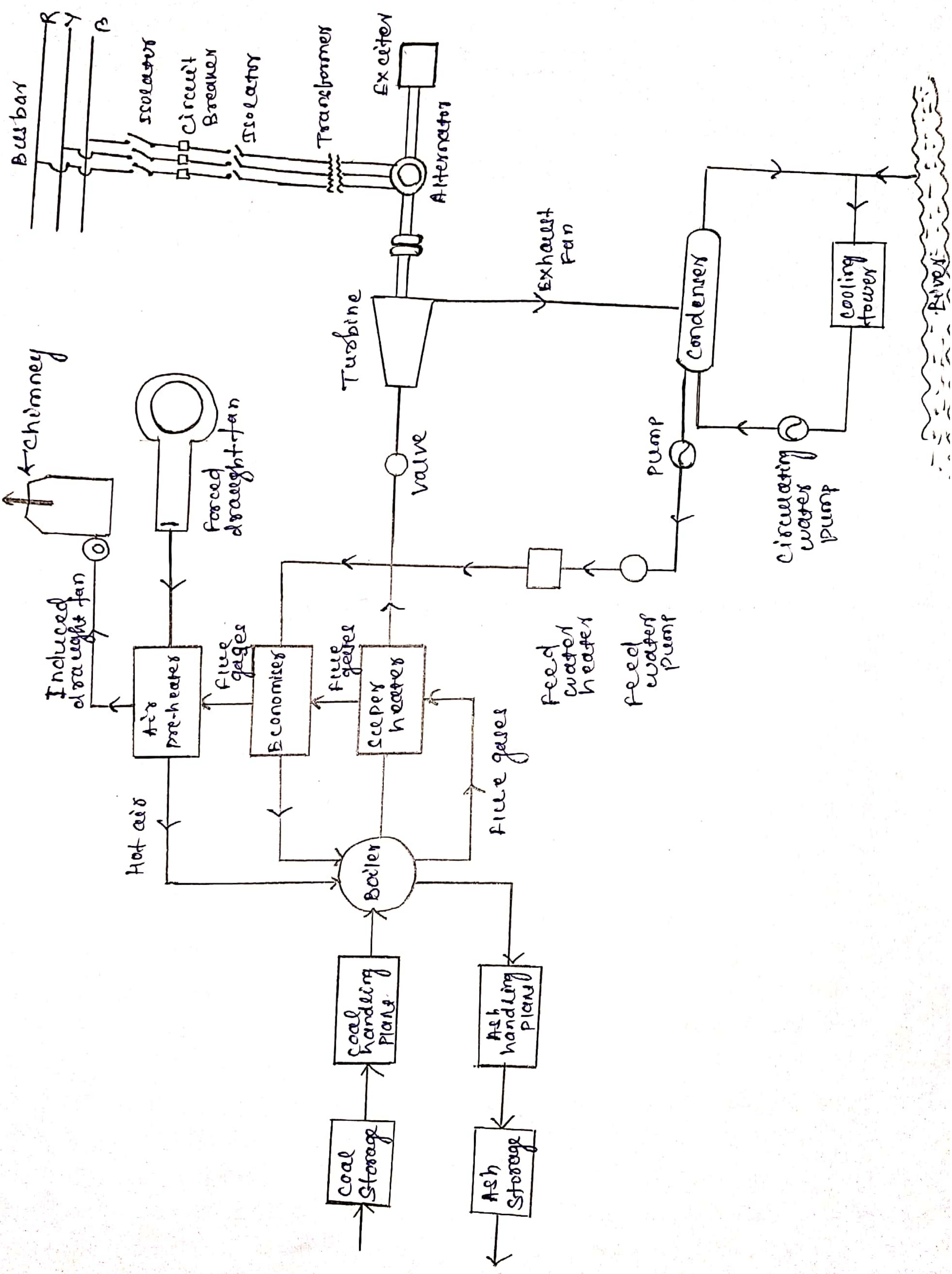
Lecture notes on

Generation Transmission & Distribution

4th sem

Electrical Engg.

Steam power station / Thermal power station



Thermal Power Plant

In thermal power plant, the whole arrangement can be divided into the following stages for the sake of simplicity.

① coal and ash handling arrangement
② steam generating plant
③ steam turbine
④ alternator
⑤ Feed water
⑥ cooling arrangement

① coal and ash handling arrangement

→ The coal is transported to the power station by road or rail and is stored in the coal storage plant.

→ From the coal storage plant, coal is delivered to the coal handling plant where it is pulverised. (crushed into small pieces)

→ Then the pulverised coal is fed to the boiler by belt conveyors.

→ The coal is burnt in the boiler and the ash is produced after the complete combustion of coal is removed to the ash handling plant and then delivered to the ash storage plant for disposal.

② steam generating plant

The steam generating plant consist of a boiler for the production of steam.

(a) Boiler :→

The heat of combustion of coal in the boiler is utilised to convert water into steam at high temperature and pressure.

(b) Superheater :→

→ The steam produced in the boiler is wet and is passed through a superheater where it is dried and superheated by the flue gases on their way of chimney.

→ The main function of superheater is to increase the overall efficiency of plant.

→ The superheated steam from the superheater is feed to steam turbine through the main valve.

(c) Economiser :→

The feed water from condenser is feed to the economiser before supplying to the boiler, the economiser extracts a part of heat of flue gases to increase the feed water temperature.

(d) Air-preheater

→ The air preheater extracts heat from flue gases and increases the temperature of air used for coal combustion and overall it increase the efficiency of plant.

③ Steam turbine

→ The dry and superheated steam from the superheater is feed to the steam turbine through main valve. Heat energy of steam when passing over the blades of turbine is converted into mechanical energy.

→ After giving heat energy to the turbine, the steam is exhausted to the condenser where it is converted into water.

④ Alternator :-

The steam turbine is coupled to an alternator. The alternator convert mechanical energy of turbine into electrical energy. The electrical output from the alternator is delivered to the busbar through T/F, CB and Isolator.

⑤ Cooling Arrangement :-

Due to scarcity of water in river, hot water from the condenser is passed on to the cooling towers where it is cooled.

Advantages

① The fuel (coal) is cheaper

② Less initial cost as compared to other generating plants.

③ It required less space.

④ It can be installed at any place irrespective of the existence of coal.

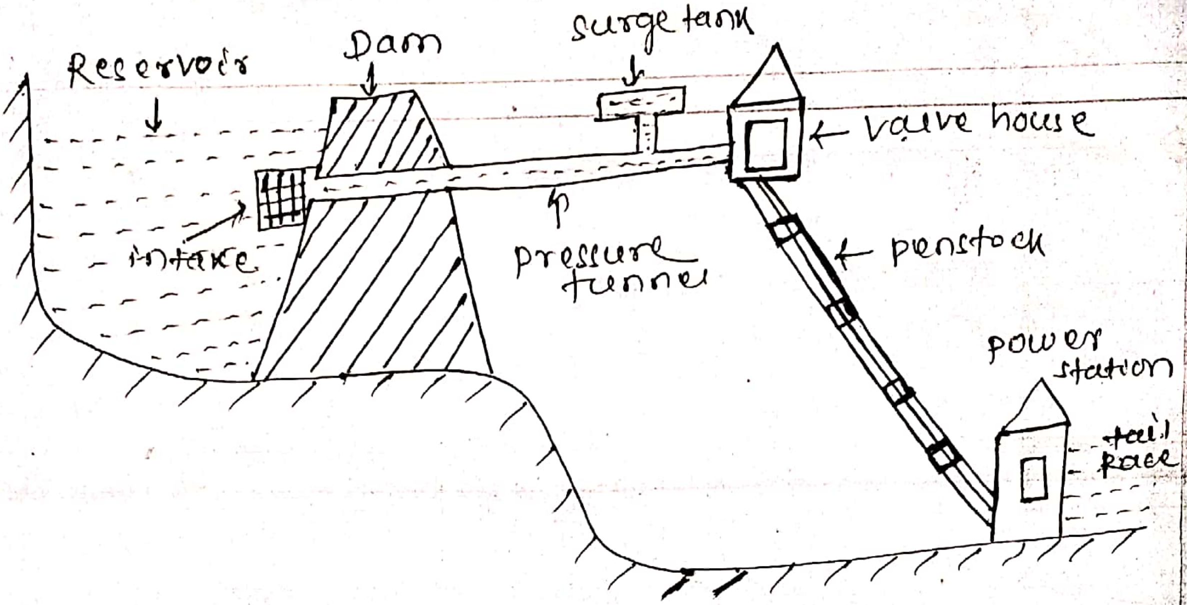
Disadvantages

→ High maintenance and operating cost.

→ Pollution of atmosphere due to fuel (coal)

→ A huge quantity of water is required.

Hydro-electric Plant



Elements of hydro-electric power plants

① **Storage Reservoir :→**

→ Its purpose is to store water.

② **Dam !→**

→ The Dam used to raise the water surface of the stream to increase an artificial head.

③ **penstock !→**

→ A penstock is the long pipe that carries the water, flowing from the reservoir towards the power generation unit.

④ **Intake !→**

→ These are the gates built on the inside of the dam to controlled water flow through water tunnel from Reservoir.

⑤ **Surgetank !→**

→ surge tank is used to avoid water hammering effect and to save penstock.

*

→ For hydro-electric power plant, a huge quantity of water is required which is store in Reservoir.

→ There is a pressure tunnel which connect reservoir to the valve house, ~~so water from~~ reservoir to valve house passes through pressure tunnel.

→ valve house contain main sluice valve for controlling water flow to the power station.

→ A surge tank is provided to avoid water hammering effect on penstock which is placed before valve house.

→ Then the water from valve house floco into the power station through penstock.

→ in power station turbine coupled with generator

→ in power station, water from penstock fall on blade of turbine, where kinetic energy and potential energy of water is converted into the rotational motion of blade,
Because of rotation of blade, shaft of turbine and also coupled generator rotate which produced Alternating current.

Advantages :→

→ They donot pollute atmosphere.

→ The lake's water can be used for irrigation purpose.

→ Hydro power project control flood.

→ Cheapest in operation and maintenance.

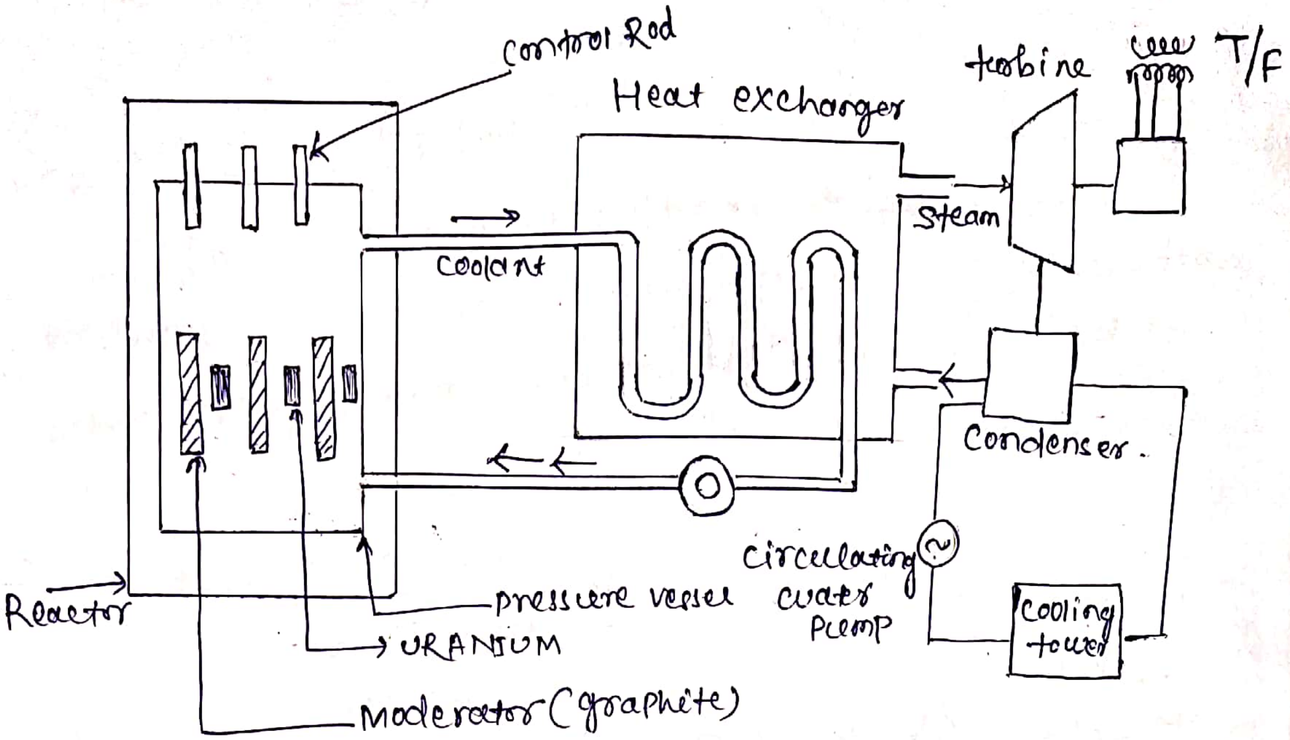
disadvantages :→

→ Dam are extremely expensive to build.

→ It depends on rain.

→ It requires large area.

Nuclear power plant



The whole arrangement of Nuclear power plant can be divided into!

1. Nuclear Reactor
2. Heat exchanger
3. steam turbine
4. condenser
5. Alternator

Nuclear Reactor

A nuclear reactor is consist of uranium rods (fuel rods), moderators and control rods.

→ In nuclear power plant, reactor used for heat generator. A huge quantity of heat energy is produced by breaking of uranium (U_{235}) a result of fission reaction and passes the heat to the heat exchanger through coolant.

→ control rods are made up of cadmium which is a strong neutron absorber and used to regulate the supply of neutron for fission.

② Heat exchanger :→

The coolant gives up heat to the heat exchanger which is utilised in raising the steam. After giving up heat, the coolant is again fed to reactor.

③ Steam turbine :→

The steam produced in the heat exchanger is supplied to the steam turbine through valve. After doing a useful work in the turbine, the steam is exhausted to condenser.

④ condenser :→

In condenser, steam is converted into water and fed to the heat-exchanger for reuse.

⑤ Alternators :→

The steam turbine drives the alternator which converts mechanical energy into electrical energy.

Advantages :→

→ The amount of fuel required is quite small.

→ A nuclear power plant requires less space as compare to other power plant.

→ It's more reliable, cheaper for running cost.

Disadvantages

→ fuel is expensive and not abundantly available every where.

→ It has high capital cost.

→ maintenance charge is high

→ Nuclear waste disposal may cause a dangerous amount of radio active pollution.

Ch-2 Transmission of Electric Power

Electric supply system

→ The conveyance of Electric power from a power station to consumer's premises is known as Electric supply system.

→ An Electric supply system consist of 3 principal components

① power station → Electric power is produced at the power station which are located at favourable places, generally quite away from the consumers.

② Transmission line → It is then transmitted over large distance to load centres with the help of conductors known as transmission line.

③ Distribution system → Finally, it is distributed to a large no. of small and big consumer's through a distribution network.

The Electric supply system can be classified into

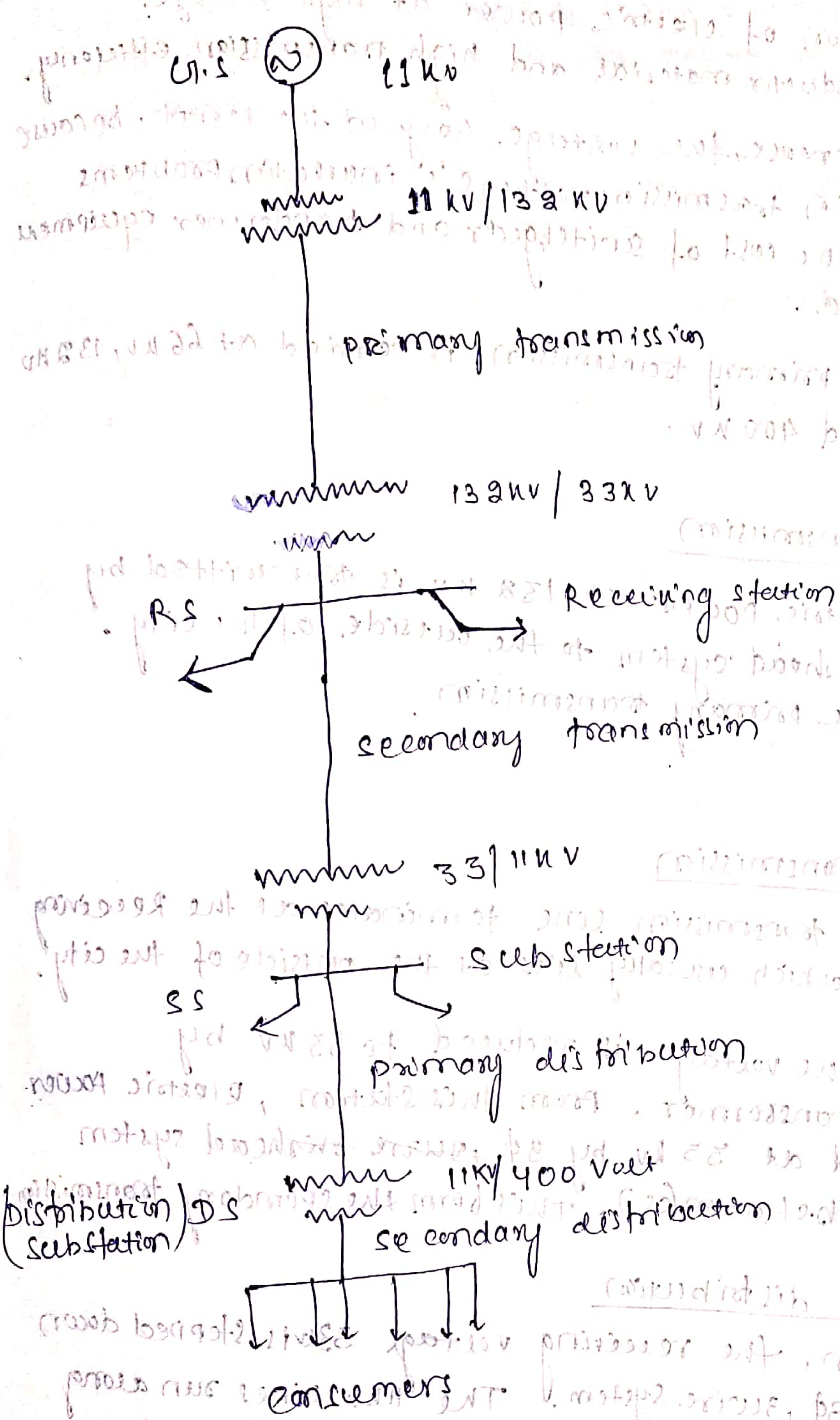
① A.C or D.C system

② overhead or underground system

③ 3φ, 3 wire system (generally adopted for generation and transmission purpose)

④ 3φ, 4 wire system (adopted for Distribution purpose)

A.C power supply scheme



① Generating station :-

G.S represents the generating station where electric power is produced by 3φ alternators operating in parallel. The usual generation voltage is 11 kV. This 11 kV is

→ stepped upto 132 kV at the generating station with the help of 3-ϕ transformers.

→ The transmission of electric power at high voltage save the conductor material and high transmission efficiency.

(we can't increase the voltage beyond the limit, because it increase in trasmission voltage's insulation problems as well as the cost of switchgear and transformer equipment is increased.

→ generally the primary transmission is carried at 66 kV, 132 kV 220 kV and 400 kV.

② primary transmission

→ The Electric power at 132 kV. is transmitted by 3ϕ, 3 wire overhead system to the outside of the city. This form the primary transmission.

③ secondary transmission

→ The primary transmission line terminates at the Receiving Station (RS) which usually lies at the outside of the city.

→ At the RS, the voltage is reduced to 33 kV by step-down Transformer. From this station, electric power is transmitted at 33 kV by 3ϕ, 3wire overhead system to various substation (SS). This form the secondary transmission.

④ The primary distribution

At substation, the receiving voltage 33kV is stepped down to 11 kV in 3ϕ, 3wire system. The 11kV lines run along the important road sides of the city. This form the primary distribution.

⑤ Secondary Distribution

→ The 11 kV distribution line is delivers to distribution sub-station (DS), which is located near the consumer's localities and step down the voltage to 400 volt, 3ϕ 4 wire for secondary distribution.

→ The voltage b/w any two phases is 400 volt and voltage b/w any phase and neutral is 230 volt.

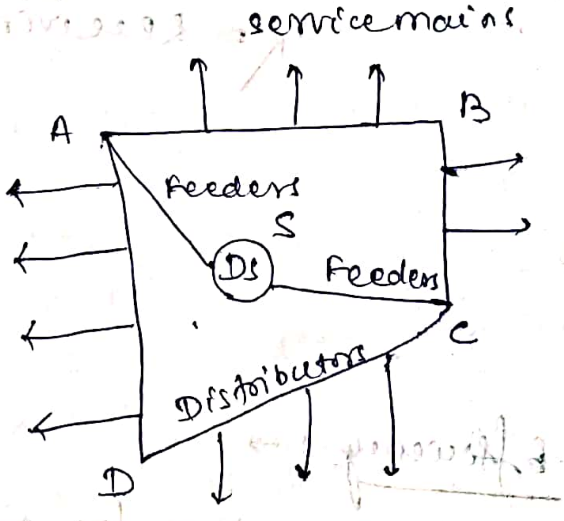
→ The single-phase residential lighting load is connected b/w any phase and Neutral, whereas 3-phase, 400 volt motor load is connected across 3phase lines directly.

* The secondary distribution system consists of

① Feeders

② Distributors

③ Service mains



Voltage Regulation

→ It's used to maintain a constant voltage in the transmission line.

→ voltage regulation is defined as the difference of supply sending voltage to the receiving voltage.

$$\boxed{\% VR = \frac{V_S - V_R}{V_R} \times 100}$$

① saving of conductor materia

② high transmission efficiency

(to reduce the power loss / I^2R lo

$$\eta = \frac{o/p}{i/p} = \frac{o/p}{o/p + loss}$$

$$= \frac{o/p}{o/p + I^2R}$$

where,

V_S = sending voltage

V_R = receiving voltage.

Efficiency :→

it's defined as the ratio of the power delivers at the receiving end to the power send from sending end.

$$\text{power efficiency } (\eta) = \frac{P_R}{P_R + (loss)} = \frac{P_R}{P_R + x(I^2R)}$$

$x = 1$ (1ϕ)

$x = 3$ (3ϕ)

$$\eta = \frac{o/p}{i/p} = \frac{V_R}{V_S} = \frac{P_R}{P_S}$$

Economics of Power Transmission

The following two fundamental economic principles which closely influence the electrical design of a transmission line will be discussed.

① Economic choice of conductor size

② Economic choice of transmission voltage

① Economic choice of conductor size (Kelvin's law).

→ It state that, the most economical area of conductor is that for which the total annual cost of transmission line is minimum.

→ The total annual cost of transmission line can be divided broadly into two parts

(a) Annual charge on capital outlay

(b) Annual cost of energy wasted in the conductor.

(a) Annual charge on capital outlay

→ In case of overhead system, it will be the annual interest and depreciation on the capital cost of conductors, supports and insulators and the cost of their erection.

→ So, Annual charge on an overhead transmission line can be expressed as:

$$\text{Annual charge} = P_1 + P_2 a \longrightarrow eq^n ①$$

P_1, P_2 = constant, a = area of X-section of conductor.

(b) Annual cost of energy wasted :→

→ The amount of energy lost in a conductor due to I^2R loss.

→ The energy lost in the conductor is proportional to 'R' and thus 'R' is inversely proportional to the area of X-section of conductor.

→ Therefore, the energy lost in the conductor is inversely proportional to area of X-section.

so Annual cost of energy wasted in an overhead transmission line can be expressed as,

$$\text{Annual cost of energy wasted} = \frac{P_3}{a} \longrightarrow eq^n ②$$

where P_3 = constant

$$\text{Total Annual cost, } C = eq^n ① + eq^n ②$$

$$= P_1 + P_2 a + \frac{P_3}{a}$$

only a = variable

Total annual cost of transmission line will be minimum if differentiation of 'c' w.r.to 'a' is zero

i.e $\frac{d(C)}{da} = 0$

$$\boxed{P \propto R \propto \frac{1}{A}}$$

$$\Rightarrow \frac{d\left(P_1 + P_2 a + \frac{P_3}{a}\right)}{da} = 0$$

$$\Rightarrow 0 + P_2 - \frac{P_3}{a^2} = 0$$

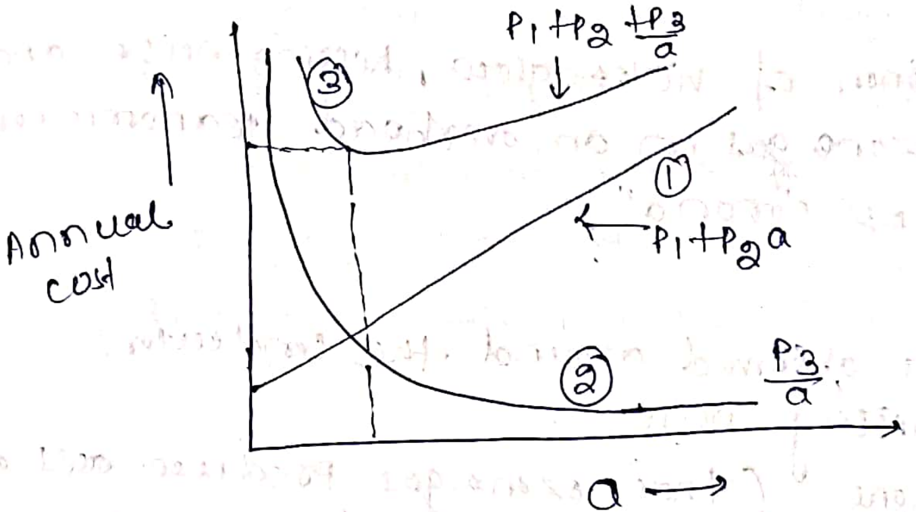
$$\Rightarrow P_2 = \frac{P_3}{a^2} \Rightarrow \boxed{P_2 a = \frac{P_3}{a}}$$

variable part of annual charge = Annual cost of energy wasted.

Kelvin's law can be stated that :→

The most economical area of conductor is that for which the variable part of annual charge is equal to the cost of energy losses per year.

Graphical illustration of kelvin's law



→ It is the graph b/w annual cost and the area of X-section of conductor.

→ The straight line (1) represent the relation b/w annual charge (P_1+P_2a) and the area of X-section of the conductor.

→ The graph ② represent the relation b/w annual cost of energy wasted and area of X-section 'a'.

→ The graph ③ represent the relation b/w total annual cost $\left(P_1+P_2a+\frac{P_3}{a}\right)$ of transmission line and area of X-section 'a'.

CORONA

"The phenomenon of violet glow, hissing noise and production of ozone gas in an overhead transmission line is known as corona".

→ A violet glow is observed around the conductor.

→ It produce a hissing noise

→ It produces ozone (that ozone gas produce acid which corrod the surface of conductor)

→ The glow is maximum over rough and dirty surfaces of the conductor.

→ It is accompanied by power loss in the form of light, heat, sound and chemical action.

(If wattmeter is connected in the ckt, then it show the reading)

→ The charging current under corona condition increases, because the corona induces harmonics current

Factors affecting corona

Since corona occurs due to the ionization of the air surrounding the line conductor, it is affected by the physical state of the atmosphere as well as by the condition of the line. The corona is affected by the following factors.

① Atmosphere :→

In the stormy weather, the No. of ions is more than normal and as such corona occurs at much less voltage as compared with fair weather.

② Conductor size :→

→ The corona is affected by the size (diameter), shape (stranded or smooth) and surface condition (dirty/clean) of the conductor.

→ The rough and irregular surface will give rise to more corona because unevenness of the surface decreases the value of breakdown voltage.

→ Thus a stranded conductor has irregular surface and hence gives rise to more corona that a solid conductor.

→ corona decreases with increase in diameter of conductor.

③ **Spacing b/w conductors :→**

with the increase in spacing b/w the conductors the electrostatic stressesare reduced and therefore, the corona effect is reduced.

④ **Line voltage :→**

At low voltage, there is no corona effect, but when the line voltage is increased to such a value that electro-static stresses developed at the conductor surface make the atmospheric air surrounding the conductor conducting, corona effect appears.

Advantages of corona

① Due to corona formation, the air surrounding the conductor becomes conducting and hence virtual diameter of the conductor is increased. The increased diameter reduces the electro-static stresses b/w the conductors.

② Corona reduces the effects of transient produced by surges.

Disadvantages of corona

① Corona is accompanied by a loss of energy. This affects the transmission efficiency of the line.

② Ozone is produce by corona and may cause corrosion of the conductors due to chemical action.

③ The current drawn by the line due to corona is non-sinusoidal and hence non-sinusoidal voltage drop occurs in the line. This may cause inductive interferance with neighbouring communication lines.

Methods of Reducing corona effects

① **By increasing conductor size :→** By increasing the conductor size Vdo is increased and corona effect can be reduced. mainly ACSR conductor is used which have a large X-sectional area.

② **By increasing conductor spacing :→** By increasing the spacing b/w conductors, the voltage at which corona occurs is raised and hence corona effects can be eliminated.

⑤ By using bundled conductors also corona effects can be avoided because effective diameter of the bundled conductor is much larger than that of the equivalent single conductor.

Ch-3 overhead lines

Main components of overhead Lines

An overhead line may be used: to transmit or distribute electric power; In general, the main components of an overhead line are:→

① **conductors!→**

Conductors which carry electric power from the sending end station to the receiving end station.

(II) **supports!→**

Supports which may be poles or towers and keep the conductors at a suitable level above the ground.

(III) **cross-arms and clamps!→**

These are used on pole structures to support the insulators and conductors.

(IV) **Insulators!→**

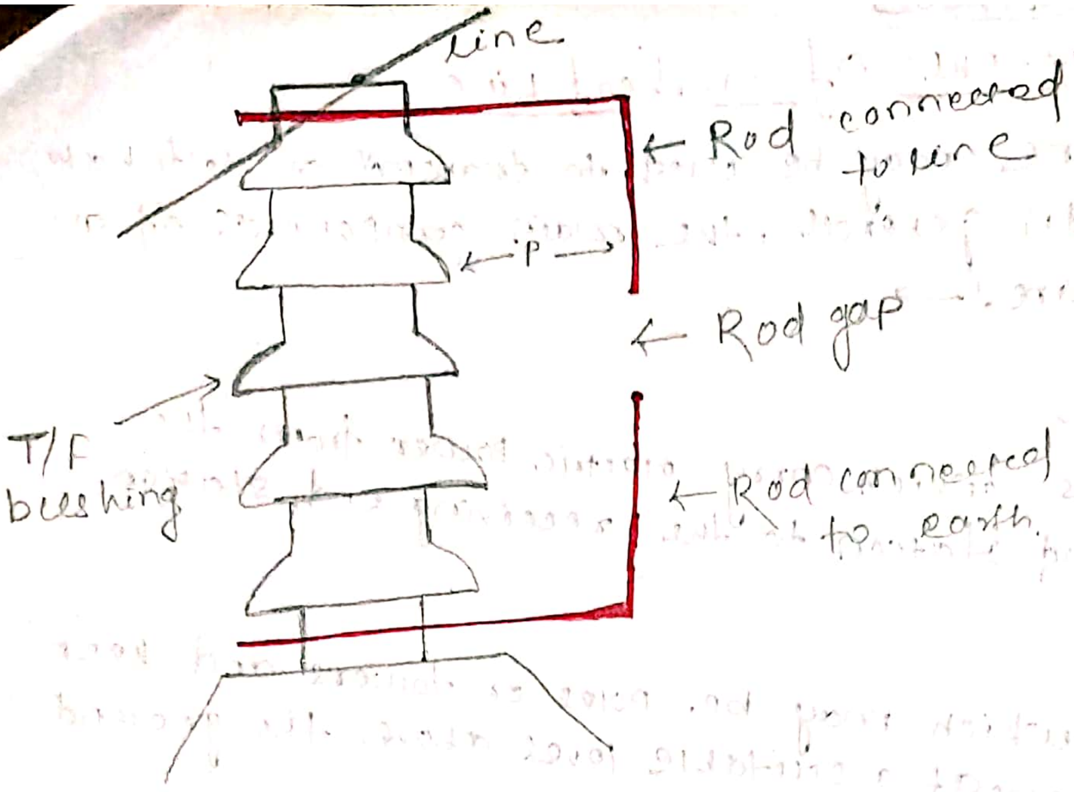
Insulators which are attached to support and insulate the conductors from the ground.

(V) **Guys and stays!→** * stay wires are galvanised steel wire strands that are used for sustaining mechanical load.

* These are used to stay power poles and tower with the help of stay wire.

(VI) **Lightening arrestors!→**

A lightning arrester is a device used on electrical power systems and telecommunications system to protect the insulator and conductors from the effects of lightning.



(VII) Earth wire :→

Earth wire is run on the top of the towers to protect the line against lighting discharges.

(VIII) Vee-Guards :→

V-guards are often provided below bare overhead lines running along or across public streets to make the line safe if it should break.

(IX) Guard wires :→

guard wires are provided above or below power lines while crossing telephone or telegraph lines. The guard wires and steel structures are solidly connected to earth.

(x) Miscellaneous items :→
Such as plate (phase plates), danger plates, lightning arrestors, anti-climbing wires etc.

Line supports :→

The line supports should have the following properties

(i) High mechanical strength to withstand the weight of conductors and wind load etc.
(ii) Light in weight without the loss of mechanical strength
(iii) cheap in cost and economical to maintain.
(iv) Longer life
(v) Good looking
(vi) Easy accessibility for erection of line conductor.

① wooden poles :→

→ These supports are cheapest, easily available, provide insulating properties and therefore these are widely used for distribution purpose in rural areas.

→ The pole below the ground level is impregnated with preservative compound like creosote oil in order to prevent it from rot.

→ 'A' and 'H' shape poles are used for distribution purpose.

→ Length of wooden pole is 10–12m, span length is upto 50mt.

The main drawbacks of wooden supports :→

(i) Tendency to rot below the ground level,
(ii) comparatively smaller life span (20-25 yr.)
(iii) less mechanical strength
(iv) Required periodical inspection.
(v) cannot be used for voltage higher than 22 kV.

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② Steel poles :→

→ The wooden poles are replaced by steel poles due to it's several disadvantages.

→ steel pole possess greater mechanical strength, longer life and permit longer spans length (50-80m)

→ such poles are generally used for distribution purposes in the cities.

→ These type of supports need to be galvanised or painted in order to increase it's life. (life span is more than 40 yr.)

→ steel poles are used for transmission purposes for 11 KV - 33 KV.

→ steel poles are 3 types

(i) Rail poles

(ii) Tubular poles

(iii) Rolled steel joints

③ RCC poles! → (Reinforced cement concrete)

→ It is used in distribution line upto 33 kV.

→ RCC - poles give good appearance, require no maintenance, have good insulating properties and resistance against chemical action, very strong, have longer life and can be used for longer span (80 - 200 m).

→ These pole may be manufactured at site itself to avoid heavy cost of transportation.

(RCC poles are very bulky and heavy)
(It need care in handling and erection)

④ Steel tower :→ (Lattice steel tower)

wooden pole
steel pole
RCC pole
} → Used for distribution line

steel tower } → It's used for Transmission line.

→ steel towers have greater mechanical strength, longer life, can withstand most severe climate condition and permit the use of longer span length (300m or more)

→ Narrow-base, lattice steel towers are used for transmission at 11kV to 33 kV and broad-base, lattice steel towers are used for transmission purposes at 66 kV and above.

Types of conductor Materials :→

The conductor material used for transmission and distribution of electric power must have the following characteristics :→

(i) High electric conductivity

(ii) High tensile strength in order to withstand mechanical stress.

(iii) Low cost so that it can be used for long distance.

