UNIT - I

ELECTRICAL CIRCUITS

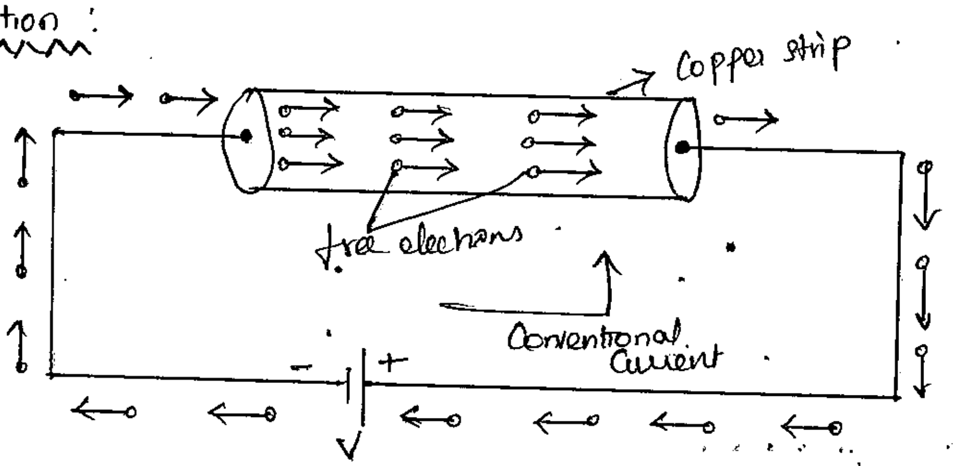
ELECTRIC CURRENT:

→ The flow of free electrons in a metal is called as electric current

(or)

→ Current is defined as the rate of flow of electrons in a Conductive (or) Semi Conductive medium.

Explanation:



→ When electric voltage is applied, then the free electrons which are negatively charged will start moving towards the positive terminal around the circuit. This direction of flow of electrons is called as electric current.

→ Unit of Current is Coulomb / sec (or) Ampere.

ELECTRIC POTENTIAL (OR) VOLTAGE:

→ The ability of the charged body to do work is called as electric potential.

$$\text{Electric potential} = V = \frac{\text{Work done}}{\text{charge}}$$

$$V = \frac{W}{Q}.$$

→ Unit of electric potential is joules / Coulomb (or) Volts.

POTENTIAL DIFFERENCE:

→ The difference in the potentials of two charged bodies is called as potential difference.

ELECTRICAL POWER:

→ The rate at which work is done in an electric ~~circuit~~ circuit is called electrical power.

$$\text{Electrical power} = \frac{\text{Work done in circuit}}{\text{Time}}$$

→ Unit of power is J/s (or) Watt.

$\boxed{1 \text{ HP} = 746 \text{ Watts}}$.

ELECTRICAL ENERGY:

→ The total work done in an electric circuit is called as electrical energy.

ENERGY SOURCE:

→ Classified into two types. They are

* Voltage source
* Current source.

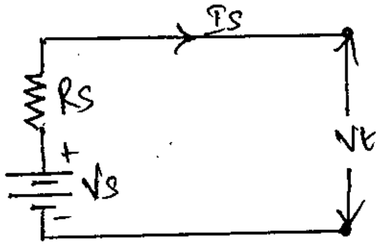
→ In each of the above two, again two types.

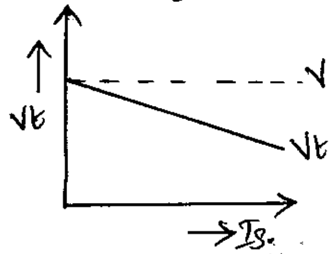
* Ideal
* Practical.

Voltage Source:

a) Practical:

$V_t = V_s - I_s R_s$





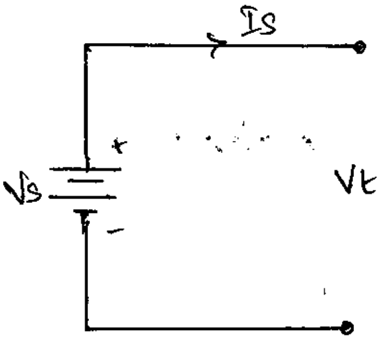
→ A practical voltage source consists of internal resistance R_s in series with the source voltage V_s.

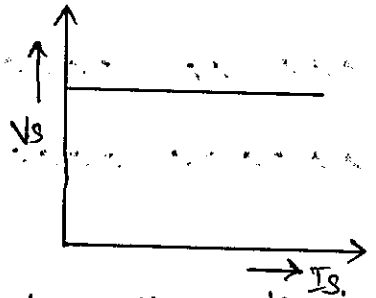
→ The terminal V_t across the load changes with change in the load current. It is due to the voltage drop across R_s.

→ As I increases, V_t decreases.

b). Ideal:

$V_s = V_t$.



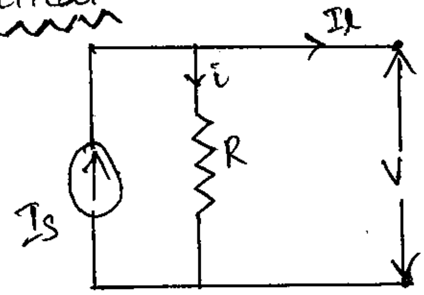


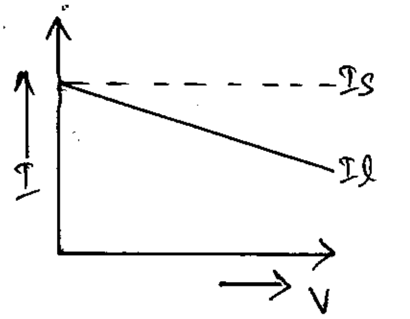
→ Here the terminal voltage V_t is independent of current.

→ It is possible only when $R_s = 0$. Hence the internal Resistance of an ideal voltage source is zero.

Current Source:

a) Practical:



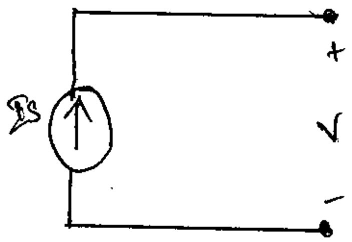


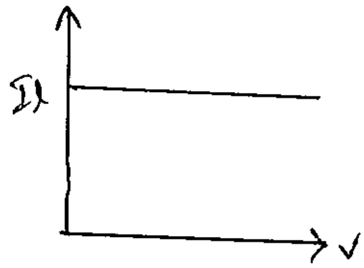
→ A Practical Current Source Consists of resistance in parallel with source.

$$I_l = I_s - i$$
$$= I_s - V/R.$$

→ As V increases, I_l decreases.

b) Ideal :





→ For an ideal Current source, load current I_l is independent of V. It is Possible only when $R = \infty$; R is open circuit.

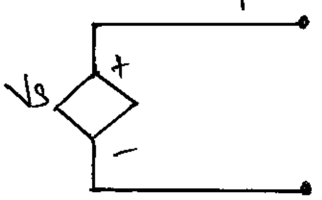
INDEPENDENT & DEPENDENT SOURCE :

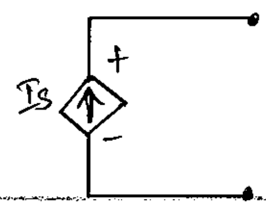
a) Independent Source :

→ Ideal source are called as independent source.
→ They are termed as uncontrolled source.
→ Their voltage and currents are fixed.

b) Dependent Source :

→ They are used in transistors & Vacuum tubes
→ Also known as Controlled source.
→ They are not fixed.





CIRCUIT ELEMENTS:

RESISTANCE:

- It is the property of a material by virtue of which it opposes the flow of electrons through the material.
- Thus the resistance restricts the flow of electric current through the material.
- The unit of resistance (R) is ohm (Ω).

INDUCTANCE:

- It is the property of a material by virtue of which it opposes any change of magnitude (or) direction of electric current passing through the conductor.
- The unit of Inductance is Henry (H).

CAPACITANCE:

- It is the capability of an element to store electric charge with in it.
- Capacitance is a measure of charge of per unit voltage that can be stored in an element.
- The unit of capacitance (C) is Farad (F).

OHM'S LAW:

- The ratio of potential difference between any two points of a conductor to the current flowing between them is constant, provided the physical condition (temperature) do not change.

$$\frac{V}{I} = \text{Constant}.$$

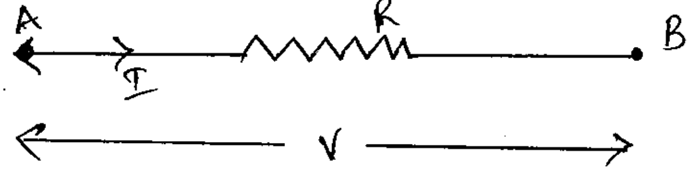
$$\frac{V}{I} = R$$

$$\boxed{V = IR}$$

$$R = \frac{V}{I}\,\Omega.$$

Illustration:

→ Let the potential difference between the points A & B be volts and currents flowing be I amps.



$$\frac{V}{I} = \text{Constant } (R).$$

→ If the voltage is doubled (2V) the current flowing will also be doubled (2I) so the ratio V/I remains the same (i,e) R.

Limitations of ohm's Law:

* ohm's law does not apply to all non Metallic Conductor.

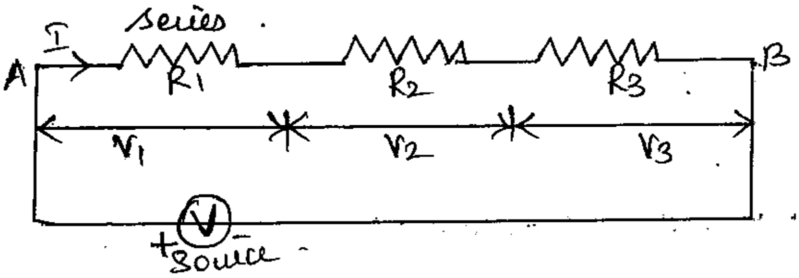
* It also does not apply to non-linear device such as zener diode, Voltage regulator tube etc.

* Ohm's Law holds good only for Constant temperature.

SERIES AND PARALLEL CIRCUITS:

SERIES CIRCUIT:

→ If the resistor are connected end to end then the combination is said to be series.



→ The Resistor R_1, R_2, R_3 are all connected end to end. The free terminal A & B are connected to the voltage source.

To find equivalent Resistor:

V - Applied voltage

I - source current

By ohm's Law

$$V_1 = IR_1$$

$$V_2 = IR_2$$

$$V_3 = IR_3$$

$$V = V_1 + V_2 + V_3$$

$$= IR_1 + IR_2 + IR_3$$

$$= I(R_1 + R_2 + R_3).$$

R_T → equivalent Resistor.

$$V = I \times R_T.$$

$$\boxed{R_T = R_1 + R_2 + R_3}$$

Concept of Series Circuit:

* The current flowing in all parts of the circuit is same.

* Voltage across the different elements will depend upon the resistance of elements.
* Voltage drop are additive.
* Resistance and power are additive.
* The applied voltage equals the sum of different voltage drops.

Voltage Division Technique:

By Ohm's Law

$$R_T = R_1 + R_2 + R_3$$

$$I = \frac{V_T}{R_T} = \frac{V}{R_1 + R_2 + R_3}$$

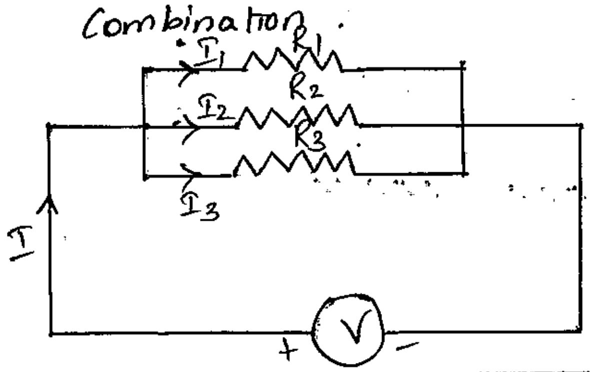
$$V_1 = I \times R_1 = \frac{V}{R_T} \times R_1 = \frac{VR_1}{R_1 + R_2 + R_3}.$$

$$V_2 = I \times R_2 = \frac{V}{R_T} \times R_2 = \frac{VR_2}{R_1 + R_2 + R_3}.$$

$$V_3 = I \times R_3 = \frac{V}{R_T} \times R_3 = \frac{VR_3}{R_1 + R_2 + R_3}.$$

PARALLEL CIRCUITS:

→ If one end of all the resistors is joined to a common point and the other ends are joined to another common point, the combination is said to be parallel combination.



→ Let R_1, R_2, R_3 be the three resistors connected between the two common terminals A & B. Let V be the voltage supplied between A & B.

→ I_1, I_2 & I_3 are the currents through R_1, R_2 and R_3.

By ohm's Law,

$$I_1 = V/R_1$$
$$I_2 = V/R_2$$
$$I_3 = V/R_3.$$

$$I = I_T = V/R.$$
$$I = I_1 + I_2 + I_3.$$
$$\frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$
$$= V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$
$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}.$$

→ $\text{Conductance} = \dfrac{1}{\text{Resistance}}.$

$$G = \frac{1}{R}.$$
$$G = G_1 + G_2 + G_3.$$

Concept of Parallel Circuits:

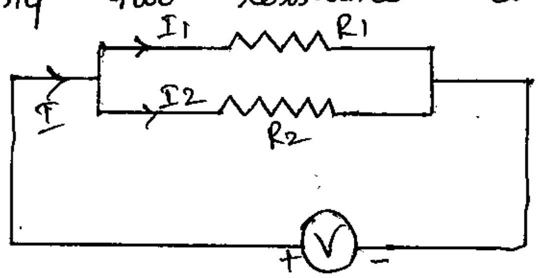
* Same voltage across all elements.
* All elements will have individual currents, depending upon the resistance of element.
* The total resistance of a parallel circuit is always less than the smallest of the resistance.

* Power are additive.
* Conductance are additive.
* Branch Currents are additive.

Current Division Technique:

Case a):

→ only two resistance Connected in parallel.



The total Current $= I$.

Current through $R_1 = I_1$

Current through $R_2 = I_2$.

→ To express I_1 & I_2 in terms of I, R_1 & R_2.

$$I_2 R_2 = I_1 R_1$$

$$\therefore I_2 = \frac{I_1 R_1}{R_2}$$

$$I = I_1 + I_2.$$

$$I_1 + \frac{I_1 R_1}{R_2} = I.$$

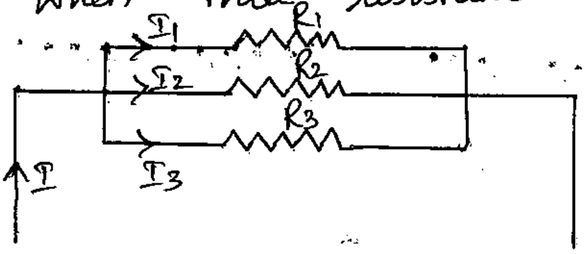
$$I_1 (R_1 + R_2) = I R_2.$$

$$I_1 = \frac{I R_2}{R_1 + R_2}$$

$$I_2 = \frac{I R_1}{R_1 + R_2}.$$

Case b)

→ When three resistance are in parallel



$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}.$$

$$R = \frac{R_1 R_2 R_3}{R_1R_2 + R_2R_3 + R_3R_1}.$$

→ To find the currents I_1, I_2 & I_3.

$$I_1 = \frac{I R_2 R_3}{(R_1R_2 + R_2R_3 + R_3R_1)}$$

$$I_2 = \frac{R_1 R_3 I}{(R_1R_2 + R_2R_3 + R_3R_1)}$$

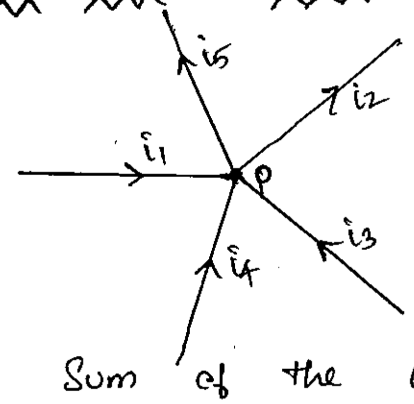
$$I_3 = \frac{I R_1 R_2}{(R_1R_2 + R_2R_3 + R_3R_1)}.$$

COMPARISON OF SERIES & PARALLEL CIRCUITS.

Series Circuit	Parallel Circuit
* The Current is same	* The current is divided inversely proportional to resistances.
* The voltage is distributed It is proportional to resistance.	* The voltage is same.
* $R = R_1 + R_2 + R_3$	* $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$.

KIRCHOFF'S LAW:

i) Kirchoff's First Law (Current Law):



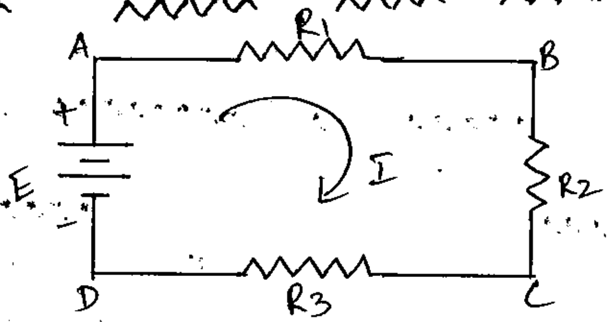
→ The Sum of the Currents flowing towards a junction is equal to the sum of the currents flowing away from it.

→ In the diagram, the Currents i_1, i_3 & i_4 flows towards the junction P.
i_2 & i_5 away from the junction.

→ According to the Kirchoff's first Law,

$$i_1 + i_3 + i_4 = i_2 + i_5$$

ii) Kirchoff's Second Law (Voltage Law):



→ In a Closed Circuit, the sum of the potential drops is equal to the sum of the potential rises.

(OR).

→ The algebric sum of EMF plus the algebraic sum of the voltage across the impedances, in any Closed Circuit is equal to zero.

$$\Sigma_{emf} + \Sigma_{IZ} = 0.$$

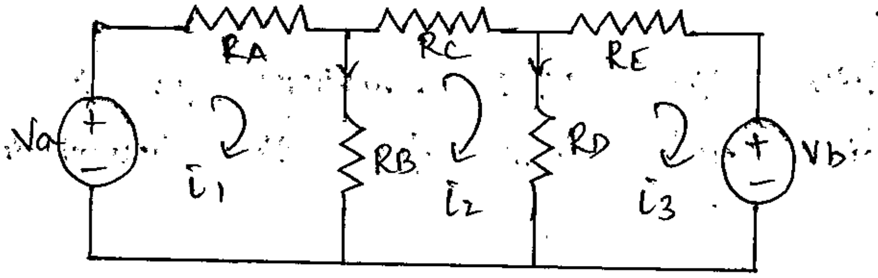
$$IR_1 + IR_2 + IR_3 = E.$$

MESH ANALYSIS

Loop Current Method:

→ The no. of independent loops is equal to $(b-n+1)$

→ This is based on KVL.



→ In this network, there are 3 nodes (i.e) $n=3$.

branches $b = 5$

Independent loops $l = b-(n+1)$

$$= 5-3+1$$

$$l = 3.$$

→ Applying KVL to 1^{st} loop,

$$V_a - I_1 R_a - (I_1 - I_2) R_B = 0.$$

$$I_1 (R_A + R_B) - I_2 R_B = V_a. \quad -(1).$$

→ Applying KVL to the Middle loop,

$$-I_2 R_C - (I_2 - I_3) R_D + (I_1 - I_2) R_B = 0.$$

$$-R_B I_1 + (R_C + R_D + R_B) I_2 - R_D I_3 = 0. \quad -(2).$$

→ Applying KVL to 3rd loop,

$$-I_3 R_E - V_b + (I_2 - I_3) R_D = 0.$$

$$-R_D I_2 + (R_D + R_E) I_3 = 0 - V_b \quad -(3)$$

$$R_{11}I_1 + R_{12}I_2 + R_{13}I_3 = V_a$$

$$R_{21}I_1 + R_{22}I_2 + R_{23}I_3 = 0$$

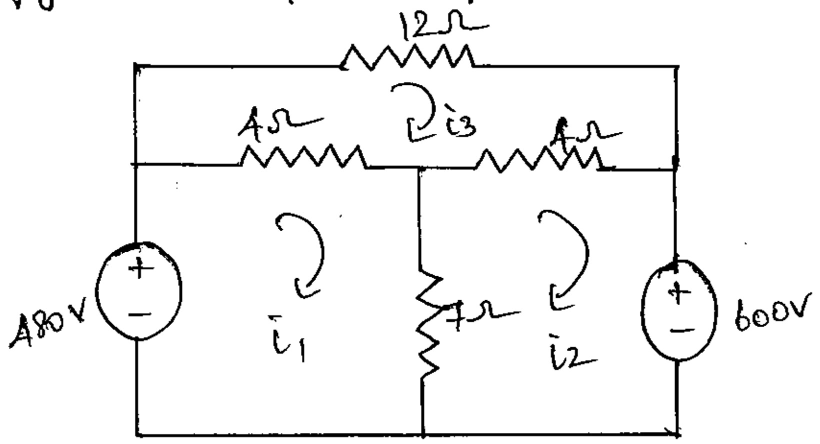
$$R_{31}I_1 + R_{32}I_2 + R_{33}I_3 = -V_b$$

$$\begin{bmatrix} R_{11} & R_{12} & R_{13} \\ R_{21} & R_{22} & R_{23} \\ R_{31} & R_{32} & R_{33} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} V_a \\ 0 \\ -V_b \end{bmatrix}$$

$$[R][I] = \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix}$$

Problem 1 :

Write the Mesh equations for the Circuit Shown in fig. and solve for the Current in 12 Ω Resistor.



Solution :

$$\begin{bmatrix} 11 & -7 & -4 \\ -7 & 11 & -4 \\ -4 & -4 & 20 \end{bmatrix} \begin{bmatrix} i_1 \\ i_2 \\ i_3 \end{bmatrix} = \begin{bmatrix} 480 \\ -600 \\ 0 \end{bmatrix}$$

$$\Delta = \begin{bmatrix} 11 & -7 & -4 \\ -7 & 11 & -4 \\ -4 & -4 & 20 \end{bmatrix}$$

$$= 11(204) + 4(-140 - 16) + (-4)(28 + 44)$$

$$\underline{\underline{\Delta = 864}}.$$

$$i_3 = \frac{\Delta_3}{\Delta}.$$

$$\Delta_3 = \begin{vmatrix} 11 & -7 & 480 \\ -7 & 11 & -600 \\ -4 & -4 & 0 \end{vmatrix}$$

$$\underline{\underline{\Delta_3 = -8640}}$$

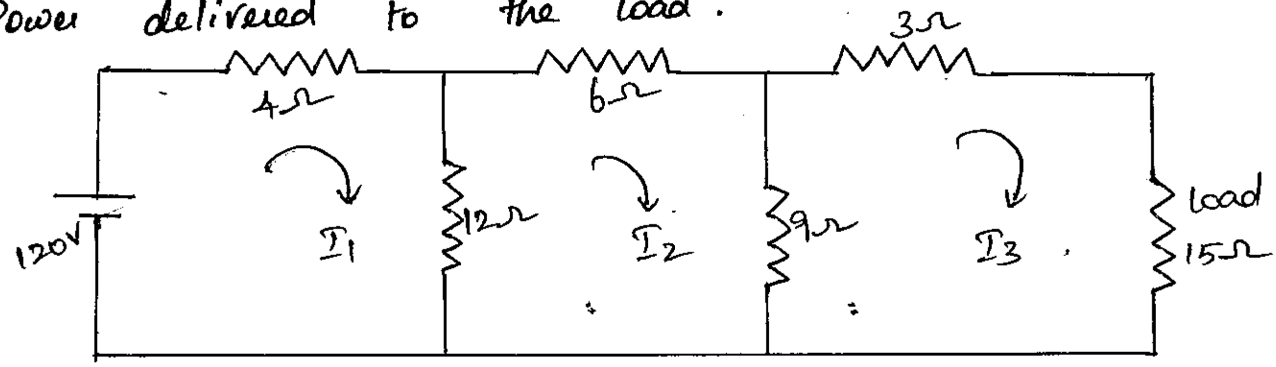
$$i_3 = \frac{-8640}{864}$$

$$\underline{\underline{i_3 = -10 \text{ Amps}}}$$

→ (−) indicates the anticlockwise direction of i_3.

Problem 2:

In the circuit, obtain the load current and the power delivered to the load.



Solution:

$$= \begin{bmatrix} (4+12) & -12 & 0 \\ -12 & (6+9+12) & -9 \\ 0 & -9 & (3+15+9) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 120 \\ 0 \\ 0 \end{bmatrix}$$

$$= \begin{bmatrix} 16 & -12 & 0 \\ -12 & 27 & -9 \\ 0 & -9 & 27 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 120 \\ 0 \\ 0 \end{bmatrix}$$

$$\Delta = \begin{bmatrix} 16 & -12 & 0 \\ -12 & 27 & -9 \\ 0 & -9 & 27 \end{bmatrix}$$

$$= 16\left(27\times 27-(-9\times -9)\right)+12\left(-12\times 27-0\times 9\right)+0$$

$$\underline{\underline{\Delta = 6480}}$$

$$\Delta_3 = \begin{vmatrix} 16 & -12 & 120 \\ -12 & 27 & 0 \\ 0 & -9 & 0 \end{vmatrix}$$

$$= 16(27\times 0 + 9\times 0)+12(-12\times 0 - 0\times 0)+120(-12\times -9-0\times 27)$$

$$\underline{\underline{\Delta_3 = 12960}}$$

$$I_3 = \frac{\Delta_3}{\Delta} = \frac{12960}{6480} = \underline{\underline{2\ \text{Amps}}}$$

→ Power in the load

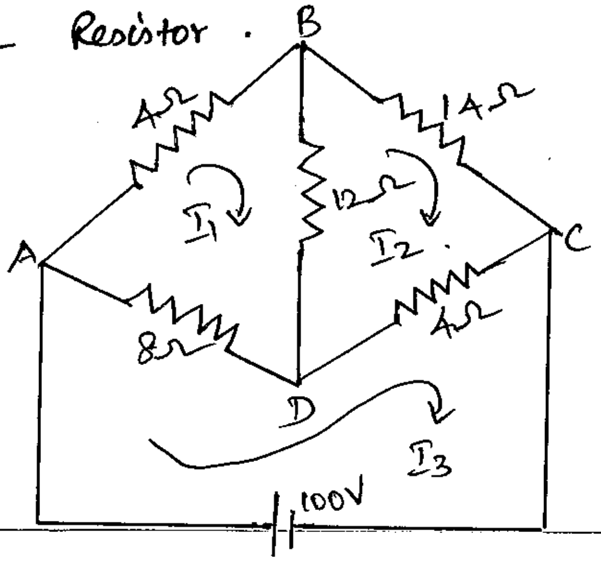
$$P = I^2 R_L$$

$$= 2^2 \times 15$$

$$\underline{\underline{P = 60\ \text{watts}}}$$

Problem 3 :

A Wheatstone bridge ABCD has resistances $AB = CD = 4\,\Omega$, $BC = 14\,\Omega$, $DA = 8\,\Omega$ and $BD = 12\,\Omega$. Between A & C, a 100V battery is connected with A as positive. Using Mesh Current Method, find the current in $12\,\Omega$ Resistor.



$$= \begin{bmatrix} (4+12+8) & -12 & -8 \\ -12 & (14+4+12) & -4 \\ -8 & -4 & (8+4) \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 100 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 24 & -12 & -8 \\ -12 & 30 & -4 \\ -8 & -4 & 12 \end{vmatrix}$$

$$= 24\left(30 \times 12 - (-4 \times -4)\right) - (-12)\left((-12 \times 12) - (-4 \times -8)\right) + (-8)\left((-12 \times -4) - (-8 \times 30)\right).$$

$$\boxed{\Delta = 3840}.$$

$$\Delta_1 = \begin{vmatrix} 0 & -12 & -8 \\ 0 & 30 & -4 \\ 100 & -4 & 12 \end{vmatrix}$$

$$\boxed{\Delta_1 = 28800}$$

$$\Delta_2 = \begin{vmatrix} 24 & 0 & -8 \\ -12 & 0 & -4 \\ -8 & 100 & 12 \end{vmatrix}$$

$$\boxed{\Delta_2 = 19200}$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{28800}{3840}$$

$$\boxed{I_1 = 7.5A}.$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{19200}{3840}$$

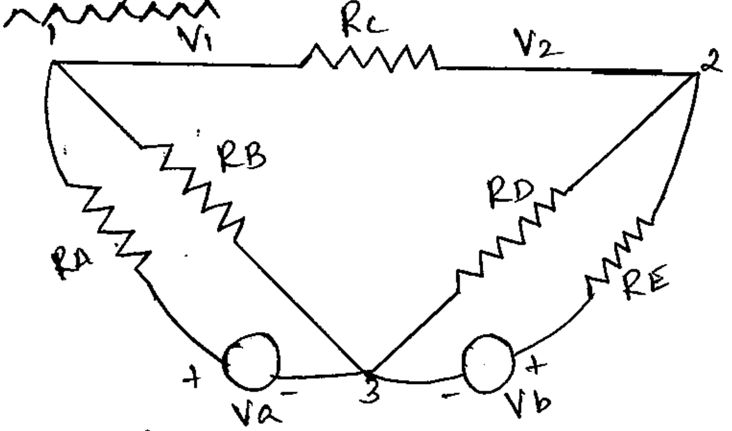
$$\boxed{I_2 = 5A}.$$

Current through Arm $BD = I_1 - I_2$

$$= 7.5 - 5$$

$$\boxed{BD = 2.5A}.$$

NODAL ANALYSIS :



→ Consider an circuit. Here node 3 is take as references.

→ V_1 & V_2 are the node voltages at nodes 1 and 2. At node 1, applying KCL,

$$\frac{V_1 - V_a}{R_A} + \frac{V_1}{R_B} + \frac{V_1 - V_2}{R_C} = 0 \quad \rightarrow (1)$$

At node 2, apply KCL.

$$\frac{V_2 - V_1}{R_C} + \frac{V_2}{R_D} + \frac{V_2 - V_b}{R_E} = 0 \quad \rightarrow (2)$$

$$= \begin{bmatrix} \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C} & -1/R_C \\ -1/R_C & \frac{1}{R_C} + \frac{1}{R_B} + \frac{1}{R_E} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} \frac{V_a}{R_A} \\ \frac{V_b}{R_E} \end{bmatrix}$$

$$= \begin{bmatrix} \frac{1}{R_A} + \frac{1}{R_B} + \frac{1}{R_C} & -1/R_C \\ -1/R_C & \frac{1}{R_C} + \frac{1}{R_D} + \frac{1}{R_E} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

$$= \begin{bmatrix} G_A + G_B + G_C & -G_C \\ -G_C & G_C + G_D + G_E \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} = \begin{bmatrix} I_1 \\ I_2 \end{bmatrix}$$

NOTE :

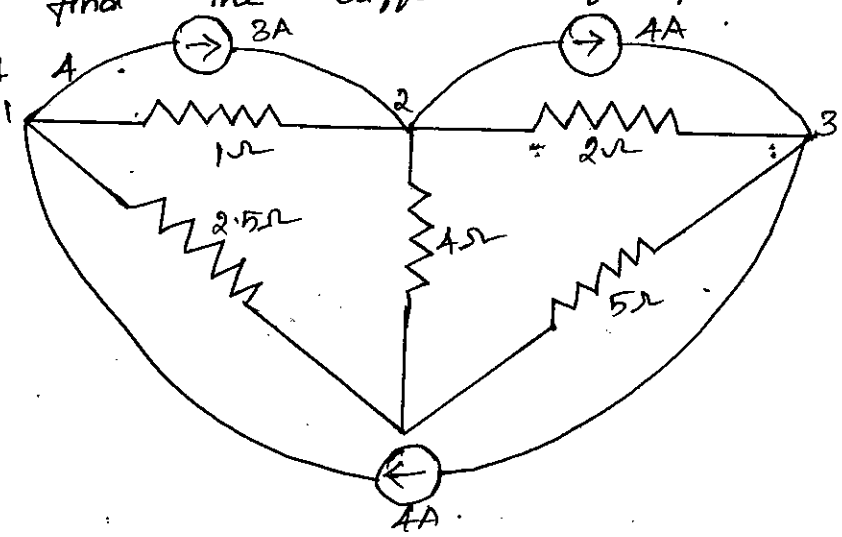
* In applying node voltage Method, Convert the Practical voltage sources into equivalent Current sources before putting in the Matrix form.

This Method can be applied for both AC & DC Circuits.

If there are 'n' nodes, then the no. of equations required is 'n-1' (i,e) the number of unknown node voltage is 'n-1'.

Problem 1 :

Frame the nodal equations of the network and hence find the difference of potential between nodes 2 & 4.



Solution :

Let the node 4 be the reference.

Let V_1, V_2 & V_3 be the node voltage at node 1, 2 and 3.

$$\begin{bmatrix} \frac{1}{2.5}+\frac{1}{1} & -1/1 & 0 \\ -1/1 & \frac{1}{1}+\frac{1}{4}+\frac{1}{2} & -1/2 \\ 0 & -1/2 & \frac{1}{5}+\frac{1}{5} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 4-3 \\ 3-4 \\ 4-4 \end{bmatrix}$$

$$= \begin{vmatrix} 1.4 & -1 & 0 \\ -1 & 1.75 & -0.5 \\ 0 & -0.5 & 0.7 \end{vmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 1 \\ -1 \\ 0 \end{bmatrix}$$

→ It is required to find the difference of potential between node 2 & 4

(i,e) $V_2 - V_4 = V_2 - 0 = V_2$.

$$V_2 = \frac{\Delta_2}{\Delta}.$$

$$\Delta = \begin{vmatrix} 1.4 & -1 & 0 \\ -1 & 1.75 & -0.5 \\ 0 & -0.5 & 0.7 \end{vmatrix}$$

$$= 1.4\,(1.225 - 0.25) + 1\,(-0.7 - 0) + 0$$

$$= 1.365 - 0.7$$

$$\underline{\underline{\Delta = 0.665}}$$

$$\Delta_2 = \begin{vmatrix} 1.4 & 1 & 0 \\ -1 & -1 & -0.5 \\ 0 & 0 & 0.7 \end{vmatrix}.$$

$$= 1.4\,(-0.7 - 0) - 1\,(0 + 0.7) + 0$$

$$= -0.98 - 0.7$$

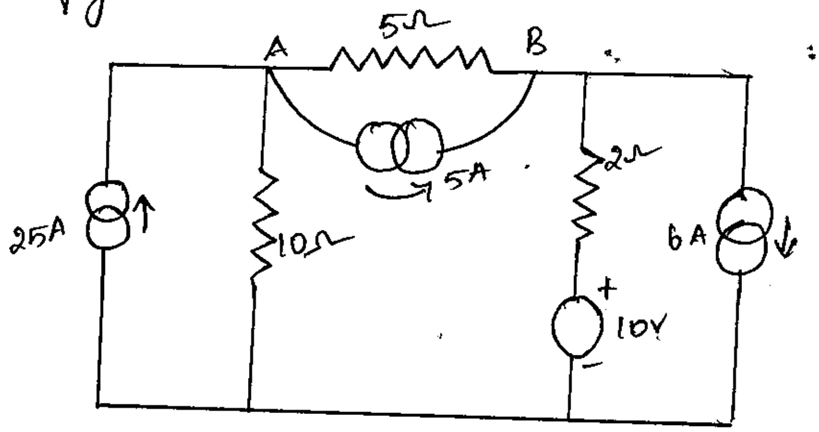
$$\underline{\underline{\Delta_2 = -1.68}}$$

$$V_2 = \frac{\Delta_2}{\Delta} = \frac{-1.68}{0.665} = -2.526\,V.$$

$$\underline{\underline{V_2 = -2.526\,\text{volts}}}$$

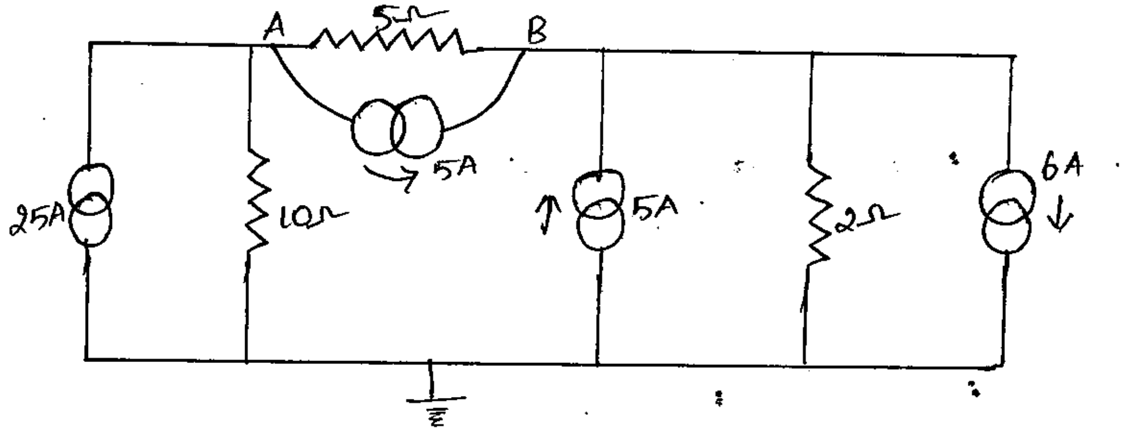
Problem 2:

Compute the voltage at node A & B in the Circuit of figure.



Solution:

→ First convert the voltage source into its equivalent current source.



→ There are two nodes A & B. Let V_A & V_B the voltage of the nodes A & B with ref. node.

$$= \begin{bmatrix} \frac{1}{10}+\frac{1}{5} & -\frac{1}{5} \\ -\frac{1}{5} & \frac{1}{5}+\frac{1}{2} \end{bmatrix} \begin{bmatrix} V_A \\ V_B \end{bmatrix} = \begin{bmatrix} 25-5 \\ 10-6 \end{bmatrix}$$

$$= \begin{bmatrix} 0.3 & -0.2 \\ -0.2 & 0.7 \end{bmatrix} \begin{bmatrix} V_A \\ V_B \end{bmatrix} = \begin{bmatrix} 20 \\ 4 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 0.3 & -0.2 \\ -0.2 & 0.7 \end{vmatrix}$$

$$= 0.21 - 0.04$$

$$\underline{\underline{\Delta = 0.17}}.$$

$$V_A = \frac{\Delta_A}{\Delta} \; ; \quad V_B = \frac{\Delta_B}{\Delta}$$

$$\Delta_A = \begin{vmatrix} 20 & -0.2 \\ 4 & 0.7 \end{vmatrix}$$

$$= 14 + 0.8$$

$$\underline{\underline{\Delta_A = 14.8}}.$$

$$\Delta_B = \begin{vmatrix} 0.3 & 20 \\ -0.2 & 4 \end{vmatrix}$$

$$= 1.2 + 4$$

$$\underline{\underline{\Delta_B = 5.2}}$$

$$V_A = \frac{\Delta A}{\Delta} = \frac{14.8}{0.17}$$

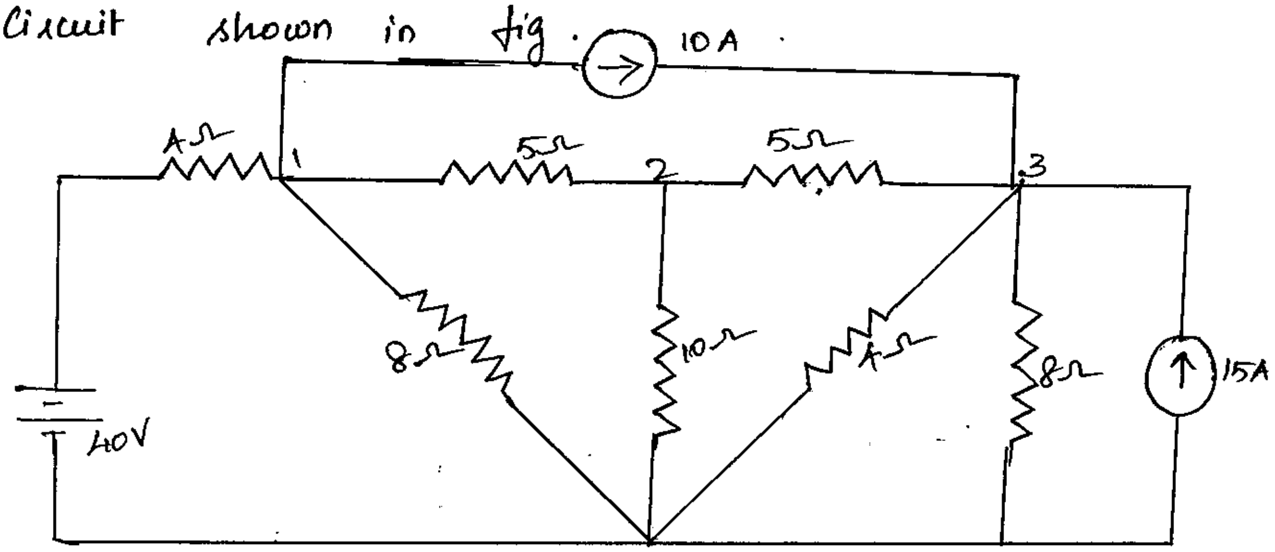
$$\underline{\underline{V_A = 87.1\ V}}.$$

$$V_B = \frac{\Delta B}{\Delta} = \frac{5.2}{0.17}$$

$$\underline{\underline{V_B = 30.6\ V}}.$$

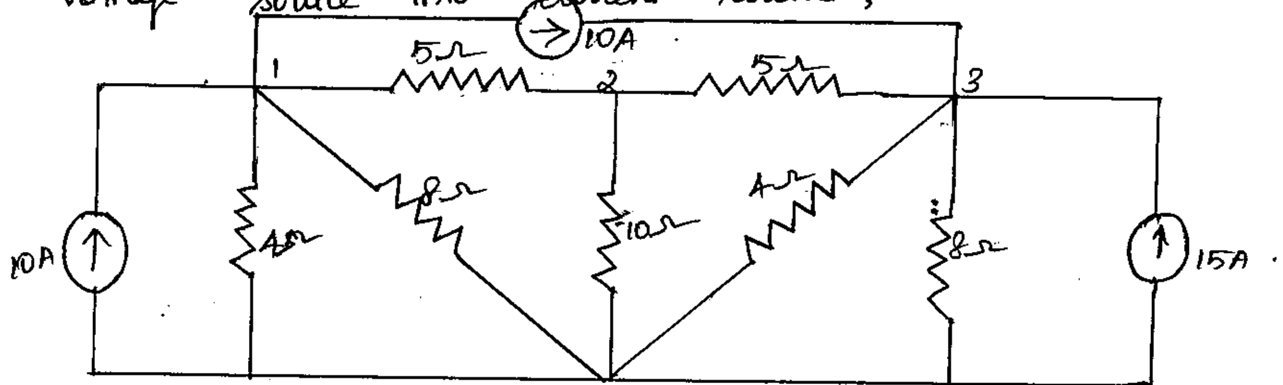
Problem 3 :

Use nodal voltage Method and hence find the power dissipated in the 10Ω resistor on the Circuit shown in fig.