(iv) Easy availability

(v) should not be brittle

(vi) Low specific gravity in order to give low weight per unit volume.

② Aluminium :-

→ Aluminium is cheaper in cost and lighter in weight and easily available.

→ It has smaller conductivity and tensile strength.

* (Conductivity of Al. is 60% of Cu.)

* (tensile strength of Al is 45% to that of Cu.)

* Specific gravity of Al. is 2.71 gm/cc is lower than that of Cu. (8.9 gm/cc), therefore, Al weight is lower than Cu.

* → The Al. conductor being liable to swing, requires larger X-arms.

→ Due to lower tensile strength and higher co-efficient of linear expansion of Aluminium, the sag is greater in Aluminium conductor.

→ Due to low melting point of Al., it cannot withstand short-circuit etc. Jointing of Aluminium is also difficult as compared to that of copper.

* AAC :→ All Aluminium conductor.

* All aluminium stranded conductors are mainly used for low voltage distribution overhead line having short spans of upto 65m.

③ Steel-cored Aluminium

(ACSR – Aluminium conductor steel reinforced)

→ Due to low tensile strength, Aluminium conductors produce greater sag. so that Al. conductor unsuitable for long distance transmission line.

→ In order to increase the tensile strength, the Al. conductor is reinforced with a core of galvanised steel wires and composite conductor is known as steel-cored aluminium.

→ ACSR has high tensile strength and lighter on weight produces small sag and therefore longer spans can be used.

Advantages of ACSR :→

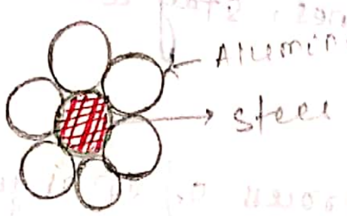
(i) ACSR has high tensile strength and lighter in weight produces small sag, therefore it can be used for longer span length.

(ii) Due to smaller sag with steel cored aluminium conductors, towers of smaller heights can be used.

(iii) ACSR conductor reduces skin effects.

(iv) ACSR conductor reduces corona losses.

(v) Because of use of larger span, the number of line supports may be reduced (about 25%). Thus the overall cost of supports, foundations, insulators and erection is also reduced. maintenance cost is considerably reduced.



① copper ! →

→ copper has high electrical conductivity

→ It has greater tensile strength.

→ due to it's high current density, smaller x-sectional area is required for conductivity and secondly, the area offered by the conductor to wind loads is reduced.

→ It's durable and has high scrap value.

drawback ! →

→ It's costly.

→ and it's easily not available.

④ Galvanised steel ! →

→ coat (iron/steel) with a protective layer of zinc.

→ Galvanised steel has poor conductivity but have very high tensile strength.

→ Due to high tensile strength, galvanised steel can be used for extremely long span.

→ Due to it's poor conductivity, it is used to transmit a small power over a small distance.

properties of galvanised steel ! →

① poor conductivity, 13% that of copper.

② High internal reactance

③ It's subjected to eddy current and hysteresis.

GI wire ! →

galvanised steel wire is limited to telecommunication lines, stay wire, earth wire, guard wire.

→ Stranded galvanised steel wires are used as guy wires and earth/ground wire.

→ In 11 kV and 33 kV lines, the earth wire is provided below the line conductors for the safety of personnels, cattles and material moving under the line as a precaution incase a line conductor snaps.

→ In case of extra-high voltage lines of 66 kV, 132 or 220 kV. the ground wire is provided above the line conductors for protection against lightening.

⑤ Cadmium copper :→

→ In some cases 1-2 % of cadmium is added with copper to increase the tensile strength by 50 %. but it's conductivity is reduced by 15 %.

→ use of cadmium copper will be economical for a line with long spans and small - cross section. i.e where the cost of caductor material is comparatively small in comparision to that of supports

→ cadmium-copper conductors are also employed for telephone and telegraph lines where current involved are quite small.

→ But due to scarcity of copper, cadmium-copper conductors on communication lines are being replaced by a ACSR conductors.

Insulators

The insulators provide necessary insulation between the conductors and supports and prevent any leakage current from conductors to earth.

For a insulator, the general properties are

(i) High mechanical strength inorder to withstand conductor load, wind load etc.

(ii) High electrical resistance of insulator material inorder to avoid leakage current to earth.

(iii) High relative permittivity so as to provide high dielectric strength.

(iv) High ratio of rupture strength to flash-over voltage

(v) The insulator material should not be porous, free-from impurities and cracks otherwise the permittivity will be lowered.

(vi) Ability to withstand large temperature variations. i.e. it should not crack when subjected to high temperature during summer and low temp. during winter.

① Types of Insulators

Various type of insulators are used for overhead transmission and distribution lines are

(1) pin type insulator.

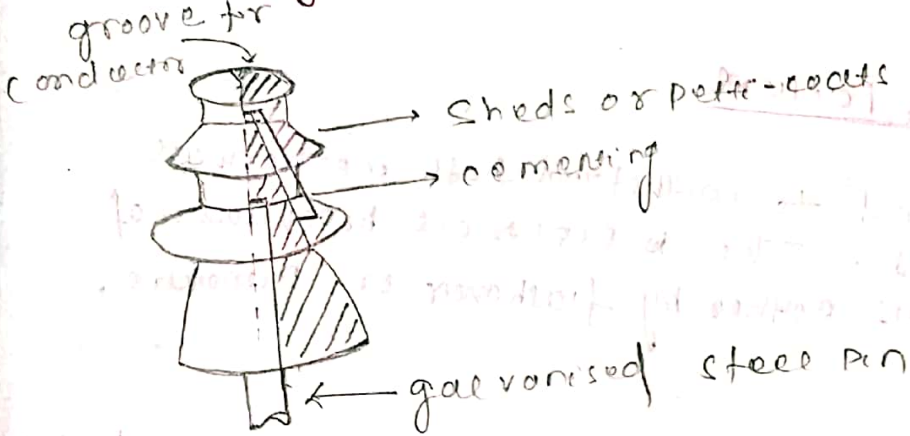
(2) suspension type insulator — string insulator.

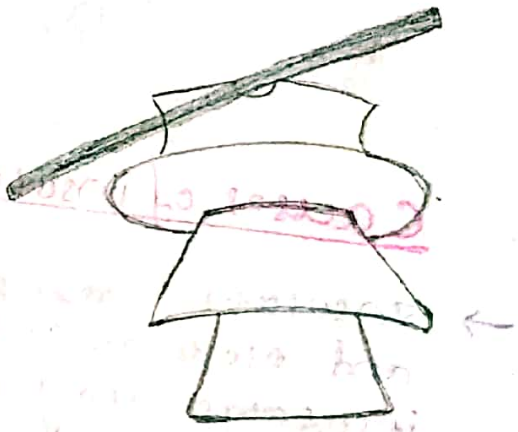
(3) strain insulator

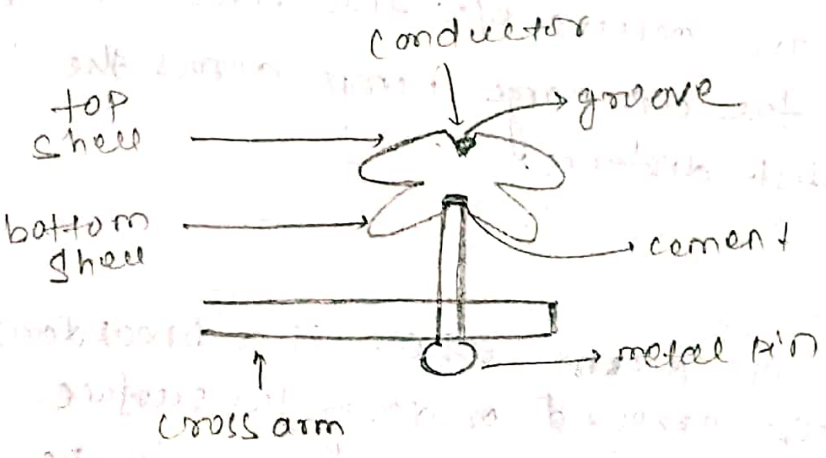
(4) shackle insulator (6) post insulator.

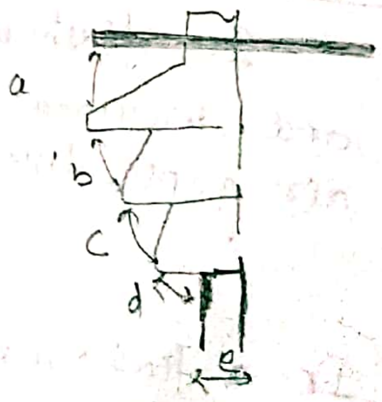
(5) stay insulator

(i) pin type-insulators









→ Pin type insulators are used for transmission and distribution of electric power at voltage upto 33 kv. Beyond the 33kv the pin insulators becomes too bulky and hence uneconomical.

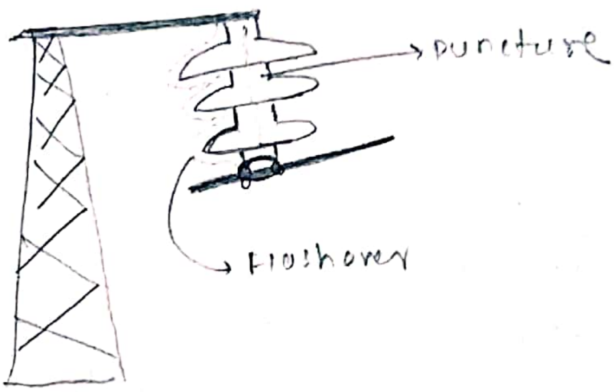
→ There is a groove on the upper end of the insulator for placing the conductor. The conductor passes through this groove and is bounded by the annealed wire of the same material as the conductor.

Causes of insulator Failure

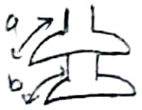
→ Insulators are required to withstand both mechanical and electrical stresses. The electrical breakdown of insulators may occurs either by flashover or Puncture.

Flash-over.

In flash over, an arc occurs b/w the line conductor and insulator pin and the discharge jumps across the air gaps, following shortest distance.



leakage path = a



leakage path = a+b

leakage path = a+b+c

Puncture

→ In case of puncture the discharge occurs from conductor to pin through the body of insulator. under this condition the insulator is permanently destroy due to excessive heat.

→ In practice, sufficient thickness of porcelain is provided in the insulator to avoid puncture by line voltage.

* The ratio of puncture strength to the flashover voltage is known as safety factor

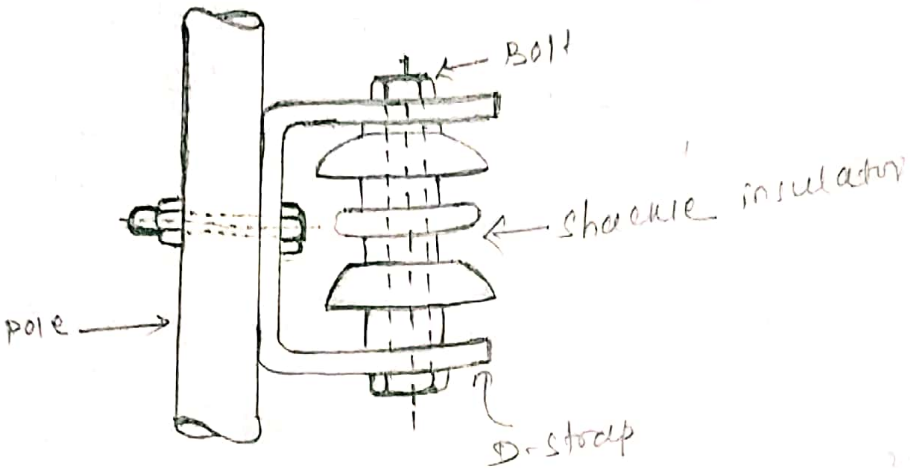
$$S.F = \frac{\text{puncture strength}}{\text{flashover voltage}}$$

* for the pin type insulator the value of S.F is about 10

* with increase in no. of sheds the leakage path increases.

$$\text{leakage current} \propto \frac{1}{\text{length of leakage path}}$$

② Shackle Insulator

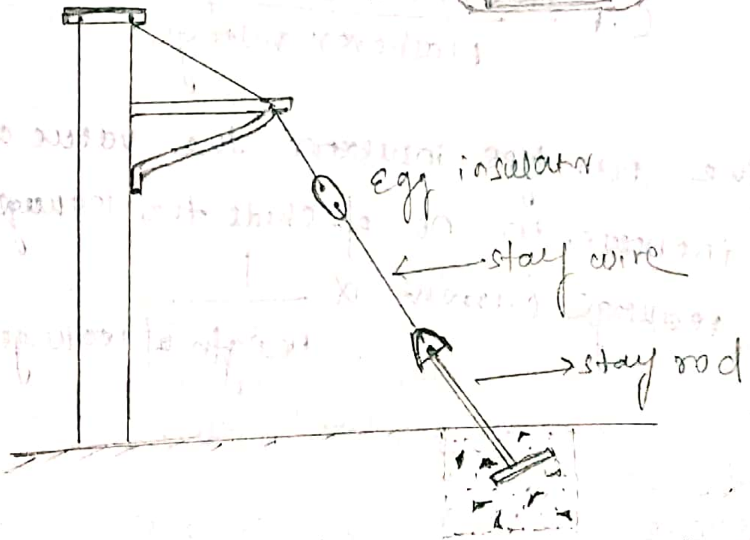


→ It is used upto 25kv.

→ Shackle insulators are frequently used for low voltage distribution line. Such insulator can be used either in horizontal position or vertical position.

→ They can be directly fixed to the pole with a bolt or to the cross-arm.

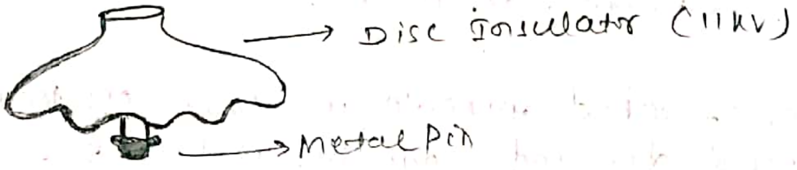
③ Stay insulator / Egg Insulator



It provide the insulation b/w stay wire and cross-arm (pole & earth)

④ String insulator

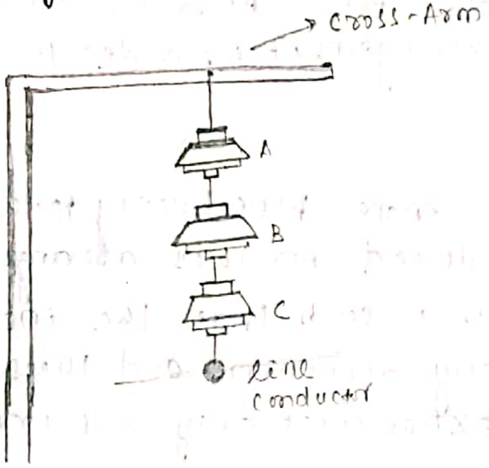
A number of disc insulators are connected in cascade (series) & each disc is rated at 11kV.



ⓐ suspension type ⓑ strain type insulator.

ⓐ suspension type Insulator

→ Above 33kV, the pin-type insulator becomes bulky and costly so it is not economical to used.



→ for high voltage (>33kV) it is a usual practice to used suspension type insulator.

→ It consist of a no. of porcelain discs connected in series by metal link in the form of a string. The conductor is suspended at the bottom end of the string while the other end of the string is connected to the cross-arm of the tower.

→ Each unit or disc is design for low voltage (upto 11kv) i.e 11kv.

Advantages

→ suspension type insulators are cheaper than pin type insulator for voltage beyond 33kV.

→ If any one disc is damaged, then that disc can be replaced instead of the whole string.

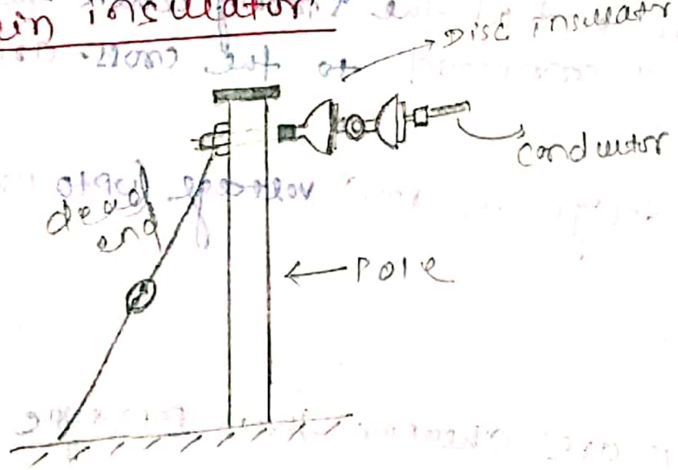
→ Each unit or disc. of suspension type insulator is designed for low voltage, usually 11kV. Depending upon the working voltage, the desired no. of discs can be connected in series.

→ In case of rapid increase in load on transmission line, the increased demand can be met by raising the line voltage than to provide another set of conductors. With suspension type insulators, additional line insulation required can be obtained easily by adding one or more discs to the string.

→ The suspension type insulators are generally used with steel towers. As the conductors run below the earthed cross-arm of the tower, therefore, this arrangement provides partial protection from lightning.

→ Suspension type insulators give more flexibility to the line and mechanical stresses are reduced in this arrangement. The connection at the cross-arm is such that the insulator string is free to swing in any direction, and thus takes up a position where it experiences only a pure tensile strength.

b) Strain insulator



→ where there is a dead end of the line, or there is a corner or a sharp curve, (diversion) or the line crosses river etc. The line is subjected to greater tension.

→ In order to relieve the line of excessive tension, strain insulators are used.

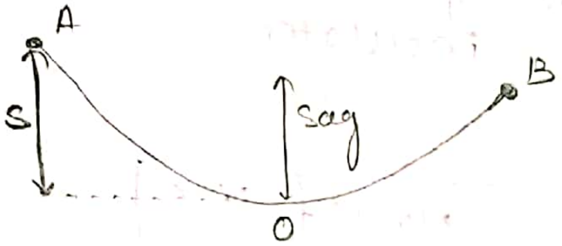
→ For low voltage (<25 kV) shackle type insulators are used as, strain insulator. However for high voltage transmission line strain insulator consist of a no. of disc insulator which are horizontally placed.

* No. of Disc in strain type insulator = 1+ No. of Disc in suspension type insulator

Voltage level (L-L)	No. of Disc
11 kV →	1
33 kV →	3
66 kV →	5
132 kV →	9
220 kV →	13-15
400 kV →	20

Sag

The difference in level between points of supports and the lowest point on the conductor is called sag.



when the conductor is suspended b/w 2 supports at the same level, it takes the shape of catenary

Factors affecting the sag in an overhead line are given below!→

(i) weight of the conductor!→ Heavier the conductor, greater will be the sag.

In locations where Ice formation takes place on the conductor, this will also cause increase in the sag.

(ii) Length of span!→ sag is directly proportional to the square of the span length.

(iii) working tension, working tensile strength!→ The sag is inversely proportional to the working tensile strength of conductor.

(iv) Temperature!→ Length of conductor increases with the rise in temp. and so that sag form.

(a) The weight 'wx' of conductor acting at a distance $\frac{x}{2}$ from 'O'.

(b) The tension 'T' acting at 'O'.

Equating the moments of above 2 forces about point 'O', we get.

$$Ty = wx \times \frac{x}{2}$$

$$y = \frac{wx^2}{2T}$$

The maximum sag is represent by the value of 's' at either of the supports 'A' and 'B'.

At support A, $x = \frac{l}{2}$, $y = s$

$$\text{sag } s = \frac{w(\frac{l}{2})^2}{2T} = \frac{wl^2}{4 \cdot 2T} = \frac{wl^2}{8T}$$

$$\boxed{s = \frac{wl^2}{8T}}$$

Calculation of sag and Tension

② When supports are at unequal level

Generally in hilly area, these type of sags are occuring in overhead lines.

Let a conductor suspended b/w 2 supports 'A' and 'B' which are at different levels.

The lowest point on the conductor is 'O'.

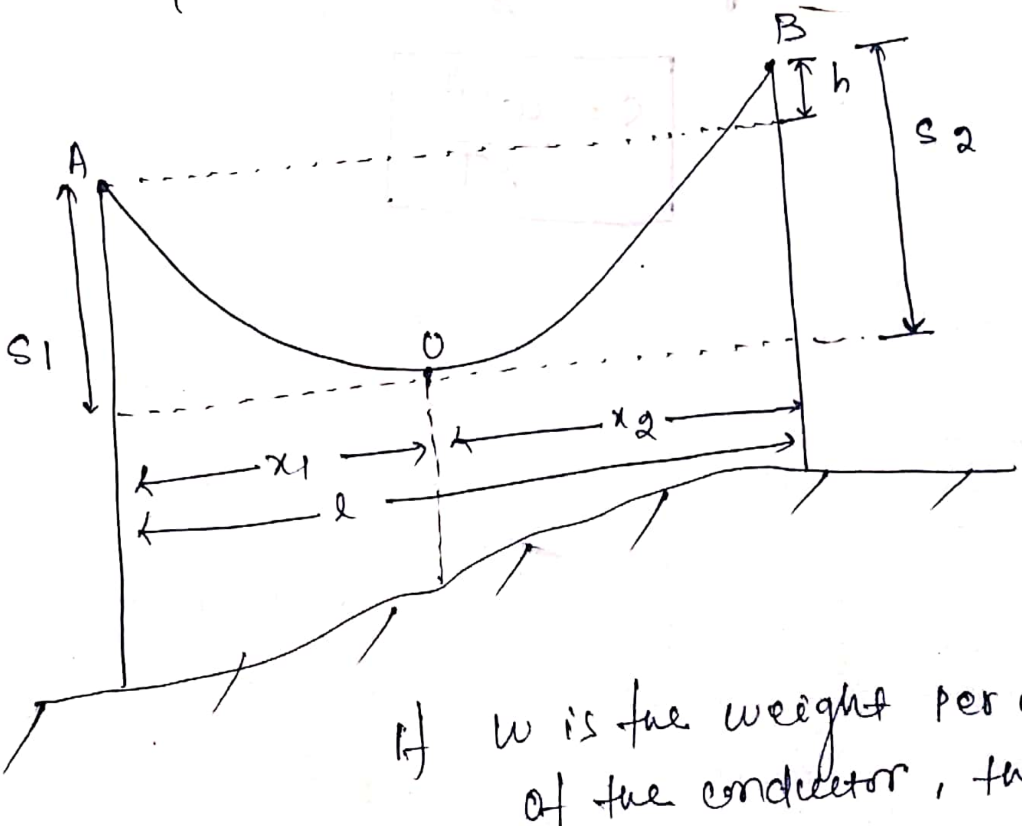
Let L = span length

h = difference in levels b/w 2 supports.

x_1 = Distance of supports at lower level (i.e A) from O

x_2 = Distance of supports at higher level (i.e B) from O

T = Tension in the conductor.



If w is the weight per unit length of the conductor, then.

$$\text{sag } S_1 = \frac{w x_1^2}{2T},$$

and sag $s_2 = \frac{wx_2^2}{2T}$

$$x_1 + x_2 = l \longrightarrow \text{eq}^n \text{①}$$

$$s_2 - s_1 = \frac{wx_2^2}{2T} - \frac{wx_1^2}{2T}$$

$$\Rightarrow h = \frac{w}{2T}(x_2^2 - x_1^2)$$

$$\Rightarrow h = \frac{w}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\Rightarrow h = \frac{wl}{2T}(x_2 - x_1)$$

$$\Rightarrow x_2 - x_1 = \frac{2Th}{wl} \longrightarrow \text{eq}^n \text{②}$$

from eqⁿ ① and eqⁿ ②, we get

$$x_2 + \cancel{x_1} = l$$
$$x_2 - \cancel{x_1} = \frac{2Th}{wl}$$

$$2x_2 = l + \frac{2Th}{wl}$$

$$\Rightarrow \boxed{x_2 = \frac{l}{2} + \frac{Th}{wl}}$$

$$x_1 + x_2 = l$$
$$x_1 = l - x_2$$
$$= l - \left(\frac{l}{2} + \frac{Th}{wl}\right)$$
$$= l - \frac{l}{2} - \frac{Th}{wl}$$

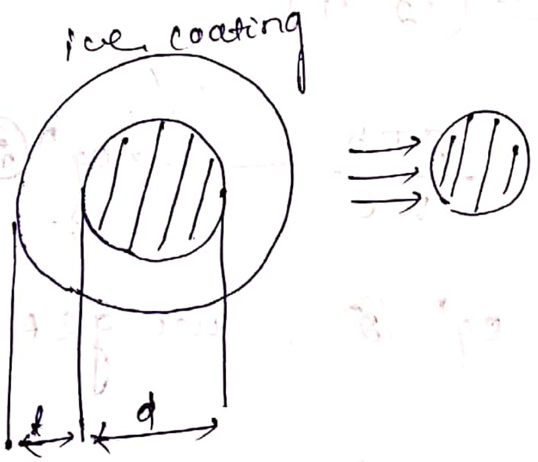
$$\boxed{x_1 = \frac{l}{2} - \frac{Th}{wl}}$$

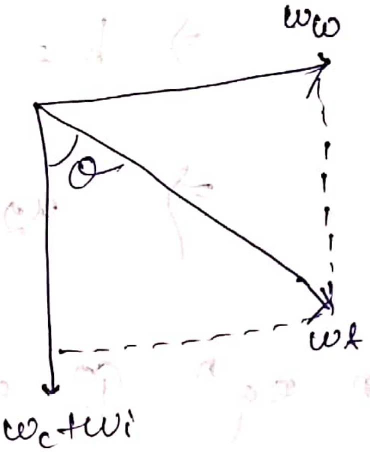
From x_1 and x_2 we can easily find out the value of s_1 and s_2.

Effect of wind and Ice loading:

Here the weight of ice acts vertically downward i.e, in the same direction as the weight of conductor, the force due to the wind is assumed to act horizontally i.e at right angle to the projected surface of the conductor.

Hence total force on the conductor is the vector sum of horizontal and vertical forces i.e





Total weight of conductor per unit length is

$$w_t = \sqrt{(w_c+w_i)^2+(w_w)^2}$$

w_c = weight of conductor per unit length
= conductor material density X volume per unit length
=

w_i = weight of ice per unit length
= density of ice X volume of ice per unit length
= density of ice $\times \left\{\frac{\pi}{4}\left[(d+2t)^2-d^2\right]\times 1\right\}$

$$\frac{\pi}{4}\left[(d+2t)^2-d^2\right] = \frac{\pi}{4}\left(\cancel{d^2}+4t^2+4dt-\cancel{d^2}\right)$$

$$= \frac{\pi}{\cancel{4}}\cancel{4}t(t+d) = \pi t(t+d)$$

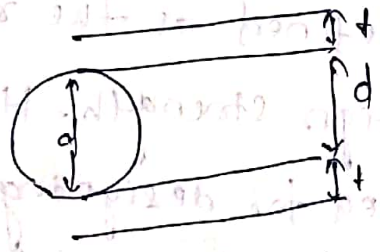
$$\boxed{w_i = \text{density of ice} \times [\pi t(d+t)] \times 1]}$$

w_w = wind force per unit length
= wind pressure per unit area × projected area per unit length

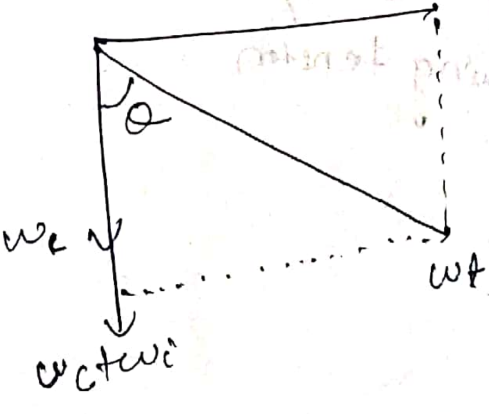
= wind pressure × [(d+2t)×1]

$$\boxed{w_w = p \times [(d+2t)\times 1]}$$

where d = diameter of conductor
and t = Radial thickness of ice coating in mt.



When the ice and wind are acting simultaneously, the lowest point of the conductor does not remain vertically down but away from it an angle α,
i.e



$$\cos\alpha = \frac{w_c+w_i}{w_t}$$

$$\boxed{\alpha = \cos^{-1}\left(\frac{w_c+w_i}{w_t}\right)}$$

for slant sag, the formula is

$$S = \frac{wl^2}{2T}$$

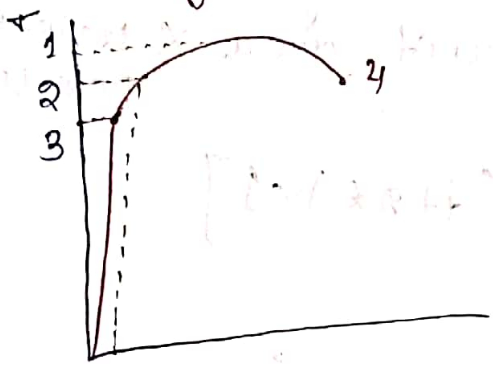
where the vertical sag = S cosθ

$\tan\theta = \frac{w_w}{w_c + w_i}$

vertical sag = S cosθ

$\theta = \tan^{-1} \frac{w_w}{w_c + w_i}$

ultimate strength



ultimate strength is measured by the maximum stress that a material can withstand while being stretched or pulled before breaking.

Safety of factor

factor of safety can be defined as the ratio of ultimate strength to the design strength. It is a constant factor that is considered for designing of machine components or structure beyond its working strength.

$$F.O.S = \frac{\text{ultimate strength}}{\text{design load/ working tension}}$$

Q.1 A 132 kV transmission line has the following data:

wt. of conductor = 680 kg/km

Length of span = 260 mt.

ultimate strength = 3100 kg.

Safety factor = 2

Calculate the height above ground at which the conductor should be supported. Ground clearance required is 10 mt.

working tension, $T = \frac{\text{ultimate strength}}{\text{safety factor}}$

$= \frac{3100}{2} = 1550$ kg

weight of conductor per mt. length, $w_c = \frac{680}{1000}$

$w_c = 0.68$ kg

maximum sag, $'s' = \frac{wL^2}{8T}$

$= \frac{0.68 \times (260)^2}{8 \times 1550}$

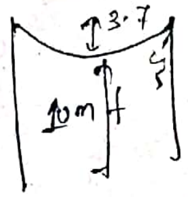
$= 3.7$ mt

The height above ground at which the conductor should be supported

= clearance + sag

= 10 + 3.7

= 13.7 mt.



Q.2 A transmission line has a span of 150 mt b/w level supports. The conductor has a cross-sectional area of 2cm². The tension in the conductor is 2000 kg. if the specific gravity of the conductor material is 9.9 gm/cm³ and wind pressure is 1.5 kg/m length; calculate the sag. what is the vertical sag.

Span length, $l = 150$ mt.

working Tension $T = 2000$ kg

wind force/m length of conductor, $w_w = 1.5$ kg/m

wt. of conductor/m length

w_c = sp. gravity x volume of 1 mt. conductor

$= 9.9 \times 2 \times 100$

$= 1980$ gm $= 1.98$ kg.

Total weight of 1 mt. length of conductor is

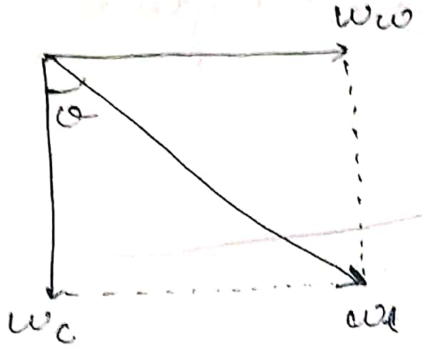
$$w_t = \sqrt{w_c^2 + w_w^2}$$

$$= \sqrt{(1.98)^2 + (1.5)^2}$$

$$= 2.48 \text{ kg}$$

$$\text{sag, } S = \frac{w_t l^2}{8T} = \frac{2.48 \times (150)^2}{8 \times 2000} = 3.48 \text{ m}$$

This is the value of slant sag in a direction making an angle θ with the vertical.



$\cos\alpha = \frac{b}{h} = \frac{w_c}{w_t}$

$\cos\alpha = \frac{1.98}{2.48}$

$\cos\alpha = 0.796,$

vertical sag

$= s\cos\alpha$

$= 3.48 \times 0.79$

$= 2.77$ m.

OR

$\tan\alpha = \frac{w_w}{w_c} = \frac{1.5}{1.98} = 0.76$

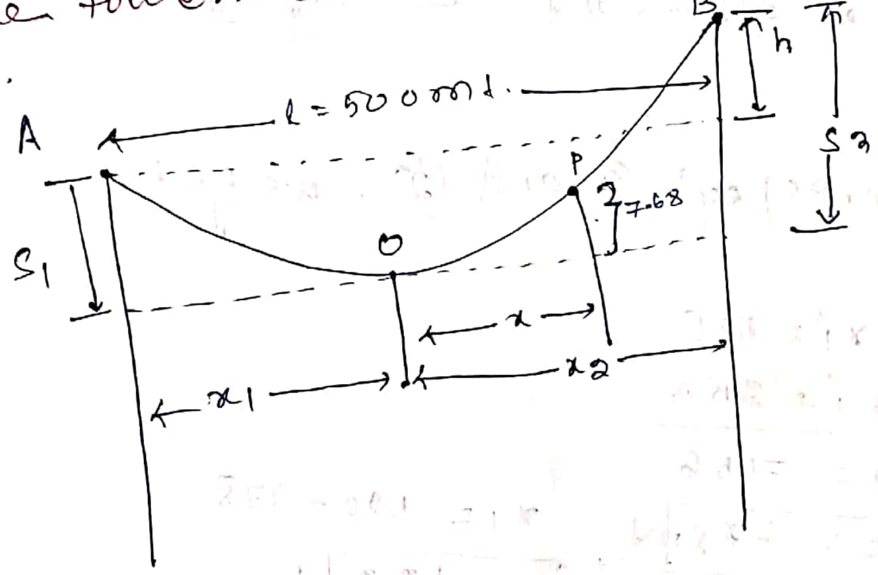
$\alpha = \tan^{-1} 0.76 = 37.25^\circ$

vertical sag $= s\cos\alpha$

$= 3.48 \times \cos 37.25^\circ$

$= 2.77$ mt.

Q.7 The tower of height 30 mt and 90 mt. respectively support a transmission line conductor at water crossing. The horizontal distance b/w the the tower is 500 mt. if the tension in the conductor is 1600 kg. Find the minimum clearance of the conductor and water and clearance mid-way b/w the supports. weight of conductor is 1.5 kg/m. Bases of the towers can be considered to be at water level.



Here l = 500 mt.

$w_c = 1.5$ kg/m

T = 1600 kg.

Difference in level b/w supports $h, = 90 - 30 = 60$ mt.

Let, The distance b/w support 'A' and 'O' is x_1

and the distance b/w support 'B' and 'O' is x_2

$x_1 + x_2 = 500$ mt. $\longrightarrow$ eq^n ①

and

sag $S_1 = \frac{w_c x_1^2}{2T}$, sag $S_2 = \frac{w_c x_2^2}{2T}$

$$h = S_2 - S_1 = \frac{w x_2^2}{2T} - \frac{w x_1^2}{2T}$$

$$\Rightarrow h = \frac{w_c}{2T}(x_2^2 - x_1^2)$$

$\Rightarrow 60 = \frac{w_c}{2T}(x_1+x_2)(x_2-x_1)$

$\Rightarrow 60 = \frac{w_c}{2T} \times 500(x_2-x_1)$

$\Rightarrow x_2 - x_1 = \frac{60 \times 2 \times T}{w \times 500} = \frac{60 \times 2 \times 1600}{1.5 \times 500}$

$\Rightarrow x_2 - x_1 = 256$ mt. $\longrightarrow$ eq^n ①

solving exps/eq^n ① and ②, we get,

$x_2 + \cancel{x_1} = 500$

$x_2 - \cancel{x_1} = 256$

$2x_2 = 756$

$\boxed{x_2 = 378}$ mt., $x_1 = 500 - 378$

$\boxed{x_1 = 122}$ mt.

Now, $S_1 = \frac{w x_1^2}{2T} = \frac{1.5 \times (122)^2}{2 \times 1600} = 7$ mt.

Now, clearance of the lowest point 'o' from water level, $= 30 - 7 = 23$ mt.

Let mid-point 'p' be at a distance 'x' from the lowest point o.

So $x = 250 - x_1 = 250 - 122 = 128$ mt.

Sag at mid-point p, $S_{mid} = \frac{wx^2}{2T} = \frac{1.5 \times (128)^2}{2 \times 1600}$

$= 7.68$ mt.

clearance of mid point 'p' from water level

$= 23 + 7.68 = 30.68$ mt.

Q.8 An over-head transmission line conductor having a Parabo configuration weighs 1.925 kg per metre of length. The area of x-section of the conductor is 2.2 cm² and the ultimate strength is 8000 kg/cm². The supports are 600m apart having 15m difference of levels. calculate the sag from the taller of the two supports which must be allowed so that the factor of safety shall be 5. Assume that ice load is 1 kg per mt. run and there is no wind pressure.

$l = 600$ mt., $w_i = 1$ kg, $h = 15$ mt.

$w_c = 1.925$ kg, $T = \frac{8000 \times 2.2}{5}$

$T = 3520$ kg

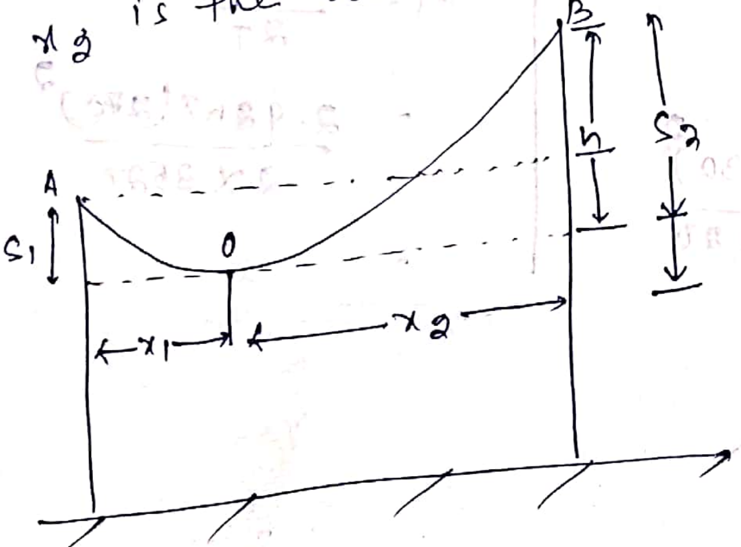
Total weight of 1 mt length of conductor is (Length of con/mt

$w_t = w_c + w_i$

$w_t = 1.925 + 1 = 2.925$ kg

Let x_1 is the distance from point 'o' to support 'A'

x_2 is the distance from point 'o' to support B.



$S_1 = \frac{w_t x_1^2}{2T}$, $S_2 = \frac{w_t x_2^2}{2T}$

$x_1 + x_2 = 600$ mt. $\longrightarrow$ eqⁿ ①

$$h = \frac{w_t x_2^2}{2T} - \frac{w_t x_1^2}{2T} = \frac{w_t}{2T}(x_2^2 - x_1^2)$$

$$\Rightarrow h = \frac{w_t}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\Rightarrow h = \frac{w_t}{2T} \cdot l\,(x_2 - x_1)$$

$$\Rightarrow 15 = \frac{w_t}{2T} \cdot 600\,(x_2 - x_1)$$

$$\Rightarrow x_2 - x_1 = \frac{15 \times 2 \times 3520}{2.925 \times 600}$$

$$\Rightarrow x_2 - x_1 = 60\,mt. \longrightarrow eq^n ②$$

by soeving eq^n ① and eq^n ②, we get

$$x_2 + \cancel{x_1} = 600$$
$$x_2 - \cancel{x_1} = 60$$
$$2x_2 = 660$$
$$\boxed{x_2 = 330\,mt}$$

$$x_2 + x_1 = l$$
$$\Rightarrow x_1 = l - x_2$$
$$\Rightarrow x_1 = 600 - 330$$
$$\Rightarrow \boxed{x_1 = 270\,mt.}$$

Ans

$$S_2 = \frac{w_t\, x_2^2}{2T}$$
$$= \frac{2.925 \times (330)^2}{2 \times 3520}$$
$$= 45.24\,mt.$$

$$S_1 = \frac{w_t\, x_1^2}{2T}$$
$$= \frac{2.925 \times (270)^2}{2 \times 3520}$$
$$=$$

Q.9 An overhead transmission line at a river crossing is supported from two towers at heights of 40m and 90mt. above water level, the horizontal distance b/w the towers being 400mt. if the maximum allowable tension is 2000 kg; find the clearance b/w the conductor and water at a point mid-way b/w the towers. weight of conductor is 1 kg/m.

here

$h = 90 - 40 = 50$ mt.

$l = 400$ mt.

$T = 2000$ kg

$w_c = 1$ kg/mt.

$x_1 + x_2 = 400$ mt. → eq^n ①

$$h = \frac{w_t x_2^2}{2T} - \frac{w_t x_1^2}{2T}$$

$$\Rightarrow h = \frac{w_t}{2T}(x_2^2 - x_1^2)$$

$$\Rightarrow h = \frac{w_t}{2T}(x_2 + x_1)(x_2 - x_1)$$

$$\Rightarrow h = \frac{w_t}{2T} . l . (x_2 - x_1)$$

$$\Rightarrow \boxed{x_2 - x_1 = \frac{2.T.h}{w_t . l}}$$

$$\Rightarrow x_2 - x_1 = \frac{2 \times 2000 \times 50}{1 \times 400}$$

$$\Rightarrow x_2 - x_1 = 500 \text{ mt.} \rightarrow eq^n ②$$

by solving eq^n ① and eq^n ② we get

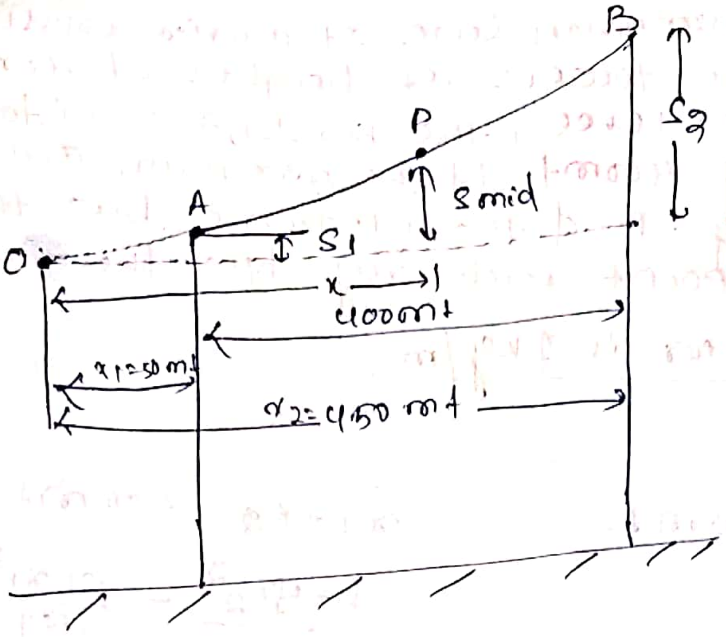
$x_2 + x_1$ → eq^n ①

$x_2 - x_1$ → eq^n ②

$$x_2 + \cancel{x_1} = 400$$
$$x_2 - \cancel{x_1} = 500$$
$$2x_2 = 900$$
$$\boxed{x_2 = 450 \text{ mt}}$$

$$x_1 = l - x_2$$
$$= 400 - 450$$
$$\boxed{x_1 = -50 \text{ mt.}}$$

Let x_1 is the distance b/w point 'O' and support 'A' & x_2 is the distance b/w point 'O' and support 'B'



Horizontal distance of mid-point 'p' from lowest point 'o' is

$x =$ Distance of A from 'o' + $\frac{400}{2}$

$= 50 + 200$

$\boxed{x = 250 \text{ mt}}$

sag at point P, $S_{mid} = \frac{w x^2}{2T} = \frac{1 \times (250)^2}{2 \times 2000}$

$S_{mid} = 15.6$ mt

sag $S_2 = \frac{w x_2^2}{2T} = \frac{1 \times (450)^2}{2 \times 2000} = 50.6$ mt.

Height of point 'B' above mid-point P

$= S_2 - S_{mid} = 50.6 - 15.6 = 35$ mt.

∴ clearance of mid-point 'p' above water level

$= 90 - 35 = 55$ mt.

Ch-4 performance of short & medium lines

→ The design and operation of a transmission line are occurs to determine the voltage drop, line losses and efficiency of transmission.

→ This values are greatly influenced by the line constant R, L and 'c' of the transmission line.

→ In this chapter, we shall develop formula by which we can calculate voltage regulation, line losses and efficiency of transmission line.

Classification of over-head lines

There are 3 types of transmission line according to Length and line voltage.

① Short transmission line :→

→ when the length of an overhead transmission line is upto 50 km and line voltage is comparatively low (<20kV), it is usually known as short transmission line.

→ Due to smaller length and lower voltage, the capacitance effects are small and hence can be neglected.

② Medium transmission line :→

→ when the length of an overhead transmission line is about 50 – 150 km and the line voltage is moderatly high (>20kV, <100kV), it is known as medium transmission line.

→ Due to sufficient length and voltage of the line, the capacitance effects are taken into account.

✱ All 3 constant R, L, C are considered in medium transmission line.

Long transmission line :→

when the length of an overhead transmission line is more than 150 km and line voltage is very high (>100kv), it is known as long transmission line.

Important Terms

① Voltage Regulation :→

The difference in voltage at the receiving end of a transmission line with no-load and full-load condition is called as voltage regulation and it is expressed as a percentage (%) of the receiving end voltage.

$$\boxed{\% V.R = \frac{V_S - V_R}{V_R} \times 100}$$

→ so the voltage regulation of a transmission line should be low.

② Transmission Efficiency :→

The ratio of receiving end power to sending end power of a transmission line is known as transmission efficiency.

$$\% \eta = \frac{\text{Receiving end power}}{\text{sending end power}} \times 100$$

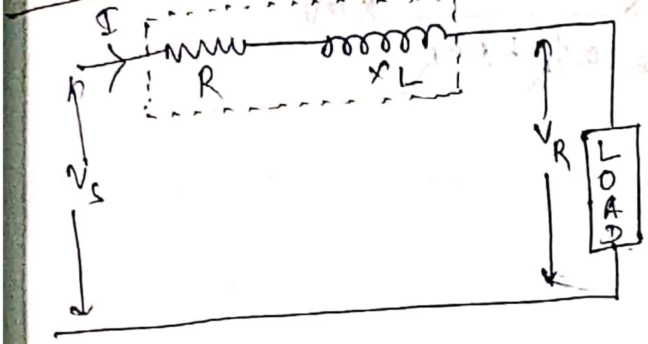
$$\% \eta = \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2 R} \times 100$$

$$\boxed{\% \eta = \frac{V_R I_R \cos\phi_R}{V_S I_S \cos\phi_S} \times 100}$$

V_R = Receiving end voltage
I_R = Receiving end current
$\cos\phi_R$ = Receiving end P.F

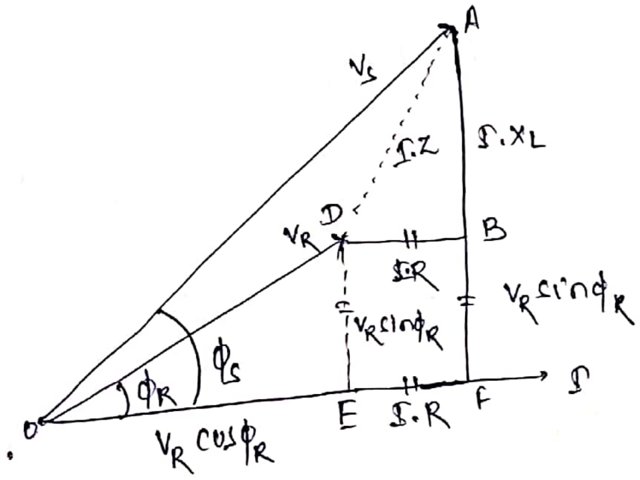
V_S = sending end voltage
I_S = sending end current
$\cos\phi_S$ = sending end P.F

Short transmission line :→



V_s = sending end voltage
V_R = Receiving end voltage
I = load current
R = loop Resistance
X_L = loop Reactance
$\cos\phi_R$ = Receiving end P.f (lagging)
$\cos\phi_s$ = sending end P.f (lagging)

Phasor diagram



By applying pythagorous theorem.

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

$$\Rightarrow (OA)^2 = (OF)^2 + (AF)^2$$

$$\Rightarrow V_s^2 = (OE + EF)^2 + (FB + BA)^2$$

$$\Rightarrow V_s = \sqrt{(V_R\cos\phi_R + I.R)^2 + (V_R\sin\phi_R + IX$$

$$\therefore \boxed{V_s = \sqrt{(V_R\cos\phi_R + I.R)^2 + (V_R\sin\phi_R + I.X_L)^2}}$$

$$\boxed{\% V_R = \frac{V_s - V_R}{V_R} \times 100}$$

$$\boxed{\text{sending end p.f} = \cos\phi_s = \frac{b}{h} = \frac{V_R\cos\phi_R + IR}{V_s}}$$

$$\boxed{\text{power delivered} = V_R I_R \cos\phi_R}$$

$$\boxed{\text{power loss} = I^2R}$$

$$\boxed{\text{sending power} = V_R I_R \cos\phi_R + I^2R}$$

% transmission efficiency $= \frac{o/p}{i/p}$

$$= \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2R} \times 100$$

Q A single Phase overhead transmission line delivers 1100 kw at 33 kV at 0.8 pf, lagging. The total resistance and inductive reactance of the line are 10Ω and 15Ω respectively. Determine: (i) sending end voltage
(ii) sending end p.f (iii) Transmission efficiency.

Ans $\cos\phi_R = 0.8$ lagging

Total line impedance $Z = R + jX_L = 10 + j15$

Receiving end voltage, $V_R = 33\,kV = 33000$ volt

line current, $I = \dfrac{1100 \times 10^3}{V_R \cos\phi_R} = \dfrac{1100 \times 10^3}{33000 \times 0.8} = 41.67$ Amp

$\cos\phi_R = 0.8$; $\sin\phi_R = 0.6$

(i) $V_s = \sqrt{(V_R\cos\phi_R + IR)^2 + (V_R\sin\phi_R + IX_L)^2}$

$= \sqrt{(33000 \times 0.8 + 41.66 \times 10)^2 + (33000 \times 0.6 + 41.66 \times 15)^2}$

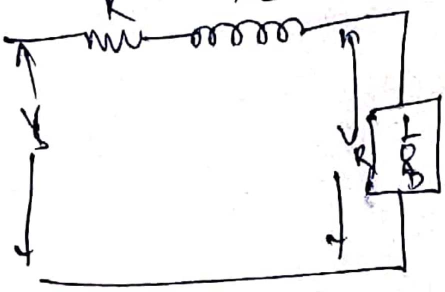
$= 33709.14$ volt.

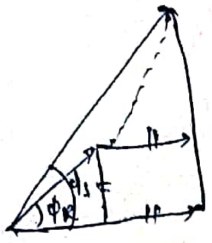
(ii) $\cos\phi_s = \dfrac{V_R\cos\phi_R + I R}{V_s} = \dfrac{33000 \times 0.8 + 41.66 \times 10}{33709.14} = 0.795$ (lagging)

(iii) efficiency $= \left(\dfrac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I^2 R}\right) \times 100$

$= \dfrac{33000 \times 41.66 \times 0.8}{33000 \times 41.66 \times 0.8 + [(41.66)^2 \times 10]} \times 100$

$= 98.44\,\%$





Q what is the maximum length in km for a 1-ϕ transmission line having copper conductor of 0.775 cm2 cross-section over which 200 kW at unity p.f and at 3300 volt are to be delivered? The efficiency of transmission is 90%. Take specific resistance as 1.725 μΩ cm.

Ans Receiving end power = 200 kW = 200,000 W

Transmission efficiency = 0.9

sending end power = $\frac{2,00,000}{0.9}$ = 2,22,222 watt
(i/p power)

Line losses = 2,22,222 − 200,000 = 22,222 watt

Line current, $I = \frac{200 \times 10^3}{3300 \times 1} = 60.6$ Amp

Let 'R Ω' be the resistance of one conductor.

Line losses = $2I^2R$

⇒ $22,222 = 2(60.6)^2 \times R$

⇒ $R = \frac{22,222}{2(60.6)^2} = 3.025\,\Omega$

⇒ $\boxed{R = \frac{\rho l}{a}}$

⇒ $l = \frac{Ra}{\rho} = \frac{3.025 \times 0.775}{1.725 \times 10^{-6}} = 1.36 \times 10^{6}$ cm = 13.6 km

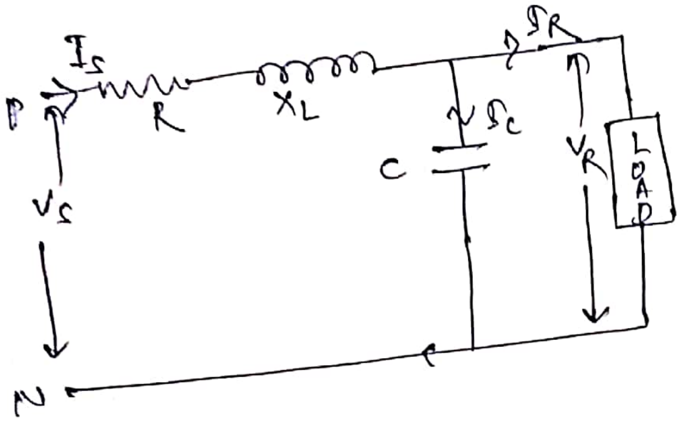
Medium transmission line :→

There are 5 methods known as localised capacitance methods for the solution of medium transmission lines are

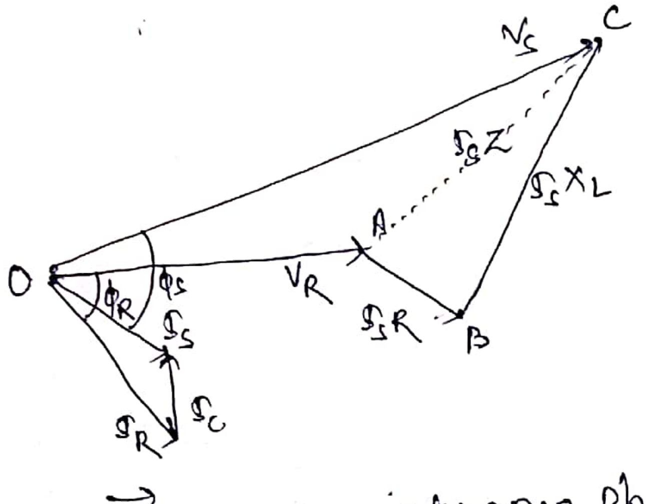
① End condenser method
② Nominal T method
③ Nominal π method

① End condenser methods

In this method, the capacitance of the line is lumped or concentrated at the receiving or load end.



I_R = load current per phase
R = Resistance per phase
X_L = inductive reactance per phase
c = capacitance per phase
$\cos\phi_R$ = Receiving end p.f (lagging)
V_S = sending end voltage per phase
$\cos\phi_S$ = sending end p.f
V_R = Receiving end voltage/phase
I_S = sending end current



Let $\vec{V_R}$ be the reference phasor.

$\vec{V_R} = V_R + j0$

load current, $\vec{I_R} = I_R \angle -\phi_R = I_R(\cos\phi_R - j\sin\phi_R)$

Capacitive current, $\vec{I_C} = j\vec{V_R}\omega C = j2\pi f C\vec{V_R}$

$X_C = \frac{1}{j\omega c}$
$= \frac{1}{j2\pi f c}$
$I_C = \frac{V_R}{X_C}$
$= \frac{V_R}{\frac{1}{j\omega c}} = V_R$

$\vec{I_s} = \vec{I_R} + \vec{I_c} = I_R(\cos\phi_R - i\sin\phi_R) + i2\pi f c V_R$

voltage drop $= \vec{I_s}\vec{Z} = \vec{I_s}(R+jX_L)$

sending end voltage $\vec{V_s} = \vec{V_R} + \vec{I_s}Z = \vec{V_R} + \vec{I_s}(R+jX_L)$

$$\boxed{\% \text{ V.R} = \frac{V_s - V_R}{V_R} \times 100}$$

% Voltage transmission efficiency $= \dfrac{\text{power delivered/phase}}{\text{power delivered/phase} + \text{losses/phase}} \times 100$

$$\boxed{\% \ \eta = \frac{V_R I_R \cos\phi_R}{V_R I_R \cos\phi_R + I_s^2 R} \times 100}$$

Q A (medium) single phase transmission line 100 km long has the following constants:

Resistance/km = 0.25 Ω , Reactance/km = 0.8 Ω

Susceptance/km = 14×10^{-6} siemen Receiving end line voltage = 66 kV.

Assuming that the total capacitance of the line is localised at the receiving end alone, determine (i) sending end current

(ii) The sending end voltage

(iii) The V.R

(iv) supply p.f

The line is delivering 15,000 kW at 0.8 p.f lagging. Draw the phasor diagram to illustrate your calculation.

$Z = R + jX_L$

$Y = \frac{1}{Z} = \frac{1}{R+jX_L}$

$I_c = \frac{V_R}{X_C}$

$= \frac{1}{X_C} \cdot V_R$

$I_c = B V_R$

Soln Total Resistance $R = 0.25 \times 100 = 25\ \Omega$

Total Reactance $X_L = 0.8 \times 100 = 80\ \Omega$

Total susceptance $B = 14 \times 10^{-6} \times 100 = 14 \times 10^{-4}\ S$

Receiving end voltage $V_R = 66000$ V

load current, $I_R = \frac{15,000 \times 10^3}{66000 \times 0.8} = 284$ Amp

$\cos\phi_R = 0.8$ $\sin\phi_R = 0.6$

Taking receiving end voltage as the reference phasor,

$\vec{V_R} = V_R + j0 = 66,000$ volt

load current $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

$= 284(0.8 - j0.6) = 227 - j170$

Capacitive current $\vec{I_C} = jB \times V_R = j14 \times 10^{-4} \times 66000 = j92$

(i) sending end current $\vec{I_S} = \vec{I_R} + \vec{I_C} = (227 - j170) + j92$

$= 227 - j78$

magnitude of $I_S = \sqrt{(227)^2 + (78)^2}$

= 240 Amp.

(ii) voltage drop = $\vec{I_S} Z = \vec{I_S}(R + jX_L)$

$= (227 - j78)(25 + j80)$

$= 5675 + j18,160 - j1950 + 6240$

$= 11,915 + j16,210$

sending end voltage, $\vec{V_S} = V_R + \vec{I_S} Z = 66000 + 11915 + j16$

$= 77915 + j16210$

magnitude of $V_s = \sqrt{(77915)^2 + (16210)^2}$

= 79583 volt.

(iii). $\% V.R = \frac{V_s - V_R}{V_R} \times 100 = \frac{79583 - 66000}{66000} \times 100 = 20.58\%$

(iv) Phase angle b/w $\vec{V_R}$ & $\vec{I_R}$ is

$$\theta_1 = \tan^{-1}\left(\frac{-78}{227}\right) = \tan^{-1}(-0.3436) = -18.96^\circ$$

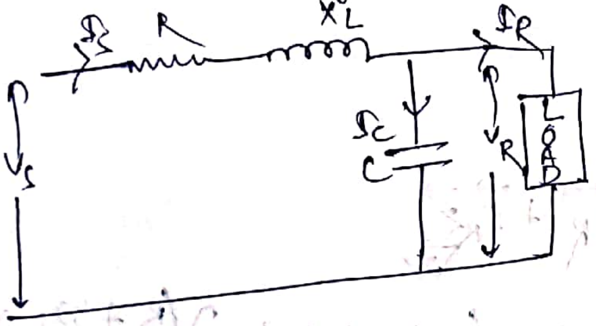
Phase angle b/w $\vec{V_R}$ & $\vec{V_s}$ is

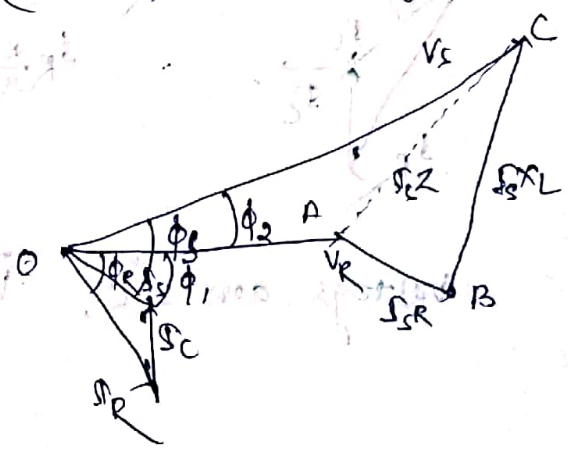
$$\theta_2 = \tan^{-1}\frac{16210}{77915} = \tan^{-1}(0.2036) = 11.50^\circ$$

supply power factor angle

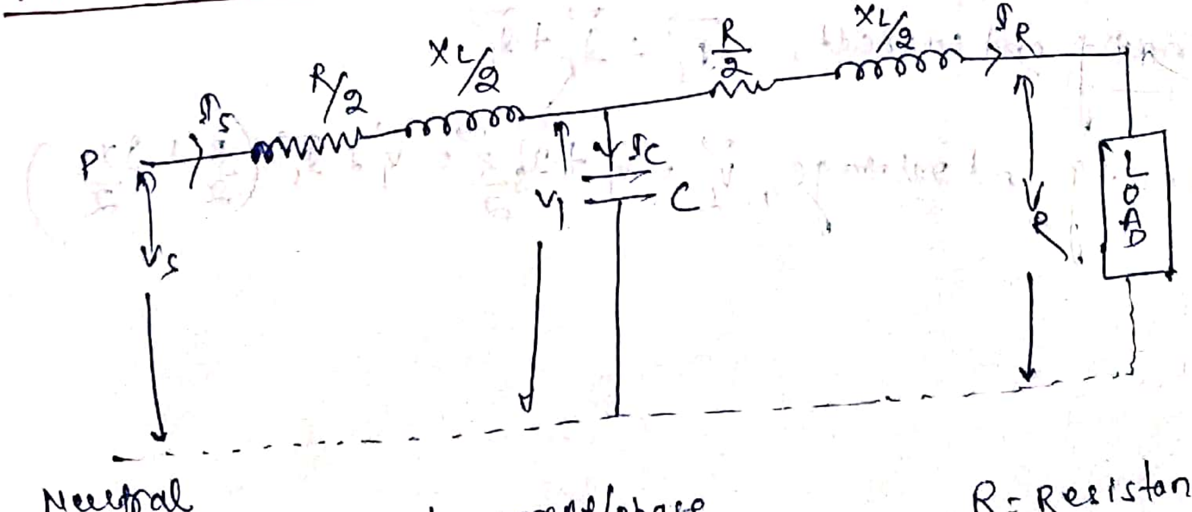
$$\theta_s = 18.96 + 11.50 = 30.46^\circ$$

supply p.f = $\cos\phi_s = \cos(30.46^\circ) = 0.86$ lag





Nominal T-Method's



I_R = load current/phase

X_L = inductive reactance/Phase

$\cos\phi_R$ = receiving end p.f

V_1 = voltage across capacitor C.

R = Resistance/Phase

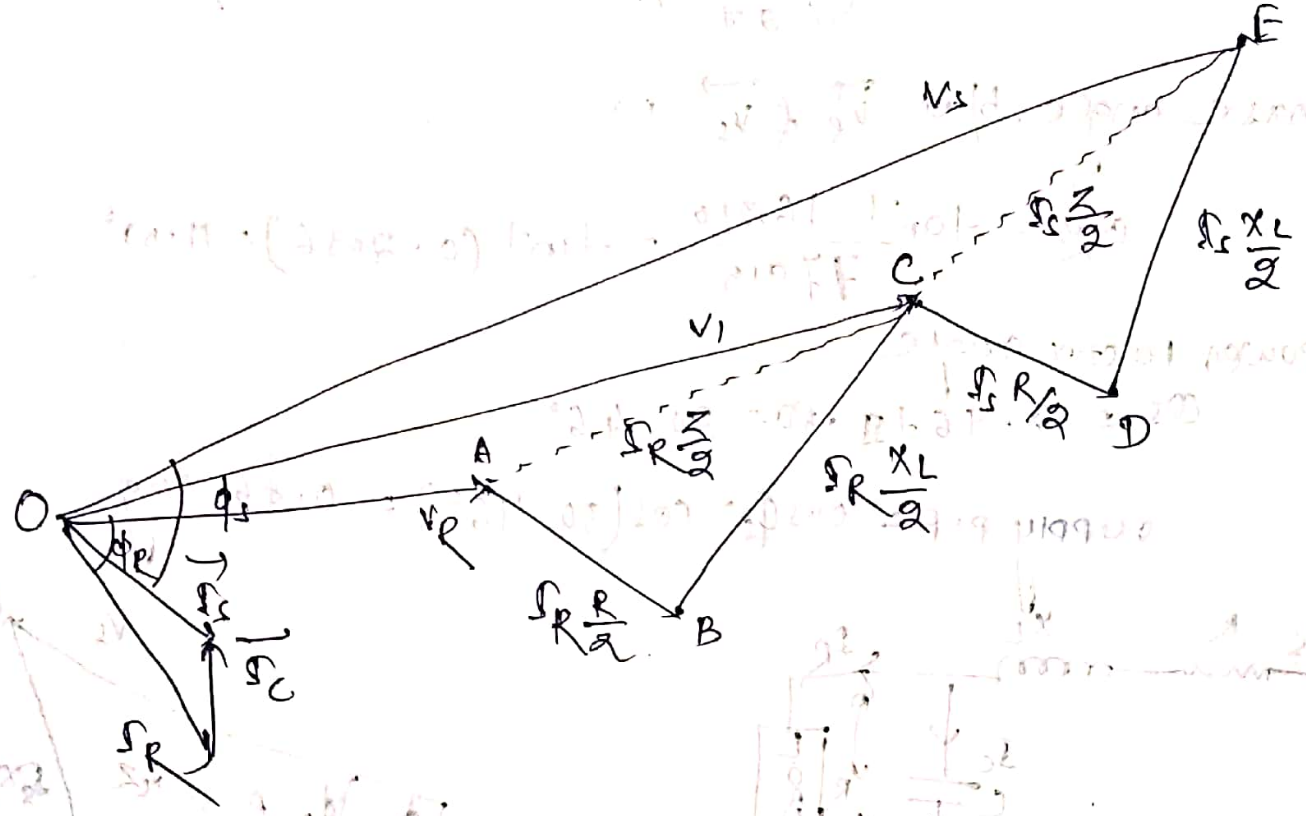
C = capacitance/phase

V_s = sending end voltage/ph

Taking receiving end voltage $\vec{V_R}$ as the reference phasor

Receiving end voltage $\vec{V_R} = V_R + j0$

load current, $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$



voltage across C, $\vec{V_1} = \vec{V_R} + \vec{I_R}\frac{\vec{Z}}{2}$

$$= V_R + I_R(\cos\phi_R - j\sin\phi_R)\left(\frac{R}{2} + \frac{jX_L}{2}\right)$$

capacitive current, $\vec{I_C} = j\omega C\vec{V_1} = j2\pi f C\vec{V_1}$

sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C}$

sending end voltage, $\vec{V_S} = \vec{V_1} + \vec{I_S}\frac{\vec{Z}}{2} = \vec{V_1} + \vec{I_S}\left(\frac{R}{2} + \frac{jX_L}{2}\right)$

Q. A 3-ϕ, 50 Hz overhead transmission line 100 km long has the following constants;

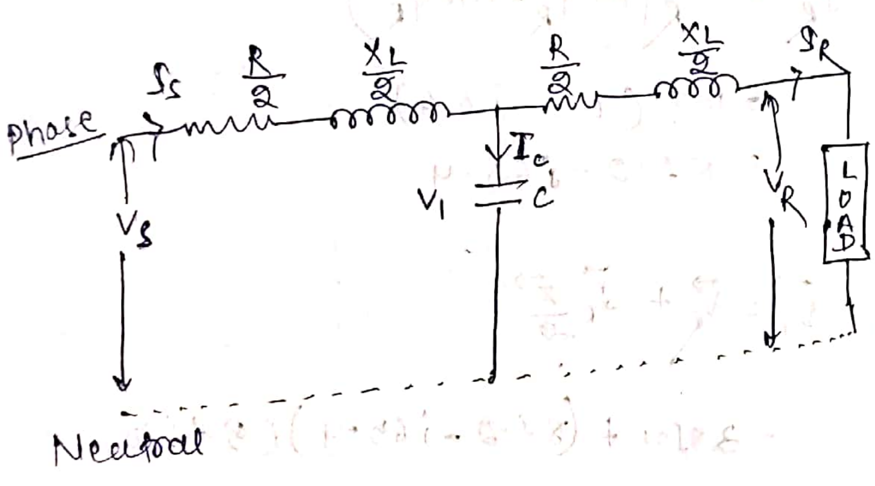
Resistance/km/phase = 0.1 Ω

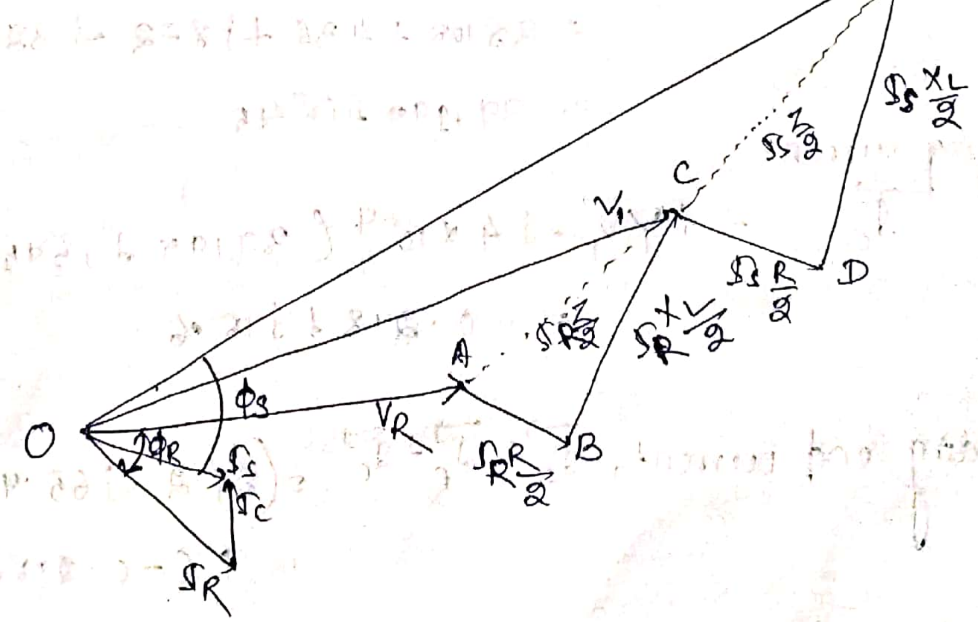
inductive reactance/km/phase = 0.2 Ω

capacitive susceptance/km/phase = 0.04×10^{-4} siemen

Determine (i) The sending end current
(ii) sending end voltage
(iii) sending end power factor
(iv) transmission efficiency when supplying a balanced load of 10,000 kw at 66 kv, p.f 0.8 lagging.