Solution :

Taking the node 4 as reference, and convert the voltage source into current source,



$$= \begin{bmatrix} \frac{1}{4}+\frac{1}{8}+\frac{1}{5} & -1/5 & 0 \\ -1/5 & \frac{1}{5}+\frac{1}{5}+\frac{1}{10} & -1/5 \\ 0 & -1/5 & \frac{1}{5}+\frac{1}{4}+1/8 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 25 \end{bmatrix}$$

$$= \begin{bmatrix} 0.575 & -0.2 & 0 \\ -0.2 & 0.5 & -0.2 \\ 0 & -0.2 & 0.575 \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \\ 25 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 0.575 & -0.2 & 0 \\ -0.2 & 0.5 & -0.2 \\ 0 & -0.2 & 0.575 \end{vmatrix}$$

$$= 0.575\,(0.287 - 0.04) + 0.2\,(-0.115 + 0) + 0.$$

$$= 0.142 - 0.023.$$

$$\underline{\underline{\Delta = 0.119}}.$$

$$V_2 = \frac{\Delta_2}{\Delta}$$

$$\Delta_2 = \begin{vmatrix} 0.575 & 0 & 0 \\ -0.2 & 0 & -0.2 \\ 0 & 25 & 0.575 \end{vmatrix}$$

$$= +0.575\,(0 + 5) - 0 + 0.$$

$$\underline{\underline{\Delta_2 = 2.875}}.$$

$$V_2 = \frac{\Delta_2}{\Delta} = \frac{2.875}{0.119}$$

$$\underline{\underline{V_2 = 24.15 \text{ volts}}}.$$

Power dissipated in 10Ω $= P = V \times I.$

$$= V \times V/R.$$

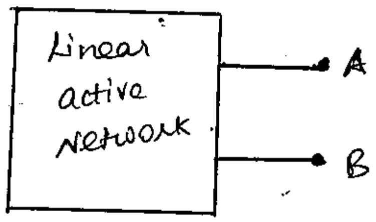
$$P = \frac{V^2}{R} = \frac{(24.16)^2}{10}$$

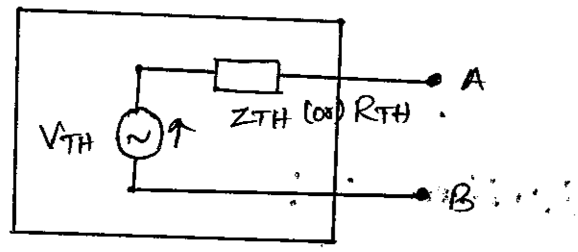
$$\underline{\underline{P = 58.4 \text{ Watts}}}.$$

THEVENIN'S THEOREM:

Statement:

→ Any linear active network with output terminals A & B can be replaced by a single voltage source ($V_{TH} = V_{OC}$) in series with a single impedance (or) (Z_{TH} (or) R_{TH}) resistance.





Thevenin's Voltage: V_{TH}

→ It is the voltage between the terminals A and B on open circuit condition. Hence it is called open circuit voltage denoted by V_{OC}.

Thevenin's Impedance: Z_{TH}

→ It is the driving point impedance at the terminals A & B when all internal source are killed. In case of DC, Z_{TH} is replaced by R_{TH}.

→ If a load impedance Z_L is across AB, find the current through it by the formula,

$$I_L = \frac{V_{TH}}{Z_{TH} + Z_L}.$$

NOTE :

* This theorem can be applied for both AC & DC circuits .

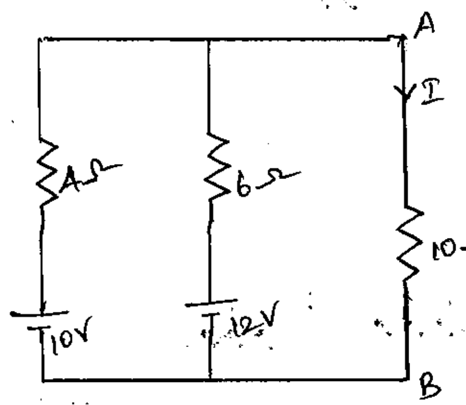
* In the thevenin's equivalent circuit , if AB terminals are short circuited , the current flowing through AB is obtained by ohm's Law .

$$I_{SC} = \frac{V_{TH}}{Z_{TH}}$$

$$Z_{TH} = \frac{V_{TH}}{I_{SC}} .$$

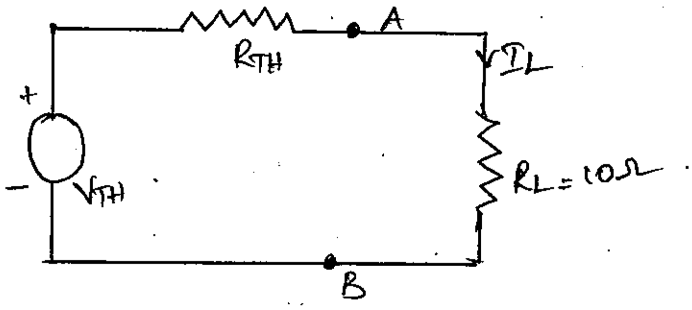
Problem 1 :

Determine the current I in the network by using Thevenin's Theorem .



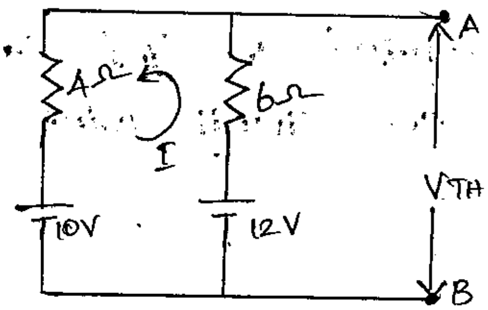
Solution :

Step 1 : The Thevenin's equivalent circuit is .



$$I_L = \frac{V_{TH}}{R_{TH} + R_L} .$$

Step 2 : To find V_{TH} :



$$I = \frac{12-10}{4+6}$$

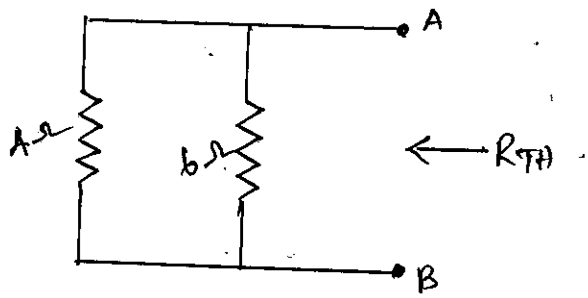
$$\underline{\underline{I = 0.2A}}$$

$$V_{TH} = V_{AB} = 6I - 12$$

$$= 6 \times 0.2 - 12$$

$$\underline{\underline{V_{TH} = -10.8\,V}}$$

Step 3 : To Calculate R_{TH} from the above circuit, s.c the source and remove the load.



$$R_{TH} = R_{AB} = 4 \parallel 6$$

$$= \frac{4 \times 6}{4+6}$$

$$\underline{\underline{R_{TH} = 2.4\,\Omega}}$$

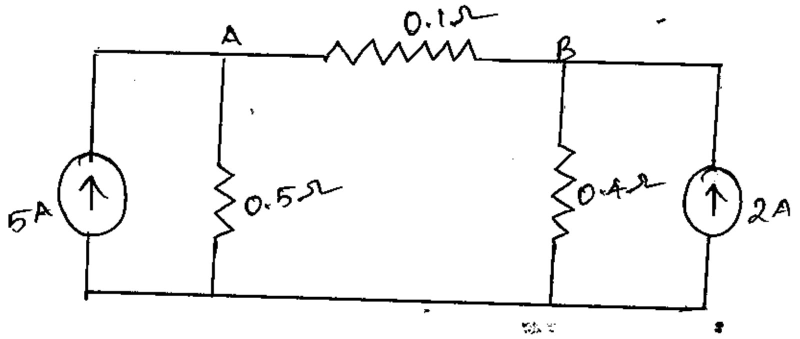
$$I_L = \frac{V_{TH}}{R_{TH}+R_L}$$

$$= \frac{10.8}{2.4+10}$$

$$\underline{\underline{I_L = 0.871\,A}}$$

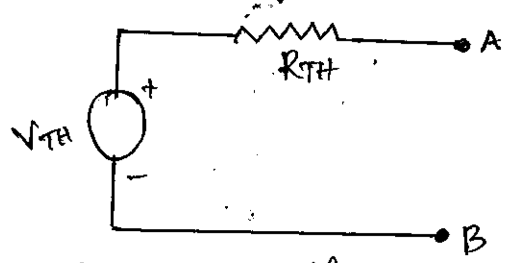
Problem 2 :

It is required to find current through the 0.1Ω resistor in the circuit using thevenin's theorem.



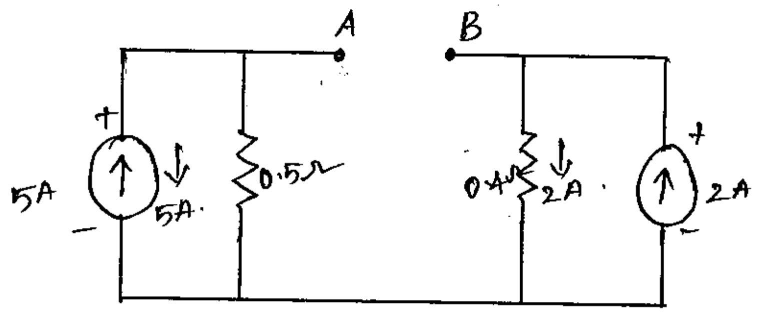
Solution :

Step 1 : Thevenin's equivalent circuit.



Step 2 : To calculate V_{TH}.

$R_L = 0.1\Omega$.

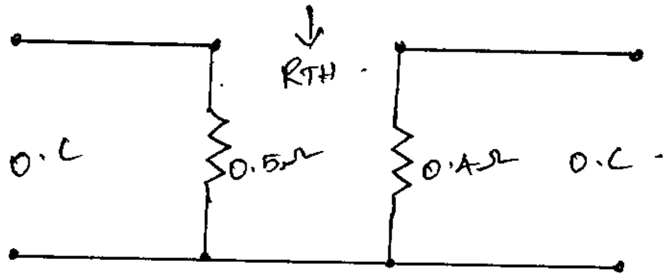


$V_{AB} = V_{TH}$.

$= -5 \times 0.5 + 2 \times 0.4$

$\underline{V_{TH} = -1.7\,V \text{ (or) } 1.7\,V}$.

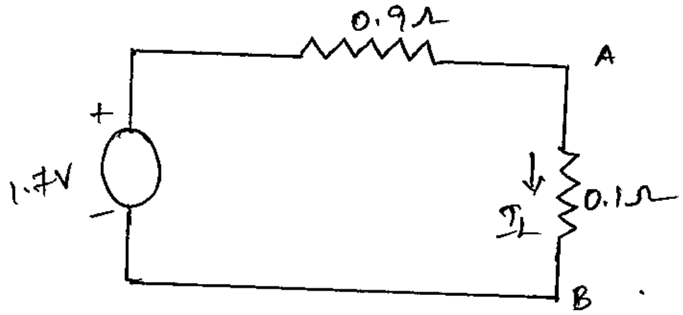
Step 3 : To Calculate R_{TH}.



$$R_{TH} = R_{AB} = 0.5 + 0.4$$

$$\underline{\underline{R_{TH} = 0.9\Omega}}$$

Step 4 :



$$I_L = \frac{V_{TH}}{R_{TH} + R_L}$$

$$= \frac{1.7}{0.9 + 0.1}$$

$$\underline{\underline{I_L = 1.7 \text{ Amps}}}$$

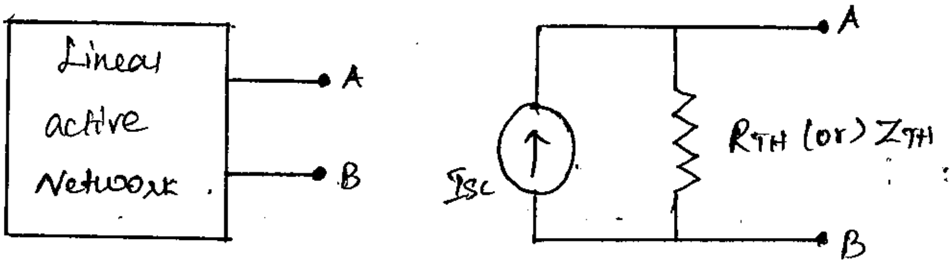
Limitations of Thevenin's Theorem.

- Not applicable to the Circuits Consisting of non linear elements.
- Not applicable to unilateral elements.
- There should not be Magnetic Coupling between the load and Circuit to be replaced by thevenin's theorem.
- In the load side, there should not be Controlled source, Controlled from some other part of the Circuit.

NORTON'S THEOREM:

Statement:

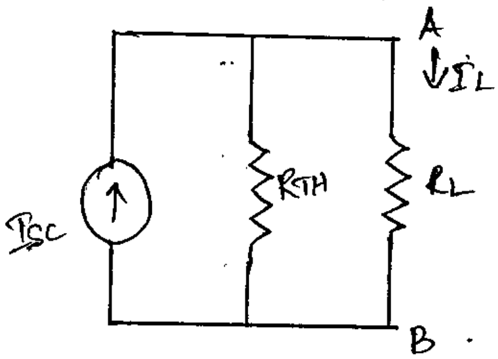
→ Any linear active network with output terminals A, B can be replaced by a single current source I_{sc} (I_N) in parallel with a single impedance (or) resistance $Z_{TH} \cdot (Z_N) = R_{TH} (R_n)$.



→ I_{sc} is the current through the terminals AB of the active network when shorted. Z_{TH} is the Thevenin's Impedances.

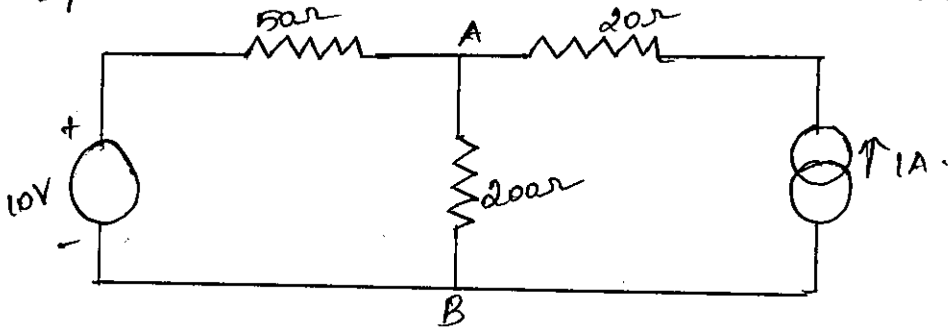
→ After evaluating the values of I_{sc} and R_{TH}, the current through R_L connected across A & B can be calculated by applying division of current formula which is expressed below:

$$\text{Current through } R_L = I_L = \frac{I_{sc} \times R_{TH}}{R_{TH} + R_L}.$$

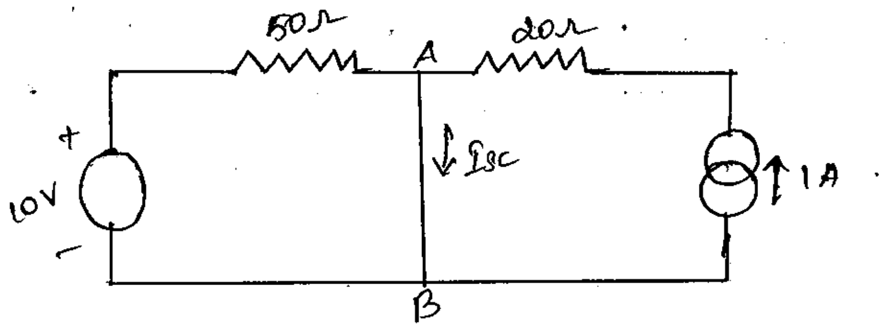


Problem 1 :

Determine the voltage across 200Ω resistor in circuit by Norton's theorem.



Solution :

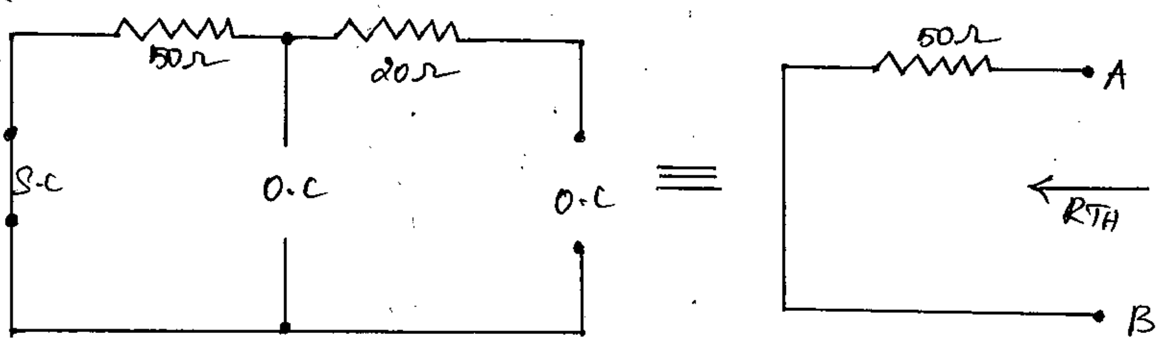


Step 1 : To find the S.C Current I_{sc}.

→ The voltage source will drive a source current of $10/50 = 0.2A$.

$$\underline{\underline{I_{sc} = 0.2+1 = 1.2A}}$$

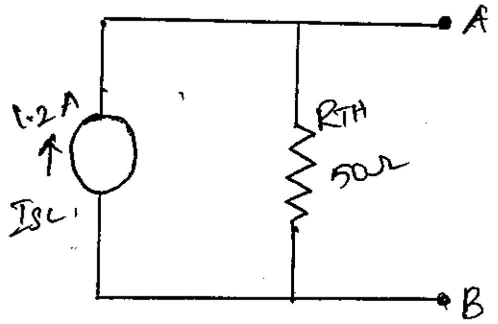
Step 2 : To find R_{TH}.



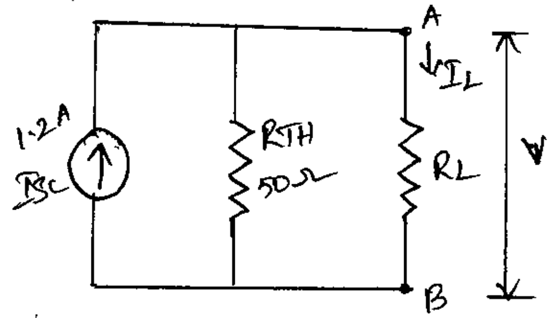
$\underline{\underline{R_L = 200\Omega}}$

$\therefore \underline{\underline{R_{TH} = 50\Omega}}$.

Step 3 : Draw the Norton's equivalent Circuit.



Step 4 : Determine I_L through R_L.



$$I_L = \frac{I_{SC} \times R_{TH}}{R_{TH} + R_L}$$

$$= \frac{1.2 \times 50}{50 + 200}$$

$$\underline{\underline{I_L = 0.24A}}$$

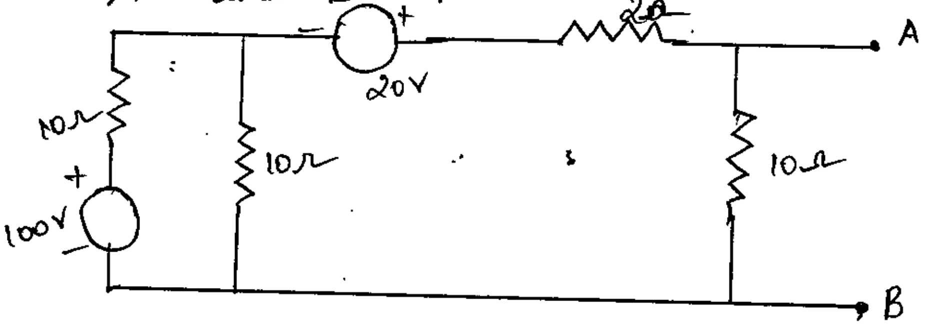
$$V_L = I_L \times R_L$$

$$= 0.24 \times 200$$

$$\underline{\underline{V_L = 48V}}$$

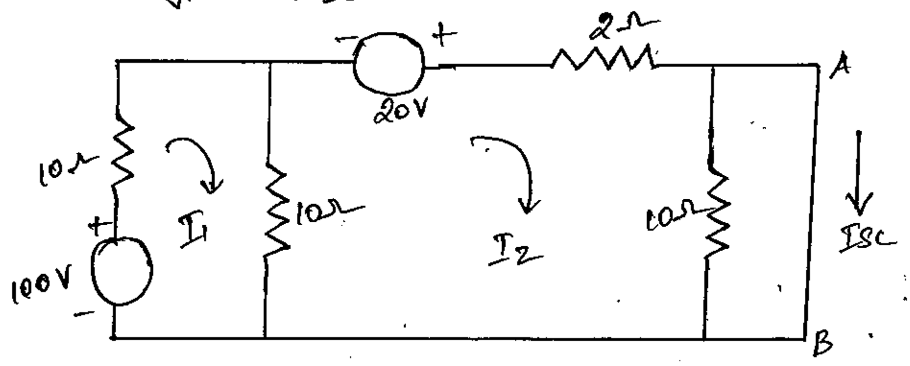
Problem 2 :

Obtain the Norton's equivalent Circuit at the terminals A and B for the Network.



Solution :

Step 1: To find I_{sc}.



→ As 10Ω is shorted, no current flows through it. Hence $I_{sc} = I_2$. Neglect presence of 10Ω, by inspection.

$$\begin{bmatrix} 20 & -10 \\ -10 & 12 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 100 \\ 20 \end{bmatrix}$$

$$\Delta = \begin{bmatrix} 20 & -10 \\ -10 & 12 \end{bmatrix}$$

$$= (20 \times 12) + (10 \times 10)$$

$$= 240 - 100$$

$$\underline{\underline{\Delta = 140}}.$$

$$\Delta_2 = \begin{bmatrix} 20 & 100 \\ -10 & 20 \end{bmatrix}$$

$$= (20 \times 20) + (10 \times 100)$$

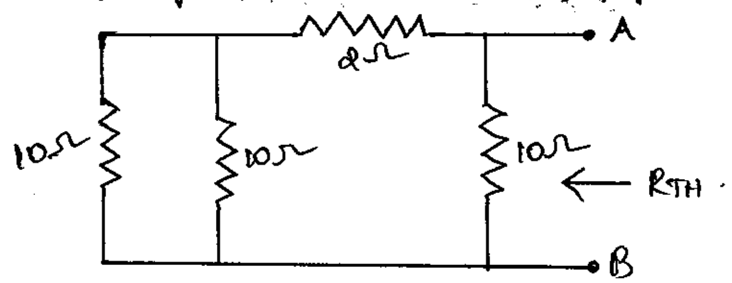
$$\Delta_2 = 400 + 1000$$

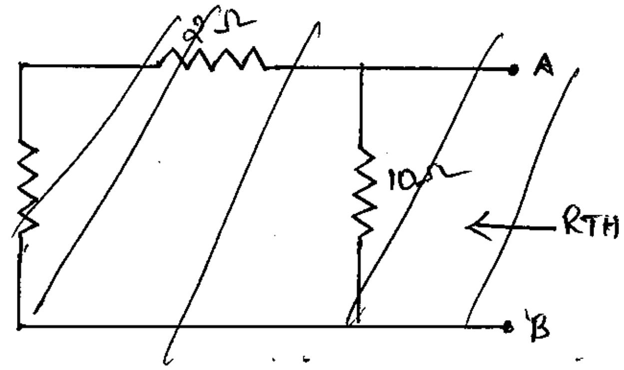
$$= \underline{1400}$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{1400}{140}$$

$$\underline{\underline{I_{sc} = I_2 = 10\,A}}.$$

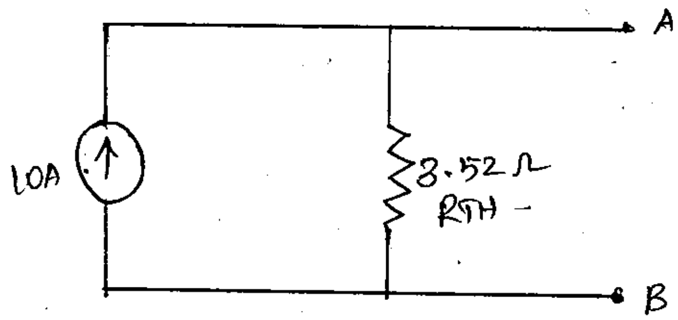
Step 2 : To find R_{TH}.





$R_{TH} = 3.52\,\Omega$.

Step 3 : Norton's equivalent is



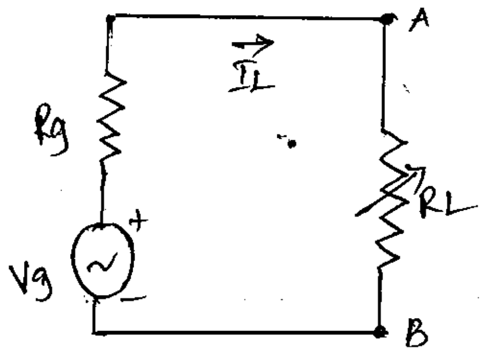
MAXIMUM POWER TRANSFER THEOREM

Case (i):

Purely resistor circuit and the load resistance is variable.

Statement:

Maximum power will be delivered from a voltage source to a load, when the load resistance is equal to the Internal resistance of the source.



→ Consider a voltage source of Generated Voltage V_g and internal resistance R_g, Connected to a load resistance R_L.

→ When the power transfer to the load is Maximum $R_L = R_g$. At this Condition the load resistance.

$$R_g + R_L = 2R_L.$$

$$I_L = \frac{V_g}{2R_L}$$

→ Power delivered to $R_L = I_L^2 R_L$

$$= \left(\frac{V_g^2}{2R_L}\right) R_L.$$

$$= \frac{V_g^2}{4} R_L.$$

The Maximum power transferred to R_L.

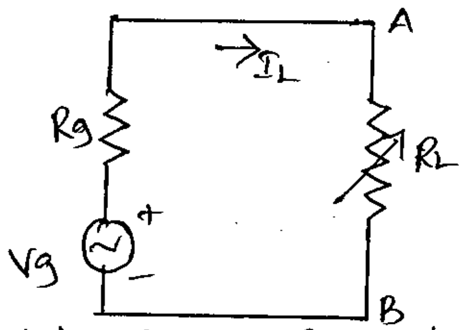
$$P_{max} = \frac{V_g^2}{4R_L}.$$

Case (ii) :

Reactance Present, and load resistance and reactance can be independently varied.

Statement :

Maximum power will be delivered from a voltage source to a load when the load impedance is the complex conjugate of the source impedance.



→ In this case, R_g and R_L of the previous case can be replaced by Z_g and Z_L.

Z_g = internal impedances of the source $R_g + jx_g$.

Z_L = load impedances = $R_L + jX_L$.

X_L = load reactance but not inductive reactance

→ Hence, when the power transfer is Maximum, the total impedance is $2R_L$.

$$P_{max} = 2R_L.$$

Case (iii) : Reactance present, but only the Magnitude of the load impedance can be varied.

Statement :

Maximum power is delivered from a voltage source of the load when the magnitude of the load impedance is equal to the magnitude of the source impedance.

→ Let θ be the angle of the load impedance.

so, $Z_L = |Z_L| \angle \theta$

$= Z_L \cos\theta + j Z_L \sin\theta$.

$$P = \frac{V_g^2 |Z_1| \cos\theta}{((R_g + |Z_L|)\cos\theta)^2 + (x_g + |Z_L|\sin\theta)^2}$$

→ For Maximum power transfer,

$$\frac{dP}{d|Z_L|} = 0.$$

→ Under this condition, and simplifying the above equation we get;

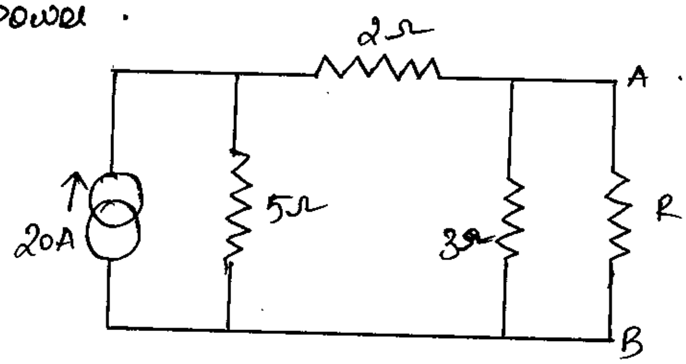
$$R_g^2 + x_g^2 = |Z_L|^2$$

(or)

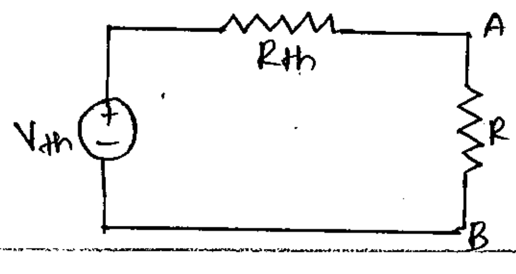
$$|Z_g| = |R_L| \text{ (or) } |Z_L|.$$

Problem 1:

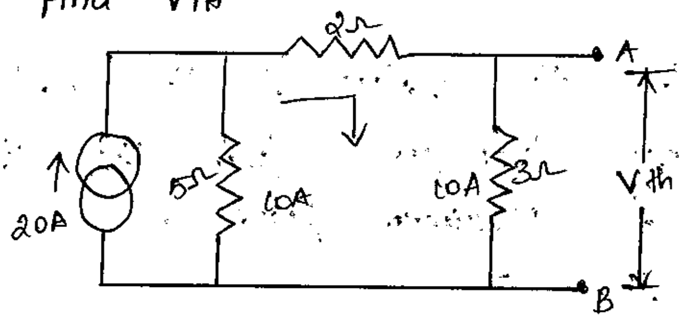
This circuit shown is fig. R absorbs Maximum power, Compute the value of R and Maximum power.



Solution: Thevenin's equivalent circuit is

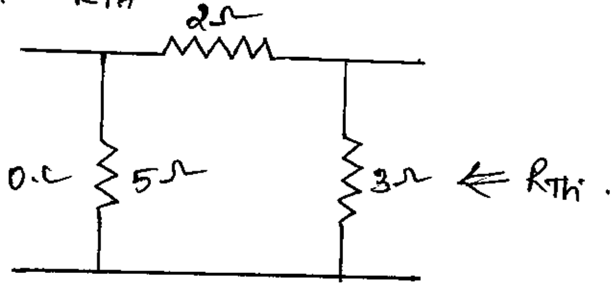


Step 1 : Find V_{TH}.



$$\underline{\underline{V_{TH} = V_{AB} = 10 \times 3 = 30V}}$$

Step 2 : Find R_{TH}.



$$R_{TH} = \frac{7 \times 3}{7+3}$$

$$\underline{\underline{R_{TH} = 2.1\Omega}}$$

Step 3 :

According to the statement of Maximum power transfer theorem, the value of R for Maximum power transfered to it $R_{TH} = 2.1\Omega$ & the Maximum power transfered.

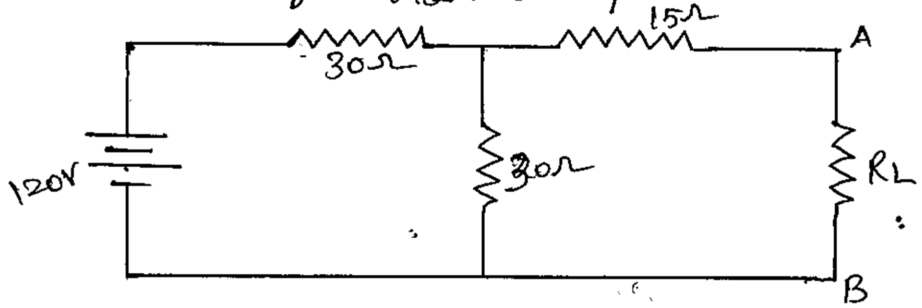
$$P = \frac{V_{TH}^2}{4R_L} = \frac{V_{TH}^2}{4R_{TH}}$$

$$= \frac{30^2}{4(2.1)}$$

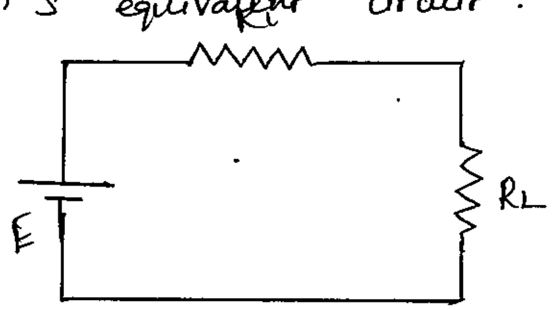
$$\underline{\underline{P = 107 \text{ Watts}}}$$

Problem 2 :

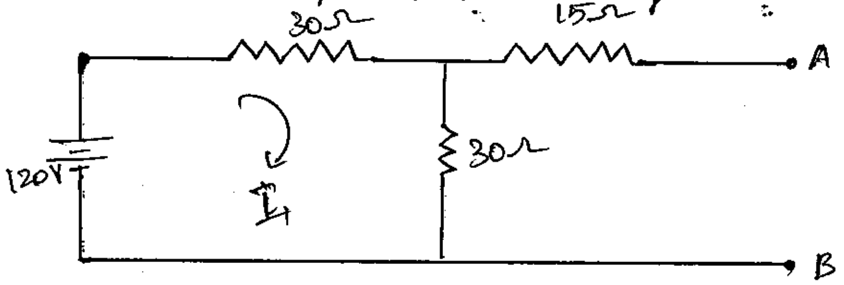
Calculate the value of the load resistance for maximum power transfered from the circuit. Also find the value of Maximum power.



Solution : Thevenin's equivalent circuit.



Step 1 : Find E = open circuit voltage at AB.



$E = V_{AB}$ = Voltage across 30Ω resistance

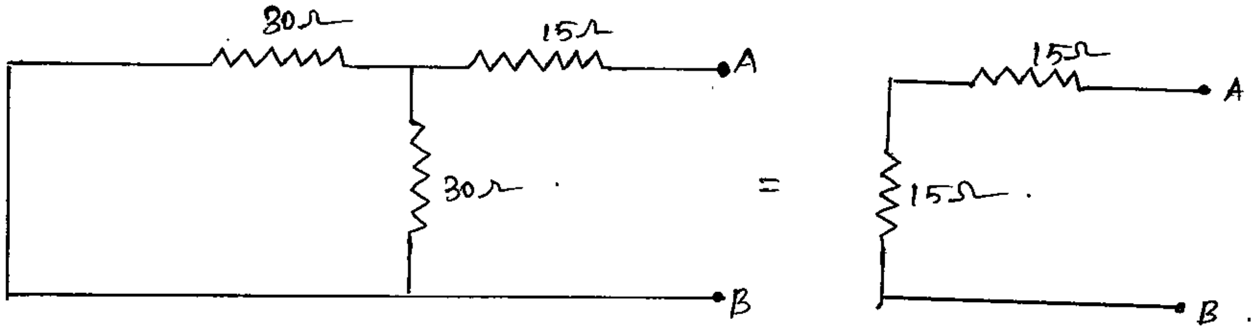
$= I \times 30$

$= \frac{120}{(30+30)} \times 30$

$\underline{\underline{E = V_{AB} = 60\,V}}$.

Step 2 : Thevenin's looking back resistance.

$\underline{\underline{R_i = 15+15 = 30\,\Omega}}$.



∴ R_L for Maximum power transfer $= R_i$

$$\underline{\underline{R_L = 30\Omega}}$$

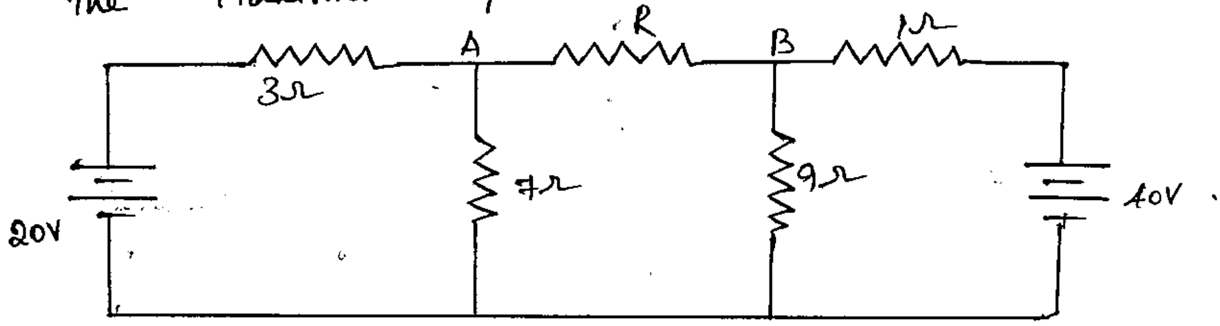
→ Maximum power at load $= \dfrac{E^2}{4R_L}$

$$= \left(\frac{60^2}{4 \times 30}\right)$$

$$\underline{\underline{P = 30 \text{ Watts}}}$$

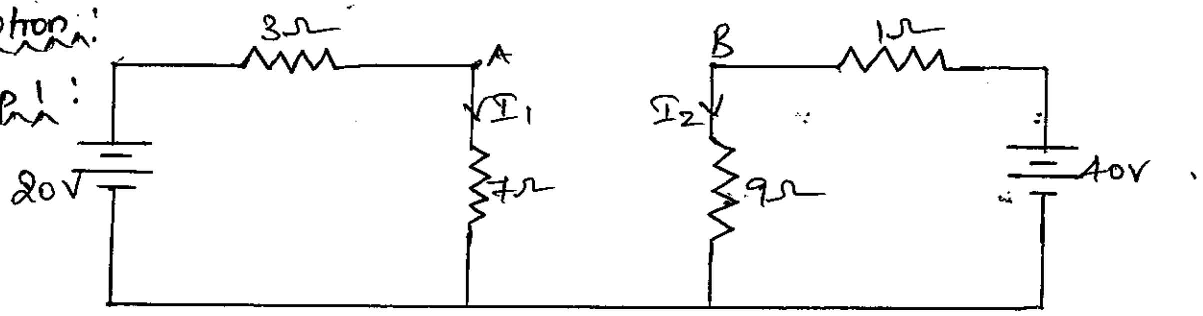
Problem 3 :

In the circuit shown below, find the resistance R to be connected between A & B. So that the power dissipated in this is a Maximum. find also the Maximum power.



Solution:

Step 1 :



→ To find E, thevenin's open circuit E, the resistance R is removed.

$$E = V_{AB}$$

$$= V_{AC} + V_{CB}.$$

$$I_1 = \frac{20}{3+7}$$

$$\underline{\underline{I_1 = 2A}}.$$

$$I_2 = \frac{40}{1+9}$$

$$\underline{\underline{I_2 = 4A}}.$$

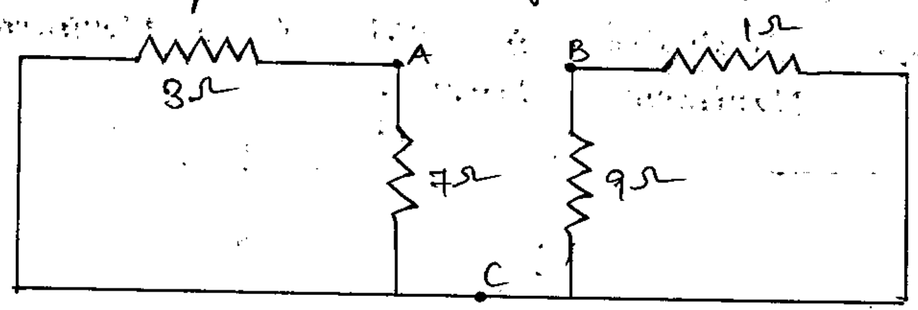
$$E = 2\times7 - 4\times9$$

$$\underline{\underline{E = -22V}}.$$

(i,e) B is positive & A is Negative.

Step 2:

To find thevenin's looking back resistance replace the voltage source by their internal resistance.

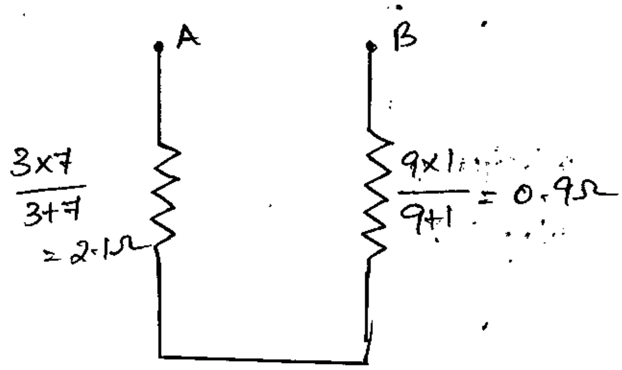


$$R_{Th} = R_i = R_{AB}.$$

$$R_{AB} = 2.1 + 0.9$$

$$\underline{\underline{R_{AB} = 3\Omega}}$$

$$\underline{\underline{R_i = R_L = 3\Omega}}.$$



Step 3 : Find I.

$$I = \frac{V}{R_i + R_L}$$

$$= \frac{22}{3+3}$$

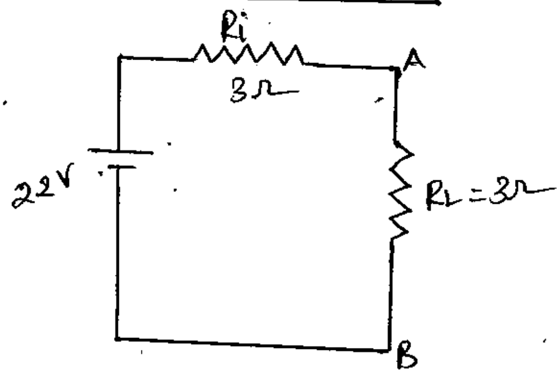
$$I = 3.67\ A.$$

Step 4 : Find Power wasted in load resistor.

$$P = I^2 R_L \ (\text{or}) \ \frac{E^2}{4R_L}$$

$$P = (3.67)^2 \times 3$$

$$P = 40.33 \text{ Watts}$$



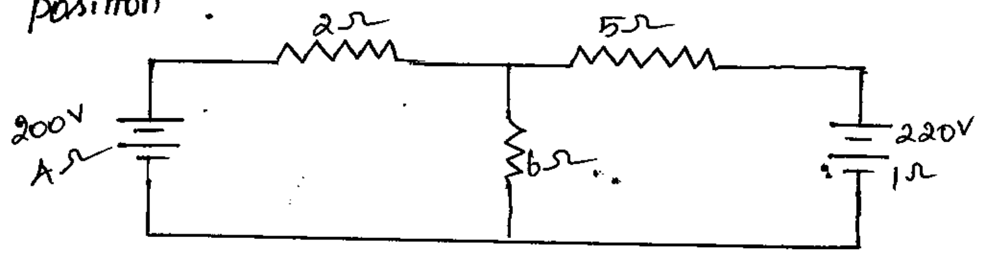
SUPER POSITION THEOREM :

Statement :

It states that " the response in a circuit with Multiple source is given by algebraic sum of responses due to individual sources acting alone".