use nominal T-method :→





Total resistance/ph $R = 0.1 \times 100 = 10\Omega$

Total reactance/ph $X_L = 0.2 \times 100 = 20\Omega$

capacitive susceptance $Y = 0.04 \times 10^{-4} \times 100 = 4 \times 10^{-4}$ S

Receiving end voltage/ph, $V_R = \frac{66000}{\sqrt{3}} = 38105$ volt

load current, $I_R = \frac{10000 \times 10^3}{\sqrt{3} \times 66 \times 10^3 \times 0.8} = 109$ Amp

$\cos\phi_R = 0.8 \quad \sin\phi_R = 0.6$

impedance/ph $= \vec{Z} = R + jX_L = 10 + j20$

(i) Receiving end voltage, $\vec{V_R} = V_R + j0 = 38{,}105$ volt

load current $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

$= 109(0.8 - j0.6)$

$= 87.2 - j65.4$

voltage across 'C', $\vec{V_1} = \vec{V_R} + \vec{I_R}\frac{\vec{Z}}{2}$

$= 38105 + (87.2 - j65.4)(5 + j10)$

$= 38105 + 436 + j872 - j327 + 654$

$= 39{,}195 + j545$

Charging current $\vec{I_C} = jY\vec{V_1} = j4 \times 10^{-4}(39195 + j545)$

$= -0.218 + j15.6$

Sending end current, $\vec{I_S} = \vec{I_R} + \vec{I_C} = (87.2 - j65.4) + (-0.218 + j15.6)$

$= 87.0 - j49.8$

$= 100\angle -29^\circ 47'$ Amp

∴ sending end current $|\vec{I_s}|$ = 100 Amp

(ii) sending end voltage $\vec{V_s} = \vec{V_1} + \vec{I_s}\frac{Z}{2}$

$= (39{,}195 + j545) + (87.0 - j49.8)(5 + j10)$

$= 39195 + j545 + 434.9 + j870 - j249$

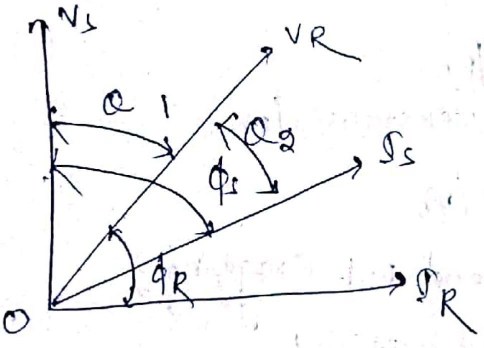
$+ 498$

$\doteq 40128 + j1170 = 40145 \angle 1°40'$ Volt

∴ line value of sending end voltage $= \sqrt{3} \times 40145$

$= 69.533$ kV

(iii) Referring to phasor diagram,



θ_1 = angle b/w $\vec{V_R}$ & $\vec{V_s}$ = 1°40'

θ_2 = angle b/w $\vec{V_R}$ & $\vec{I_s}$

29°, 47'

$\phi_s = \theta_1 + \theta_2$

$= 1°40' + 29°47'$

$= 31°27'$

sending end p.f $\cos\phi_s = \cos(31°27') = 0.853$ lagging

(iv) sending end power $= 3 V_s I_s \cos\phi_s = 3 \times 40145 \times 100 \times 0.853$

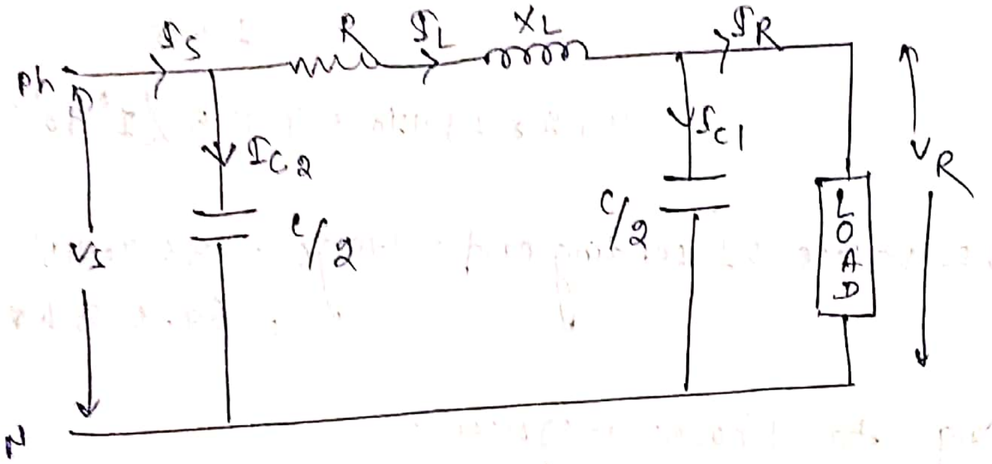
$= 10273105$ watt $= 10273.105$ kW

power delivered = 10,000 kW

∴ Transmission efficiency $= \frac{10{,}000}{10273{,}105} \times 100 = 97.34\%$

Nominal π - methods

In this method, capacitance of each conductor (i.e line to neutral) is divided into two halves; one half being lumped at the sending end and the other half at the receiving end



I_R = load current/ph

R = Resistance/ph

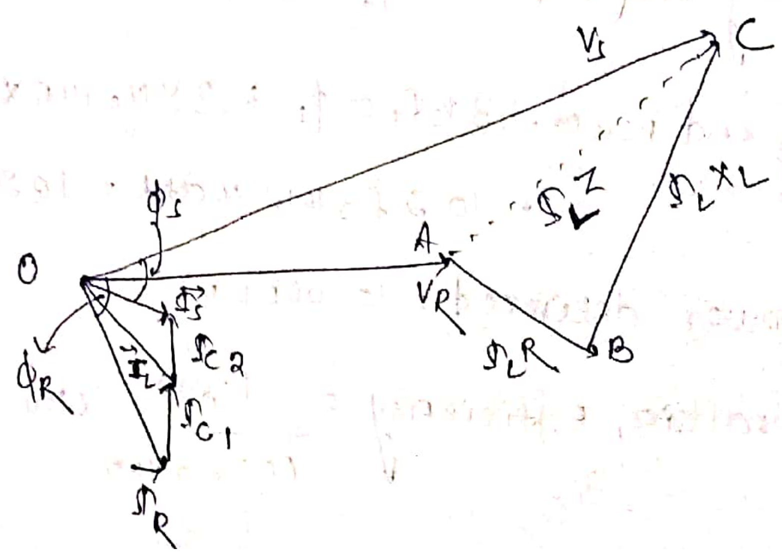
X_L = inductive reactance/ph

C = capacitance/ph

$\cos\phi_R$ = receiving end p.f (lagging)

V_s = sending end voltage/ph

Taking $\vec{V}_R$ as the reference Phasor.



$\vec{V_R} = V_R + j0$

load current $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R)$

charging current at load end is

$$\vec{I_{C1}} = j\omega\left(\frac{C}{2}\right)\vec{V_R} = j\pi f C \vec{V_R}$$

Line current, $\vec{I_L} = \vec{I_R} + \vec{I_{C1}}$

sending end voltage, $\vec{V_S} = \vec{V_R} + \vec{I_L}\vec{Z}$

$$= \vec{V_R} + \vec{I_L}(R + jX_L)$$

charging current at the sending end is

$$\vec{I_{C2}} = j\omega\left(\frac{C}{2}\right)\vec{V_S} = j\pi f C \vec{V_S}$$

∴ sending end current $\vec{I_S} = \vec{I_L} + \vec{I_{C2}}$

Q A 3ϕ, 50 Hz, 150 km line has a resistance, inductive reactance and capacitive shunt admittance of 0·1Ω, 0·5Ω and 3×10^{-6} S per km per phase. If the line delivers 50 MW at 110 kV and 0·8 pf lagging, determine the sending end voltage and current. Assume a nominal π circuit for the line.

Ans

Total resistance /ph = $R = 0{\cdot}1 \times 150 = 15\Omega$

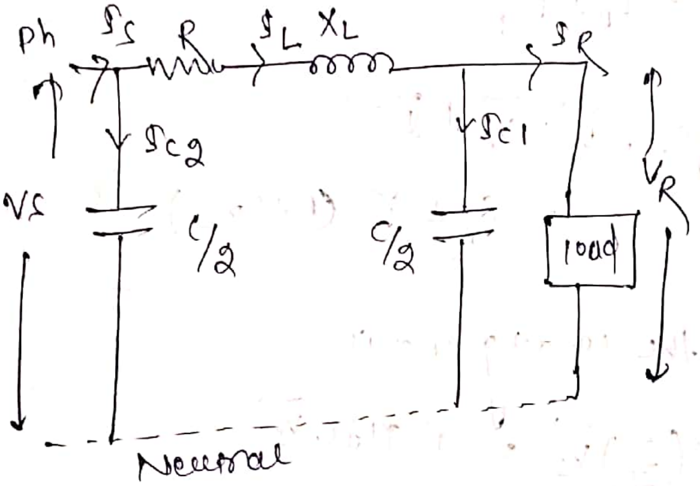
Total reactance /ph = $X_L = 0{\cdot}5 \times 150 = 75\Omega$

capacitive admittance /ph = $Y = 3 \times 10^{-6} \times 150 = 45 \times 10^{-5}$ S

Receiving end voltage /ph $V_R = \frac{110 \times 10^3}{\sqrt{3}} = 63508$ volt

load current, $I_R = \frac{50 \times 10^6}{\sqrt{3} \times 110 \times 10^3 \times 0.8} = 328$ Amp

$\cos\phi_R = 0.8$ $\sin\phi_R = 0.6$



Taking Receiving end voltage as the reference phasor, we have

$\vec{V_R} = V_R + j0 = 63,508$ volt

load current $\vec{I_R} = I_R(\cos\phi_R - j\sin\phi_R) = 328(0.8 - j0.6)$

$= 262.4 - j196.8$

charging current at the load end is

$\vec{I_{C1}} = \vec{V_R}\, j\frac{Y}{2} = 63508 \times j\frac{45 \times 10^{-5}}{2} = j14.3$

line current $\vec{I_L} = \vec{I_R} + \vec{I_{C1}} = (262.4 - j196.8) + j14.3$

$= 262.4 - j182.5$

sending end voltage, $\vec{V_s} = \vec{V_R} + \vec{I_L}\vec{Z}$

$= \vec{V_R} + \vec{I_L}(R + jX_L)$

$= 63508 + (262.4 - j182.5)(15 + j75$

$= 63,508 + 3936 + j19,680 - j2737.5$

$+ 13,688$

$= 81,131 + j16942.5 = 82,881\angle 11°47$

Scanned by CamScanner

∴ line to line sending end voltage $= 82881 \times \sqrt{3}$

$= 143550$ volt

$= 143.55$ kV

charging current at the sending end is

$$I_{C2} = j \vec{V_s} \frac{Y}{2} = (81131 + j\,16942.5)\; j\,\frac{45 \times 10^{-5}}{2}$$

$$= -3.81 + j\,18.25$$

sending end current $\vec{I_s} = \vec{I_L} + \vec{I_{C2}} = (262.4 - j\,182.5)$

$+ (-3.81 + j\,18.25)$

$= 258.6 - j\,164.25$

$= 306.4 \angle -32.4^\circ$ Amp

$= 306.4$ Amp

sending end current I_s

Ch-5 EHV Transmission

5.1 EHV AC transmission

5.1.1 Reasons for adoption of EHV AC transmission

① **Reduction of electrical losses**

→ Line losses are reduced since line losses are inversely proportional to the transmission voltage.

$$\boxed{I^2R \propto \frac{1}{V}}$$

② **Increase in transmission efficiency**

Transmission efficiency increases because of reduction in line losses.

③ **Improvement of voltage regulation**

→ Improvement of voltage regulation because of reduction of voltage drop.

④ **Reduction of conductor material Requirement.**

→ Lesser conductor material is required because current is inversely proportional to voltage.

$$\boxed{I \propto \frac{1}{V}}$$

⑤ Interconnection of power system in a large network can be possible.

⑥ Increase in transmission capacity of the line.

5.1.2 Problems involved in EHV transmission

Corona loss and Radio interference.

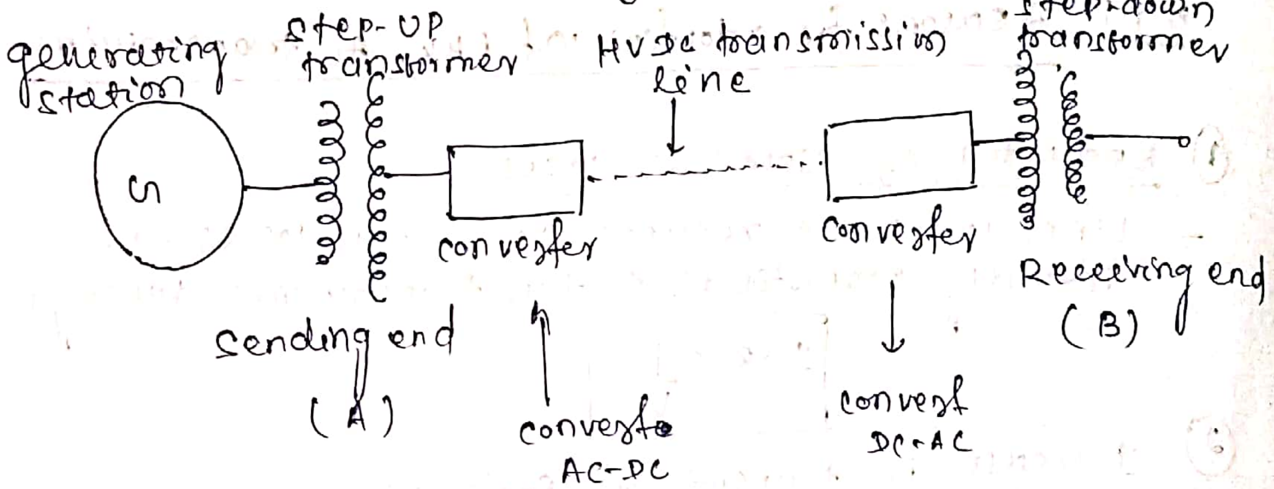
① Corona loss and Radio interference.

② Heavy supporting structures and Erection difficultie

③ Insulation Requirement.

5.2 HVDC transmission

Principle of HVDC system operation



5.2.1 Advantages of HVDC transmission system

① **Cheaper in cost:→**

→ The HVDC transmission line require two conductor while 'ac' system requires 3 conductors to carry power.

② No skin and ferranti effect.

③ **Lower Transmission Losses:→**

→ HVDC transmission system require only two conductor and therefore, the power losses in a 'dc' line are lesser than the 'ac' line system.

④ **Better voltage Regulation:→**

→ There is no inductance, hence the voltage drop due to inductive reactance does not exist in 'dc' transmission line. Thus voltage Regulation is better in 'DC' system.

⑤ Ground can be used as a return conductor.

⑥ No charging current.

⑦ No switching transient

⑱ No stability limit.

⑨ It requires less space as compared to HVAC transmission with same voltage rating and size.

⑩ Lesser corona losses and Radio interference.

→ The corona loss is directly proportional to $(f+25)$ where 'f' is the frequency. so corona loss in 'dc' system are lesser than in 'ac' system.

Limitation of HVDC transmission

① costly terminal equipments! →

→ The HVDC transmission system require expensive components like converters, filters

② More maintenance of line insulators.

③ converter control is quite complex.

④ Additional filters are required at various stages of HVDC transmission system. to remove harmonics.

⑤ DC circuit breaking system is costlier than ac circuit breaking system.

(Ch-6)
Distribution system

→ That part of power system which distribute electric power for local use is known as distribution system. Distribution system is nothing is a conductor.

In general, the distribution system is the electrical system b/w the sub-station fed by the transmission system and the consumers meters.

→ It is generally consist of

(i) Feeders

(ii) distributors

(iii) service connection/ service main

Feeders

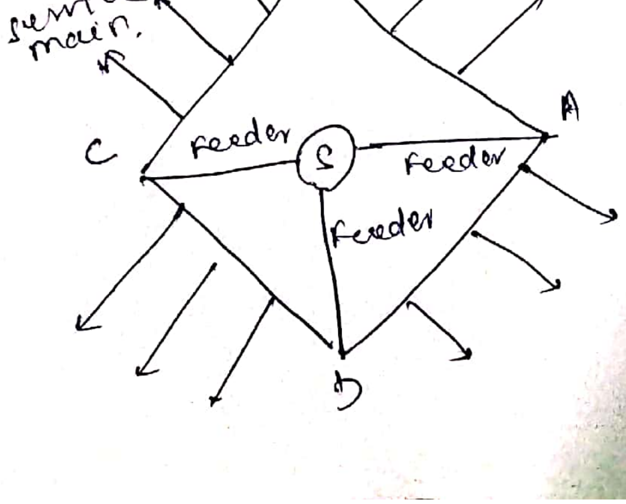
(i) A Feeder is a conductor which connects the substation to the area where power is to be distributed.

(ii) Generally, no tapping are taken from the feeder so that current in it remains the same throughout

Distributor

A distributor is a conductor from which tappings are taken for supply to the consumers.

→ The current is not constant because tappings are taken at various places along it's length.



AB, BC, CD, AD are distributors.

service main :

A service mains is generally a small cable which connects the distributor to the consumer's terminals .

classification of distribution systems

A distribution system may be classified according to !

(i) Nature of current : According to nature of current it is 2 types ① AC distribution system

② DC distribution system.

AC system is adopted for distribution of electric power as it is simpler and more economical than direct current method .

(ii) Types of construction !

According to construction it is classified as

(a) overhead system

(b) underground system .

* overhead system is generally employed for distribution as it is 5 to 10 times cheaper than equivalent underground system .

(iii) scheme of connection

According to scheme of connection , the distribution system may be classified as

(a) Radial system

(b) ring main system.

(c) interconnected system .

Ac distribution (Nature of current)

Ac system is generally prefer in generation, transmission and distribution. The main behind that is (i) Alternating voltage can be conveniently changed in magnitude by using T/F.

(ii) High transmission and distribution voltage reduce the current in the conductor and the losses in line is less.

The a.c distribution system is classified into
(i) Primary distribution system
(ii) secondary distribution system

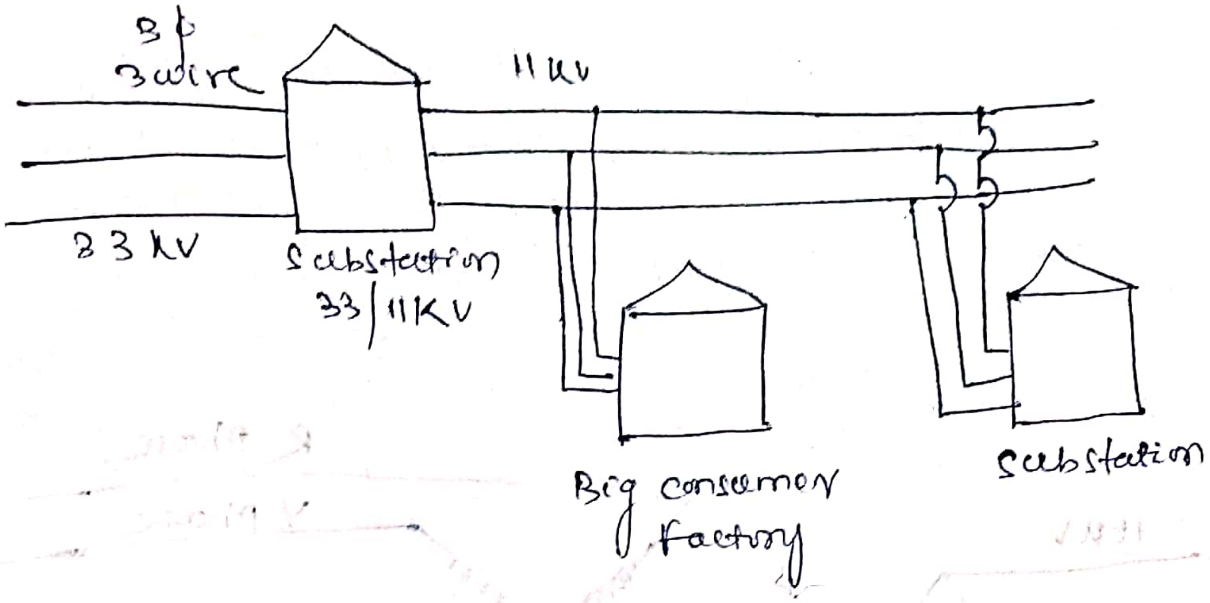
① primary distribution system

→ This voltage is generally higher than utilization and handles large blocks of electrical energy than the average low-voltage consumers uses

→ primary distribution voltages are 11 kv, 6.6 kv and 3.3 kv.

→ primary distribution is carried out by 3-Phase 3-wire system.

(industry, workshop, substation



(2) secondary distribution system

→ This distribution system includes the range of voltage at which the ultimate consumer utilises the electrical energy delivered to him.

→ The secondary distribution employes 400/230 volt. (3φ, 4 wire system)

→ The primary distribution circuit delivered power to various substation, called distribution substation.

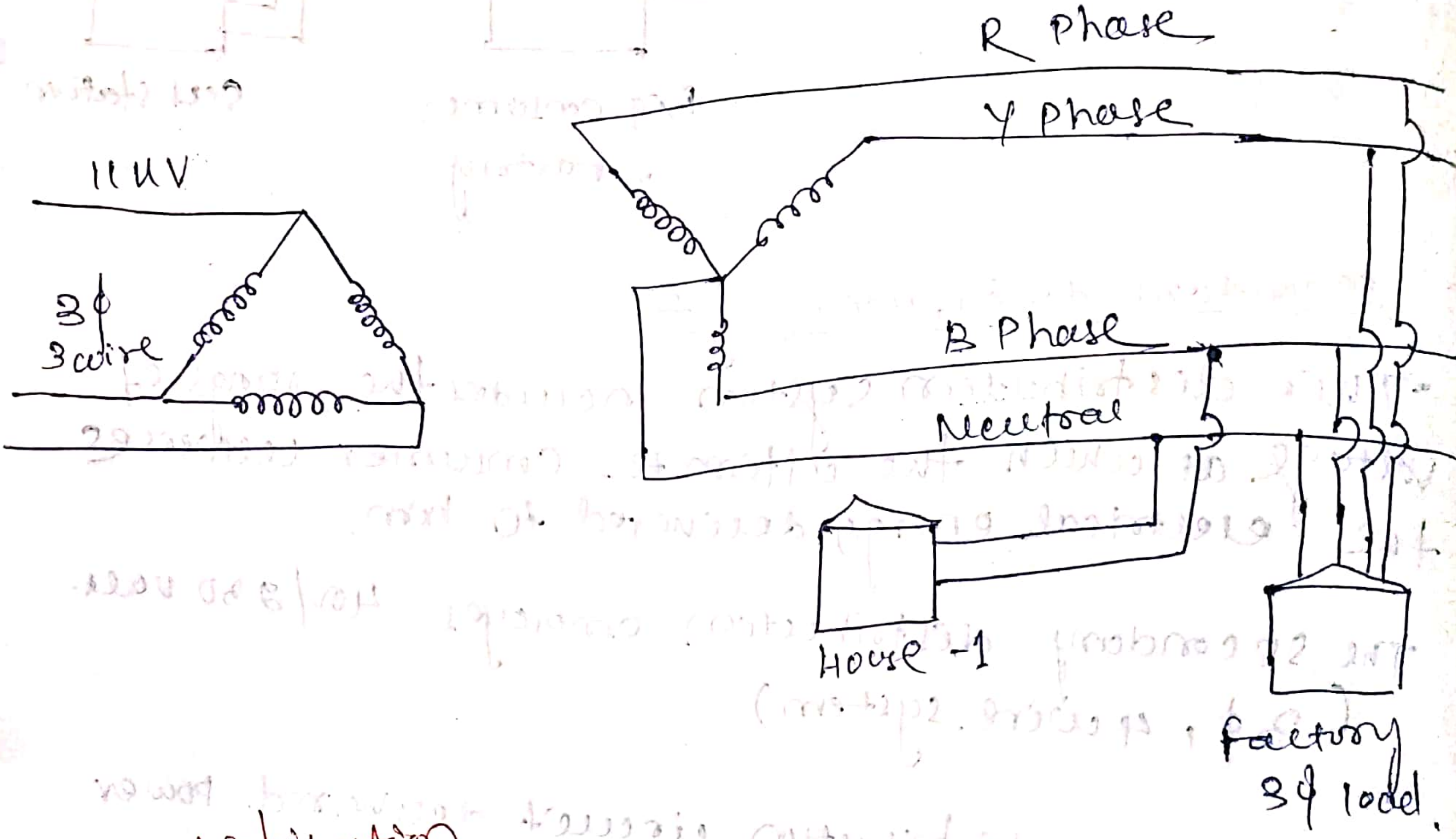
* The substations are situated near the consumer's localities and contain step-down T/F.
* At distribution substation the voltage is stepped down to 400 volt. and The system is 3φ, 4wire.

Phase - Phase
400 volt

Phase - Neutral
230

Phase, N ← connected to load (1φ)

3φ → connected to 3 Phase load, Motor



D.C distribution

For certain application, d.c supply is absolutely necessary. DC supply is required for the certain operation of variable speed machinary (i.e dc Motors).

→ The d.c supply from the substation may be obtained in the form of (i) 2 wire or (ii) 3-wire for distribution.

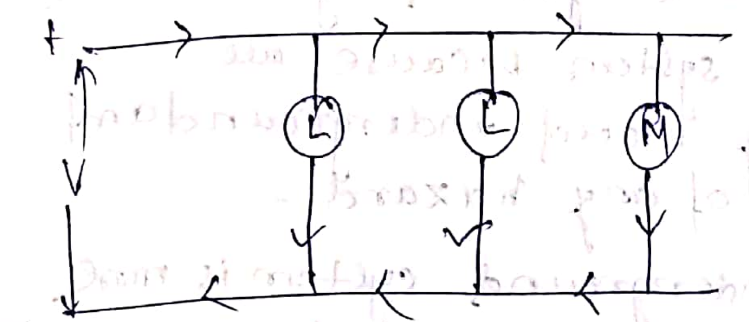
(i) 2 wire d.c. system

It consist of 2 wire i.e positive and negative

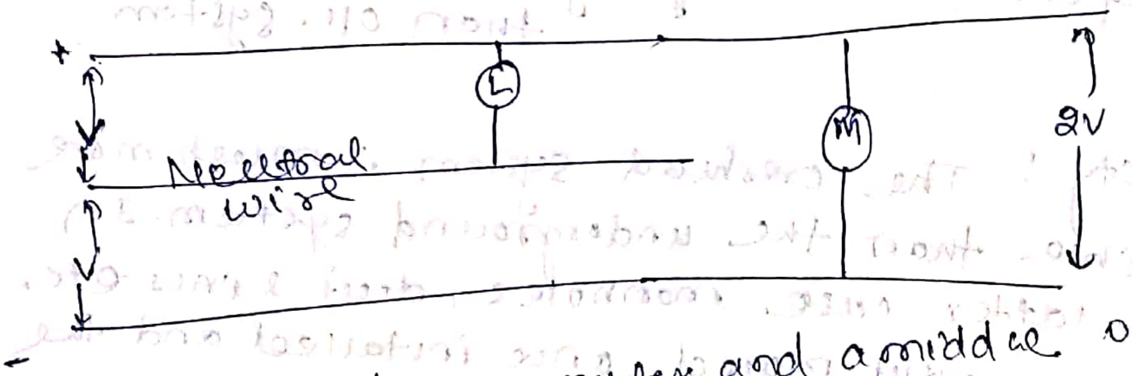
→

→ The loads such as lamps, motors etc. are connected in parallel b/w the two wires.

→ This system is never used for transmission purposes due to low efficiency but may be employed for distribution of d.c power.



(ii) 3 wire d.c system



→ It consist of two outer and a middle or neutral wire which is earthed at substation.

Overhead versus underground system

- ✱ overhead lines are generally mounted on wooden, concrete or steel poles which are arranged to carry distribution T/F in addition to the conductors.
- ✱ The underground system uses conduits, cables and manholes under the surface of street and sidewalks.
- ✱ the comparison b/w OH and U.g. cables

(i) public safety : The underground system is more safe than overhead system because all distribution wiring placed underground and are little chance of any hazard.

(ii) initial cost : The underground system is more expensive due to the high cost of trenching, conduits, cables, manholes and other special equipments. U.g system is 5 time more than OH. system.

(iii) Flexibility : The overhead system is much more flexible than the underground system. In the latter case manholes, duct lines etc. are permanently placed once installed and the load expansion can only be met by laying new lines. however on an overhead system, poles, wires, transformers etc, can be easily shifted to meet the changes in load conditions.

(iv) faults : The chances of faults in underground system are very rare as the cables are laid underground and are generally provided with better insulation.

Connection schemes of distribution system

① Radial system

All distribution of electrical energy is done by constant voltage system.

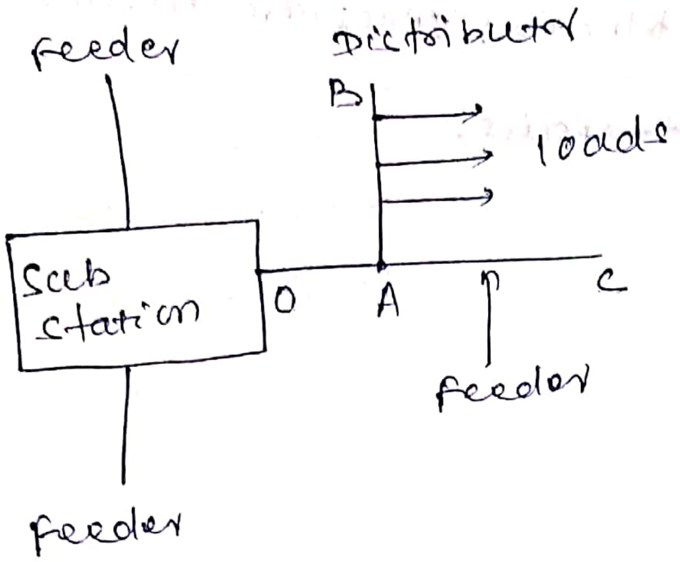
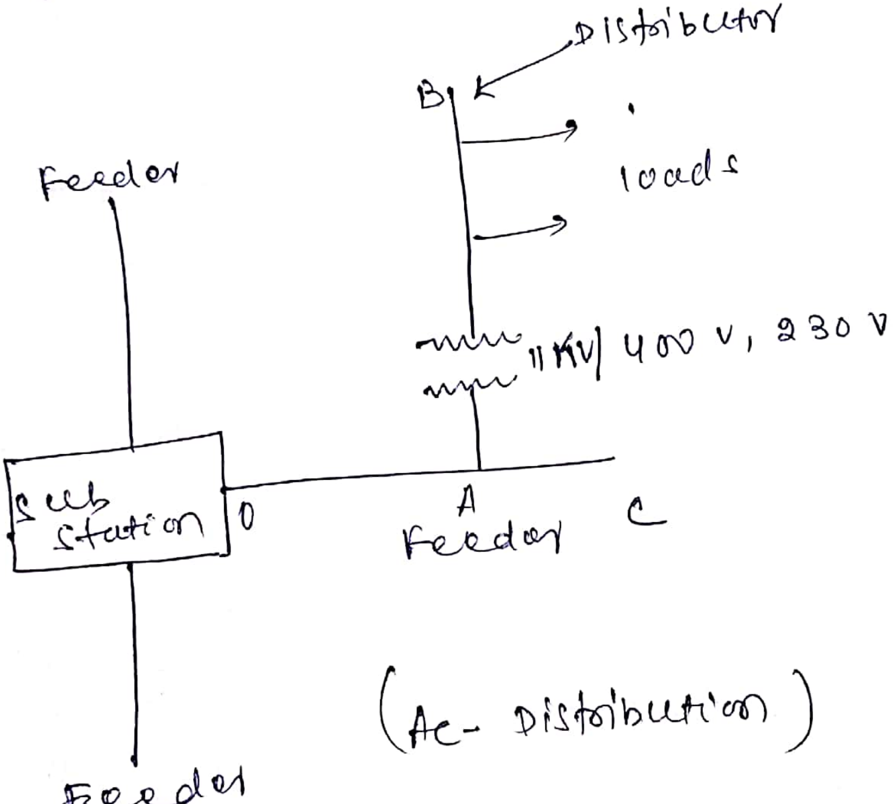


fig. (1) (DC- distribution)



(AC- Distribution)

(fig - 2)

→ In this system, separate feeders radiate from a single sub-station and feed the distributors at one end only

→ In single line diagram OC is the feeder, supplies a distributor AB at point A.

→ The radial system is employed only when power is generated at low voltage and the substation is located at the centre of the load.

Advantages ① simplest distribution. ckt & lowest initial cost.

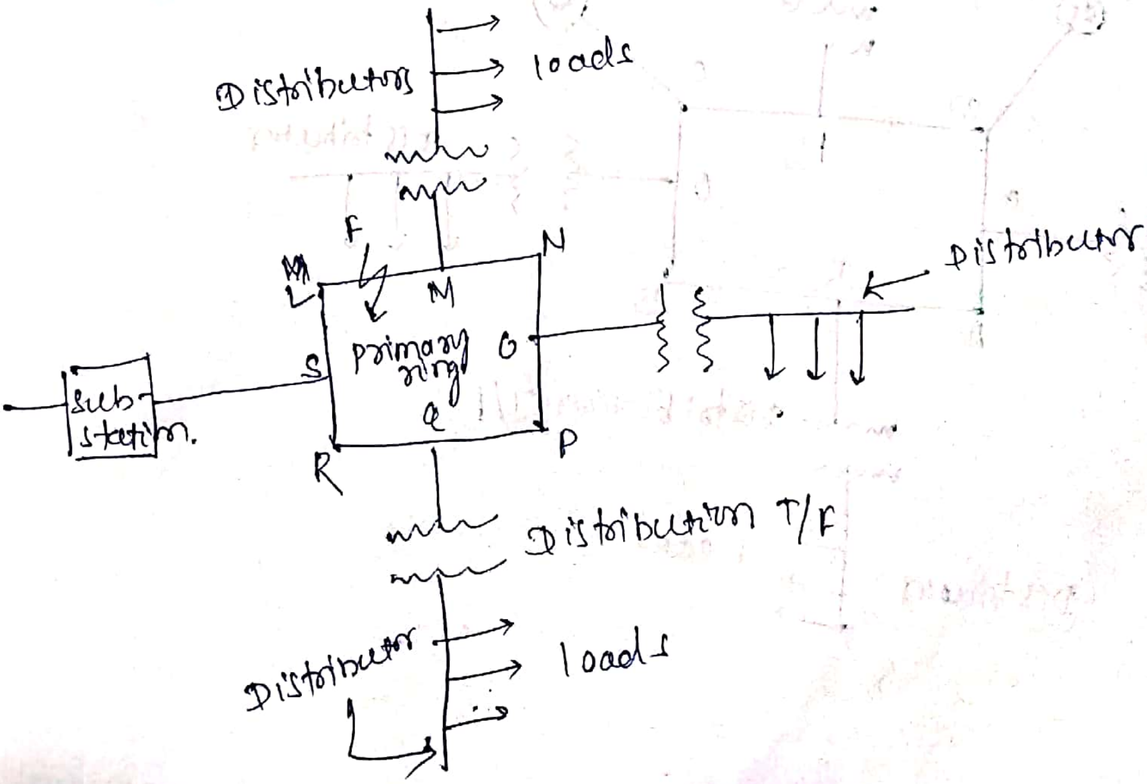
dis advantages ① The end of the distributor nearest to the feeding point will be heavily loaded.

② The consumers are dependent on a single feeder and single distributor. Therefore, any fault on the feeder or distributor cuts off supply to the consumers who are on the side of the fault away from the substation.

③ The consumers at the distant end of the distributor would be subjected to serious voltage fluctuation when the load on the distributor changes.

* Due to this limitation, this system is used for short distance only.

② Ring mains system



→ In this system, the primaries of distribution T/F form a loop. The loop ckt starts from the sub-station bus-bars, make a loop through the area to be served, and returns to the substation.