Problem 1 :

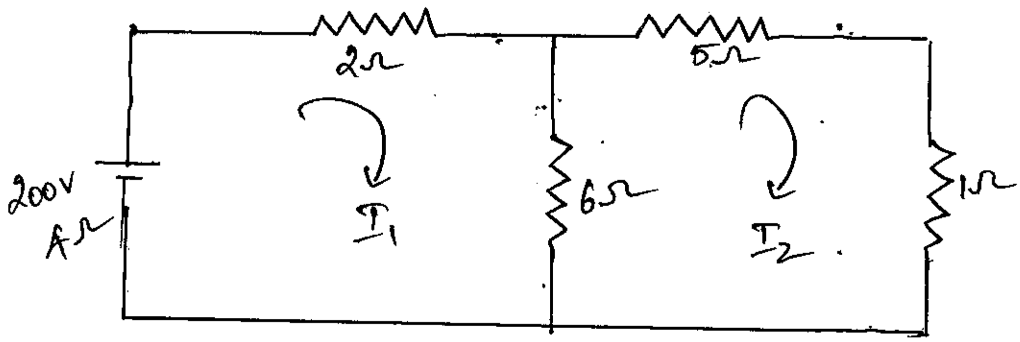
Find the current through the 6Ω resistor in the following circuit by the principle of super position.



Solution :

Step 1 :

→ 200V battery acting alone and the 220V battery is replaced by their internal resistance.



→ By using Mesh Current Analysis.

$$\begin{bmatrix} 2+6+4 & -6 \\ -6 & 5+1+6 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 200 \\ 0 \end{bmatrix}$$

$$\begin{pmatrix} 12 & -6 \\ -6 & 12 \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} 200 \\ 0 \end{pmatrix}$$

$$\Delta = \begin{vmatrix} 12 & -6 \\ -6 & 12 \end{vmatrix}$$

$$= 144 - 36$$

$$\underline{\Delta = 108}$$

$$\Delta_1 = \begin{vmatrix} 200 & -6 \\ 0 & 12 \end{vmatrix}$$

$$= 200 \times 12 - 0 .$$

$$\underline{\underline{\Delta_1 = 2400}}$$

$$\Delta_2 = \begin{vmatrix} 12 & 200 \\ -6 & 0 \end{vmatrix}$$

$$= 0 + 200 \times 6$$

$$\underline{\underline{\Delta_2 = 1200}} .$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{2400}{108}$$

$$\underline{\underline{I_1 = 22.22\,A}} .$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{1200}{108}$$

$$\underline{\underline{I_2 = 11.11\,A}} .$$

Current through $6\,\Omega$ Resistor

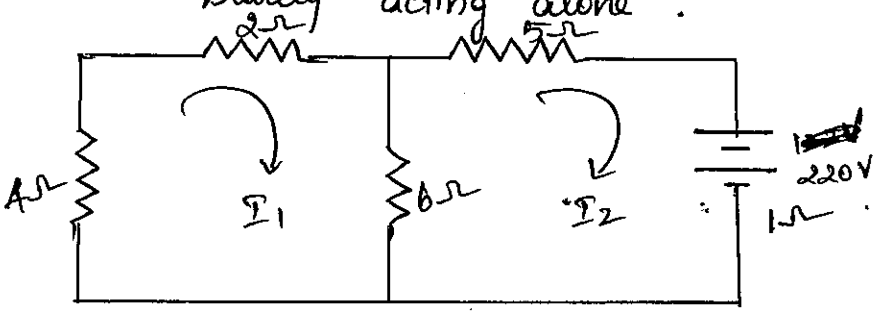
$$I_1 - I_2$$

$$22.22 - 11.11$$

$$\underline{\underline{= 11.11\,A}} .$$

Step 2 :

220V battery acting alone .



by applying Mesh Current analysis .

$$\begin{pmatrix} 4+2+6 & -6 \\ -6 & 6+5+1 \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} 0 \\ -220 \end{pmatrix} .$$

$$= \begin{pmatrix} 12 & -6 \\ -6 & 12 \end{pmatrix} \begin{pmatrix} I_1 \\ I_2 \end{pmatrix} = \begin{pmatrix} 0 \\ -220 \end{pmatrix}$$

$$\Delta = \begin{pmatrix} 12 & -6 \\ -6 & 12 \end{pmatrix}$$

$$\underline{\underline{\Delta = 108}}$$

$$\Delta_1 = \begin{pmatrix} 0 & -6 \\ -220 & 12 \end{pmatrix}$$

$$= 0 - (220 \times 6)$$

$$\underline{\underline{\Delta_1 = -1320}}$$

$$\Delta_2 = \begin{vmatrix} 12 & 0 \\ -6 & -220 \end{vmatrix}$$

$$\Delta_2 = 12 \times (-220) - 0$$

$$\underline{\underline{\Delta_2 = -2640}}$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{-1320}{108}$$

$$\underline{\underline{I_1 = -12.22A}}$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{-2640}{108}$$

$$\underline{\underline{I_2 = -24.44A}}$$

Current through 6Ω Resistor $= I_1 - I_2$

$$= -12.22 + 24.44$$

$$= \underline{\underline{12.22A}}$$

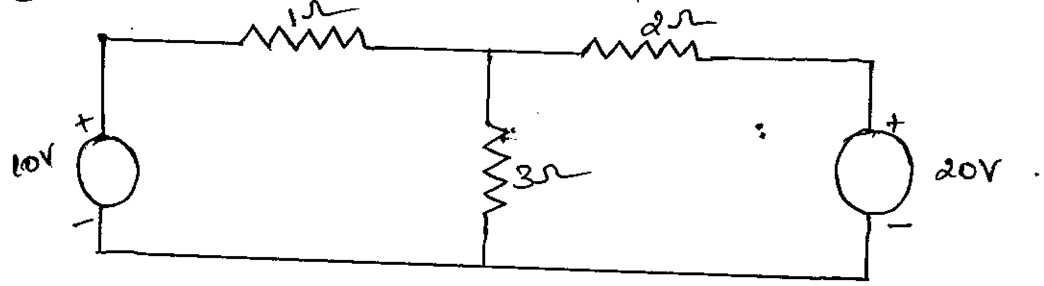
Step 3 :

Total Current $= 11.11 + 12.22$

$$= \underline{\underline{23.33A}}$$

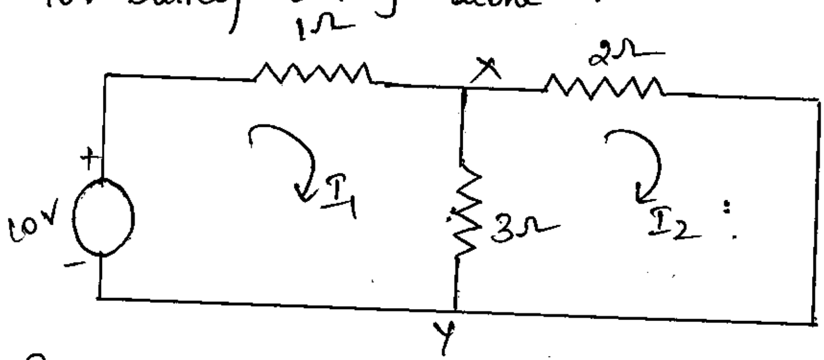
Problem 2 :

Using Super position theorem find the current through 3Ω Resistance in circuit :



Solution :

Step 1 : 10V battery acting alone.



By Using Mesh Current Analysis,

$$\begin{bmatrix} 1+3 & -3 \\ -3 & 3+2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 4 & -3 \\ -3 & 5 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 10 \\ 0 \end{bmatrix}$$

$$\Delta = \begin{vmatrix} 4 & -3 \\ -3 & 5 \end{vmatrix}$$

$$= 4 \times 5 - (-3 \times -3)$$

$$\underline{\underline{\Delta = 11.}}$$

$$\Delta_1 = \begin{vmatrix} 10 & -3 \\ 0 & 5 \end{vmatrix}$$

$$= 10 \times 5 - 0$$

$$\underline{\underline{\Delta_1 = 50}}$$

$$\Delta_2 = \begin{vmatrix} 4 & 10 \\ -3 & 0 \end{vmatrix}$$

$= 4 \times 0 - (-3 \times 10)$

$\underline{\underline{\Delta_2 = 30}}$

$I_1 = \frac{\Delta_1}{\Delta} = \frac{50}{11}$

$\underline{\underline{I_1 = 4.54A}}$

$I_2 = \frac{\Delta_2}{\Delta} = \frac{30}{11}$

$\underline{\underline{I_2 = 2.72A}}$

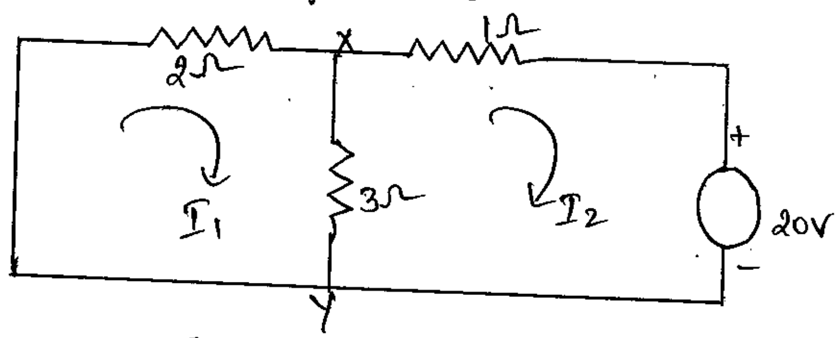
Current through 3Ω Resistor

$I_1' = I_1 - I_2$

$= 4.54 - 2.72$

$\underline{\underline{I_1' = 1.82A}}$

Step 2 : 20V battery acting alone.



$$= \begin{bmatrix} 1+3 & -3 \\ -3 & 3+2 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} 0 \\ -20 \end{bmatrix}$$

$$= \begin{vmatrix} 4 & -3 \\ -3 & 5 \end{vmatrix} \begin{vmatrix} I_1 \\ I_2 \end{vmatrix} = \begin{vmatrix} 0 \\ -20 \end{vmatrix}$$

$$\Delta = \begin{vmatrix} 4 & -3 \\ -3 & 5 \end{vmatrix}$$

$= 4 \times 5 - (-3 \times -3)$

$\underline{\underline{\Delta = 11}}$

$$\Delta_1 = \begin{vmatrix} 0 & -3 \\ -20 & 5 \end{vmatrix}$$

$$= 0 - (-3 \times -20)$$

$$\Delta_1 = -60$$

$$\Delta_2 = \begin{vmatrix} 4 & 0 \\ -3 & -20 \end{vmatrix}$$

$$= 4 \times (-20) - 0$$

$$\Delta_2 = -80$$

$$I_1 = \frac{\Delta_1}{\Delta} = \frac{-60}{11}$$

$$I_1 = 5.45A$$

$$I_2 = \frac{\Delta_2}{\Delta} = \frac{-80}{11}$$

$$I_2 = 7.27A$$

$\therefore$ Current through 3Ω Resistor

$$I_2' = I_1 - I_2$$

$$= -5.45 - (7.27)$$

$$I_2' = 1.82A$$

Step 3 :

$$I = I_1' + I_2'$$

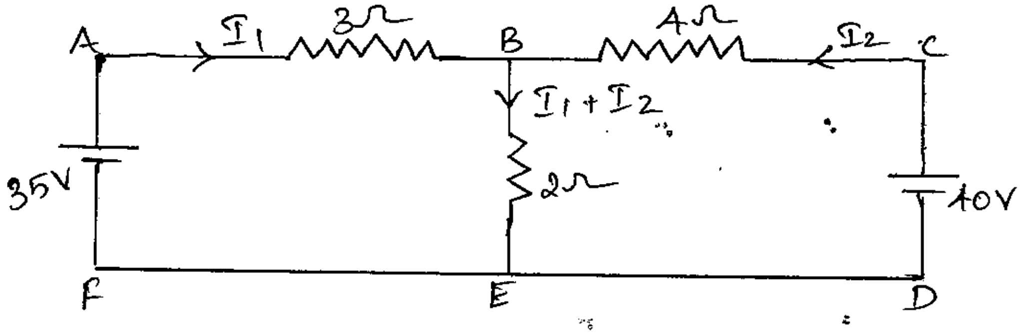
$$= 1.82 + 1.82$$

$$I = 3.64A$$

KIRCHOFF'S LAW:

Problem 1:

Calculate the Current in 2Ω Resistor.



Solution:

In the closed loop ABEFA.

$$-3I_1 - 2(I_1 + I_2) + 35 = 0$$

$$-3I_1 - 2I_1 - 2I_2 = -35$$

$$-5I_1 - 2I_2 = -35 \rightarrow (1)$$

In the closed loop ABCDEFA:

$$= -3I_1 + 4I_2 - 40 + 35 = 0$$

$$= -3I_1 + 4I_2 = 5 \rightarrow (2)$$

(1) × 2 $\quad = -10I_1 - 4I_2 = -70 \rightarrow (3)$

(2) + (3) $\quad = +13I_1 = +65$

$$I_1 = \frac{65}{13}$$

$$I_1 = 5A$$

Sub the value of I_1 in eq^n (1),

$$-5(5) - 2I_2 = -35$$

$$-25 - 2I_2 = -35$$

$$I_2 = 5A$$

→ Then Current in 2Ω Resistor $I_1 + I_2$

$I = 5 + 5$

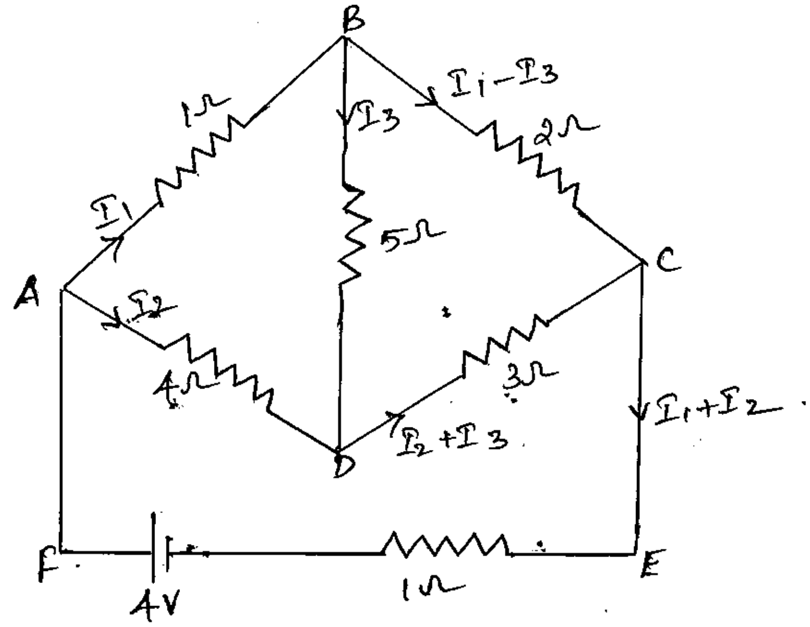
$I = 10A$.

Problem 2 :

A Wheat stone bridge ABCD is arranged as follows. AB = 1Ω, BC = 2Ω, CD = 3Ω, DA = 4Ω. A galvanometer of resistance 5Ω is connected between B & D. A battery of 4 V with internal resistance 1Ω is connected between A & C. Calculate,

i) The Magnitude & direction of Current in 5Ω resistor

ii) The resistance between A & C.



Solution :

For loop ABDA.

$$-1\times I_1 - 5\times I_3 + 4\times I_2 = 0.$$

$$-I_1 + 4I_2 - 5I_3 = 0 \longrightarrow (1)$$

For loop BCDB

$$-2(I_1 - I_3) + 3(I_2 + I_3) + 5I_3 = 0.$$

$$-2I_1 + 2I_3 + 3I_2 + 3I_3 + 5I_3 = 0.$$

$$-2I_1 + 3I_2 + 10I_3 = 0 \longrightarrow (2).$$

For loop ABCEFA.

$$-1\times I_1 - 2(I_1 - I_3) - 1(I_1 + I_2) + 4 = 0.$$

$$-I_1 - 2I_1 + 2I_3 - I_1 - I_2 = -4.$$

$$-4I_1 - I_2 + 2I_3 = -4 \rightarrow (3).$$

$$(1) \times 2 \Rightarrow -2I_1 + 8I_2 - 10I_3 = 0 \rightarrow (4)$$

$$(2) - (4) \Rightarrow -2I_1 + 3I_2 + 10I_3 = 0$$

$$-2I_1 + 8I_2 - 10I_3 = 0$$

$$-5I_2 + 20I_3 = 0 \rightarrow (5)$$

$$(2) \times 2 \Rightarrow -4I_1 + 6I_2 + 20I_3 = 0 \rightarrow (6)$$

$$(3) - (6) \Rightarrow -7I_2 - 18I_3 = -4 \rightarrow (7)$$

$$(5) \times 7 \Rightarrow -35I_2 + 140I_3 = 0 \rightarrow (8)$$

$$(7) \times 5 \Rightarrow -35I_2 - 90I_3 = -20 \rightarrow (9)$$

$$(8) - (9) \Rightarrow 230I_3 = 20$$

$$I_3 = \frac{20}{230}$$

$$\underline{\underline{I_3 = 0.087\,A}} \rightarrow (10)$$

Sub (10) in (5) $\underline{\underline{I_2 = 0.348\,A}} \rightarrow (11)$

Sub eqⁿ (10) & (11) in eqⁿ (1)

$$\underline{\underline{I_1 = 0.957\,A}}$$

Total current supplied by battery

$$I = I_1 + I_2$$

$$= 0.957 + 0.348$$

$$\underline{\underline{I = 1.305\,A}}$$

P.d between A & C = EMF of battery − Drop in battery

$$= 4 - 1.305 \times 1$$

$$= \underline{\underline{2.695\,V}}$$

Resistance between A & C $= \dfrac{\text{P.d across AC}}{\text{Battery Current}}$

$$= \frac{1.695}{1.305}$$

$$= \underline{\underline{2.065\,\Omega}}$$

UNIT-I
ELECTRICAL CIRCUITS
PART A

1. What is meant by linear and nonlinear elements?

Linear element shows the linear characteristics of voltage Vs current. Nonlinear element the current passing through it does not change linearity with the linear change in applied voltage at a particular frequency.

2. What is meant by active and passive elements?

If a circuit element has the capability of enhancing the energy level of a signal passing through it is called an active element. Passive elements do not have any intrinsic means of signal boosting.

3. What is meant by unilateral and bilateral elements?

If the magnitude of the current passing through an element is affected due to change in the polarity of the applied voltage is called unilateral elements. If the current magnitude remains the same even if the applied EMFs polarity is changed is called bilateral elements.

4. Define Ohms Law.

The potential difference across any two ends of a conductor is directly proportional to the current flowing between the two ends provided the temperature of the conductor remains constant.

5. Mention the disadvantages of Ohm's Law.

□ It does not apply to all non metallic conductors

□ It also does not apply to non linear devices such as zener diode, vacuum tubes etc.

□ It is true for metal conductors at constant temperature. If the temperature changes the

□ law is not applicable.

6. What is a node, a junction and a branch?

□ A node of a network is an equipotential surface at which two or more circuit elements are

□ joined.

□ A junction is that point in a network where three or more circuit elements are joined.

□ A branch is that part of a network which lies between two junction points.

7. What is a super node?

The region surrounding a voltage source which connects the two nodes directly is called super node.

8. State voltage division rule.

Voltage across a resistor in a series circuit is equal to the total voltage across the series elements multiplies by the value of that resistor divided by the total resistance of the series elements.

9. State current division rule.

The current in any branch is equal to the ratio of the opposite parallel branch resistance t the total resistance value, multiplies by the total current in the circuit.

10. Give the steps to draw a Dual Network
In each loop of a network place a node Draw the lines connecting adjacent nodes passing through each element and also to the reference node.

11. What are the classifications of Circuit elements?
- Active element
- Passive element
- Lumped and distributed elements
- Bilateral and unilateral elements
- Linear and non linear elements.

12. Sate superposition theorem.
It states that the response of a linear circuit with multiple sources is given by algebraic sum of response due to individual sources acting alone.

13. State Thevenins theorem
It states that any linear bilateral network can be replaced by a single current source VTH, in series with single impedance Zth

14. State Norton's theorem
It states that any linear bilateral network can be replaced by a single current source, IN in parallel with single impedance Zth.

15. State maximum power transfer theorem.
Max power is transferred to load impedance if the load impedance is the complex conjugate of the source impedance.

16. State the steps to solve the super position theorem.
- Take only one independent voltage or current source.
- Obtain the branch currents.
- Repeat the above for other sources.
- To determine the net branch current just add the current obtained above.

17. What is the limitation of superposition theorem?
- Superposition theorem is valid only for linear systems.
- This theorem can be applied for calculating the current through or voltage across in particular element.
- But this superposition theorem is not applicable for calculation of the power.

18. State the steps to solve the Thevenin's Theorem
- Remove the load resistance and find the open circuit voltage Voc
- Deactivate the consta t sources (fro voltage source remove it by internal resistance & for current

□ source delete the source by OC) and find the internal resistance (RTH) of the source side looking

□ through the open circuited load terminals

□ Obtain the thevenin's equivalent circuit by connecting VOC in series with RTh Reconnect the load resistance across the load terminals.

19. List the applications of Thevinins theorem.

□ It is applied to all linear circuits including electronic circuits represented by the

□ controlled source.

□ This theorem is useful when t is desired to know the effect of the response in network

□ or varying part of the network

IL= VOC / (RTH+RL)

20. State the steps to solve the Norton's theorem.

□ Remove the load resistor and find the internal resistance of the source N/W by

□ deactivating the constant source.

□ Short the load terminals and find the short circuit current

□ Norton's equivalent circuit is drawn by keeping R TH in parallel with ISC

□ **IL= (ISC.RTH) / (RTH+RL)**

21. Write some applications of maximum power transfer theorem.

□Power amplifiers

□Communication system

□Microwave transmission

22. What are the limitations of maximum power transfer theorem?

□ The maximum efficiency can be obtained by using this theorem is only 50% . It is because of 50% of the power is unnecessarily wasted in Rth.

□ Therefore this theorem only applicable for communication circuits and not for power.

□ circuits where efficiency is greater importance rather than power delivered

23. Define source transformation.

The current and voltage sources may be inter changed without affecting the remainder of the circuit, this technique is the source transformation. It is the tool for simplifying the circuit.

24. Explain the purpose of star delta transformation.

The transformation of a given set of resistances in star to delta or vice versa proves extremely useful in circuit analysis and the apparent complexity of a given circuit can sometime by very much reduce.

UNIT –II
AC CIRCUITS

UNIT – II

AC CIRCUITS

Generation of Alternating voltage and Current:

→ Alternating voltage is generated by rotating a coil in a stationary magnetic field. It can also be generated by rotating a magnetic field within a stationary coil. Rotating field method is the mostly used one for generation of alternating voltage. Alternating supply is invariably used for domestic & Industrial applications.

Sinusoidal Alternating Quantity:

→ An alternating quantity which varies according to sine of the angle θ is known as sinusoidal alternating quantity.

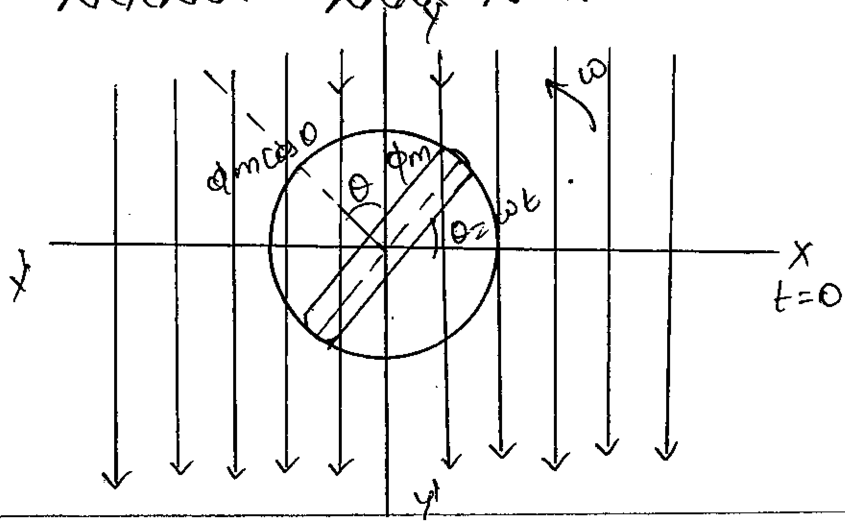
→ All over the world sinusoidal voltages and currents are selected for generation of electrical power. The following are the reasons.

* The sinusoidal voltage and currents produce low iron and copper losses in AC rotating machines and transformers. It improves the efficiency.

* Sinusoidal voltage and current will offer less interference to nearby telephone lines.

* They produce less disturbance in the electrical circuit

Equation of Sinusoidally varying emf and current:



→ Consider a rectangular coil with N turns. It is rotated in an uniform Magnetic field in anticlock wise direction.

Let B – flux density of the field in wb/m^2

ω – Angular velocity of the coil in radians/sec

→ The time is measured from the positive x-axis. After 't' seconds of rotation, the coil is rotated through an angle $\theta = \omega t$.

→ In this position, resolve the flux into two components. One component is perpendicular to the plane of the coil. The other one is parallel to the plane of the coil. The component of flux at right angles to the plane of the coil is,

$$\phi = \phi_m \cos\theta$$
$$= \phi_m \cos\omega t .$$

→ only this flux links with the coil. The instantaneous emf induced,

$$e = -\frac{d(N\phi)}{dt}$$

$$= -\frac{N d\phi}{dt}$$

$$= -\frac{N d(\phi_m \cos\omega t)}{dt}$$

$$= -N\phi_m\omega(-\sin\omega t)$$

$$e = \omega N\phi_m \sin\omega t .$$

→ When $\sin\omega t$ is Maximum (=1), then e is Maximum & is denoted by E_m

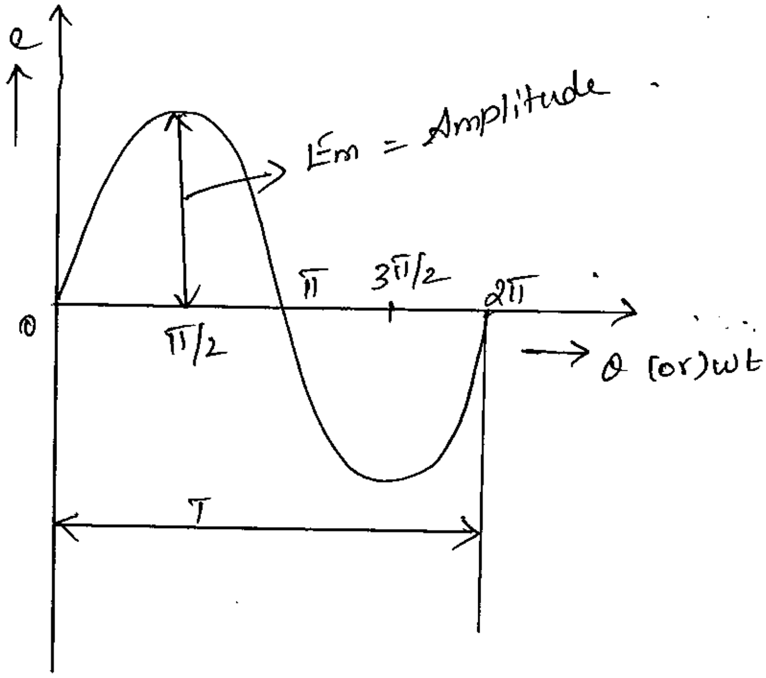
$$E_m = \omega N\phi_m .$$

Therefore, the above equation for e becomes.

$$e = E_m \sin\omega t = E_m \sin\theta .$$

→ This equation is called the standard sinusoidal equation of the voltage. The value of e depends on $\sin\theta$.

→ The above equation can be graphically represented as below. It is called voltage wave form.



Wave Form:

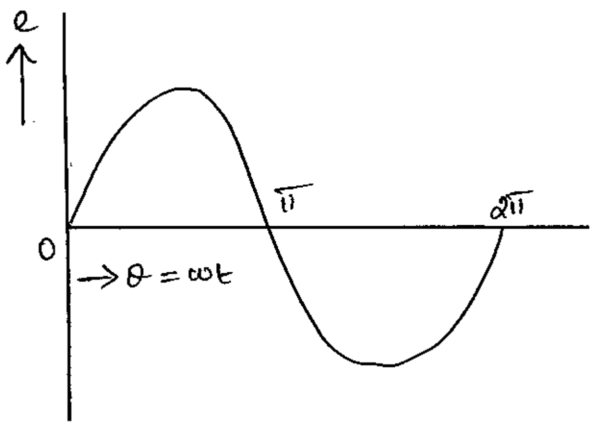
→ It is the graph drawn between the alternating quantity as ordinate and time as abscissa.

→ The alternating quantity may be either voltage (or) current (or) flux. Accordingly the wave form is known as voltage W/F, current W/F (or) flux W/F.

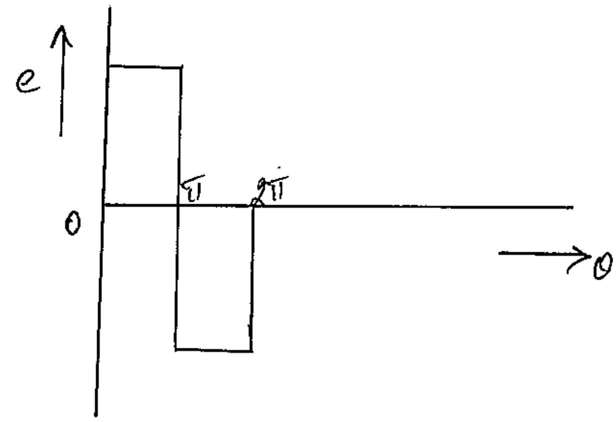
→ There are many types of W/F.

* Sinusoidal W/F
* Rectangular W/F
* Triangular W/F
* Saw-tooth W/F
* Trapezoidal W/F
* Stepped W/F.

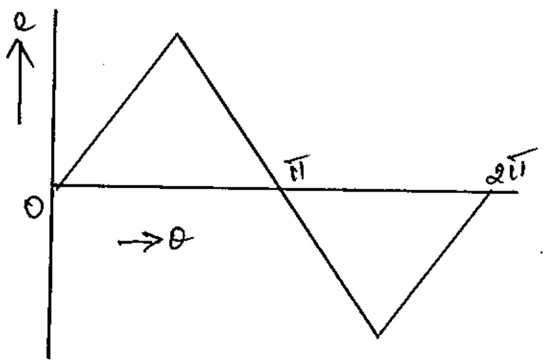
Sinusoidal W/F :



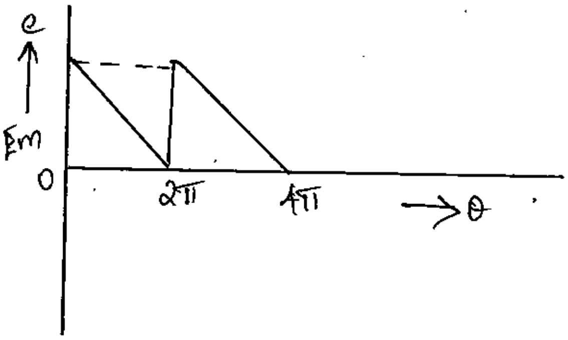
Rectangular W/F :



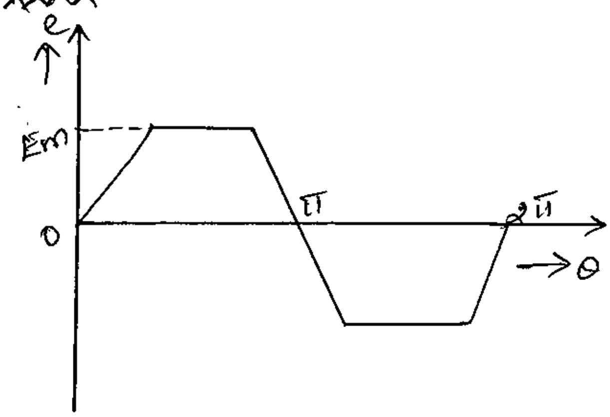
Triangular W/F :



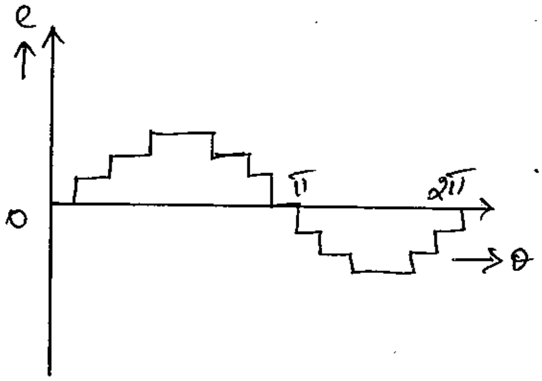
Saw - tooth W/F :



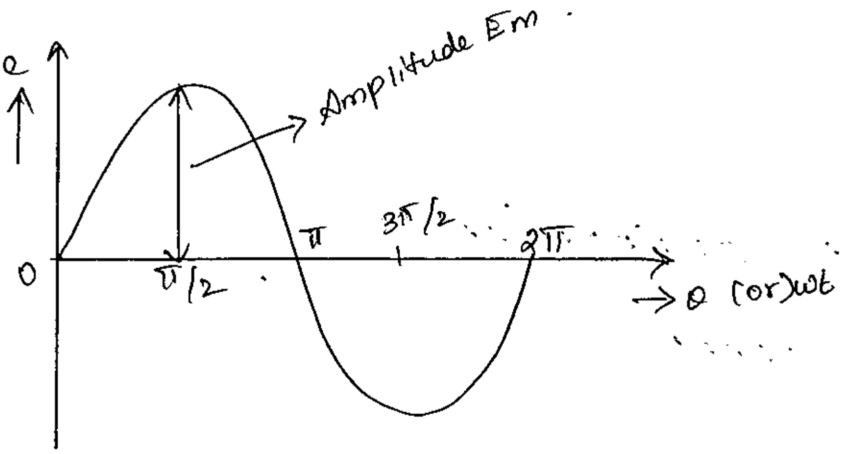
Trapezoidal W/F:



Stepped W/F:



Cycle:



→ It is a set of positive and negative portions of W/F.

Time Period:

→ The time required for an alternating quantity to Complete one cycle is called the time period and is denoted by T.

Frequency:

→ The no. of cycles per second is called frequency and is denoted by f. It is measured in cycles/second (cps) (or) Hz.

$$f = 1/T.$$

Amplitude:

→ The maximum value of the alternating quantity in a cycle, is called amplitude. It is also known as peak value (or) crest value.

Relation between ω & f:

Angular distance = angular velocity × time.

$$\theta = \omega \times t.$$

When $\theta = 360° = 2\pi$ radians, one cycle is completed.

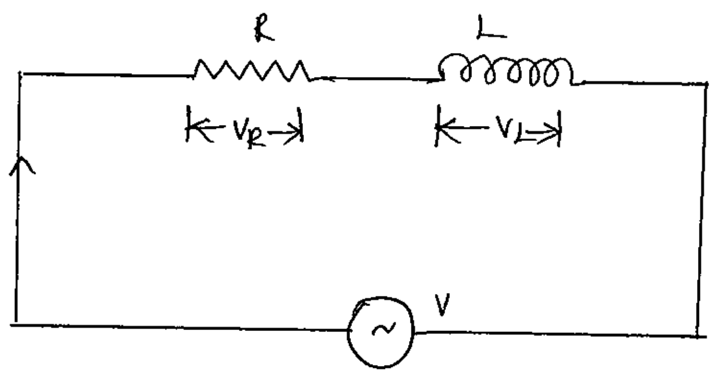
$$2\pi = \omega T$$

$$\omega = \frac{2\pi}{T}$$

$$\omega = 2\pi f.$$

POWER AND POWER FACTOR:

R-L SERIES CIRCUIT:



→ Let us consider a circuit in which a pure resistance R ohms and a purely inductive coil of inductance L henries are in series.

Let $V = V_m \sin \omega t$ be the applied voltage.

i = Circuit current at any instant

I = Effective value of circuit current

V_R = potential difference across resistor

V_L = potential difference across Inductor.

f = Frequency of applied voltage.

→ The voltage across the resistor is given by,

$$V_R = I.R \quad (\text{in phase } I).$$

→ The voltage across the inductor is given by,

$$V_L = I X_L \quad (\text{Leads } I \text{ by } 90°)$$

→ Therefore the applied voltage $= V = V_R + jV_L$.

$$= I.R + jIX_L$$

$$= I(R + jX_L)$$

$$V = I.Z.$$

Where Z is called as impedance of the circuit

$$Z = R + jX_L.$$

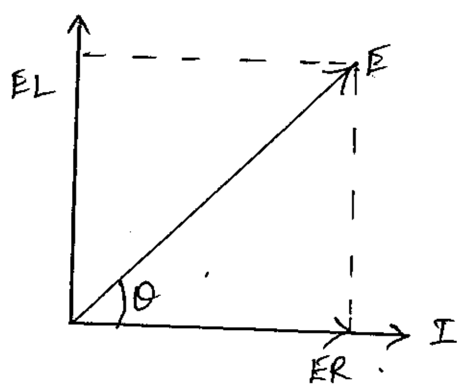
Which has a Magnitude and phase angle.

$$|Z| = \sqrt{R^2 + X_L^2}$$

The phase angle is given by,

$$\angle Z = \theta = \tan^{-1}\left(\frac{X_L}{R}\right)$$

$$Z = |Z| \angle \theta$$



→ θ is the angle by which the total voltage E is out of phase from the Current I.

a) POWER:

→ The equation for the Current and voltage would be

$$i = I_m \sin\omega t$$

$$e = E_m \sin(\omega t + \theta)$$

$$P = ei = E_m I_m \sin\omega t \sin(\omega t + \theta)$$

$$P = \frac{1}{2\pi}\int_0^{2\pi} E_m I_m \sin\omega t \sin(\omega t+\theta)\, d(\omega t).$$

$$= \frac{E_m I_m}{2}\cos\theta = \frac{E_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}}\cos\theta.$$

$$P = EI\cos\theta.$$

Apparent power (S) (or) Complex Power:

→ It is defined as the product of r.m.s value of voltage (V) and Current (I). It is denoted by S.

$$S = VI \text{ (volt-amp)}.$$

Real (or) True power (P) (or) Actual Power:

→ It is defined as the product of the applied voltage and active Components of the Current. It is measured in watts (or) KW.

$$P = VI\cos\phi.$$

Reactive power (or) Quadrature power (Q):

→ It is defined as the product of the applied voltage and the reactive Components of the Current. It is also defined as imaginary Components of the apparent power. It is Measured in volt-amp Reactive (VAR) (or) KVAR.

$$Q = VI\sin\phi.$$

Power Factor:

→ Power factor is defined as the ratio of the true power to apparent power.

$$P.F = \frac{\text{True power}}{\text{Apparent power}}$$

$$= \frac{VI\cos\phi}{VI}$$

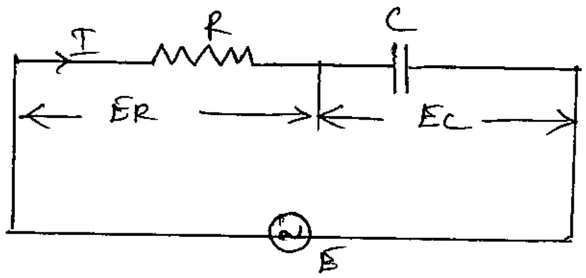
$$P.F = \cos\phi.$$

→ It is also defined as the ratio of resistance to impedance

$$\cos\phi = R/Z.$$

→ The power factor of the circuit varies between 0 to 1 for R-L circuit.

R-C SERIES CIRCUIT:



→ Consider R-C series circuit. The equations are given below.

$$E_R = I.R$$

$$E_C = I \times X_C.$$

$$X_C = \frac{1}{\omega C}.$$

→ E_R & E_C are not in phase as they are drops in the resistance and capacitance.

$$E = IR - jIX_C$$

$$E = I(R - jX_C)$$

$$E = IZ$$

$$|Z| = \sqrt{R^2 + X_C^2}$$

$$\theta = \tan^{-1}\left(\frac{E_C}{E_R}\right)$$

(or)

$$\theta = \tan^{-1}\left(\frac{X_C}{R}\right).$$

→ Therefore the total voltage E lags behind the current I by θ.

$$Z = |Z| \angle -\theta .$$

$$\text{Power factor} = \cos\phi$$

$$\cos\phi = R/Z .$$

Power Calculation:

i) Actual power (or) Real power :

$$P = VI\cos\phi \ (W).$$

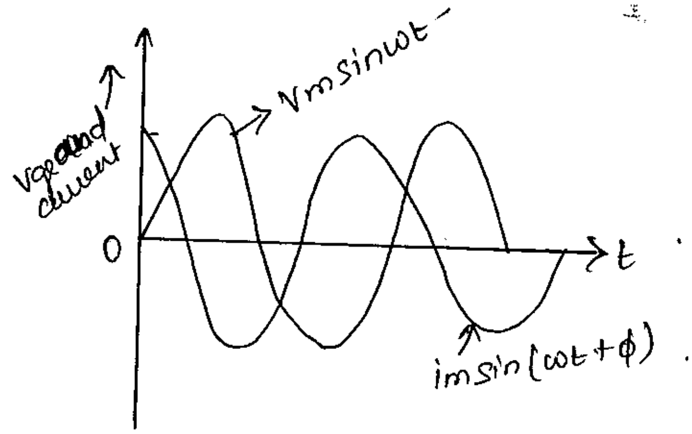
ii) Reactive power (or) Quadrature power :

$$Q = VI\sin\phi \ (VAR).$$

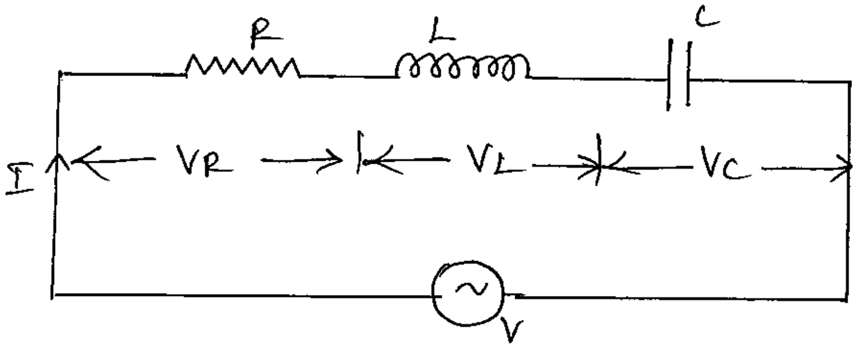
iii) Apparent power (or) Complex power.

$$S = VI \ (VA).$$

Waveform:



SERIES RLC CIRCUIT :



→ Consider a Circuit having resistance R (Ω), inductance (L) and Capacitance (C) all Connected in series.

Let the applied voltage be $V = V_m \sin \omega t$.

i = Circuit Current at any instant.

I = Effective value of Circuit Current.

V_R = Potential difference across resistor

V_L = potential difference across Inductor

V_C = potential difference across capacitor

f = Frequency of applied voltage.

→ The same Current I flows through R, L, C. Here I is takes as reference vector.

Voltage across $R = V_R = IR$

Voltage across $L = V_L = I X_L \angle 90°$ V leads current by 90°

$= jIX_L$.

Voltage across $C = V_C = IX_C \angle -90°$

$= -jIX_C$ V lags Current by 90°.

Applied voltage $= V = V_R + V_L + V_C$.

$= V = I(R + j(X_L - X_C))$.