→ In the single line diagram LMNOPQRS form a closed feeder.

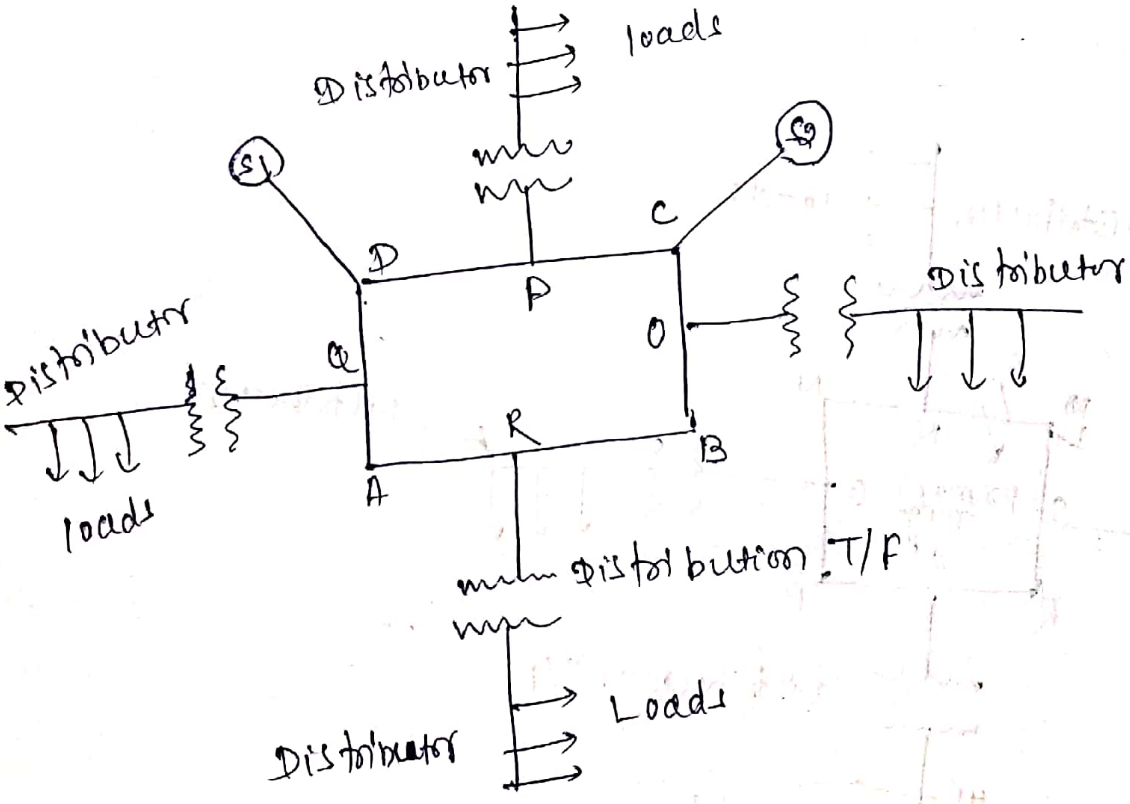
→ Then the distributors are tapped from different point M, 'O' & 'Q' of the feeder through distribution T/F.

Advantages

→ There are less voltage fluctuation at consumer's terminals.

→ The system is very reliable as each distributor is fed through two-feeders. In the event of fault on any section of the feeder, The continuity of supply is maintained.

Interconnected system



→ when the feeder ring is energised by two or more than two generating station or sub-station, It is called inter-connected system.

→ In single line diagram, the closed feeder ring ABCD is supplied by two substations S_1 and S_2 at point D and 'C' respectively.

→ Distributors are connected to point O, P, Q, and R of the feeder ring through distribution T/F.

Advantages

→ It increases the service reliability.

→ Any area fed from one generating station during peak load hours can be fed from the other generating station. This reduces reserve power capacity and increase efficiency of the system.

DC distribution system.

However, for certain applications, DC supply is absolutely necessary. For example, d.c supply is required for the operation of variable speed machinery (e.g DC motors), electro chemical work and electric traction.

→ For this purpose a.c power is converted into D.C power at the sub-station by using converting machinery e.g mercury are rectifiers, rotary converters and motor-generator sets.

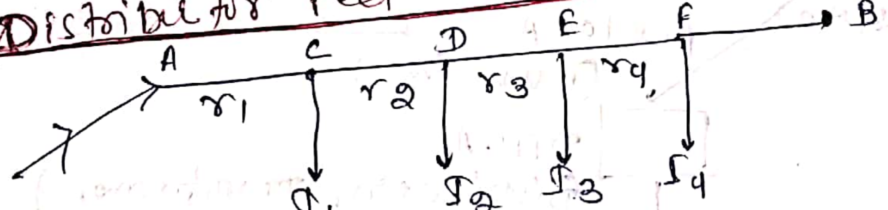
→ The D.C supply from the sub-station is conveyed to the required places for distribution.

Types of D.C Distributors

The most general method of classifying d.c distributors is the way they are fed by the feeders. On this basis, d.c distributors are classified as:

① Distributor fed at one end
② Distributor fed at both end
③ Ring Distributor

① Distributor fed at one end :→



* It is easy to see that the minimum potential will occur at point 'F' which is farthest from the feeding point A

Let r_1, r_2, r_3 & r_4 be the resistance of both wires (go & return) of the sections AC, CD, DE, EF of the distributor respectively.

current fed from point A = $I_1+I_2+I_3+I_4$

current in section AC = $I_1+I_2+I_3+I_4$

current in section CD = $I_2+I_3+I_4$

current in section DE = I_3+I_4

current in section EF = I_4

voltage drop in section
AC = $r_1(I_1+I_2+I_3+I_4)$
CD = $r_2(I_2+I_3+I_4)$
DE = $r_3(I_3+I_4)$
EF = $r_4 I_4$

So Total voltage drop in distributor
$= r_1(I_1+I_2+I_3+I_4)+r_2(I_2+I_3+I_4)+r_3(I_3+I_4)+r_4I_4$

Q: A two wire DC distributor cable AB is 2 km long and supplies loads of 100A, 150 A, 200A and 50 Amp situated 500m, 1000m, 1600 mt and 2000 mt from the feeding point A. Each conductor has a resistance of 0.01 Ω per 1000 m. calculate the p.d at each load point if a p.d of 300 V is maintained at point 'A'.

Resistance per 1000 m of distributor $2 \times 0.01 = 0.02\Omega$

Resistance of section AC, $R_{AC} = 0.02 \times \frac{500}{1000}$

$= 0.01 \Omega$

Resistance of section CD, $R_{CD} = 0.02 \times \frac{500}{1000} = 0.01 \Omega$

Resistance of section DE, $R_{DE} = 0.02 \times \frac{600}{1000} = 0.012 \Omega$

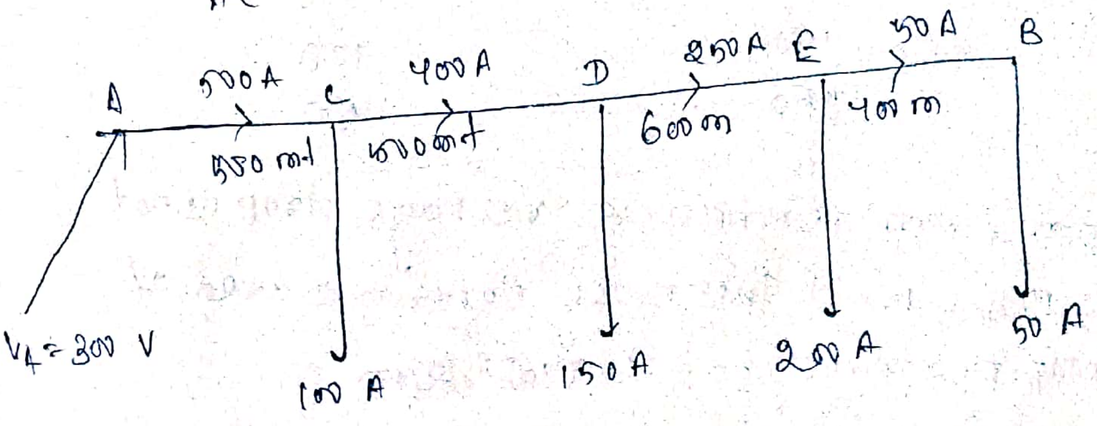
Resistance of section EB, $R_{EB} = 0.02 \times \frac{400}{1000} = 0.008 \Omega$

$I_{EB} = 50$ Amp

$I_{DE} = 50 + 200 = 250$ Amp

$I_{CD} = 250 + 150 = 400$ Amp

$I_{AC} = 400 + 100 = 500$ Amp



P. D at load point C, V_C = voltage at A - voltage drop in AC

$= V_A - I_{AC} R_{AC}$

$= 300 - 500 \times 0.01 = 295$ Amp

P. D at load point D, $V_D = V_C - I_{CD} R_{CD}$

$= 295 - 400 \times 0.01 = 291$ V

P. D at load point E, $V_E = V_D - I_{DE} R_{DE}$

$= 291 - 250 \times 0.012 = 288$ V

P. D at load point B, $V_B = V_E - I_{EB} R_{EB}$

$= 288 - 50 \times 0.008 = 287.6$ V

Q. 2 A 2-wire d.c distributor AB is 300 mt long. It is fed at point A. The various loads and their positions are given below.

At point	distance from A in mt.	concentrated load in Amps
C	40	30
D	100	40
E	150	100
F	250	50

if the maximum permissible voltage drop is not to exceed 10 V, find the cross-sectional area of the distributor. Take $\rho = 1.78 \times 10^{-8}$ Ωm.

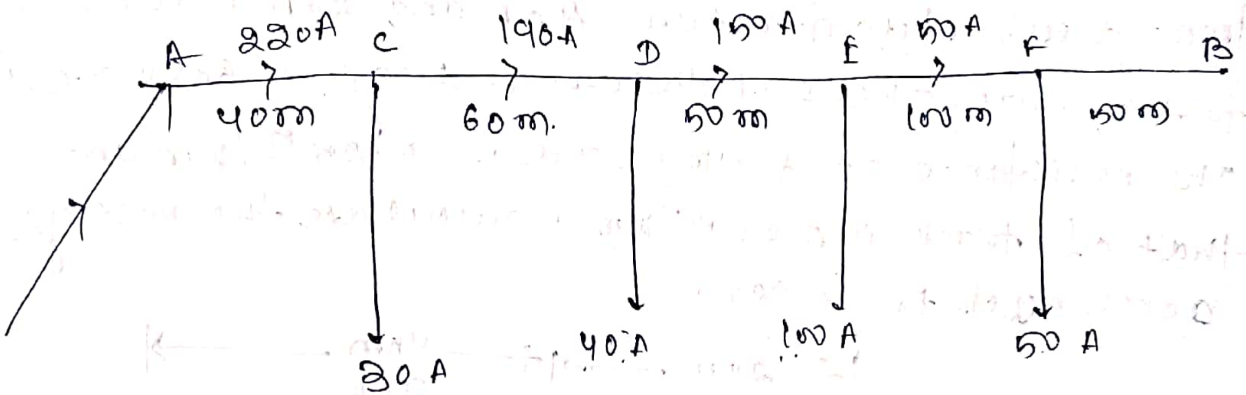
Ans suppose that resistance of 100 mt length of the distributor is r ohms.

Then resistance of various sections of the distributor is

$R_{AC} = 0.04 r \Omega$ $R_{EF} = 1 r \Omega$

$R_{CD} = 0.6 r \Omega$

$R_{DE} = 0.5 r \Omega$



$I_{AC} = 220$ Amp $I_{DE} = 150$ Amp

$I_{CD} = 190$ Amp $I_{EF} = 50$ Amp

Total voltage drop over the distributor

$= I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EF} R_{EF}$

$= 220 \times 0.4 r \Omega + 190 \times 0.6 r + 150 \times 0.5 \Omega$
$+ 50 \times r$

$= 327 r$

As the maximum permissible drop in the distributor is 10 volt.

$10 = 327 r$ ✓

$r = 10/327 = 0.03058\,\Omega$ ✓

X. sectional area of conductor

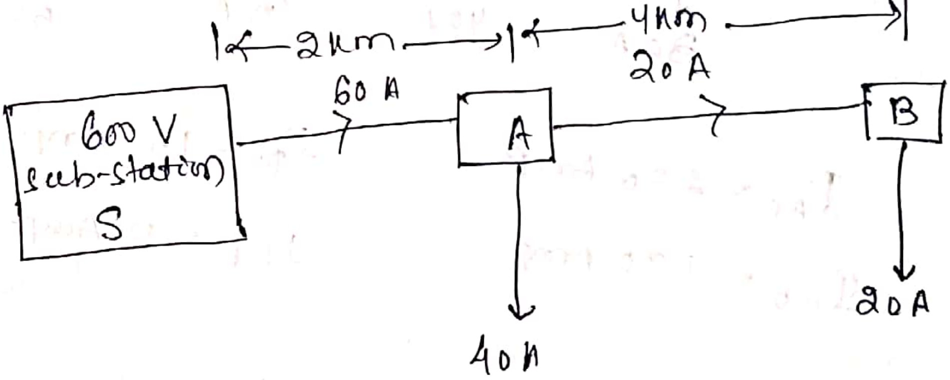
$$(a) = \frac{\rho l}{r/2} = \frac{1.78 \times 10^{-8} \times 100}{\frac{0.03058}{2}} = 116.4 \times 10^{-6}\,m^2$$

$$= 1.164\ cm^2$$

$$\boxed{\frac{r}{2} = \frac{\rho L}{A}}$$

$$\boxed{A = \frac{\rho L}{(r/2)}}$$

③ Two tram cars (A & B). 2 km and 6 km away from a sub-station return 40 A and 20 A respectively to the rails. The substation voltage is 600 V d.c. The resistance of trolley wire is 0.25 Ω/km and that of track is 0.03 Ω/km. calculate the voltage across each tram car.



Resistance of trolley wire and track/km

$= 0.25 + 0.03 = 0.28\,\Omega$

current in section SA = 40+20 = 60 A

current in section AB = 20 A

voltage drop in section SA = 60 × 0.28 × 2 = 33.60 V

voltage drop in section AB = 20 × 0.28 × 4 = 22.4V

voltage across tram A = 600 − 33.6 = 566.4 volt

voltage across tram B = 566.4 − 22.4 = 544V distribution fed at both ends   (concentrated loading)

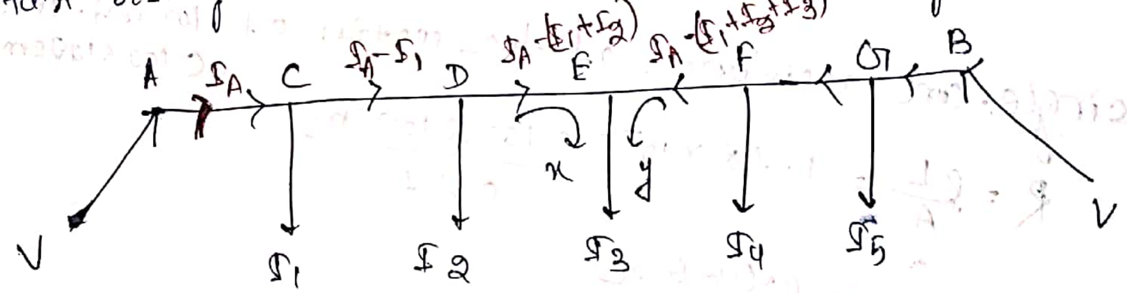
① Two ends fed with equal voltages :→

② Two ends fed with unequal voltages :→

whenever possible, it is desirable that a long distributor should be fed at both ends instead of at one end only. since total voltage drop can be considerably reduced without increasing the cross-section of the conductor. The two ends of the distributor may be supplied with ① equal voltage ② unequal voltage.

① Two ends fed with equal voltages :→

Let a AB distributor fed at both ends with equal voltage 'V' volt, and having concentrated load I_1, I_2, I_3, I_4 and I_5 at point C, D, E, F & G respectively. (As we move away from one of the feeding points 'A', P.d goes on decreasing till it reaches the minimum value at some load point say E, and then again start rising and becomes 'V' volt at other feeding point B)



The current I_1 & I_2 supplies from feeding point 'A'
The load current I_4 & I_5 supplies from feeding point 'B'
and the load current 'I_3' supplies from both feeding point 'A' & 'B'

$$I_3 = x + y$$

∴ at point of minimum potential (E), the current comes from both ends of the distributor.

$I_{AC} = I_A$, $I_{CD} = I_A - I_1$, $I_{DE} = I_A - (I_1 + I_2)$

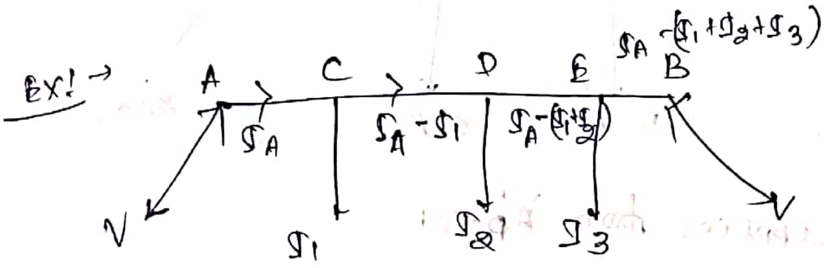
$I_{EF} = I_A - (I_1 + I_2 + I_3)$, $I_{FG} = I_A - (I_1 + I_2 + I_3 + I_4)$

⇒ Voltage at point 'B' is

$$V_B = V_A - \left[I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EF} R_{EF} + I_{FG} R_{FG} + I_{GB} R_{GB} \right]$$

$$\Rightarrow \quad V_B = V_A - \Big\{ [I_A R_{AC}] + (I_A - I_1) R_{CD} + [I_A - (I_1 + I_2)] R_{DE} + [I_A - (I_1 + I_2 + I_3)] R_{EF} + [I_A - (I_1 + I_2 + I_3 + I_4)] R_{FG} + [I_A - (I_1 + I_2 + I_3 + I_4 + I_5)] R_{GB} \Big\}$$

Ex! →



$I_{AC} = I_A$

$I_{CD} = I_A - I_1$

$I_{DE} = I_A - (I_1 + I_2)$

$I_{EB} = I_A - I_1 - I_2 - I_3$

$= I_A - (I_1 + I_2 + I_3)$

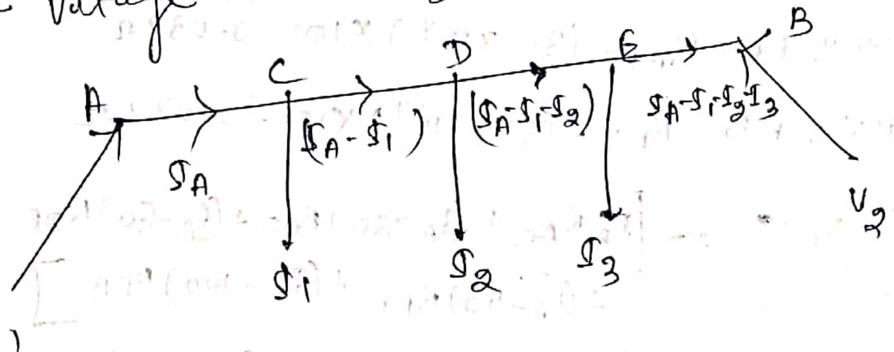
② Two ends feds with unequal voltages !→

Let AB distributor fed with unequal voltage.

At point 'A' is feed with V_1 volt and

B is feed with V_2 volt

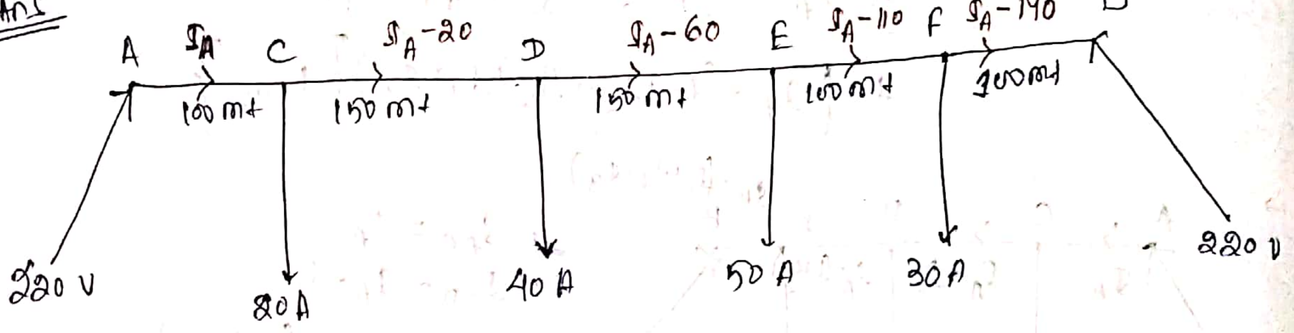
The vatage at B is $V_B = V_1 - (I_A R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE} + I_{EB} R_{EB})$



Q.1 A 2-wire, d.c street mains AB, 600 mt long is fed from both ends at 220V. Loads of 20 A, 40 A, 50 A and 30 A are tapped at distance of 100mt, 250 mt, 400 mt and 500mt from the end A respectively. If the area of X-section of distributor is 1 cm². find the minimum consumer voltage

Take $\rho = 1.7 \times 10^{-6} \Omega \, cm$.

Ans



Let 'I_A' Amp current supplies from 'A' point

Resistance of 1mt length of distributor (go & Return)

$$R = \frac{2\rho L}{A} = \frac{2 \times 1.7 \times 10^{-6} \times 100 \text{ cm}}{1 \text{ cm}^2} = 3.4 \times 10^{-4} \Omega$$

Resistance of section AC, $R_{AC} = (3.4 \times 10^{-4}) \times 100 = 0.034 \Omega$

Resistance of section CD, $R_{CD} = (3.4 \times 10^{-4}) \times 150 = 0.051 \Omega$

Resistance of section DE, $R_{DE} = (3.4 \times 10^{-4}) \times 150 = 0.051 \Omega$

Resistance of section EF, $R_{EF} = (3.4 \times 10^{-4}) \times 100 = 0.034 \Omega$

Resistance of section FB, $R_{FB} = (3.4 \times 10^{-4}) \times 100 = 0.034 \Omega$

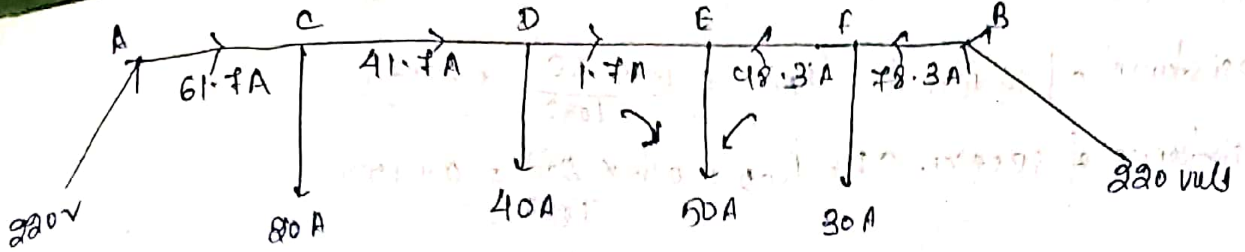
voltage at 'B' $V_B = V_A - [I_A R_{AC} + (I_A - 20) R_{CD} + (I_A - 60) R_{DE}$
$+ (I_A - 110) R_{EF} + (I_A - 140) R_{FB}]$

$220 = 220 - [0.034 I_A + 0.051 (I_A - 20) + 0.051 (I_A - 60)$
$+ 0.034 (I_A - 110) + 0.034 (I_A - 140)]$

$\Rightarrow 220 = 220 - [0.204 I_A - 12.58]$

$\Rightarrow 0.204 I_A = 12.58$

$\Rightarrow I_A = \frac{12.58}{0.204} = 61.7$ Amp



'E' is the point of minimum potential.

∴ minimum consumer voltage

$$V_E = V_A - (I_{AC} R_{AC} + I_{CD} R_{CD} + I_{DE} R_{DE})$$

$$= 220 - (61.7 \times 0.034 + 41.7 \times 0.051 + 1.7 \times 0.051)$$

$$= 220 - 4.31$$

$$= 215.69 \text{ volt}$$

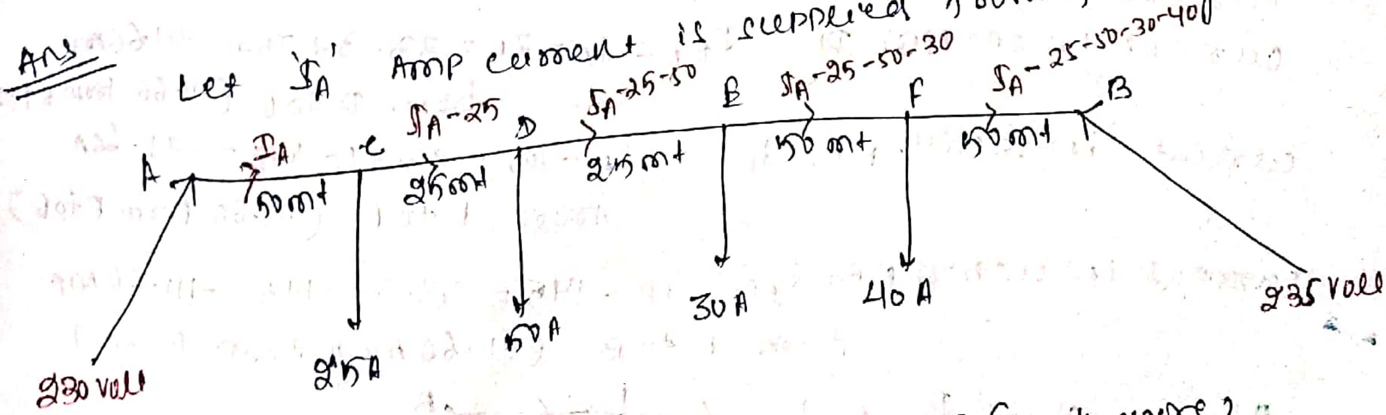
Q.2

A 2-wire DC distributor AB is fed from both ends. At feeding point A, the voltage is maintained as at 230 V and at B 235 volt. The total length of the distributor is 200 mt and loads are tapped off as under:

25A at 50 mt. from A
50 A at 75 mt. from A
30 A at 100 mt. from A
40 A at 150 mt. from A

The resistance per kilometre of one conductor is 0.3Ω calculate;
(i) currents in various sections of the distributor
(ii) minimum voltage and the point at which it occurs.

Ans Let 'I_A' Amp current is supplied from feeding point 'A'.



Resistance of 1000 mt. length of distributor (both wire)

$$= 2 \times 0.3 = 0.6\,\Omega$$

Resistance of section AC, $R_{AC} = 0.6 \times \frac{50}{1000} = 0.03\Omega$

Resistance of section CD, $R_{CD} = 0.6 \times \frac{25}{1000} = 0.015\Omega$.

Resistance of section DE, $R_{DE} = 0.6 \times \frac{25}{1000} = 0.015\Omega$

Resistance of section EF, $R_{EF} = 0.6 \times \frac{50}{1000} = 0.03\Omega$

Resistance of section FB, $R_{FB} = 0.6 \times \frac{50}{1000} = 0.03\Omega$

Voltage at point 'B' $V_B = V_A - [I_A R_{AC} + (I_A - 25)R_{CD} + (I_A - 75)R_{DE} + (I_A - 105)R_{EF} + (I_A - 145)R_{FB}]$

$$\Rightarrow 235 = 230 - [0.03 I_A + 0.015(I_A - 25) + 0.015(I_A - 75) + 0.03(I_A - 105) + 0.03(I_A - 145)]$$

$$\Rightarrow 235 = 230 - [0.12 I_A - 9]$$

$$\Rightarrow I_A = \frac{239 - 235}{0.12} = 33.34 \text{ Amp}$$

(i) current in section AC, $I_{AC} = I_A = 33.34$ Amp

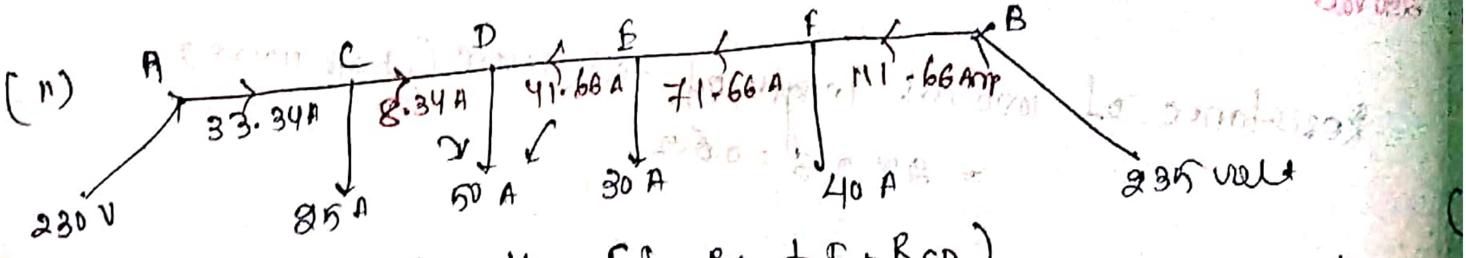
current in section CD, $I_{CD} = I_A - 25 = 33.34 - 25 = 8.34$ Amp

current in section DE, $I_{DE} = I_A - 75 = 33.34 - 75 = -41.66$ Amp from D to E (41.66 from E to

current in section EF, $I_{EF} = I_A - 105 = 33.34 - 105 = -71.66$A from E to F (71.66 from F to E)

current in section FB, $I_{FB} = I_A - 145 = 33.34 - 145 = -111.66$ Amp from F to B (111.66 Amp from B to F)

(ii)



Voltage at D, $V_D = V_A - (I_{AC} R_{AC} + I_{CD} R_{CD})$
$= 230 - (33.34 \times 0.03 + 8.34 \times 0.015)$
$= 230 - 1.125 = 228.875$ volt

Ring distributor

(i) A distributor arrange to form a closed loop and fed at one or more point is called a ring distributor.

(ii) such a distributor starts from one point, makes a loop through the area to be served, and return to original point.

Advantages! → The main advantages of ring distributor is that by proper choice in the no. of feeding points, great economy in copper can be affected.

* Ring distributor is equivalent to a straight distributor fed at both ends with equal voltages.

Q.1

A 2 wire d.c ring distributor is 300 mt long and is fed at 240 V. at point 'A'. At point B, 150 mt from A, a load of 120 Amp is taken and at 'C', 100 mt in the opposite direction, a load of 80 Amp is taken, if the resistance per 100 mt of single conductor is 0.03Ω, find,

current in each section of distributor

(i) current in each section of distributor

(ii) voltage at point B and C'

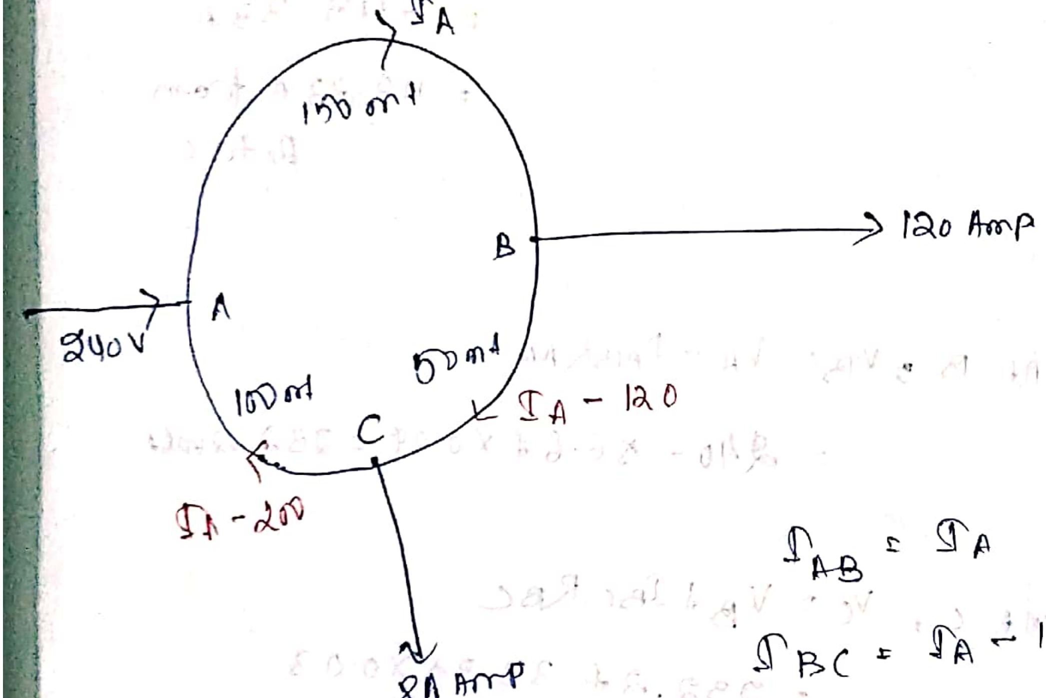
Solution. Resistance per 100 mt of distributor

$= 2 \times 0.03 = 0.06\,\Omega$

Resistance of section (AB) $R_{AB} = 0.06 \times \frac{150}{100} = 0.09\Omega$

Resistance of section BC, $R_{BC} = 0.06 \times \frac{50}{100} = 0.03\Omega$

Resistance of section CA, $R_{CA} = 0.06 \times \frac{100}{100} = 0.06\Omega$



$I_{AB} = I_A$

$I_{BC} = I_A - 120$

$I_{CA} = I_A - 200$

According to Kirchhoff's voltage law, the voltage drop in the closed loop ABCA is zero i.e

$$I_{AB} R_{AB} + I_{BC} R_{BC} + I_{CA} . R_{CA} = 0$$

$$0.09 I_A + 0.03 (I_A - 120) + 0.06 (I_A - 200) = 0$$

$$\Rightarrow 0.09 I_A + 0.03 (I_A - 120)$$

$$\Rightarrow 0.18 I_A = 15.6$$

$$\Rightarrow I_A = \frac{15.6}{0.18} = 86.67 \text{ Amp}$$

Current at section AB, $I_{AB} = I_A = 86.67$ A from A to B.

Current at section BC, $I_{BC} = I_A - 120 = 86.67 - 120$

$= -33.33$ A Amp

$= 33.33$ from C to B

current at section CA, $I_{CA} = I_A - 200 = 86.67 - 200$

$= -113.33$ A

$= 113.33$ A from A to C

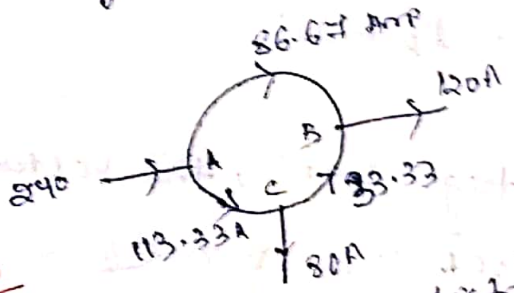
(ii) voltage at point B, $V_B = V_A - I_{AB}R_{AB}$

$= 240 - 86.67 \times 0.09 = 232.2$ volt

voltage at point C, $V_C = V_B + I_{BC} R_{BC}$

$= 232.2 + 33.33 \times 0.03$

$= 233.2$ volt.



Q.2

A 2 wire, d.c distributor ABCDEA in the form of a ring main is fed at point 'A' at 220 volt and is located as under:

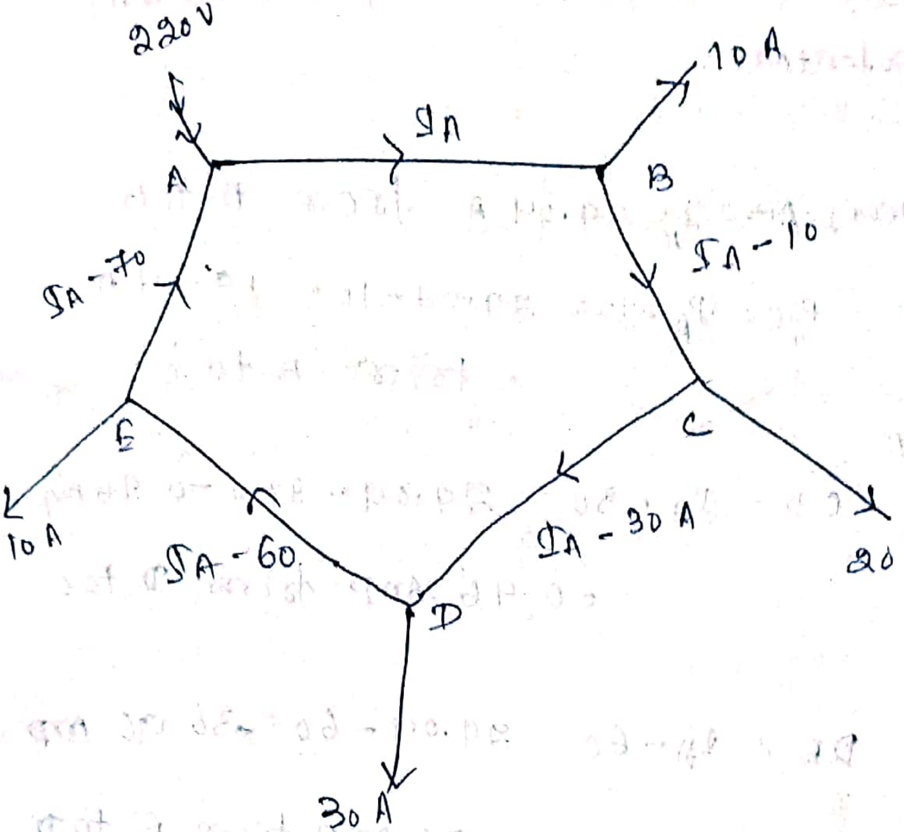
10 A at B : 20 A at C : 30 A at D and 10 A at E

The resistance of various section (go and return) are AB = 0.1 Ω, BC = 0.05 Ω, CD = 0.01 Ω

DE = 0.025 Ω and EA = 0.075 Ω

Determine (i) The point of minimum potential

(ii) current in each section of distributor



$I_{EA} = I_A - 70$

$I_{CD} = I_A - 30$

$I_{AB} = I_A$

$I_{DE} = I_A - 60$

$I_{BC} = I_A - 10$

$R_{EA} = 0.075\Omega$

$R_{CD} = 0.01\Omega$

$R_{AB} = 0.01\Omega$

$R_{DE} = 0.025\Omega$

$R_{BC} = 0.05\Omega$

(i) According KVL, the in the closed loop ABCDEA is zero i.e

$$I_{AB}R_{AB} + I_{BC}R_{BC} + I_{CD}R_{CD} + I_{DE}R_{DE} + I_{EA}R_{EA} = 0$$

$$\Rightarrow 0.01I_A + 0.05(I_A - 10) + 0.01(I_A - 30) + 0.075(I_A - 70) + 0.025(I_A - 60) = 0$$

$$\Rightarrow 0.26 I_A = 7.55$$

$$\Rightarrow I_A = 7.55/0.26 = 29.04 \text{ Amp}$$

It is clear that 'C' is the point of minimum potential.

(ii)

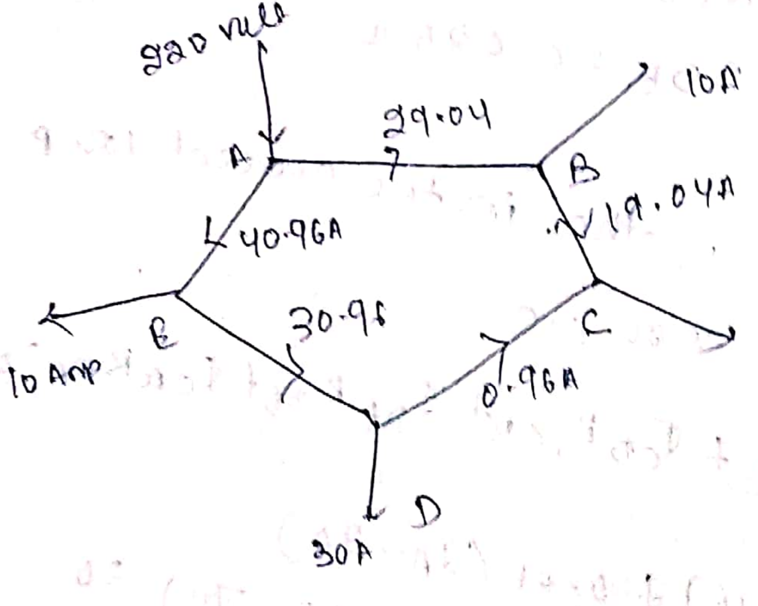
current in section AB = I_A = 29.04 A from A to B

" " BC = $I_A - 10 = 29.04 - 10 = 19.04$ A from B to C'

" " CD = $I_A - 30 = 29.04 - 30 = -0.96$ Amp = 0.96 Amp from D to C

" " DE = $I_A - 60 = 29.04 - 60 = -30.96$ Amp = 30.96 Amp from E to D

" " EA = $I_A - 70 = 29.04 - 70 = -40.96$ = 40.96 Amp from A to E



Ac distribution calculation

Ac distribution calculations differ from D.C distribution in the following respects.

(1)

In d.c distribution system, the voltage drop is due to resistance alone, However in a.c system. the voltage drops are due to the combined effect of resistance, inductance and capacitance.

(ii) In d.c system, addition and substraction of current or voltage are done arithmatically but in a.c system, these operations are done vectorically (phasor sum)

(iii) In a.c system p.f is considered.

In a.c system supply or receiving end voltage

(iv) It may be referred to supply or receiving which is regarded as the reference vector.

(v) It may be referred to the voltage at the load point itself.

* In this methods, voltage current and impedances are expressed in complex notation and the calculation are made exactly as in d.c distribution.

Methods of solving Ac. distribution problems

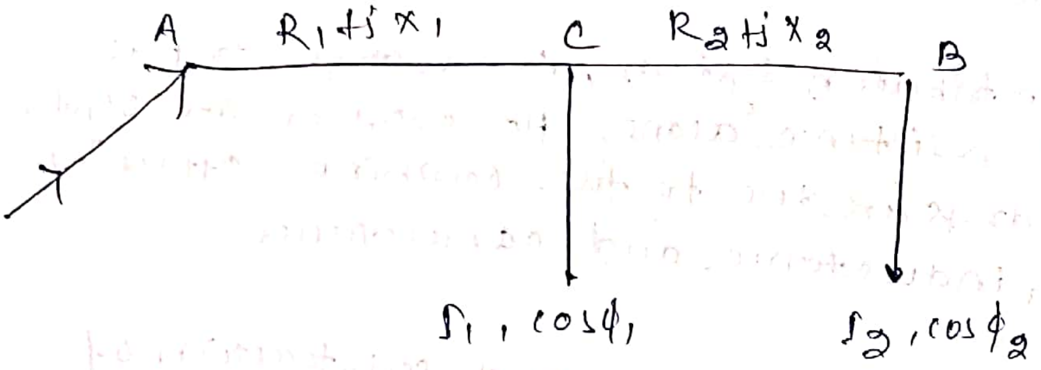
(1) In ac distribution calculation, p.f of various load currents have to be considered since current in different sections of the distributor will be the vector sum of load currents and not the arithmatic sum.

→ The p.f of load current may be given w.r.to receiving or sending end voltage

(i) w.r.to load voltage itself.

(ii) w.r.to

① Power factors referred at receiving end voltage



let I_1, I_2 = are tapped off at point C & B

$\cos\phi_1, \cos\phi_2$ = P.F at 'C' and 'B' (lagging pf)

$R_1 X_1, R_2 X_2$ = Resistance and reactance of section AC & CB.

V_B = Receiving end voltage (V_B) as the reference vector.

Impedance of section AC, $\vec{Z_{AC}} = R_1 + jX_1$

impedance of section CB, $\vec{Z_{CB}} = R_2 + jX_2$

load current at point C, $\vec{I_1} = I_1(\cos\phi_1 - j\sin\phi_1)$

load current at point B, $\vec{I_2} = I_2(\cos\phi_2 - j\sin\phi_2)$

current in section CB, = $\vec{I_{CB}} = \vec{I_2} = I_2(\cos\phi_2 - j\sin\phi_2)$

current in section AC = $\vec{I_{AC}} = \vec{I_1} + \vec{I_2}$

$$\vec{I}_{AC} = \vec{I}_1 + \vec{I}_2$$

$$= I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)$$

voltage doop in section CB,

$$\vec{V}_{CB} = \vec{I}_{CB}\vec{Z}_{CB} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$$

voltage doop in section AC,

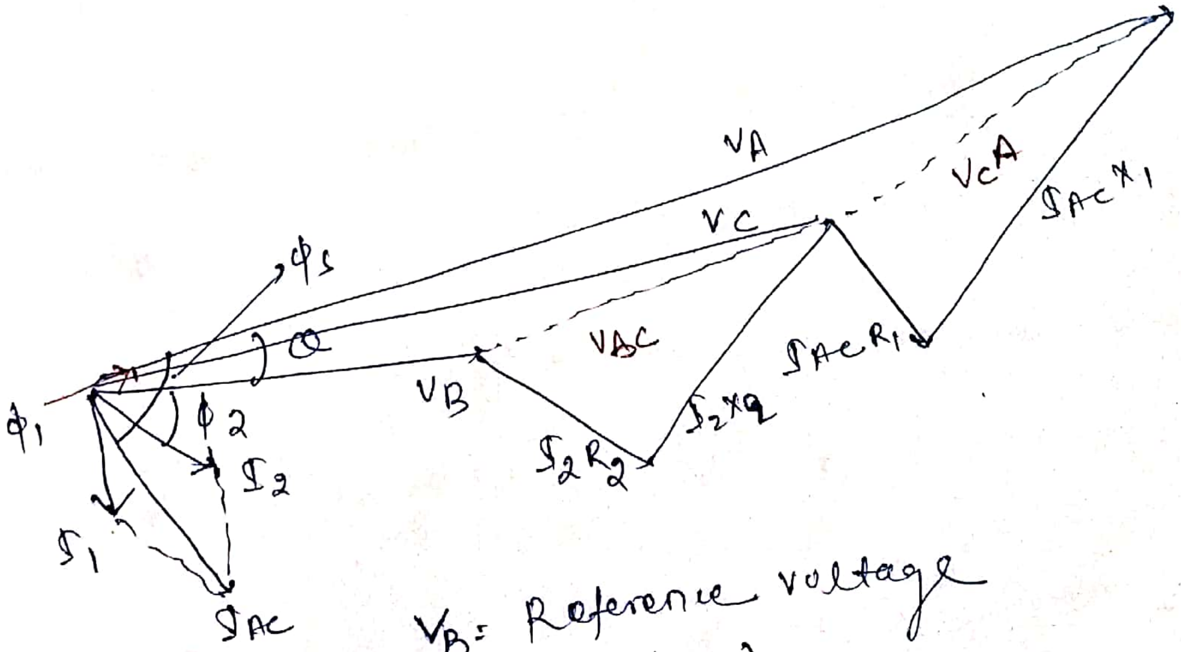
$$\vec{V}_{AC} = \vec{I}_{AC}\,\vec{Z}_{AC} = (\vec{I}_1 + \vec{I}_2)\,Z_{AC}$$

$$= (I_1\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)(R_1 + jX_1)$$

$$\boxed{\vec{V}_A = \vec{V}_B + \vec{V}_{CB} + \vec{V}_{AC}}$$

sendeng end voltage

$$\boxed{\text{sendeng end current} = \vec{I}_1 + \vec{I}_2 \quad (\vec{I}_A)}$$



VB = Reference voltage
(Vc and and VA)

Q.1

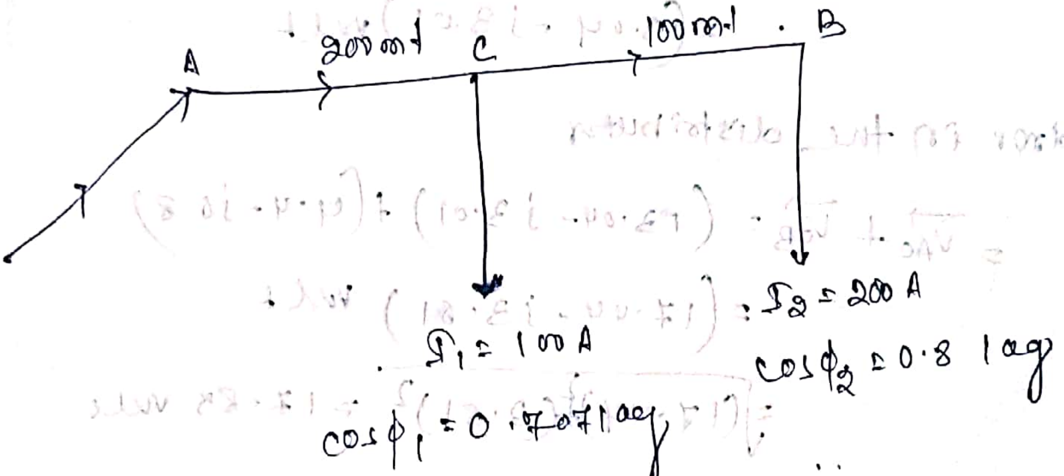
A single phase a.c. distributor AB 300 mt long is fed from end A and is loaded as under.

(i) 100 A at 0.707 p.f lagging 200 m from point A

(ii) 200 A at 0.8 p.f lagging 300 m from point A

The load resistance and reactance of the distributor is 0.2 Ω and 0.1 Ω per kilometre. Calculate the total voltage drop in the distributor. The load power factor refers to the voltage at the far end.

Ans impedance of distributor /km = $(0.2+j0.1)\,\Omega$



impedance of section AC, $\vec{Z_{AC}} = (0.2+j0.1) \times \frac{200}{1000} = (0.04+j0.02)\,\Omega$

impedance of " CB, $\vec{Z_{CB}} = (0.2+j0.1) \times \frac{100}{1000} = (0.02+j0.01)\,\Omega$

V_B (voltage at B) is the reference voltage

load current at point B = $I_2 = I_2(\cos\phi_2 - j\sin\phi_2) = 200(0.8-j0.6)$
$= (160-j120)$ A

load current at point 'c' = $I_1 = I_1(\cos\phi_1 - j\sin\phi_1) = 100(0.707-j0.707)$
$= (70.7-j70.7)$ A

current in section CB, $\overrightarrow{I_{CB}} = I_2 = (160 - j120)A$

current in section AC, $\overrightarrow{I_{AC}} = I_1 + I_2$

$= (70.7 - j70.7) + j(160 - j120)$

$= (230.7 - j190.7)A$

voltage drop in section CB,

$\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\ \overrightarrow{Z_{CB}} = (160 - j120)\ (0.02 + j0.01)$

$= (4.4 - j0.8)$ volts.

voltage drop in section AC,

$\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\ \overrightarrow{Z_{AC}} = (230.7 - j190.7)\ (0.04 + j0.02)$

$= (13.04 - j3.01)$ volt

voltage drop in the distributor

$= \overrightarrow{V_{AC}} + \overrightarrow{V_{CB}} = (13.04 - j3.01) + (4.4 - j0.8)$

$= (17.44 - j3.81)$ volt

$= \sqrt{(17.44)^2 + (3.81)^2} = 17.85$ volt

Ch-7 underground cables

Advantages of underground cables →

→ less lightning effect.
→ less maintenance cost
→ less chance of fault
→ smaller voltage drop
→ better general apperance.

Disadvantages of underground cables :→

→ greater installation cost
→ Introduce insulation problem for high voltage.
→ fault finding is difficult.

properties of underground cables :→

An underground cable essentially consist of one or more conductors covered with suitable insulation and surrounded by a protecting cover.

In general, a cable must fulfil the following necessary requirement :

(i) The conductor used in cables should be tinned stranded copper or aluminium of high conductivity.

(ii) The conductor should be stranded which increase it's flexibility.

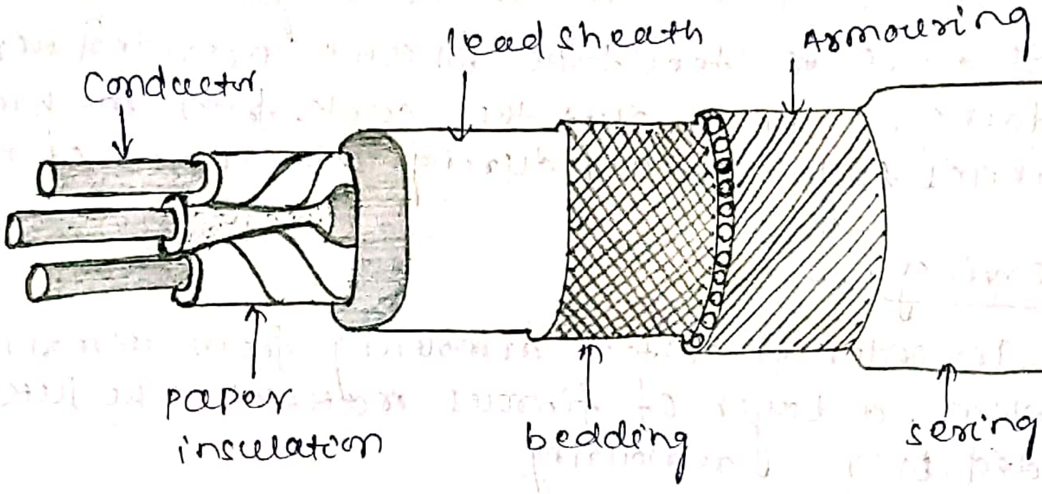
(iii) conductor should have suitable size that carry desire load current without over heating.

(iv) limited voltage drop

(v) cable must have proper thickness of insulation in order to give high degree of safety and reliability at the voltage for which it is designed.

(vi) The cable must be provided with suitable mechanical protection, so that it may withstand the rough use in laying it.

Construction of cable



① Core or conductor :→

→ A cable may have one or more than one conductor depending upon the type of service for which it is used.

→ The conductors are made of tinned copper or aluminium and are stranded in order to provide flexibility to the cable.

② Insulation :→

→ Each conductor is provided with a suitable thickness of insulation, The thickness of layer depending upon the voltage to be withstand by the cable.

③ Metallic sheath :→

→ A metallic sheath of lead or aluminium is provided over the insulation to protect the cable from moisture, gases or ~~another~~ other damaging liquid (acid & alkalies)

④ Bedding :→

→ A layer of fibrous material like jute is applied over the metallic sheath which is called a bedding.

→ A protect the metallic sheath from corrosion and mechanical injury due to armouring.

⑤ **Armouring** ! →

→ It consist of one or two layer of galvanised steel wire or steel tape which is provided over the bedding. It protect the cable from mechanical injury while laying it and during the course of handling.

⑥ **Serving** ! →

In order to protect armouring from atmospheric condition, a layer of fibrous material like jute is provided over armouring.

Insulating material for cable

Ingeneral the insulating material used in cable should have the following properties :→

(i) High insulation resistance to avoid leakage current

(ii) High dielectric strength to avoid electrical breakdown of the cable.

(iii) High mechanical strength to withstand the mechanical handling of cables.

(iv) Non-hygroscopic (it should not absorb moisture from air or soil)

(v) non-inflammable

(vi) Low cost so as to make the underground system a variable proposition.

(vii) unaffected by acid or alkali's to avoid and prevent the cable from chemical action.

Types of insulating Matericals

① Rubber

→ Rubber has high dielectric strength which is about 30 kv/mm and resistivity of insulation is $10^{17} \Omega/cm$

→ It has high insulating properties

→ But in pure rubber the major drawbacks are

✱ It's maximum safe temp is low i.e 38°c

✓ It absorb moisture

* As it is very soft, so there is a chance of damage due to rough handling and ages when exposed to light.
* deform when warm and brittle when cold
* sticky

so that pure rubber is not used for insulation.

② VIR (vulcanised india Rubber)

* It is a mixture of pure rubber and mineral material such as zinc oxide, red lead etc and 3-5% of sulphur.
* The compound so formed is rolled into thin sheets and cut into strips.
* The rubber compound is then applied to the conductor and is heated to a temp. of about 150°c
* The whole process is called vulcanisation and that product is known as VIR.

Advantages ! →

* It has greater mechanical strength,
* good electrical insulator
* does not absorb moisture from atmosphere natural

③ Impregnated paper (Saturated paper)

- → It has high dielectric strength (50 kV per mm)
- → It has good insulation resistance
- → it has low cost.

disadvantages

- → It absorb moisture (hygroscopic in nature), so that it always provided with some protective covering and never left unsealed.
- → To make it non-inflammable, paper is impregnated with some compound like paraffin, naphthenic and resin

(It consist of chemically pulped paper made from wood chippings and impregnated with some compound such as paraffinic or napthenic material)

④ Varnished cambric

- * It is a cotton cloth impregnated and coated with varnish.
- * The cambric is lapped on to the conductor in the form of a tape and it's surface are coated with petroleum jelly compound to allow for the sliding of one turn over another turn as the cable is bent.
- * As the varnished cambric is hygroscopic, therefore such cables are always provided with metallic sheath.

⑤ PVC (Poly-vinyl chloride)

- * It is obtained from polymerisation of acetylene and is in the form of white powder.
- * Then it is combined with plasticizer which make the compound in liquid form in high boiling point.

Classification of cable

Cable for underground service may be classified into 2 way

① The type of insulating material ~~is~~ used for their manfacture

② The voltage for which they are manufacture.

According to the voltage, the cables are

① Low-tension (L.T) cables - upto 1000 V

② High-tension (H.T) cables - upto 11 KV

③ super-tension cable (S.T) → from 22 KV to 33 KV

④ Extra high tension (E.H.T) cables → from 33 KV to 66 KV

⑤ Extra super tension (E.S.T) cables → beyond 132 KV.
(Extra super voltage cable)

Accordinging to NO. of conductor

① Single core cable

② Multi core cable
↓
2-core
3-core } depend upon the service.
4-core

Single core cable / (Low-Tension cable)

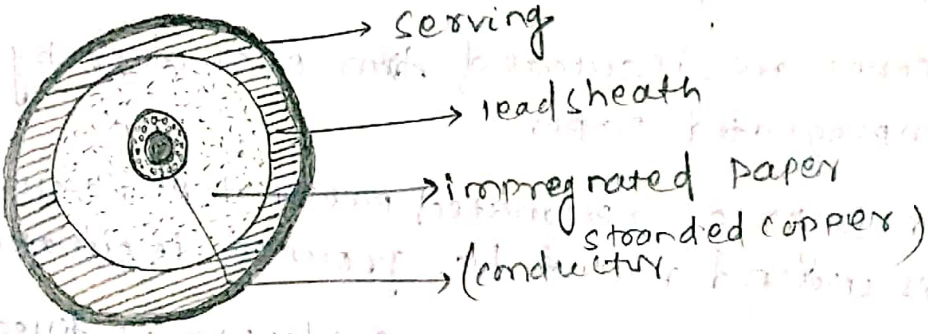
* It has ordinary construction because the stresses developed in the cable for low-voltages are generaly small.

- It consists of one circular core of tinned stranded copper or aluminium insulated by layer of impregnated paper

- The insulation is surrounded by a lead sheath which prevent the entry of moisture.

- In order to protect the lead sheath from corrosion, a serving is provided over the lead sheath.

(The single core cables are not usually armoured in order to avoid excessive sheath losses)



3-core cables :→ (For 3-ϕ services)

- For power supply either 3-core cable or 3-single core cable may be used.

- For voltage upto 66 kv, 3-core cable is preferred due to economic reason.

- for voltage beyound 66 kv, 3-core cables becomes too larger and unwieldy and therefore, single-core cables are used.

Types of cables, generally used for 3-ϕ supply / service

① Belted cables - (upto 11 kv)
② screened cables - (From 22kv - 66 kv)
③ pressure cables - (beyond 66 kv)

① Belted cables :→

→ Belted cables are used for voltage upto 11 kv. but in extraordinary cases It's used upto 22 kv.

→ The cores are insulated from each other by layer of impregnated paper.

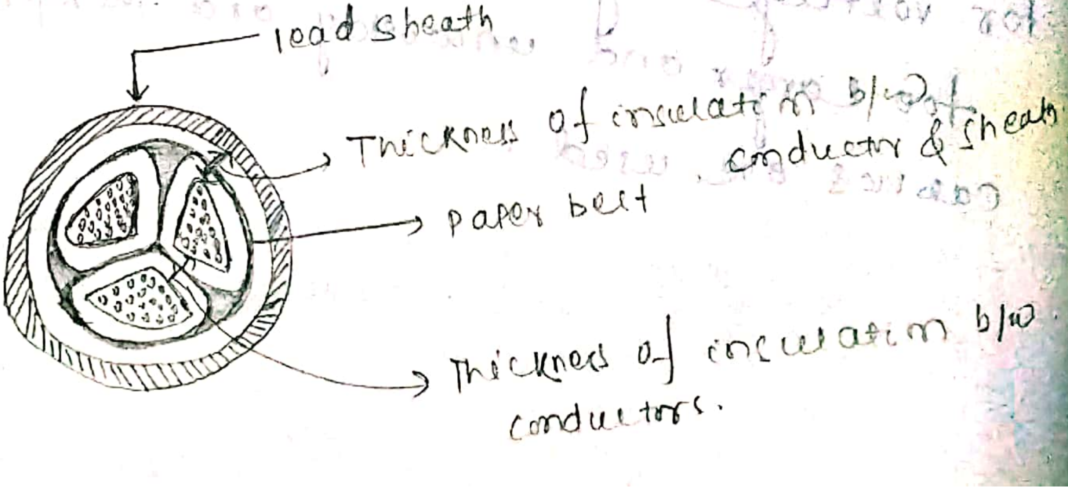
→ Another layer of impregnated paper tape, called paper belt is wound round the grouped insulated cores.

→ A gap between, insulated conductor is filled with fibrous insulating material to give a circular x-section to the cable.

→ The belt is covered with lead sheath to protect the cable against moisture and mechanical injury.

→ The lead sheath is covered with one or 2 layer of armouring with an outer serving.

→ This types of cables is suitable for low and medium voltage.



② screened cables :-

These cables are used upto 33 kv, but in particular cases these are extended upto 66 kv.

It is 2 types ① H-Type cable ← designed by H. Hochstadter
② S.L type cable

① H-type cable :-

→ In this cable, each core is insulated by layer of impregnated paper.

→ The insulation on each core is covered with a metallic screen which usually consist of a perforated aluminium foil.

(The cores are laid in such a way that metallic screens make contact with one another)

→ The three cores are then wrapped around using a conductor belt made of copper woven fabric tape.

→ H-type cable does not have an insulating belt; however it has the lead sheath followed by bedding, armouring and then a serving.

→ The core screens in the cable are all electrically connected to both the conducting belt and the lead sheath. This ensures that they are at the earth potential and all the electrical stresses are therefore purely radial, hence reduced dielectric losses.

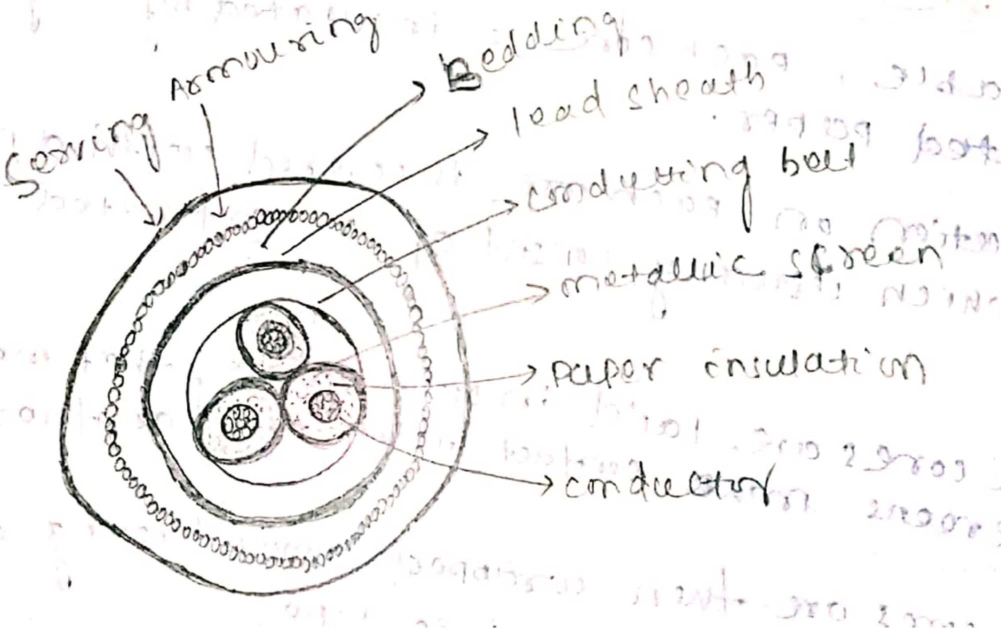
Advantages of H-type cables

① Metallic screen improve the heat dissipation of the cable.

② No-formation of air pocket and voids in the dielectric, hence a high breakdown strength and less dielectric losses.

disadvantages! →

This cables are only suitable for low and medium voltage of upto 33 kV, but can reach 66 kV at times.



② S.L type cable. (Separately lead sheath)

* It's basically H-type cable, each core is first insulated with an impregnated paper then each insulated core is covered by its own lead sheath.

* Then all 3 cores are covered with cotton tape, then armouring and serving are provided over the cotton tape.

(No-lead covering is provided surrounding all the 3-cores in addition to their individual lead sheath.)

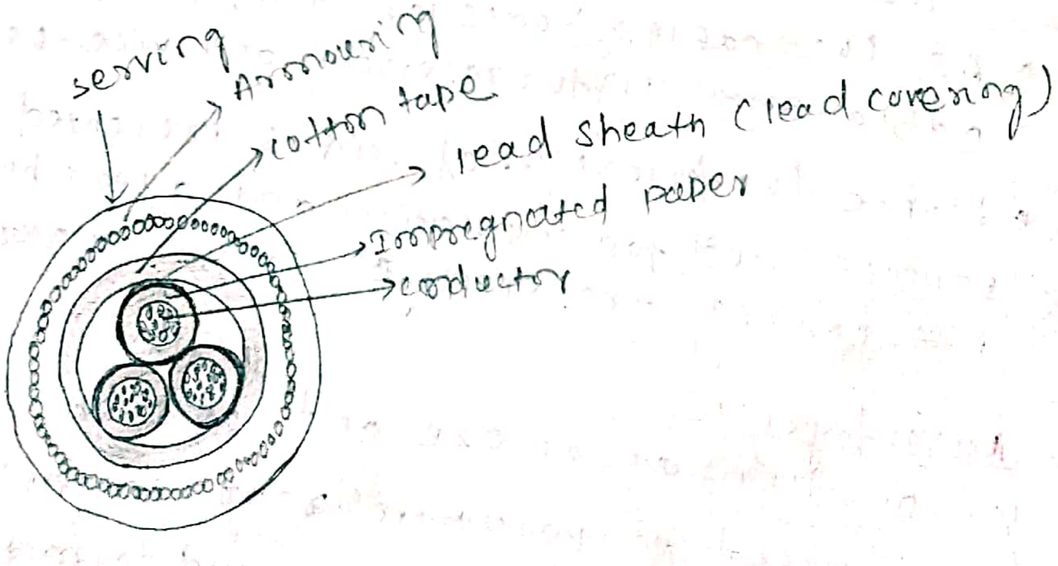
The advantages of S.L type cable over H-type cable.

* Bending of cables becomes easy due to the elimination of overall lead sheath.

* The separate sheaths minimise the possibility of core-to-core breakdown.

disadvantages:-

* The disadvantages of SL type cable is that the manufacturing is difficult because of thinner lead sheaths which is thinner than single sheath of H-cable.



Pressure cable :→

For voltage beyond 66 kv, solid type cables are unreliable because there is a danger of breakdown of insulation due to the presence of voids. when the operating voltages are greater than 66 kv, pressure cables are used. In such cables, voids are eliminated by increasing the pressure of compound and for this reason they are called pressure cables.

2 types of pressure cables

① oil-filled cables
② gas pressure cables

① Oil-filled cables :→

- ✱ In this type of cable, a hollow conductor of soft-drawn stranded copper, fed by oil reservoirs placed at interval along the route of the cable.
- ✱ The oil is maintained underpressure by these reservoir.
- ✱ As the cable heats on load, oil is driven from the cable ~~cable~~ in the reservoir and vice-versa.
- ✱ Hence the formation of void is prevented. Impregnated paper is used for insulation and a leadsheath and a jute covering are employed to give waterproof.

Advantages :→

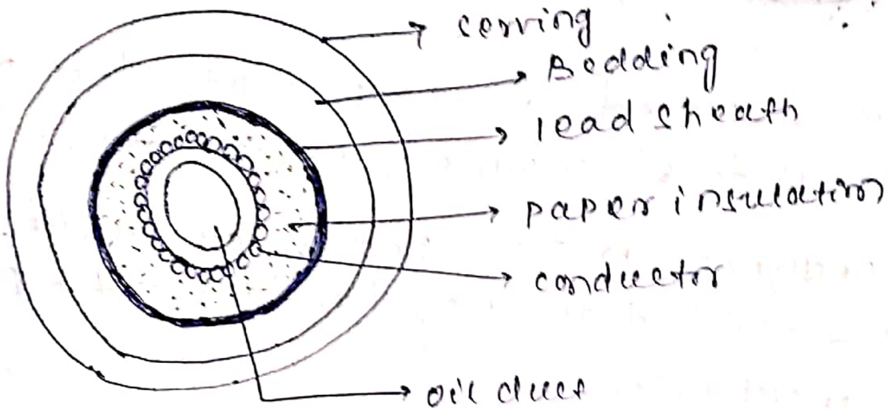
1) smaller overall size and smaller weight.
2) Increased temperature range in service possible
3) No ionisation, oxidation and formation of voids
4) High current rating (voltage rating)
5) High maximum permissible stress.

disadvantages :→

- High cost
- laying of cable and maintenance are complicated.

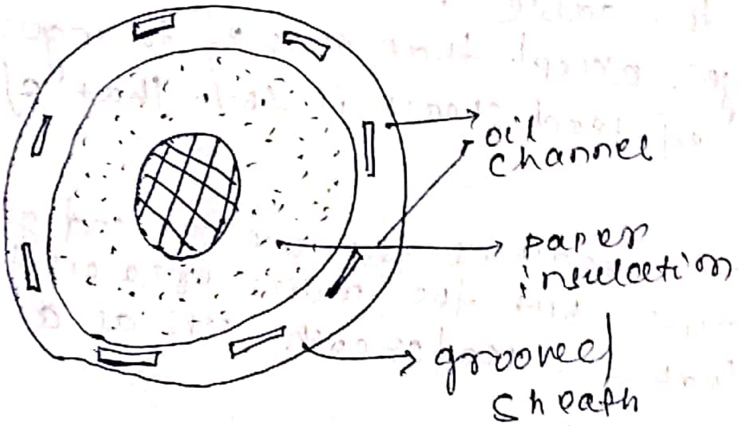
It is 3 types

① single core conductor channel.



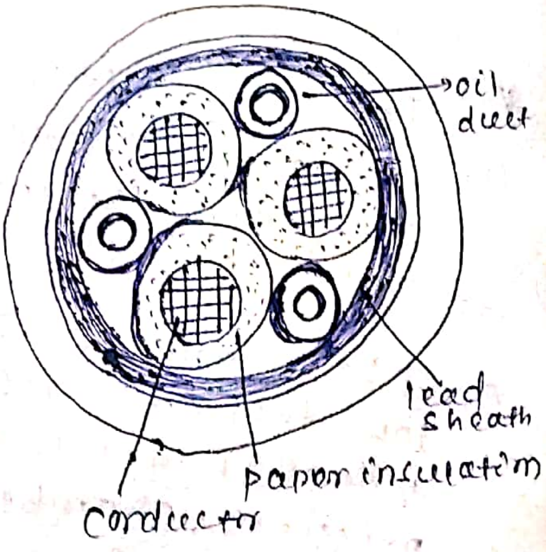
- Here the oil pressure compresses the layer of paper insulation and prevents the possibilities of void formation.
- The system is so designed that when the oil gets expanded due to increase in cable temp. the extra oil collects in the reservoir. However when the temp falls during light load condition, the oil from the reservoir flow to the channel.