→ The Impedance of the circuit is defined by,

$$Z = \frac{V}{I}$$

$$Z = R + j(X_L - X_C)\,\Omega$$

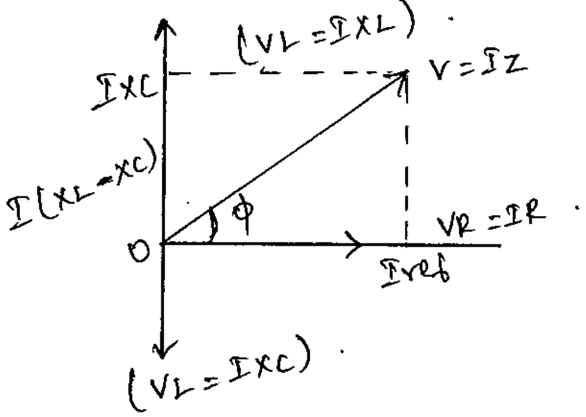
$$|Z| = \sqrt{R^2 + (X_L - X_C)^2}$$

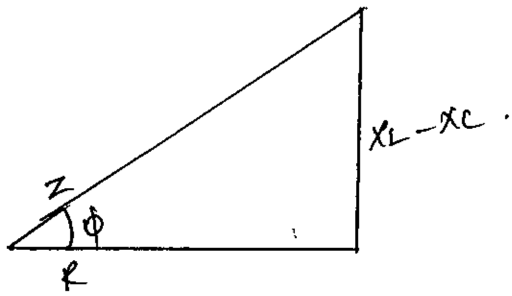
$X_L - X_C = X$ is called net reactance.

If $X_L > X_C$; the circuit behave like a RL circuit.

If $X_C > X_L$; the circuit behave like a RC circuit.

Case (i) : If $X_L > X_C$.





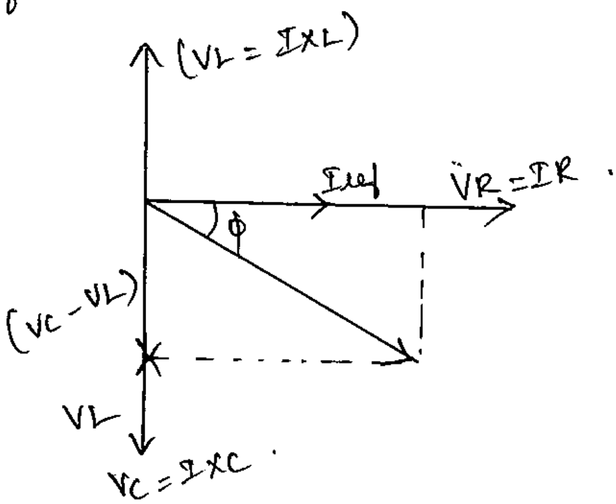
$$\tan\phi = \frac{X_L - X_C}{R}$$

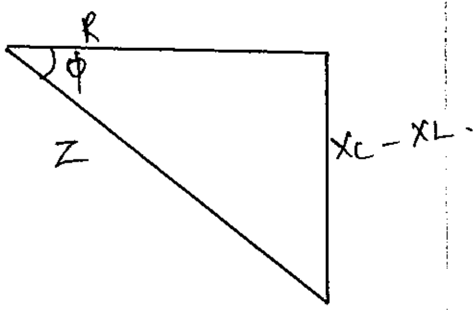
$$\tan\phi = \frac{(\omega L - 1/\omega C)}{R}$$

$$\phi = \tan^{-1}\left(\left(\frac{\omega L - 1/\omega C}{R}\right)\right)$$

$$P.F = \cos\phi = R/Z$$

Case (ii) If $X_C > X_L$:





$$\tan\phi = \frac{X_C - X_L}{R}$$

$$\phi = \tan^{-1}\left(\frac{X_C - X_L}{R}\right)$$

$$P.F = \cos\phi = R/Z.$$

Power Calculation:

i) Actual (or) Real power $P = VI\cos\phi$ Watts

ii) Reactive (or) Quadrature $Q = VI\sin\phi$ (VAR)

iii) Complex (or) Apparent $S = VI$ Volt amp.

Power Factor:

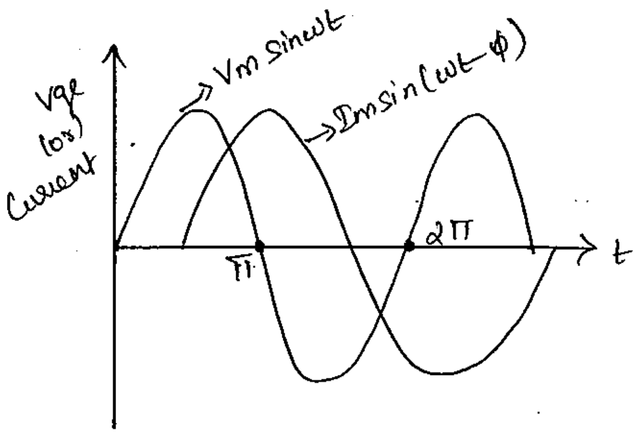
$$P.F = \cos\phi = \frac{\text{Real power}}{\text{Apparent power}}.$$

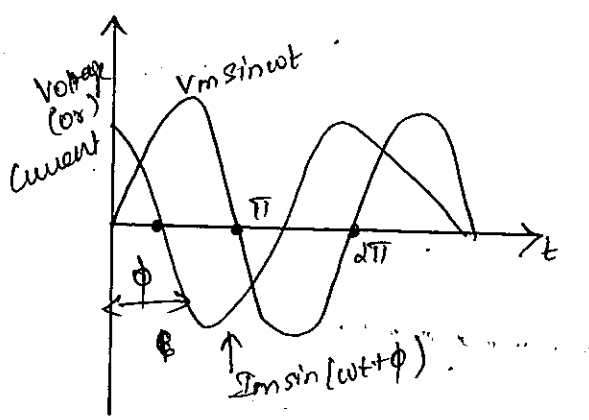
Waveform:

→ If the applied voltage is given as $v = V_m \sin\omega t$ then the current equation is given by $i = I_m \sin(\omega t \pm \phi)$.

+ for case (ii) $X_C > X_L$

− for case (i) $X_L > X_C$.





R.M.S (Root Mean Square) Value (or) Effective value:

→ The steady current which when flowing through a given resistor for a given time produces the same amount of heat as is produced by the alternating current when flowing through the same resistor for the same time is called R.M.S (or) Effective value of the alternating current.

To find the R.M.S value of a sinusoidal alternating quantity:

$$i = I_m \sin\theta$$

$$I_{RMS}^2 = \frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta$$

$$= \frac{1}{\pi}\int_0^{\pi} i^2 d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{\pi} (1-\cos 2\theta) d\theta$$

$$= \frac{I_m^2}{2\pi}\left(\theta - \frac{\sin 2\theta}{2}\right)_0^{\pi}$$

$$= \frac{I_m^2}{2\pi}(\pi - 0)$$

$$= \frac{I_m^2}{2}$$

$$I_{RMS} = \frac{I_m}{\sqrt{2}} = 0.707 \times I_m$$

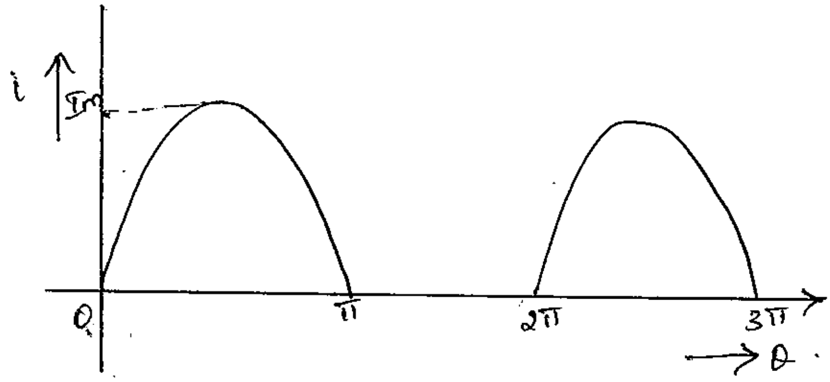
→ For a sinusoidal quantity, RMS value

= 0.707 × Maximum value.

R.M.S Value:

$$\text{R.M.S value} = \sqrt{\left(\frac{\text{Area of the squared wave}}{\text{base}}\right)}.$$

RMS value of Half Wave Rectified Waveform:



$$i = I_m \sin\theta \quad , \quad 0 < \theta < \pi$$

$$= 0 \quad , \quad \pi < \theta < 2\pi$$

$$I_{rms} = I$$

$$I^2 = \frac{1}{2\pi}\int_0^{2\pi} i^2 d\theta$$

$$= \frac{1}{2\pi}\int_0^{\pi} i^2 d\theta + 0 .$$

as there is no waveform from π to 2π

$$= \frac{1}{2\pi}\int_0^{\pi} (I_m \sin\theta)^2 d\theta$$

$$= \frac{I_m^2}{2\pi}\int_0^{\pi} \sin^2\theta \, d\theta$$

$$= \frac{I_m^2}{2 \times 2\pi}\int_0^{\pi} (1 - \cos 2\theta) \, d\theta .$$

$$= \frac{I_m^2}{4\pi}(\pi)$$

$$I^2 = \frac{I_m^2}{4}$$

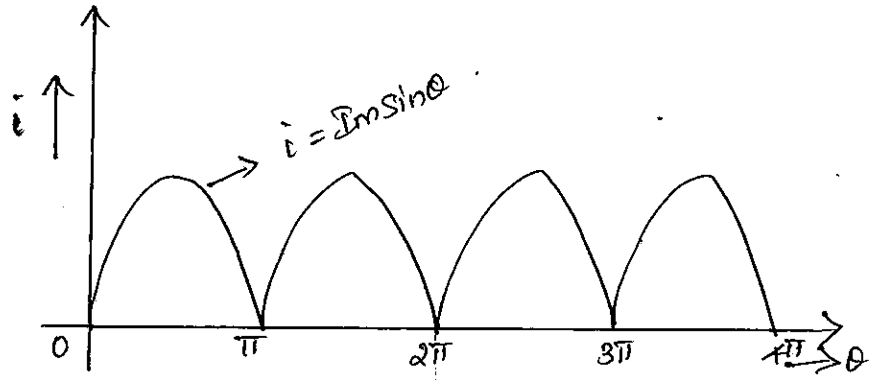
$$I = \sqrt{\left(\frac{I_m^2}{4}\right)}$$

$$= \frac{I_m}{2}$$

$$I = 0.5 I_m .$$

For a half Wave Rectified Wave form, RMS value = 0.5 x Maximum Value .

RMS value of a full wave Rectified sinusoidal wave form:



$$I_{rms}^2 = \frac{1}{\pi}\int_0^\pi i^2 d\theta$$

$$= \frac{1}{\pi}\int_0^\pi (I_m \sin\theta)^2$$

$$= \frac{I_m^2}{2\pi}\int_0^\pi (1-\cos 2\theta)\,d\theta$$

$$= \frac{I_m^2}{2\pi}\left(\theta - \frac{\sin 2\theta}{2}\right)_0^\pi$$

$$= \frac{I_m^2}{2\pi}\times\pi$$

$$I_{rms}^2 = \frac{I_m^2}{2}$$

$$\therefore I_{rms} = \frac{I_m}{\sqrt{2}}$$

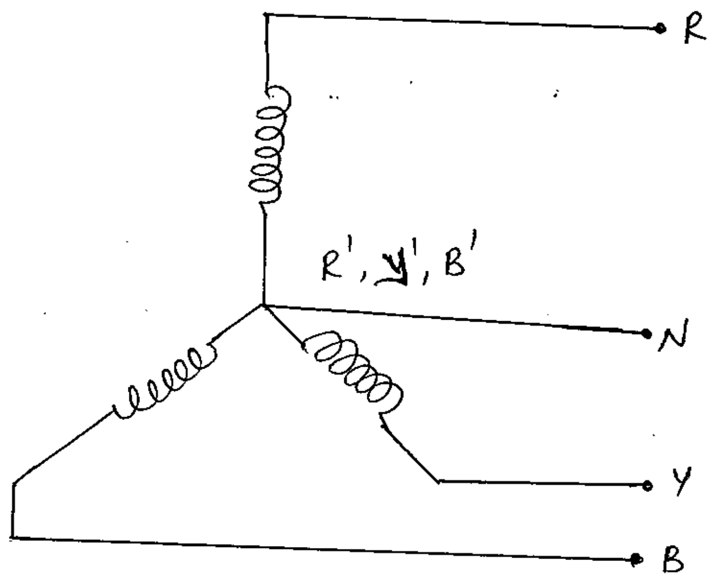
$$I_{rms} = 0.707\, I_m$$

For a full wave Rectified wave form

RMS value = 0.707 × Maximum value.

THREE PHASE BALANCED CIRCUITS:

Star (or) Wye (Y) Connection:



→ In star connection, one terminal of each is connected together at a common point N and the other three terminals are connected to external load through three conductors called lines. The external load may be either star connected (or) delta connected. The point N is called neutral point (or) neutral.

→ A wire brought out from neutral is called neutral conductor. The three line conductors and neutral wire provide 3ϕ 4 wire system.

→ Usually three windings of a 3ϕ alternator are connected in star. The neutral point is connected to ground.

Line voltage and phase voltage in star system:

→ The voltage across each coil is called phase voltage denoted by E_p (or) E_ϕ. It is also the voltage between each line & neutral.

→ E_{RN}, E_{YN} & E_{BN} are 3ϕ voltages. In a balanced supply system, these voltages are equal in magnitude & displaced by 120°.

$$|E_{RN}| = |E_{YN}| = |E_{BN}| = |E_\phi|.$$

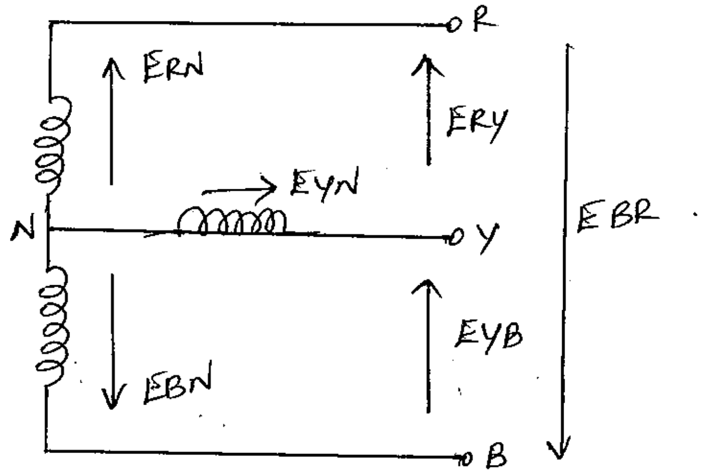
→ If E_{RN} is taken as reference for RYB phase sequence, we can express,

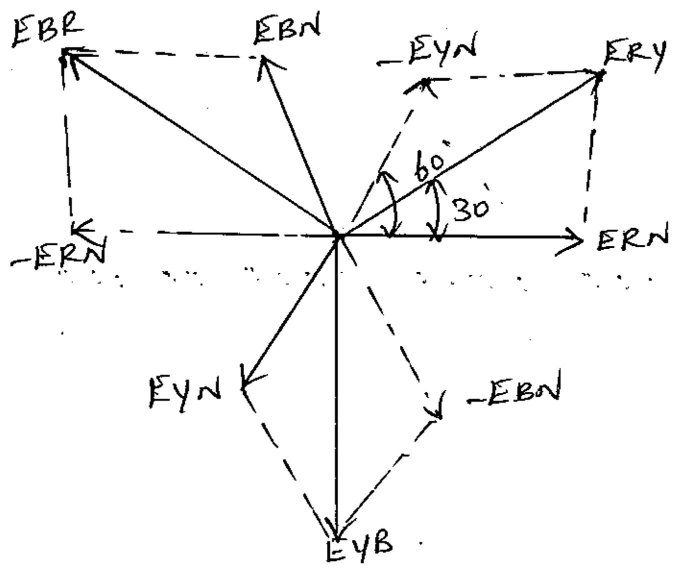
$$E_{RN} = E_\phi \angle 0^\circ$$

$$E_{YN} = E_\phi \angle -120^\circ$$

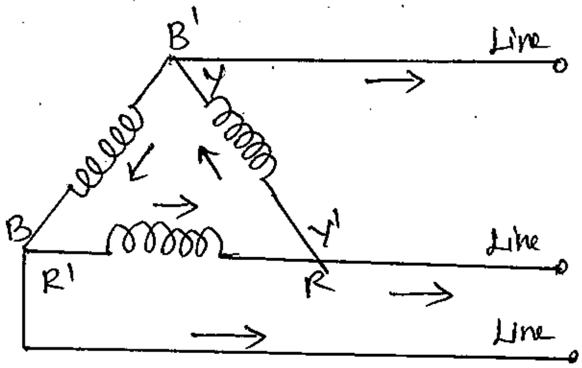
$$E_{BN} = E_\phi \angle 120^\circ .$$

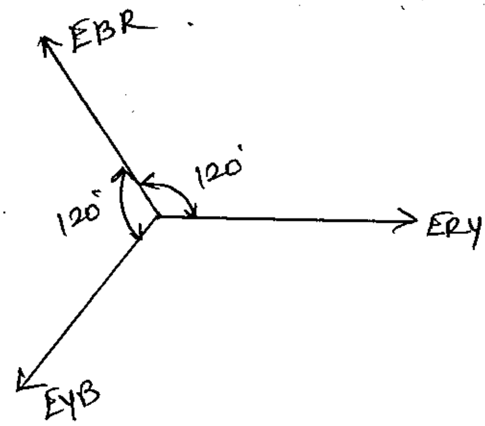
→ The voltage between any two lines is called line-to line voltage (or) simply line voltage denoted by E_L. Here E_{RY}, E_{YB} and E_{BR} are the line voltages.





Delta (Δ) (or) Mesh Connection:





→ If the three Coils are connected such, that the start of one coil is connected to the finish of the next Coil, the result is delta connection.

→ Here R' is connected to Y, Y' to B and B' to R. Thus a closed Mesh is formed, hence the name mesh Connection. The supply lines in delta connection are taken from the three junctions. Thus a delta Connection gives 3ϕ 3wire supply system. The phases are connected between the line terminals. The voltage between any two lines is the line Voltage E_L.

→ Hence in a balanced delta connected System.

$$|E_{RY}| = |E_{YB}| = |E_{BR}| = E_L = E_\phi .$$

→ For a phase sequence of RYB.

$$E_{RY} = E_\phi \angle 0^\circ = E_\phi (1+j0)$$

$$E_{YB} = E_\phi \angle -120^\circ = E_\phi \left(-0.5 - j\frac{\sqrt{3}}{2}\right)$$

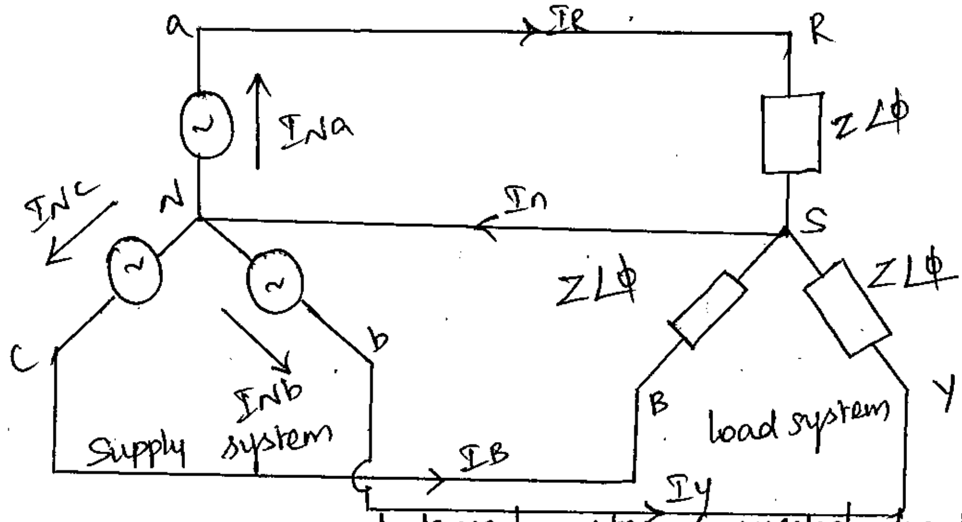
$$E_{BR} = E_\phi \angle 120^\circ = E_\phi \left(-0.5 + j\frac{\sqrt{3}}{2}\right).$$

→ The phasor sum of line voltages

$$= E_{RY} + E_{YB} + E_{BR} = 0 .$$

Balanced Star Connected load :

→ The 3ϕ Generators supply energy to the loads which may be connected either in star (or) delta. When the load impedances in all the 3ϕ are identical, the load is said to be balanced.