② single-core sheath channel oil filled cable



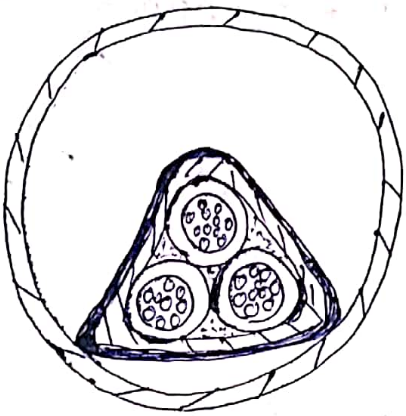
- The conductor is solid similar to that of solid cable and is paper insulated and oil ducts are provided in the metallic sheath

③ 3-core oil-filler cable



- The oil ducts are located in the filler spaces.

Gas Pressure cable :→



- * The cable is placed in a gas tight steel pipe, The pipe is filled with dry nitrogen gas.
- * The gas pressure produce radial compression and closes the voids that may formed b/w the layers of paper insulation.

***Advt :→**

- * such cables can carry more load current and operate at higher voltage than a normal cable.
- * maintenance cost is small and the nitrogen gas helps in quenching any flame.

dis-adv :→

- * overall cost is veryhigh

- * The construction of the cable is similar to that of an ordinary solid type except that it is of triangular shape and thickness of lead sheath is 75% that of solid cable.

- * The triangular section reduces the weight and gives low thermal resistance but the main reason for triangular shape is that the leadsheath acts as a pressure chamber.

Laying of underground cables

There are 3 main methods of laying underground cables.

① direct laying
② draw-in system
③ solid system

① Direct laying

→ In this method, a trench of about 1.5 mt deep and 45 cm wide is dug.

→ Then the trench is covered with a layer of fine sand (about 10 cm thickness) and a cable is laid over this sand bed.

→ The sand prevents the entry of moisture from the ground and protect the cable from corrosion.

→ After the cable has been laid in the trench, it is covered with another layer of sand of about 10 cm thickness.

→ The trench is then covered with bricks and other materials inorder to protect the cable from mechanical injury.

→ When more than one cabe is to be laid in the same trench the minimum spacing b/w them is about 30 - 40 cm.

→ It reduce the effect of mutual heating and fault occuring in one cable doesnot effect the other.

Advantages :-

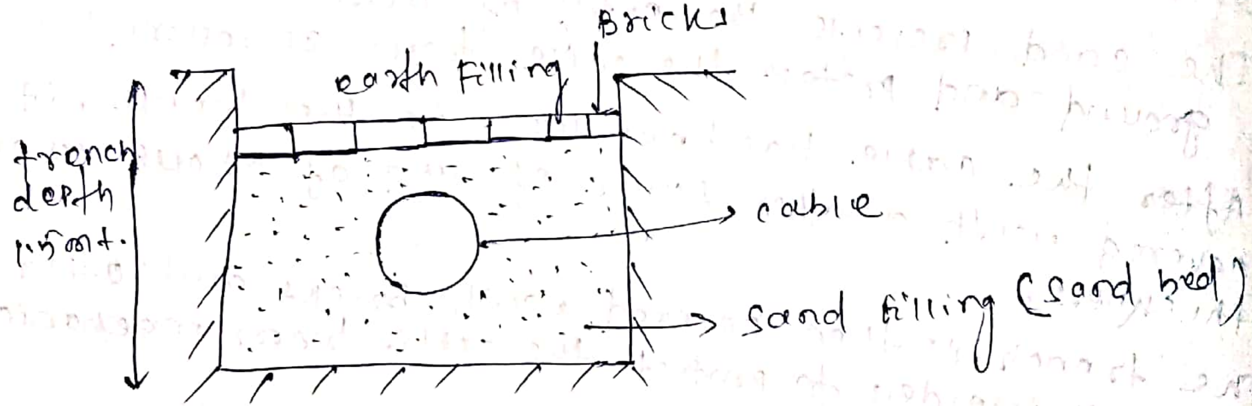
→ It is a simple and cheap method

→ It provide better condition for heat dissipation.

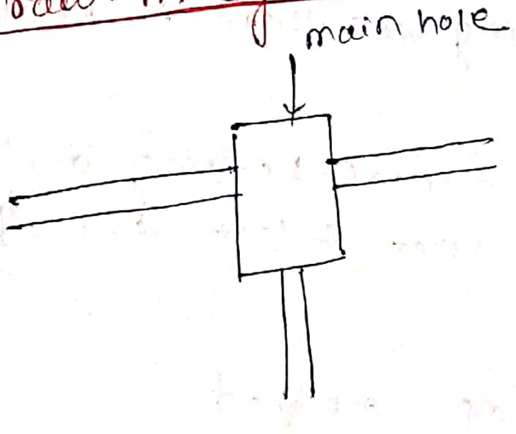
→ It is a clean and safe method as the cable is invisible and free from external disturbances.

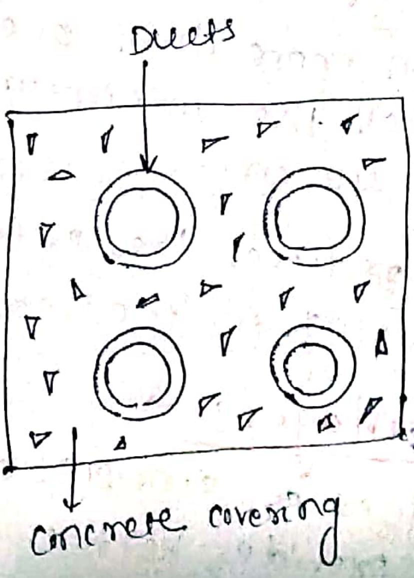
disadvantages :—

- → Localisation of fault is difficult.
- → The maintence cost is very high
- → It cannot be used in congested areas (where excavation is expensive and inconvenient)
- → The cable sheath may sometimes undergo chemical changes and get damaged due to impurities presen in the soil.
- → Extension of load is possible only by a completely new excavation which may cost as much as the original work.



② **Draw-in system**





- In this method a line of conduit or tube made of either iron, clay or cement concrete are laid in the trench side by side.
- separate pipes are provided for each cables laid in the same trench.
- The diameter of the pipe must be greater than the diameter of cable.
- The width of the trench depends upon the no. of pipes to be used.
- Normally spacing of 0.25 to 0.75 is maintained b/w two pipes.
- The pipes terminate in a underground chamber known as main hole.
- It is employed for pulling-in cable through the pipe and jointing the incoming cable and out going cable.
- In this system, cables are not provided with armouring only serving is given inorder to protect them when being pulled into the ducts.

Advantages :→

→ As armouring is not present joint becomes simpler and maintenance cost is reduced.

→ cable repair, alternation and addition to the cable network are possible through digging soil.

→ There is very less chance of fault occurance due to strong mechanical protection provided by the system.

→ This system offers long life to cable.

disadvantages

→ Initial cost is very high.

→ unfavourable conditions for dissipation of heat.

→ current carrying capacity of the cables is reduced due to the close grouping of cables.

③ Solid System :→

→ In this method of laying the cable is laid in open pipes made of cast iron or treated wood.

→ After the cable is laid in position the pipe is filled with a bituminous compound.

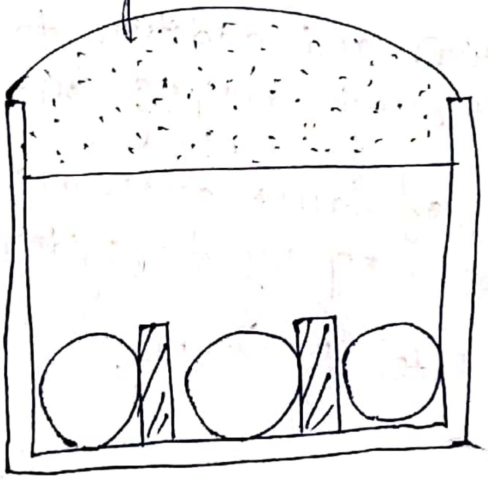
disadvantages :→

→ It's more expensive

→ It requires skilled labour and favourable weather condition.

→ Due to poor heat dissipation facility the current carrying capacity of the cable is reduced.

∴ due to all these disadvantages, this method of laying underground cables is rarely used nowadays.



* laying and repair require more time.
* laying and repair cannot be carried out in rainy season

Types of Cable faults

∴ If a fault does occur, it is difficult to locate and repair the fault because conductors are not visible.

There are 3 types of fault which occur in underground cable.

① open-circuit fault
② short-circuit fault
③ Earth-fault

Loop tests for Location of Fault in underground cables

There are several methods for locating the faults in underground cables. However, two popular methods known as loop tests are:

① Murray loop test
② varley loop test

These simple tests can be used to locate the earth fault or short-ckt fault in underground cable.

① Murray loop test

(i) Earth fault :→ Earth fault by murray loop test.

AB = sound cable
CD = faulty cable
F = Earth fault occur at point F.

The point D of faulty cable and point B' of sound cable are connected through a low resistance

Murray Loop test

The murray loop test is the most common and accurate method of locating earth fault or short-ckt fault in under-ground cables.

① Earth-Fault

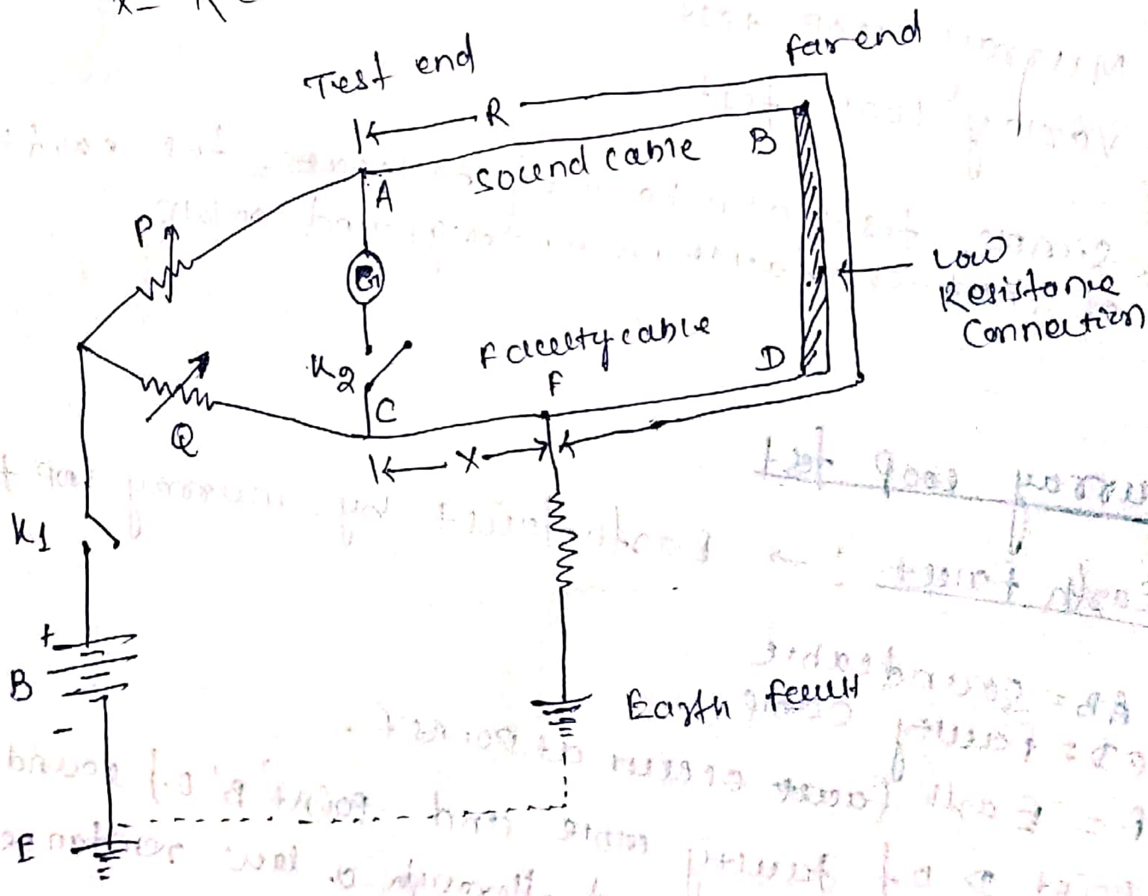
Location of Earth fault by murray loop test.

AB = sound cable
CD = faulty cable
F = Fault occurs at point 'F'

→ The point D of faulty cable is jointed to the point 'B' of the sound cable through a low resistance link.

→ Two variable resistance P and Q are joined to ends of 'A' and 'C' respectively and serve as the ratio arms of the wheatstone bridge.

R = Resistance of the conductor from point 'A' to 'F'
X = Resistance of the conductor from point 'C' to 'F'



P, Q, R and X are the four arms of wheatstone bridge

→ The resistance 'P' and 'Q' are varied till the galvanometer indicates zero deflection.

under balanced condition, we have

$$\frac{P}{Q} = \frac{R}{X}$$

$$\Rightarrow \frac{P}{Q} + 1 = \frac{R}{X} + 1$$

$$\Rightarrow \frac{P+Q}{Q} = \frac{R+X}{X}$$

if 'r' is the resistance of each cable,

then $R+X = 2r$

$$\frac{P+Q}{Q} = \frac{2r}{X}$$

$$\Rightarrow \boxed{X = \frac{Q}{P+Q} \times 2r}$$

if 'l' is the length of each cable in mt.

then resistance per mt. of cable $= \frac{r}{l}$

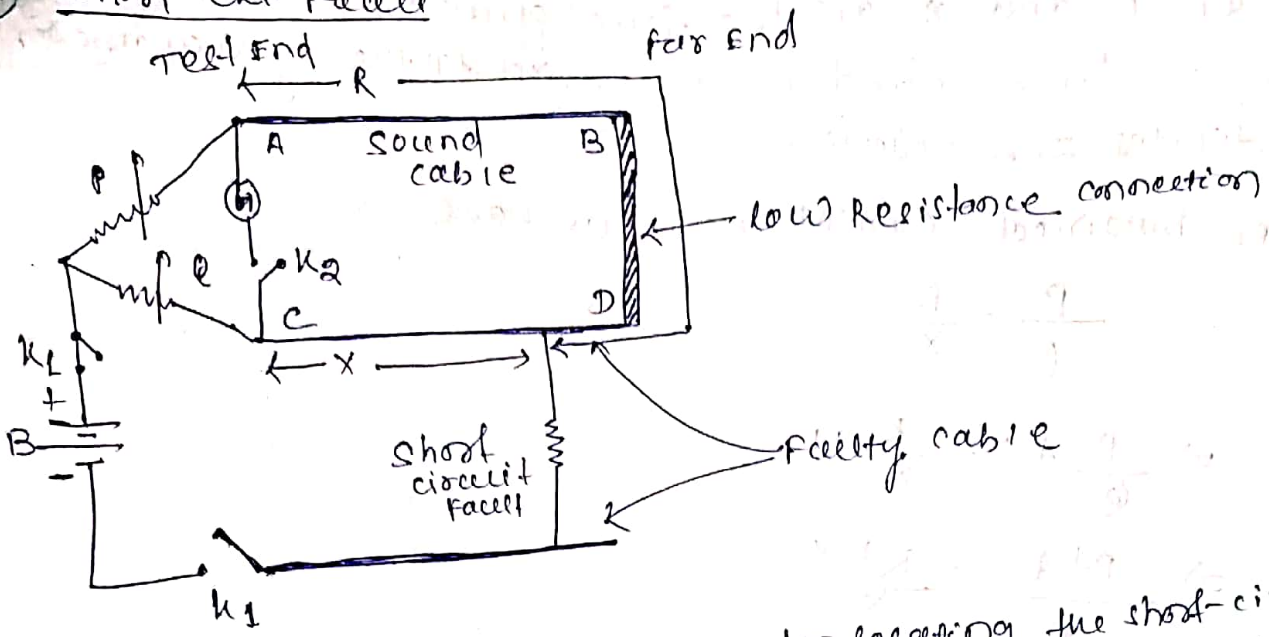
Distance of fault point from test end is:

$$\therefore d = \frac{X}{\left(\frac{r}{l}\right)} = \frac{Q}{P+Q} \times 2r \times \frac{l}{r} = \frac{Q}{P+Q} \times 2l$$

$$\boxed{d = \frac{Q}{P+Q} \times \text{loop length in mt.}}$$

Thus position of the fault is located.

⑪ Short Ckt Fault



→ This is the circuit connection for locating the short-circuit fault by murray loop test. Again P, Q, R, and X are the four arms of the bridge. (Fault resistance is in the battery circuit and not in the bridge circuit)

→ The bridge in balanced by adjusting the resistance 'P' and 'Q'

→ In balanced position of the bridge we get

$$\frac{P}{Q} = \frac{R}{X} \quad \Rightarrow \frac{P}{Q} + 1 = \frac{R}{X} + 1$$

$$\Rightarrow \frac{P+Q}{Q} = \frac{R+X}{X} = \frac{2r}{X} \quad \Rightarrow d = \frac{Q}{P+Q} \times (\text{loop length}) \text{ in mt.}$$

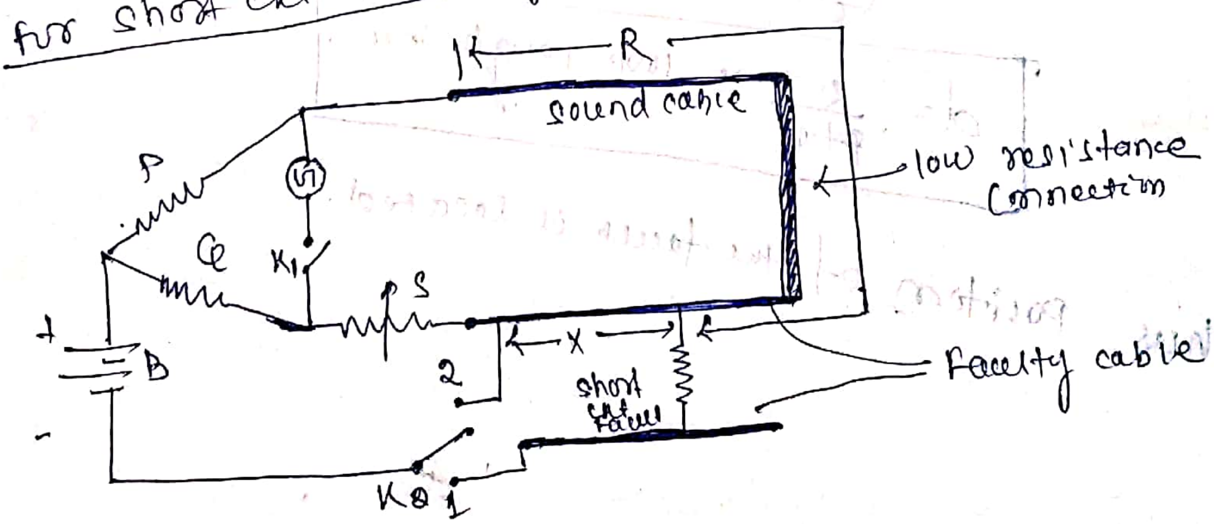
$$\Rightarrow X = \frac{Q}{P+Q} \times 2r$$

Thus position of the fault is located.

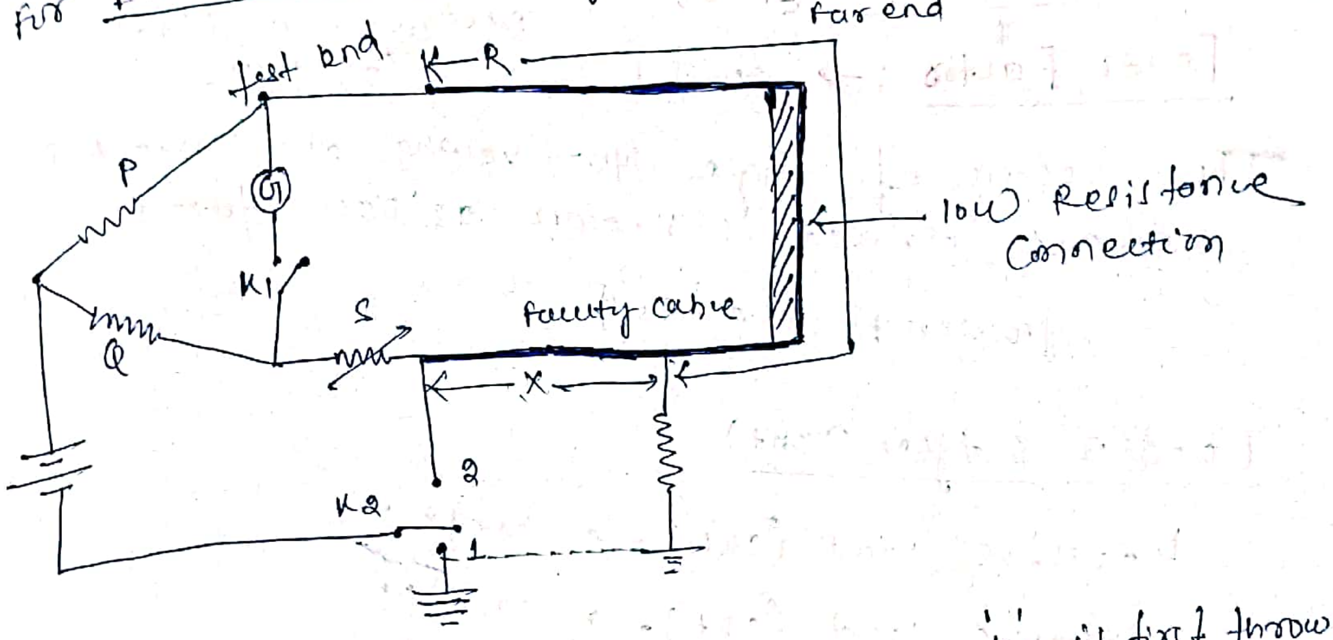
Varley loop test

→ Here, the ratio arms 'P' and 'Q' are fixed resistance, Balance is obtained by adjusting the variable resistance 'S' connected to the test end of the faulty cable.

for short ckt test Diagram



For Earth Fault test Diagram



for Earth fault or short cut fault, the key 'K2' is first thrown to position '1'. The variable resistance 'S' is varied till the bridge is balanced for resistance value of S1. Then

$$\frac{P}{Q} = \frac{R}{X+S_1}$$

$$\Rightarrow \frac{P+Q}{Q} = \frac{R+X+S_1}{X+S_1}$$

$$\Rightarrow X = \frac{Q(R+X)-PS_1}{P+Q} \longrightarrow ①$$

Now, key K2 is thrown to position 2 and bridge is balanced with new value of resistance S2, Then

$$\frac{P}{Q} = \frac{R+X}{S_2}$$

$$\Rightarrow (R+X)Q = PS_2 \rightarrow ②$$

from eqn ① & ②, we get

$$\boxed{X = \frac{P(S_2-S_1)}{P+Q}}$$

since the values of P, Q S1 and S2 are known, the value of 'X' can be determined.

loop resistance $= R+X = \frac{P}{Q}S_2$

if r is the resistance of the cable per mt., Then distance of fault from test end is $\boxed{d = \frac{X}{r}}$ m.

Economics Aspects (Ch-8) → studies about economic activities of a man.

→ particular parts

Power Factor :→ (cos ϕ)

The cosine of angle b/w voltage and current in an a.c circuit is unown as power factor.

power Factor = cos ϕ

Load is 3 types (ckt)

Resistive load (ckt) → cos ϕ = 1

inductive load (ckt) → cos ϕ < 1

capacitive load (ckt) → cos ϕ > 1

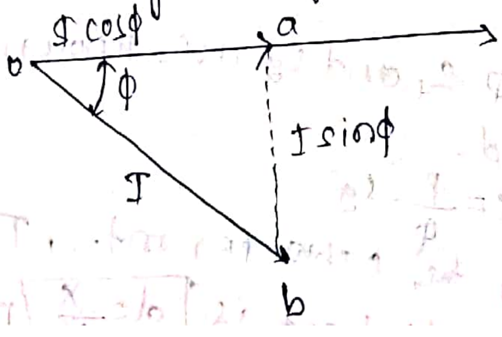
* if the ckt is inductive, then current lags behind the voltage and the p.f is referred to as lagging

* If the ckt is capacitive, then current leads the voltage and the p.f is referred to as leading.

* If the ckt is resistive, then current overlap the voltage and the p.f is reffered to as unity.

*Lagging p.f

Let the inductive ckt taking a lagging current 'I' from supply voltage 'v';



Disadvantages of Low power factor

* $P = V_L I_L \cos\phi$ (For single phase supply)

$$I_L = \frac{P}{V_L \cos\phi}$$

$P = \sqrt{3}\, V_L I_L \cos\phi$ (For 3-φ supply)

$$I_L = \frac{P}{\sqrt{3}\, V_L \cos\phi}$$

Here 'P' depend on 'cosφ', where 'P' is the power consumed in the ckt.

So cosφ. Play an important role in a.c ckt.

$P = V_{ph} I_{ph} \cos\phi$

$P = 3 V_{ph} I_{ph} \cos\phi$

$= \sqrt{3} V_L I_L \cos\phi$

* For constant 'P' and 'V' current I is inversely proportional to the P.F

$$I \propto \frac{1}{P.F}$$

$$\boxed{I \propto \frac{1}{\cos\phi}}$$

when cosφ ↓, I ↑ (higher the load current)

cosφ ↑, I ↓ (lower the load current)

A powerfactor less than unity results in the following disadvantages

① Large kVA rating of equipment.

The electrical machinary (i.e alternators, Transformers, switchgear) is always rated in kVA.

$$\cos\phi = \frac{\text{Active Power}}{\text{~~Reactive~~ Apparant Power}} = \frac{KW}{KVA}$$

$$\Rightarrow \uparrow KVA = \frac{KW}{\cos\phi \downarrow}$$

∴ It is clear that KVA rating of the equipment is inversely proportional to P.F!

∴ Therefore, at low P.F, the rating of KVA of the equipment has to be made more, making the equipment larger and expensive.

② greater conductor size :→

$$I_L = \frac{P}{\sqrt{3} V_L \cos\phi}$$

if P & V_L is constant then

$$\boxed{I_L \propto \frac{1}{\cos\phi}}$$

* Here P.F is inversely proportional to I_L so that load current will high at low P.F

* so that conductor will have to carry more current at low power factor.

Ex:→ For 1-φ, AC Motor, The I/P power is 10 KW at full-load. The terminal voltage is 250 volt

At unity P.F, the load current = $I_L = \frac{10 \times 10^3}{250 \times 1} = 40A$

At 0.8 lag P.F, the load current = $I_L = \frac{10 \times 10^3}{250 \times 0.8} = 50A$

when P.F ↓, the current value ↑, we required greater size conductor.

(III) large copper losses :→

- The large current at low p.f causes more I^2R losses in all the elements of the supply system.
- This results in poor efficiency. $\eta = \frac{o/p}{i/p}$

(IV) poor voltage regulation :→

The large current at low lagging p.f causes greater voltage drops in alternators, transformers, transmission lines and distributors. So the voltage regulation ~~[illegible]~~ is more ~~increases~~ due to this voltage drop. & ~~to~~ to maintain voltage drop within permissible limits, extra equipments is required (voltage Regulator)

(V) Reduced handling capacity of system

The lagging p.f reduces the handling capacity of all the elements of the system. It is because the reactive component of current prevents the full utilisation of installed capacity.

Causes of low p.f

Normally, the p.f of the whole load on the supply system is lower than 0.8.

① most of the a.c motors are of induction type (1ϕ, 3ϕ induction Motor) which have low lagging p.f.

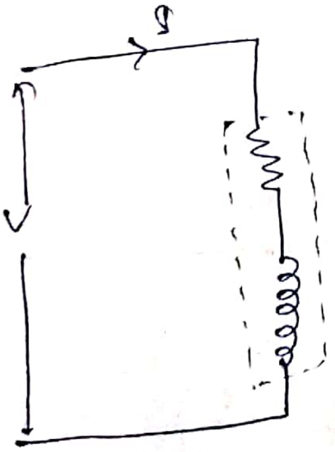
These motors works at a power factor which is extremely small on light load (0.2-0.3) and rises to 0.8-0.9 at full-load.

(ii) Arc lamps, electric discharge lamps and industrical heating furnaces operate at low lagging power factor.

(iii) The load on the power system is varing; being high during morning and evening and low at other times. During low load period, supply voltage is increased which increases the magnetisation current. This results in the decreased power factor.

Power factor improvement

- * The low power factor is mainly due to that most of the power loads are inductive and therefore, take lagging currents. In order to improve the p.f, some device taking leading power should be connected in parallel with load. One of such devices can be a capacitor.
- * The capacitor draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the p.f of the load.



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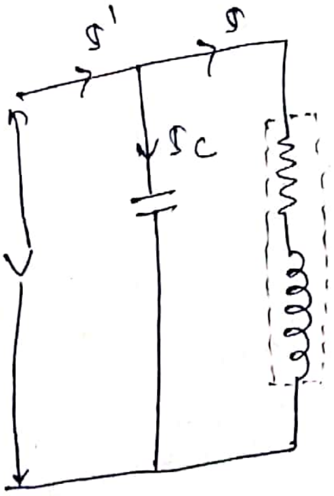

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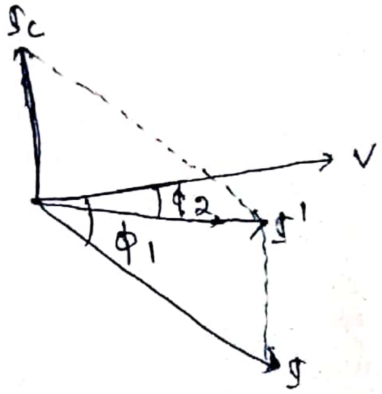


$\phi_1 > \phi_2$

so $\cos\phi_1 < \cos\phi_2$

so p.f improved.

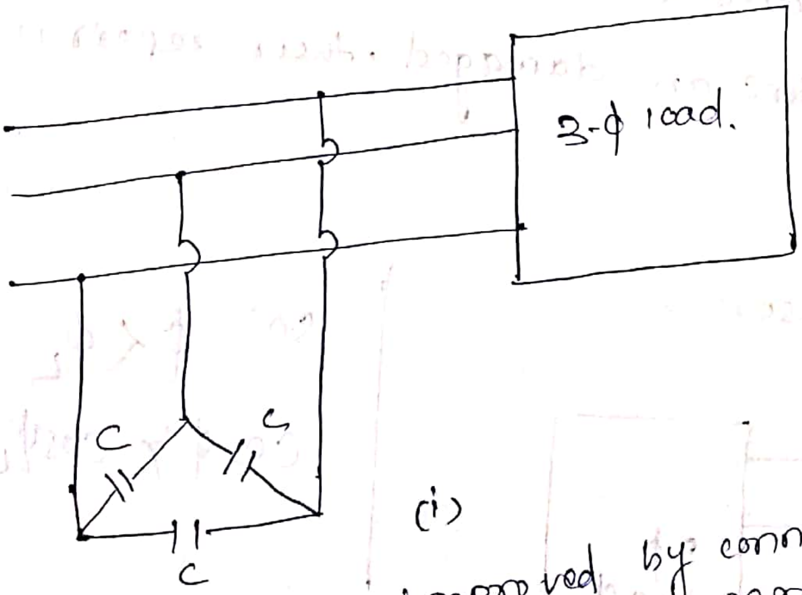
Power Factor improvement equipment

Normally, P.F of the whole load on a large generating station is in the region of 0.8 to 0.9. However it is lower and in such cases it is generally desirable to take special steps to improve the P.F.

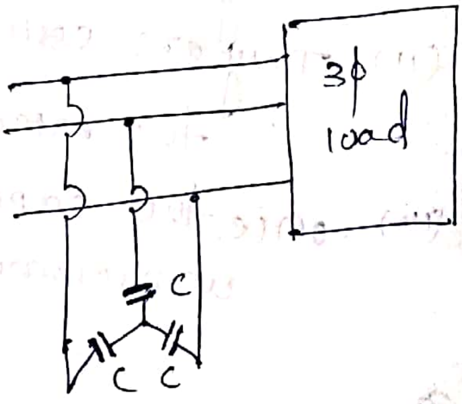
There are 3 methods / equipments :→

① static capacitor
② synchronous condenser
③ phase advancers

① Static capacitor :→



(i)



(ii)

- The P.F can be improved by connecting capacitors in parallel with the equipment operating at lagging P.F.
- The capacitor (static capacitor) draws a leading current and partly or completely neutralises the lagging reactive component of load current. This raises the P.F of the load.
- For 3-ϕ load, the capacitors can be connected in delta or star.

Advantages :→

① They have low losses

② They require little maintenance as there are no rotating parts

③ They can be easily installed as they are light and require no foundation.

④ They can work under ordinary atmospheric condition.

disadvantages :→

(i) They have short service life ranging from 8 to 9 yrs.

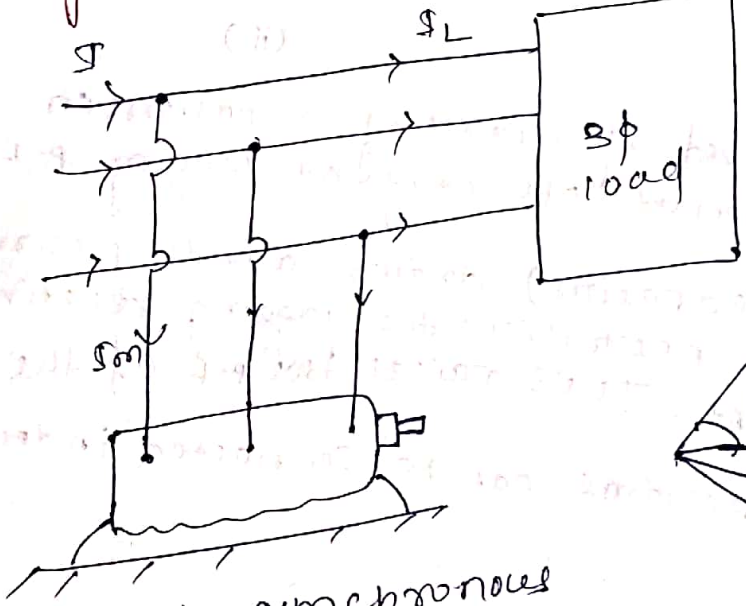
(ii) They are easily damaged if the voltage exceeds the rated value.

(iii) once the capacitors are damaged, their repair is uneconomical.

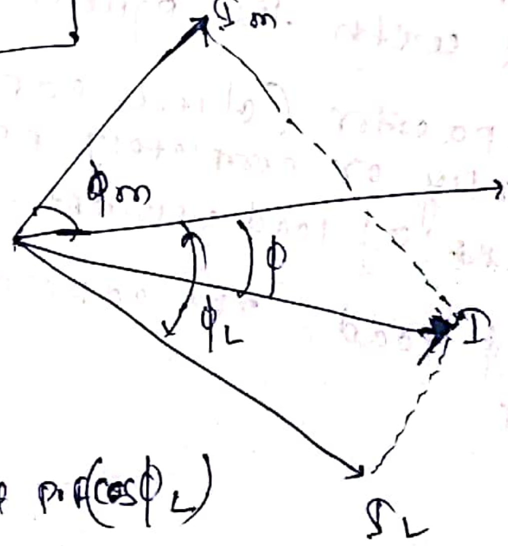
② synchronous condenser :→

so $\phi < \phi_L$

$\cos\phi > \cos\phi_L$



3-φ synchronous Motor



* 3φ load taking current I_L at p.f $(\cos\phi_L)$ the synchronous condenser takes the current I_m, at leading p.f $\cos\phi_m$. 'I' is phasor sum of I_L & I_m and lag 'V' by 'φ'.

* A synchronous motor takes a leading current when over-excited and therefore, behaves as a capacitor.

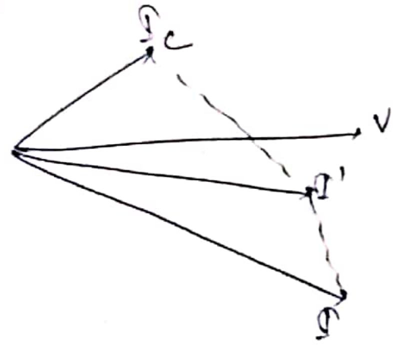
* An over-excited synchronous motor running on no-load is known as synchronous condenser, and under this condition it behaves as a capacitor, which draws leading current.

* When such a machine is connected in parallel with the supply, it takes a leading current which partly neutralises the lagging reactive component of the load. Thus the P.F is improved.

* Synchronous condensers are generally used at major bulk supply substations for P.F improvement.

Advantages:-

(i) By varying the field excitation, the magnitude of current drawn by the motor can be changed by any ~~[illegible]~~ amount.



(2) The motor windings have high thermal stability to short circuit currents.

(3) The faults can be removed easily.

Disadvantages:-

(i) There are considerable losses in the motor

(ii) maintenance cost is high

(iii) It produces noise

(iv) Except in sizes above 500 kVA, the cost is greater than that of static capacitors of the same rating.

(v) As a synchronous motor has no self-starting torque, therefore, an auxiliary equipment has to be provided for this purpose.

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① Load curve :→

The curve showing the variation of load on the power station w.r.to time is known as a load curve.

OR

Load curve is the graphical representation of load (in kw or MW) in proper time sequence and the time in hours. It shows the variation of load on the power station.

load curve is 3 types

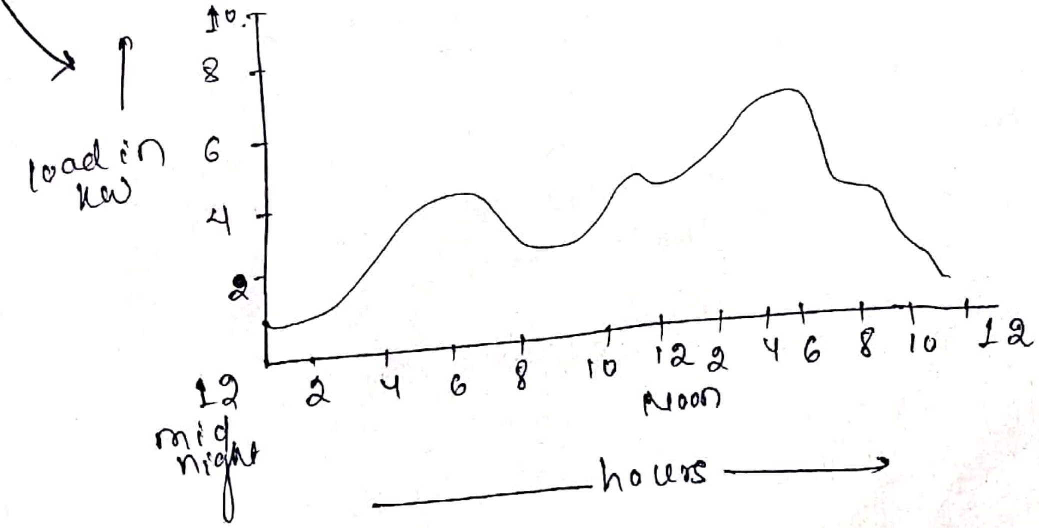
① **Daily load curve :→**

when the load curve is plotted for 24 hours a day, then it is called daily load curve.

② **Monthly load curve :→**

* when the load curve is plotted for a month, then it is called monthly load curve and it is obtained from the daily load curves of that month.

* for this purpose, average values of power over a month at different times of the day are calculated and then plotted on the graph.



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⑧ Maximum demand :→

* It is the greatest demand of load on the power station during a given period.

(OR)

* The maximum demand is the power consumed over a predetermined period of time, which is usually b/w 8-30 minutes.

* maximum demand is generally less than the connected load because all the consumers do not switch on their connected load to the system at a time.

* The knowledge of maximum demand is very important as it helps in determining the installed capacity of the station.

* The station must be capable of meeting the maximum demand.

⑨ Connected load !→

* It is the sum of continuous rating of all the equipments connected to supply system.

A power station supplies load to thousand of consumers. Each consumer has certain equipment installed in this premises. The sum of the continuous rating of all the equipments in the consumer's premises is the "connected load" of the consumers.

✓ The sum of the connected loads of all the consumers is the connected load to the power station.

$5 \times 100 + 500 = 1000$ watt

④ Demand factor! →

It is the ratio of maximum demand on the power station to it's connected load i.e

$$\text{Demand factor} = \frac{\text{Maximum demand}}{\text{connected load}}$$

$D.F < 1$

The value of demand factor is usually less than 1. it is expected because maximum demand on the power station is generally less than the connected load.

Demand factor < 1

because maximum demand < connected load.

EX! → maximum demand = 80 MW

connected load = 100 MW

$$\text{Demand factor} = \frac{80}{100} = 0.8$$

* It helps in determining the capacity of the plant equipment.

⑤ Average load ! →

The average of loads occuring on the power station in a given period (day / month / year) is known as average load or average demand.

$$\text{Daily average load} = \frac{\text{No. of units (kwh) generated in a day}}{24 \text{ hours.}}$$

$$\text{Monthly average load} = \frac{\text{No. of units (kwh) generated in a month}}{\text{No. of hours in a month.}}$$

$$\text{Yearly average load} = \frac{\text{No. of units (kWh) generated in a year}}{8760 \text{ hours}}.$$

⑥ Load Factor :→

The ratio of average load to the maximum demand during a given period is known as load factor i.e

$$\text{Load factor} = \frac{\text{Average load}}{\text{maximum Demand}} = \frac{\text{Average load} \times T}{\text{max}^m\text{. demand} \times T}$$

$$= \frac{\text{units generated in } T \text{ hours}}{\text{max}^m \text{demand} \times T \text{ hours}}$$

Load factor is always less than 1.

because Average load < maximum demand.

* Higher the load factor of power station, lesser will be the cost per unit generated.

⑦ Diversity Factor

The ratio of the sum of individual maximum demands to the maximum demand on power station is known as diversity factor i.e

$$\text{Diversity factor} = \frac{\text{sum of individual maximum demands}}{\text{max. demand on power station}}$$

The diversity factor always greater than 1.

$$\boxed{D.F > 1}$$

because sum of individual max. demand > max. demand on power station.

The greater the diversity factor, the lesser is the cost of generation of power.

A power station supplies load to various types of consumers whose maximum demands generally do not occurs at the same time.

⑧ **Plant capacity factor**

It is the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period i.e

$$\text{Plant capacity factor} = \frac{\text{actual energy produced}}{\text{max. energy that could have been produced}}$$

$$= \frac{\text{average demand} \times T}{\text{plant capacity} \times T}$$

$$= \frac{\text{average demand}}{\text{Plant capacity}}.$$

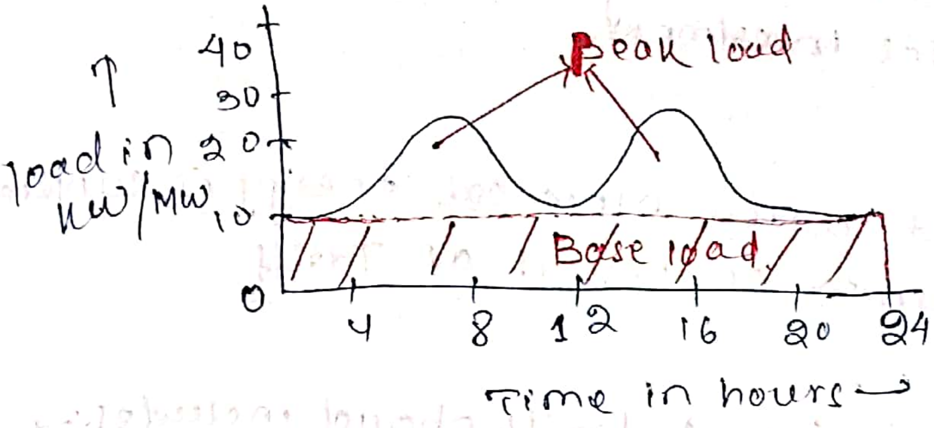
Plant capacity :→ The max^m energy that could have been produced.

$$\text{Plant capacity factor} = \frac{\text{actual energy produced}}{\text{Plant capacity}}.$$

Load on the Power station can be considered in two parts, namely

① Base load

② peak load



① Base load !→ The ~~Al~~ unvarying load which occurs almost the whole day on the station is known as base load.

* in figure 10 MW is the base load of the station

* As base load on the station is almost of constant nature, therefore it can be suitably supplied without facing the problems of variable load.

② peak load !→ The various peak demands of load over and above the base load of the station is known as peak load.

curve

Ch-9 Tariff

The supply company has to ensure that the tariff is such that it not only recovers the total cost of producing electrical energy but also earns profit on the capital investment.

* The rate at which electrical energy is supplied to a consumer is known as Tariff.

Objectives of Tariff :→ A tariff should includes:→ the following items

(i) Recovery of cost of producing electrical energy at the power station.

(ii) Recovery of cost on the capital investment in transmission and distribution systems.

(iii) Recovery of cost of operation and maintenance of supply of electrical energy i.e metering equipments, billing etc.

(iv) A suitable profit on the capital investment.

Different type of tariff

① simple tariff :→

- Where there is a fixed rate per unit of energy consumed, it is called a simple tariff or uniform rate tariff.
- The price doesnot very with increase or decrease in no. of units consumed.

~~Disadvantages~~

② Flat rate Tariff :→

when different types of consumers are charged at different uniform per unit rates, it is called a flat rate tariff.

Advantages :→

The advantage of such a tariff is that it is more fair to different types of consumers and is quite simple in calculation.

disadvantages :→

→ Since the flat rate tariff varies according to the way the supplies is used, separate meters are required for lighting load, power load etc. This makes the application of such a tariff expensive and complicated.

→ A particular class of consumers is charged at the same rate irrespective of the magnitude of energy consumed. However a big consumers should be charged at a lower rate as in his case the fixed charges per unit are reduced.

③ Block rate tariff :→

When a given block of energy is charged at a specific rate and the succeeding block of energy are charged at progressively reduced rates, it is called a block rate tariff.

→ In block rate tariff, the energy consumption is divided into blocks and the price per unit is fixed in each block.

→ The price per unit in the first block is the highest, and it is progressively reduced for the succeeding blocks of energy.

Ex :→ For first 30 units → 60 paise per unit

Next 25 unit → 55 paise per unit

and the remaining Addl. unit → 30/per unit

may be charged at the rate of 30 paise per unit

④ Two part Tariff :→

when the rate of electrical energy is charged on the basis of maximum demand of the consumer and the units consumed, it is called a two-part tariff.

→ In two-part tariff, the total charge to be made from the consumer is split into two components.

① Fixed charges → depends upon the maximum demand of the consumer is while

② Running charges, ↳ depends upon the no. of units consumed by the consumers.

Total charges = Rs (b × kw + c × kwh)

b = charge per kw of maximum demand

c = charge per kwh of energy consumed.

→ This types of tariff is mostly applicable to industrial consumers who have appreciable maximum demand.

Advantages :→

(i) It is easily understood by the consumers

(ii) It recovers the fixed charges which depend upon the maximum demand of the consumers but are independent of the units consumed.

Disadvantages

(i) The consumer has to pay the fixed charges irrespective of the fact whether he has consumed or not consumed the electrical energy.

(ii) There is always error in assessing the maximum demand of the consumers.

Q.1

A consumer has a maximum demand of 200 kW at 40% load factor. if the tariff is RS.100 per kW of maximum demand plus 10 paise per kwh, Find the overall cost per kwh.

$$\text{Load Factor} = \frac{\text{average load}}{\text{maximum demand}}$$

$$\text{average load for yr.} = \frac{\text{No. of units consumed (kwh)}}{8760 \text{ hrs.}}$$

$$\Rightarrow \text{Load factor} = \frac{\text{No. of units consumed (kwh)}}{\text{max}^m \text{ demand} \times 8760}$$

$$\Rightarrow \text{No. of units consumed (kwh)} = \text{Load factor} \times \text{max}^m \text{demand} \times 8760$$

$$= 0.4 \times 200 \times 8760$$

$$= 700800 \text{ kWh}$$

$$\text{Annual charges} = \text{Annual Max}^m \text{ demand} + \text{Annual energy consumed}$$

$$= (a \times kw + b \times kwh)$$

$$= (100 \times 200 + 0.1 \times 700800)$$

$$= 90080$$

$$\text{overall cost/kwh} = \text{Rs. } \frac{90080}{700800} = 0.1285 = 12.85 \text{ paise}$$

Ch-10 substation

Bus-Bar Arrangement in sub-station

→ There are several bus-bar arrangements that can be used in a sub-station. This arrangements depends upon various factors such as system voltage, position of sub-station, degree of reliability, cost, etc.

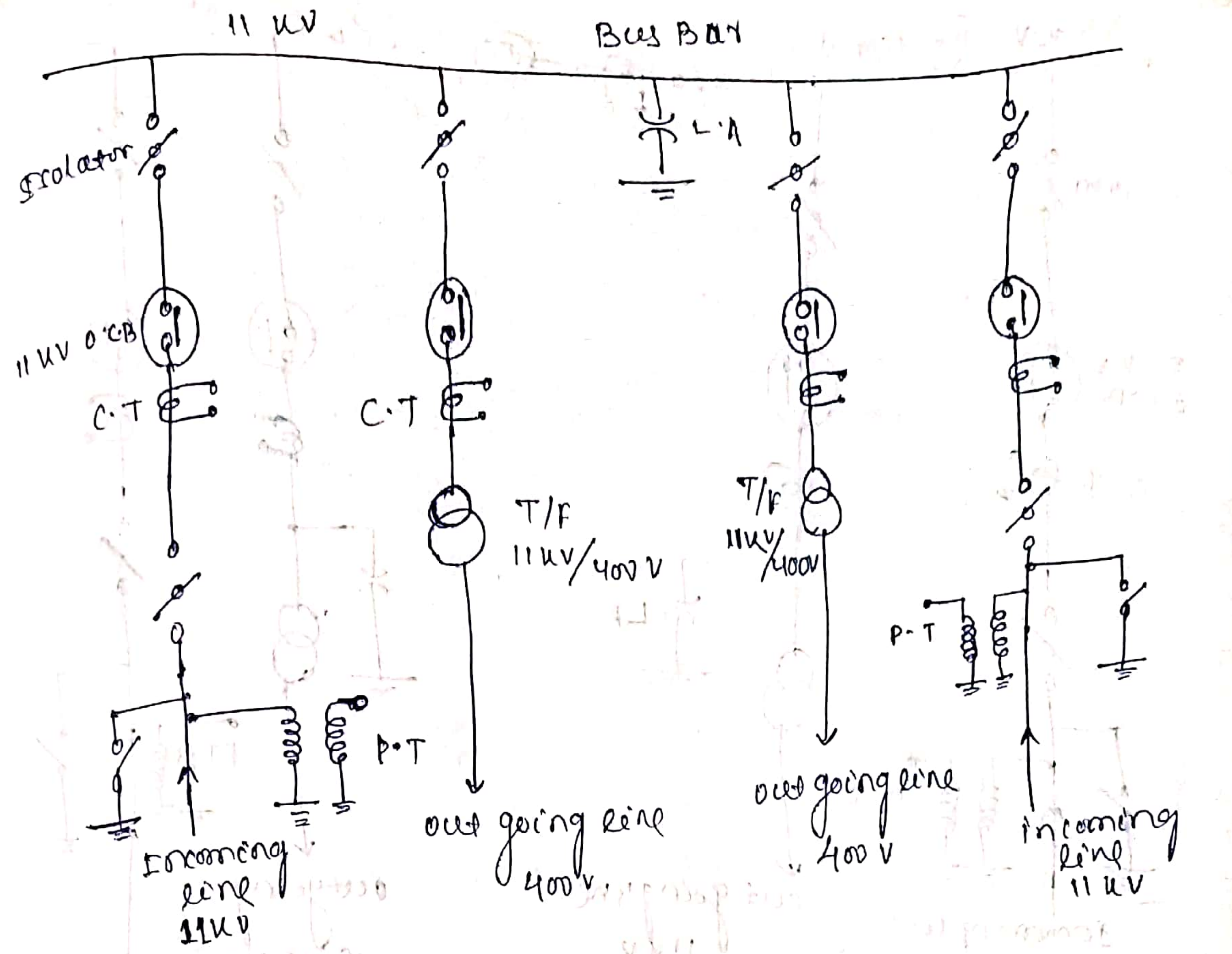
(1) single Bus-bar arrangement :→

→ It consist of a single bus-bar and all the incoming and out going lines are connected to it.

Advantages
- (i) Low initial cost.
- (ii) Less maintenance.
- (iii) simple operation.

disadvantages
- (i) If repair is to be done on the bus, bus-bar or a fault occurs on the bus, There is a complete interruption of the supply.
- (ii) This arrangement is not used for voltage above 33 kV.

Here 2, 11 kV incoming line and 2, 400 V outgoing line connected to single bus.



(2) Single bus-bar system with sectionalisation

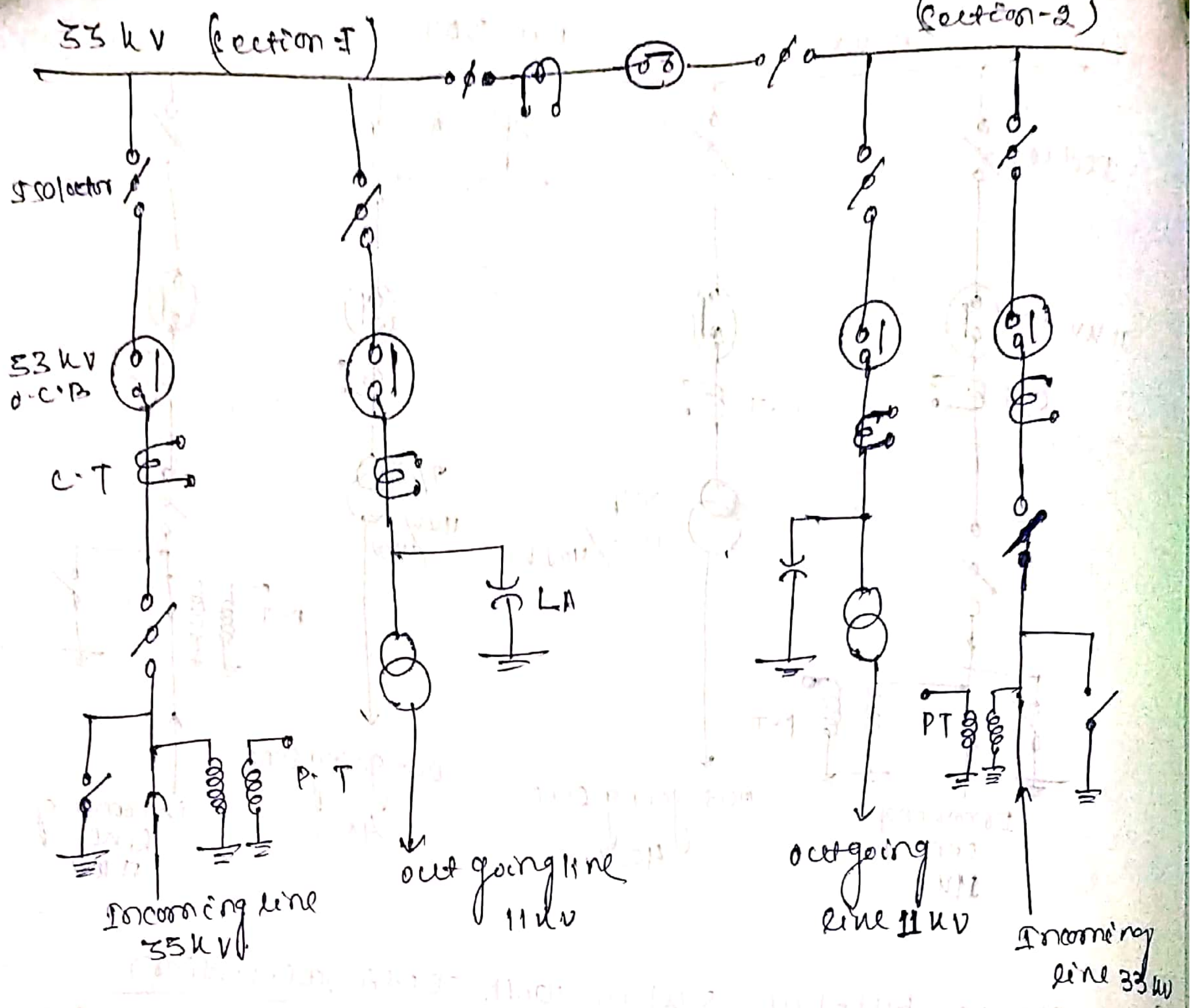
→ In this arrangement, the single bus-bar is divided into two section with circuit CB and isolator. and load is equally distributed on all the section.

Advantages

(i) If a fault occurs on any section of the bus, then that section can be isolated without affecting the supply from other section.

(ii) Repair and maintenance of any section of the bus bar can be carried out by de-energising that section only, eliminating the possibility of complete shut-down.

→ This arrangement is used for voltage upto 33 kv.

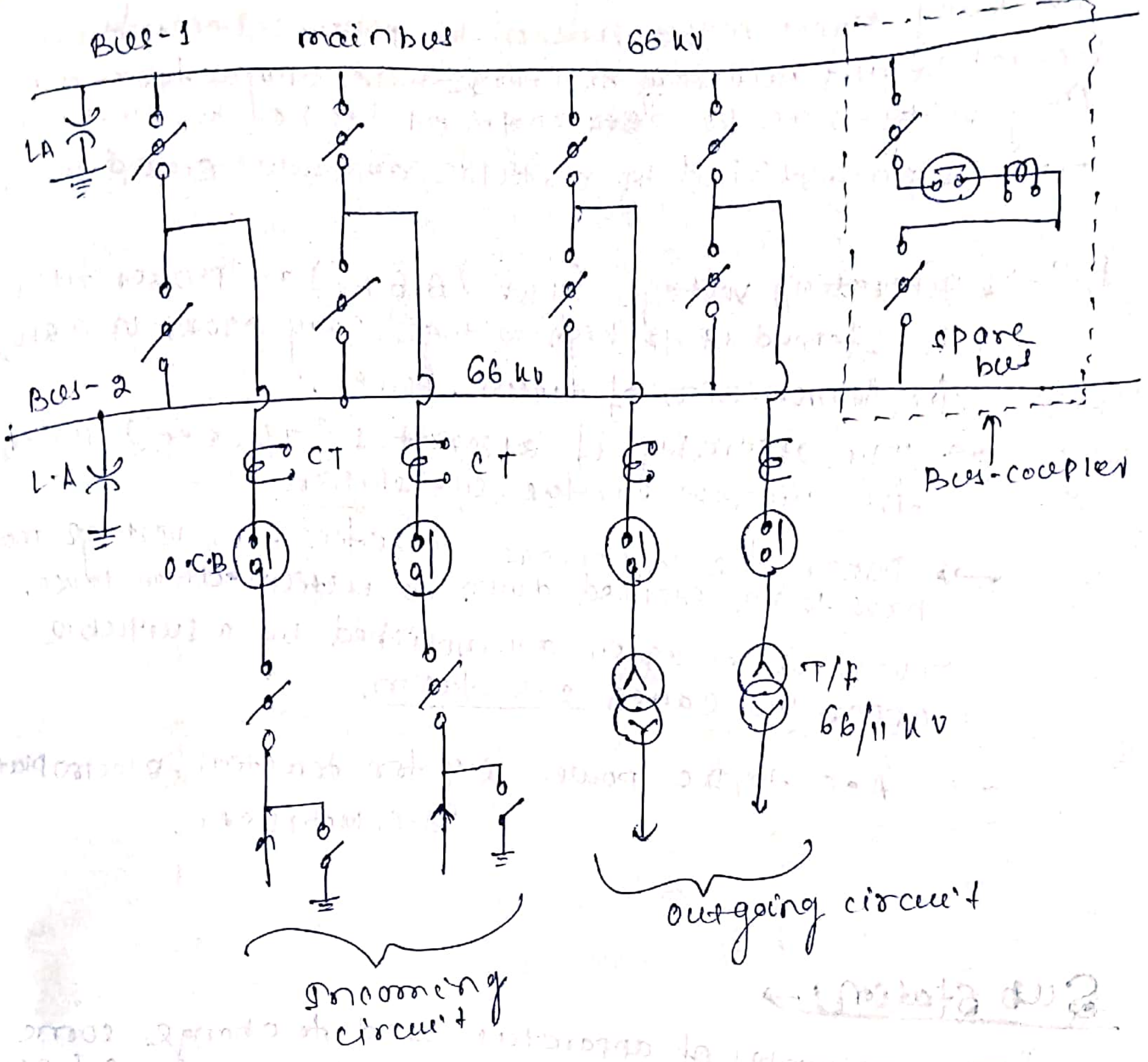


(ii) Duplicate-bus-bar arrangements:→

→ In this system, it consist of 2 bus-bars (i) main bus bar and (ii) spare bus-bar.

→ ordinarily, the incoming and out-going line always connected to the main bus-bar, but however in case of repair or fault occuring on main bus, the continuity of supply to the circuit can be ~~transfer~~ maintained by transferring it to the spare bus by using bus-coupler.

→ For voltage above 33 kV, duplicate bus-bar system is frequently use.



Substation :→

→ Main function of substations are to receive energy transmitted at high voltage from the generating station, reduce the voltage to a value appropriate for local distribution and provide facilities for switching.

Ex:→ 11 kV or 6.6 kV

→ Receive energy

11 kV/6.6 kV ⟶ 132 kV/220 kV

→ Reduce energy

132 kV ⟶ 440 volt.

→ switching operation

* Some sub-stations are simply switching stations where different connections b/w various transmission line are made, others are converting sub-stations which either convert ac into DC or viceversa or convert frequency from higher to lower or viceversa.
* It disconnect the ckt or equipments during fault time.
* out going voltage canbe regulated. For street light, switching control canbe installed at sub-station.

* At many places in the line of the power system, it may be desirable and necessary to change some characteristics (e.g voltage, ac-DC, frequency, p.f etc) of the electric supply. This is accomplished by suitable apparatus called sub-station.

EX:→ * generation voltage (11 kV / 6.6 kV) at power station is stepped up to high voltage (say 220 kV or 132 kV) for transmission of electric power.

→ The assembly of apparatus (T/F etc) used for this purpose is the sub-station.

→* Near the consumers localities, the voltage may have to be stepped down to utilisation level. This job is again accomplished by a suitable apparatus called sub-station.

→ A.C to D.C powe e.g for traction, electro plating, d.c Motors etc.

Sub station:→

"The assembly of apparatus used to change some characteristics (e.g voltage, ac to D.C, frequency, p.f etc) of electric supply is called a sub-station."

The following are the important points which must be kept in view while laying out a sub-station:

(i) It should be located at a proper site. It should be located at the (As far as possible, centre of gravity of load)

(ii) It should provide safe and reliable arrangement (for safety, consideration must be given to the maintenance of regulation clearance, facilities for carrying out repairs and maintenance, abnormal occurrences such as possibility of explosion or fire etc. For reliability, consideration must be given for good design and construction, the provision of suitable protective gear etc.)

(iii) It should be easily operated and maintained.
(iv) It should involve minimum capital cost.

Classification of sub-stations

There are two most important ways of classifying them, are according to (a) service requirement
(b) constructional features.

(a) According to service requirement

A sub-station maybe called upon to change voltage level or improve power factor or convert A.C power to D.C power etc.

According to the service requirement, sub-station maybe classified into:→

(i) Transformer sub-station:→

✓ Those sub-station which change the voltage level of electric supply are called T/f sub-station.

→ These sub-station receive power at some voltage & deliver it at some other voltage.

→ ~~Thes~~ most of the sub-station in the power system are of this type,

(ii) Switching sub-station:→

These substation do not change the voltage level. i.e incoming and outgoing lines have the same voltage. However, they simply perform the switching operation of power line (Such substations are meant for switching operation of power lines without transforming the voltage)

(iii) Power factor correction sub-station:→

✓ Those sub-station which improve the power factor of the system are called power factor correction sub-station.

→ Such sub-stations are generally located at the receiving end of transmission lines.

→ The sub-stations generally use synchronous condensers as the power factor improvement equipment.

(4) **frequency changer sub-station!** → Those sub-station which change the supply frequency are known as frequmeency change sub-station.

→ such a frequency change may be required for industries utilisation.

(5) **Converting sub-station!** → Those sub-station which change a.c power into D.C power are called converting sub-station.

for such purpose as traction, electroplating, electric welding.

(6) **Industrial sub-station!** →

Those sub-stations which supply power to individual industrial concerns are known as industrial sub-stations.

(b) **According to constructional features!** →

→ A sub-stations has many components (e.g circuit breakers, switches, fuses, instruments etc) which must be housed properly to ensure continuous and reliable service.

According to constructional features, the sub-stations are classified as:

(1) **Indoor sub-station!** →

→ For voltage upto 11 kv, the equipment of the sub-station is installed indoor because of economic consideration.

Such sub-stations are usually for a voltage upto 11kv but can be erected for the 53 kv and 66 kv when the surrounding atmosphere is contaminated with impurities such as conductive metal corroding gases and fumes, dust etc.

(2) **Out-door sub-stations!** →

For such sub-stations are usually for voltage above 66 kv.

It is 2 types.

① pole-mounted substation :→

→ Such substations are erected for mounting distribution transformer of capacity upto 250 KVA.

→ Such substations are cheapest, simple and smallest of substation.

② Foundation mounted substation!→

The T/F of capacity above 250 KVA the transformers are heavy for pole mounting. Such substations are usually for voltages of 33 KV and above.

③ underground substation :→

In the thickly populated areas, the spaces available for equipment and building is limited and the cost of land is high. under such situation, the sub-stations is erected underground.

Transformer sub-station!→

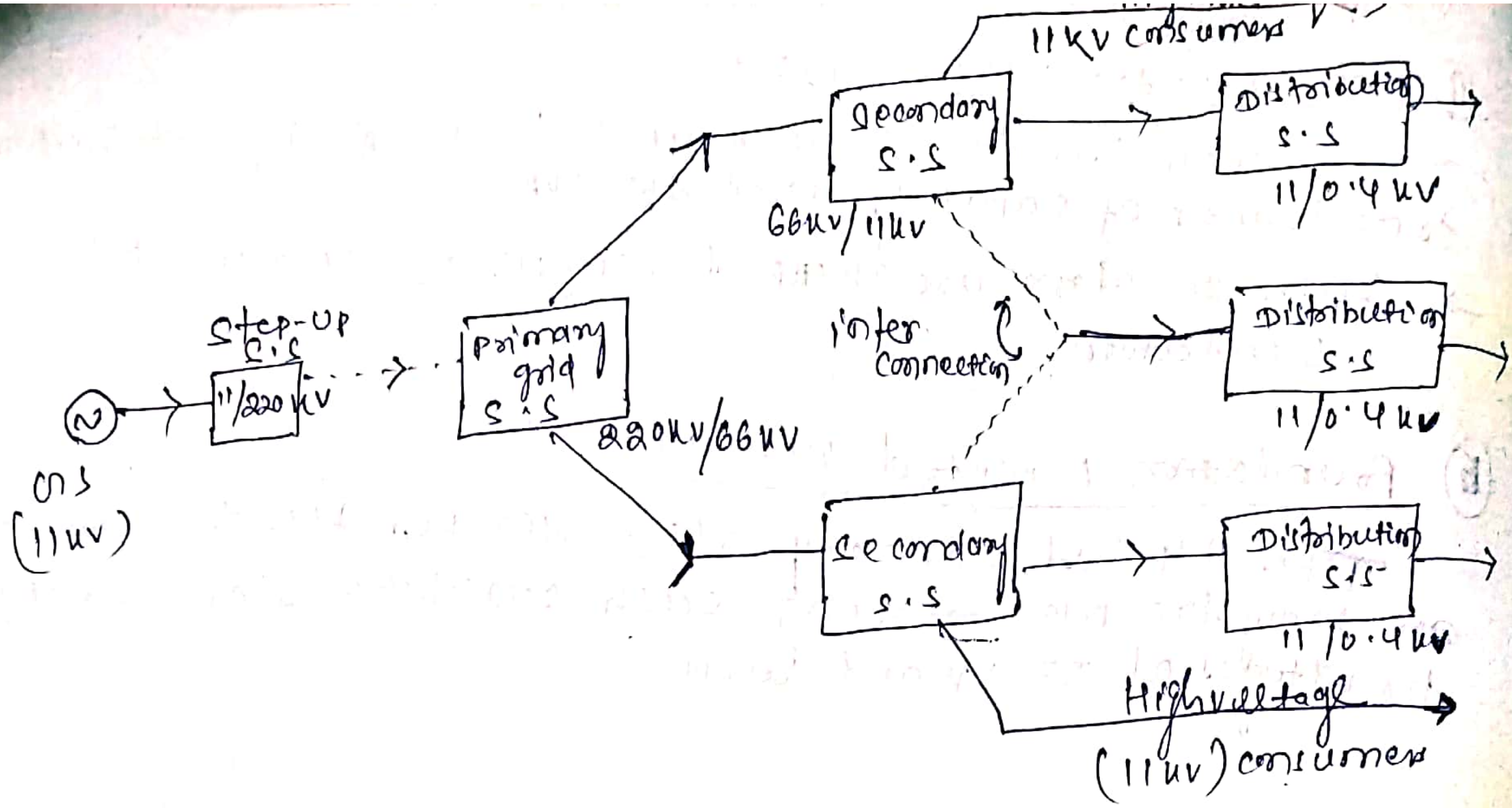
In transformer sub-station, transformer is the main component employed to change the voltage level. T/F sub-station may be classified as!→

(i) Step-up Transformer substation!→

The generated voltage, which is usually low (3.3, 6.6, 11 or 33 KV), is stepped up to primary transmission voltage, so that huge blocks of power can be transmitted over long distances to the load centres economically. (11 KV - 220KV)

(ii) primary grid substation!→

electric power at 220 KV is transmitted by 3ϕ, 3 wire overhead system to the outskirts of the city. Here electric power is received by the primary grid sub-station which reduces the voltage level to 66 KV for secondary transmission. (220KV—66KV)



(iii) **Secondary sub-station:→** From the primary grid substation, electric power is transmitted at 66kV by 3ϕ, 3wire system to various secondary sub-station located at the strategic points in the city. At the secondary sub-station the voltage is further stepped down to 11kV.

→ The 11kV lines run along the important road sides of the city. It maybe noted that big consumers (having demand more than 50kW) are generally supplied power at 11kV for further handling with their own sub-statio

④ **Distribution S/S !→**

→ The electric power from 11kV lines is delivered to distribution S/S. These S/S are located near the consumers localities and step-down the voltage to 400V, 3ϕ-4wir for supplying to the consumers.

underground S/S

In thickly populated cities, there is scarcity of land as well as the prices of land are very high. This has led to the development of underground s/s. In such s/s, the equipment is placed underground.

While laying out an underground s/s, the following point must be kept in view.

→ The size of the station should be minimum as possible.

→ There should be reasonable access for both equipment and personnel.

→ There should be provision for emergency light and protection against fire.

There should be good ventilation.

→ There should be provision for remote indication of

→ There should be excessive rise in temp. So that H.V supply can be disconnected.

→ The T/f, switches and fuses should be air cooled to avoid bringing oil into the premises.