→ Shows a balanced star connected load of impedance Z in each phase.

$$Z = |Z|\angle\phi$$

→ In the 3ϕ 4 wire system the neutral point N of the supply is connected to the star point S of the load. The wire NS is called neutral wire.

$$I_{Na} = I_R = I_{RS}.$$

→ That is the current in phase a of the alternator = current in line a = current in phase R of the load.

$$I_{Nb} = I_Y = I_{YS}$$

$$I_{NC} = I_B = I_{BS}.$$

→ Thus, the currents flowing through the voltage sources flow through the line conductors and through the load elements.

$$I_L = I_\phi \quad \text{for star connection.}$$

→ The given star connected load is equivalent to three 1ϕ circuits.

$$I_R = \frac{E_{aN}}{Z} = \frac{E_\phi \angle 0}{Z\angle\phi} = I_\phi \angle -\phi$$

$$I_Y = \frac{E_{bN}}{Z} = \frac{E_\phi \angle -120^\circ}{Z\angle\phi} = I_\phi \angle -\phi - 120^\circ$$

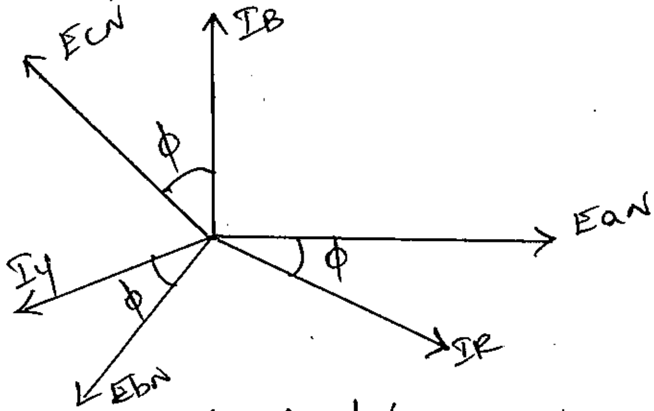
$$I_B = \frac{E_{cN}}{Z} = \frac{E_\phi \angle 120^\circ}{Z\angle\phi} = I_\phi \angle -\phi + 120^\circ .$$

→ By applying, KCL at the star point S

$$I_n = I_R + I_Y + I_B .$$

→ As the line currents form a balanced system,

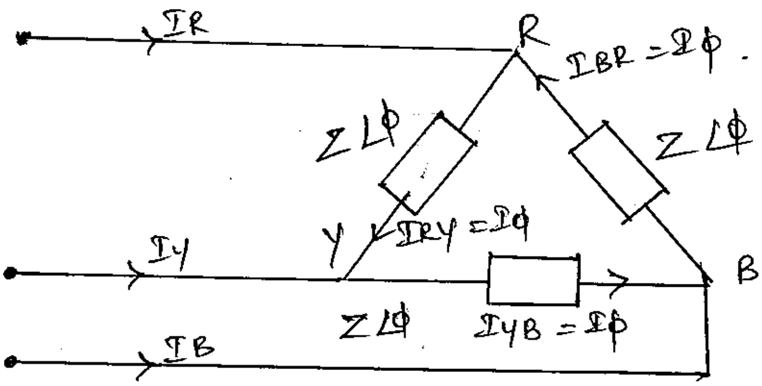
$$I_R + I_Y + I_B = 0 \Rightarrow I_n = 0 .$$

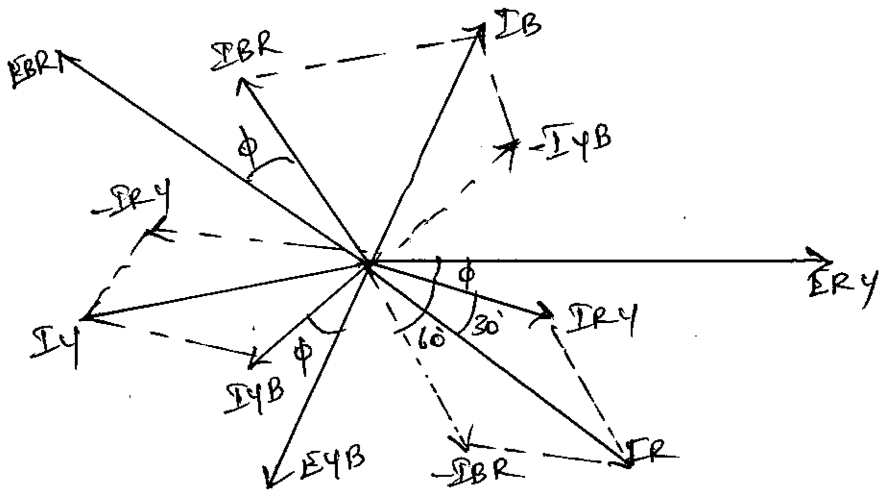


Balanced Delta Connected load:

$$Z = |Z| \angle\phi$$

→ Assume the phase sequence to be RYB. Taking E_{RY} as reference.





$$I_{RY} = \frac{E_{RY}\angle 0}{Z\angle\phi} = \frac{E\phi}{Z}\angle{-\phi} = I\phi\angle{-\phi}$$

$$I_{YB} = \frac{E_{YB}\angle{-120^\circ}}{Z\angle\phi} = \frac{E\phi\angle{-120^\circ}}{Z\angle\phi} = I\phi\angle{-\phi-120^\circ}$$

$$I_{BR} = \frac{E_{BR}\angle 120^\circ}{Z\angle\phi} = \frac{E\phi}{Z}\angle{-\phi+120^\circ}$$

$$= I\phi\angle{-\phi+120^\circ}$$

→ By KCL, we get

$$I_R = I_{RY} - I_{BR} = I_{RY} + (-I_{BR})$$

→ From the phasor diagram.

$$|I_R|^2 = |I_{RY}|^2 + |-I_{BR}|^2 + 2\,|I_{RY}|\,|I_{BR}|\cos 60^\circ$$

$$= |I\phi|^2 + |I\phi|^2 + |I\phi|\,|I\phi| = 3\,|I\phi|^2$$

$$\therefore |I_R| = \sqrt{3}\,|I\phi|$$

$$|I_L| = \sqrt{3}\,|I\phi|.$$

→ In polar form, taking E_{RY} as reference.

$$I_R = \sqrt{3}\, I\phi \angle{-\phi-30^\circ}$$

$$I_Y = \sqrt{3}\, I\phi \angle{-\phi-150^\circ}$$

$$I_B = \sqrt{3}\, I\phi \angle{-\phi+90^\circ}$$

UNIT – II

AC CIRCUITS

1. Define Angular Frequency (ω)

Angular frequency is defined as the number of radians covered in one second(ie the angle covered by the rotating coil). The unit of angular frequency is rad/sec.

2. Define Phasor?

A sinusoidal alternating quantity can be represented by a rotating line called a Phasor.

3. Define Phase Difference?

When two alternating quantities of the same frequency have different zero points, they are said to have a phase difference. The angle between the zero points is the angle of phase difference.

4. Define In phase?

Two waveforms are said to be in phase, when the phase difference between them is zero. That is the zero points of both the waveforms are same.

5. Define Average value?

Average Value The arithmetic average of all the values of an alternating quantity over one cycle is called its average value.

6. Define RMS value?

The effective or RMS value of an alternating quantity is that steady current (dc) which when flowing through a given resistance for a given time produces the same amount of heat produced by the alternating current flowing through the same resistance for the same time.

7. Define Form factor?

It is the ratio of RMS value to the average value of an alternating quantity is known as Form Factor .

8. Define Peak factor?

Peak Factor or Crest Factor: It is the ratio of maximum value to the RMS value of an alternating quantity is known as the peak factor.

9. Define Power factor?

The power factor in an AC circuit is defined as the cosine of the angle between voltage and current ie., $\cos\Phi$.

10. Define Real power?

The power due to the active component of current is called as the active power or real power. It is denoted by P.

11. Define Reactive power?

The power due to the reactive component of current is called as the reactive power. It is denoted by Q.

12. Define Apparent power?

The apparent power is the total power in the circuit. It is denoted by S.

UNIT – III
ELECTRICAL MACHINES

UNIT III

ELECTRICAL MACHINES

DC GENERATORS :

→ Dc Generator works on the principle of Faraday's law of Electromagnetic Induction.

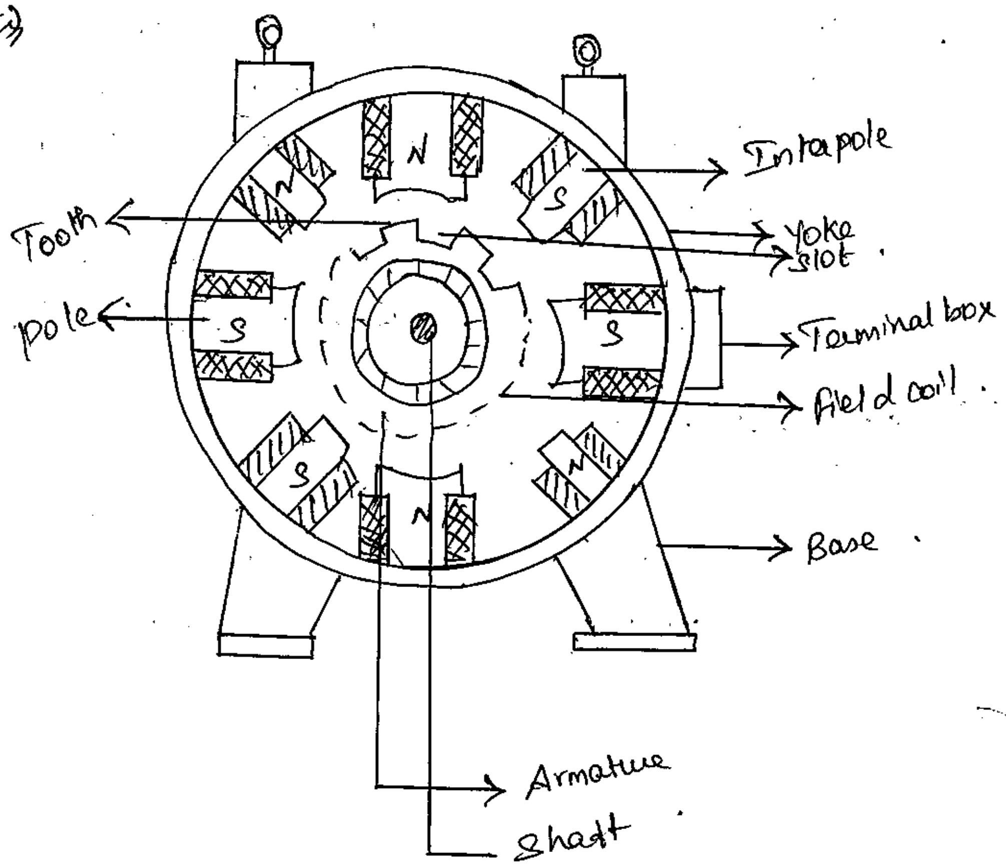
→ It converts Mechanical energy into Electrical energy.

Construction of Dc Generator :

→ The Dc Generator has the following parts :

* Yoke
* pole
* poleshoe
* Field coil
* Inter pole
* Airgap
* Armature
* slot
* Teeth
* Commutator
* Shaft
* Base
* Terminal Box
* Eye bolt.

~~Yoke (or)~~



* **Yoke (or) Magnetic frame:**

→ It has two functions.

* It provides Mechanical support for the Machine and act as a Cover for the Machine.

* It forms the portion of Magnetic Circuit. The yoke is made of Cast iron for smaller Machines. For larger Machines it is always made of fabricated steel either in one (or) More no. of pieces.

* **Magnetic poles:**

→ The field Magnets Consist of pole cores and pole shoes.

They spread out the flux in the air gap.

They support the field coils.

→ The pole cores and pole shoes are built with thin laminations of steel. The Cores are laminated to reduce eddy current loss.

* **Field Coils:**

→ Field Coils are usually wound with enamelled copper wire. Sometimes cotton insulation is used. Sufficient space is left between the layers for ventilating purposes.

→ The North & South pole depend upon the direction of Current flow through the field coil.

* **Inter poles (or) Commutating poles:**

→ In large size DC Generator, interpoles are provided. The function of these poles is to improve Commutation & to reduce armature reaction.

→ The Excitation Coils on the interpoles are Connected in Series with the armature.

*** Armature:**

-> The armature Core is Keyed to the Machine shaft and it rotates between the field poles. It Consist of slotted steel laminations.

-> The laminations are insulated from each other by thin Coating of varnish. The purpose of laminating the core is to reduce the eddy current loss.

-> Armature winding is wound in two ways.

* Lap winding

* Wave winding..

*** Commutator:**

-> The emf induced in the armature is AC in nature. Commutator Converts this AC to DC.

*** Brushes:**

-> Brushes are made of Carbon & rest on the Commutator. The brushes Carry current from the Commutator to the external stationary load.

*** Bearings and end Cover:**

-> End Covers are made of Cast iron (or) fabricated Steel. They are fitted to both ends of the yoke.

-> Ball bearing (or) roller bearings are fitted inside the end Cover. Armature shaft is mounted over these bearings.

Principle of Operation of DC Generator:

-> Whenever a Conductor cuts the Magnetic flux, dynamically emf is induced in it, according to Faraday's law of Electromagnetic Induction. This emf causes a Current to flow, if the Conductor Circuit is closed.

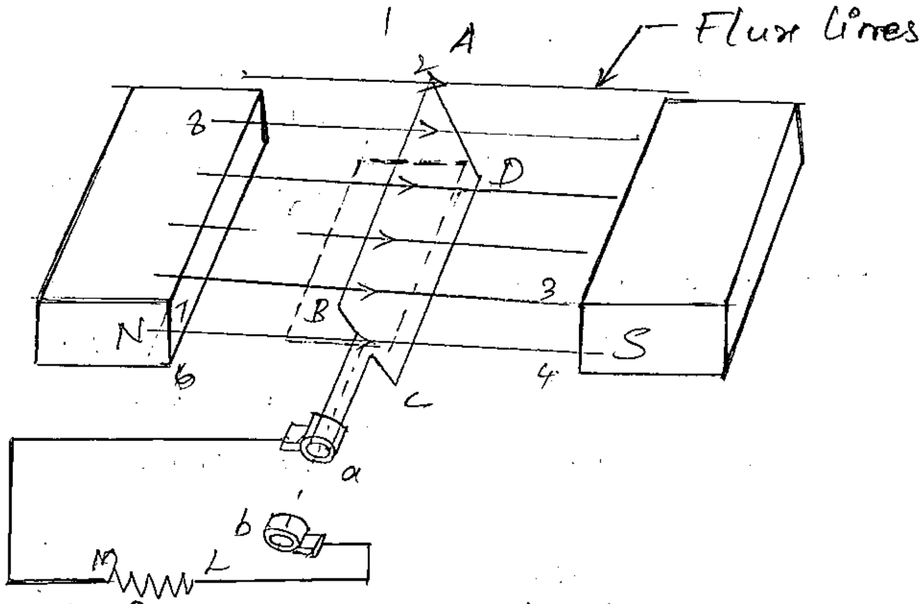
-> The direction of induced emf is Given by 'Flemings Right hand Rule'.

→ The Important Components of a generator are

* A Magnetic field
* Conductor
* Motion of Conductor with respect of Magnetic field.

→ In DC Generator, a stationary Magnetic field is produced by field Magnet. The armature Consists of Conductors is rotated inside the Magnetic field by a prime mover.

→ The prime Mover May be a turbine (or) Diesel engine (or) petrol engine. The nature of emf induced in the armature is Alternating (AC). The AC emf is Converted into unidirectional emf (DC) by means of Commutator.



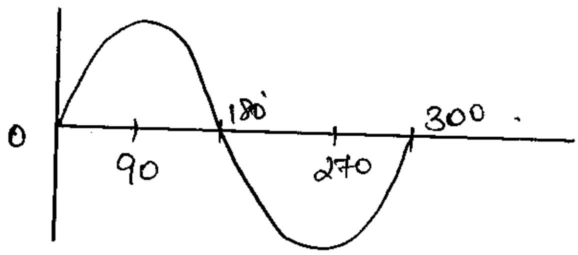
→ Fig. Shows a single loop of Copper Coil ABCD Moving in a Magnetic field. The two ends of the Coil are joined to two slip rings a and b. These Slip rings are insulated from each other.

→ The brushes Collect the Current induced in the Coil and supply it to the external load.

→ When the Coil rotates inside the Magnetic field the flux linked with the Coil changes and hence emf is induced in the coil, which is proportional to the rate of change of flux linkages.

-> Assume the coil is rotating in clockwise direction. When the plane of the coil is at right angles to the flux lines (i,e) in position 1, ($\theta = 0°$) the flux link with the coil is maximum, but the rate of change of flux linkages is minimum. Because in this position coil does not cut any flux lines. Therefore no emf is induced in the coil at position 1.

-> Now the coil moves to position 3 from position 1. When the coil reached to position 3 ($\theta = 90°$), the coil plane is horizontal to the flux line, the flux linked with the coil is minimum, but the rate of change of flux linkage is maximum. Therefore maximum emf is induced in the coil.



-> In the next quarter revolution from position 3 to 5 ($\theta = 90°$ to $180°$), the flux linked with the coil gradually increases, but the rate of change of flux linkages decreases. Therefore the emf induced is zero at position 5.

-> Now the coil moves from position 5 to 7 ($180°$ to $270°$), the emf induced in the coil is in the reversed direction. Therefore the emf induced is negative maximum. Then the coil moves from position 7 to 1, ($270°$ to $360°$), the flux linked with the coil gradually increases, but the rate of change of flux linkages decreases. The emf induced is zero at position 1. Thus the emf induced in the coil is an alternating emf.

-> If the slip rings are replaced by split rings, the alternating emf will become unidirectional current (DC).

EMF EQUATION OF DC GENERATOR:

ϕ - flux per pole in Wb

Z - Total No. of armature conductors

P - No. of poles

A - No. of parallel paths

A - 2 for Wave winding

A - P for Lap Winding

N - Speed

→ According to Faraday's Law of electromagnetic Induction, average emf in each conductor is equal to the rate of change of flux in Wb per second

$$e = N\frac{d\phi}{dt}$$

→ In one revolution flux cut by each armature conductor $(d\phi) = \phi P$ Wb.

→ Time taken by the armature to Complete 'N' revolutions $= 1$ Minute

$= 60$ sec.

→ Time taken by the armature to complete one revolution $(dt) = \frac{60}{N}$

→ Emf Induced in each Conductor $= \frac{d\phi}{dt}$

$$= \frac{\phi P}{\frac{60}{N}} = \frac{\phi P N}{60} \text{ Volts}.$$

$$P = Z/A.$$

→ EMF Induced in DC Generator $E_g = \frac{\phi P N \times Z}{60A}$.

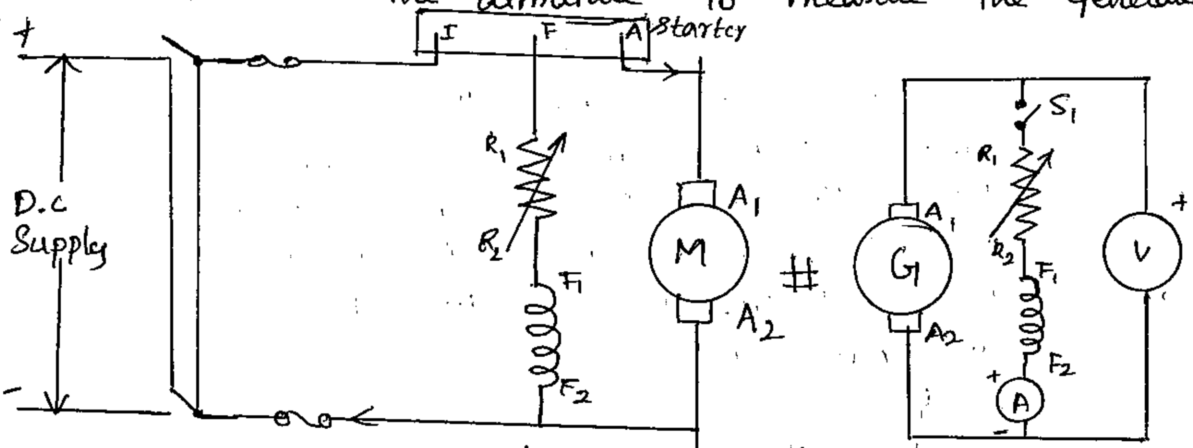
$$\boxed{E_g = \frac{\phi Z N P}{60A}}.$$

CHARACTERISTICS OF DC GENERATORS:

a) No Load characteristics (or) open circuit characteristics:

For self excited DC shunt generator:

→ The field winding of self excited shunt generator, is excited by the voltage induced in the armature. The generator is coupled to a prime mover. To measure the field current, an armature is connected in series with the field winding and a voltmeter is connected across the armature to measure the generated emf.



Self excited shunt generator.

→ At no load, the generator is driven at rated constant speed by the help of prime mover. When the generator is run at the rated speed with field circuit disconnected by opening the switch S. The voltmeter across the armature reads the residual voltage. This is because of the presence of the residual magnetism in the field system.

→ Then the switch S_1 is closed and the excitation current through the field winding is increased from zero and the emf induced at each value of field current is noted.

→ EMF equation of DC generator $E_g = \frac{\phi Z N P}{60 A}$.

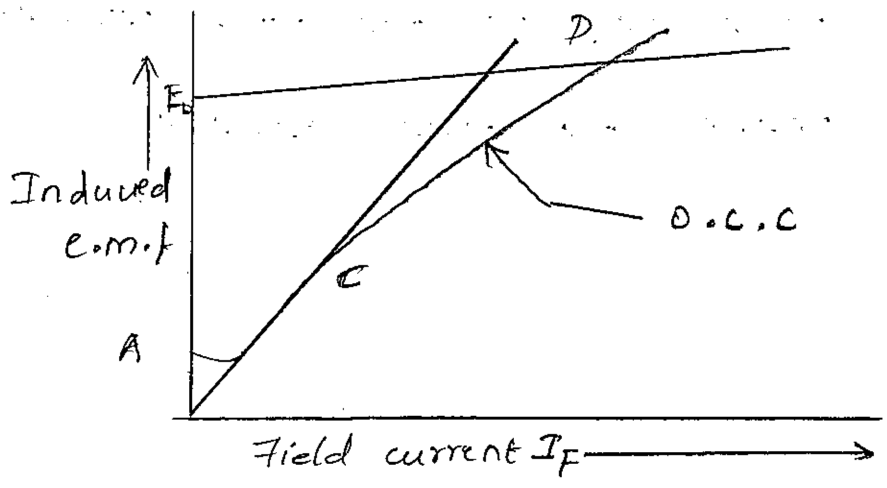
If speed is constant, the above equation becomes

$$E_g = K\phi$$

$$E_g \propto \phi$$

$$\phi \propto I_f.$$

Hence the EMF is directly proportional to field Current.



→ When the field Current is less, the Induced emf will be directly proportional to the field current and it increases along the straight line AC.

→ When the field Current is increased beyond certain level, the field Magnet gets saturated. Therefore the induced emf will not increase in proportion to the field current. Instead it increases along the Curve CD.

b) Load Characteristics of Dc Generators.

For Dc Shunt Generator:

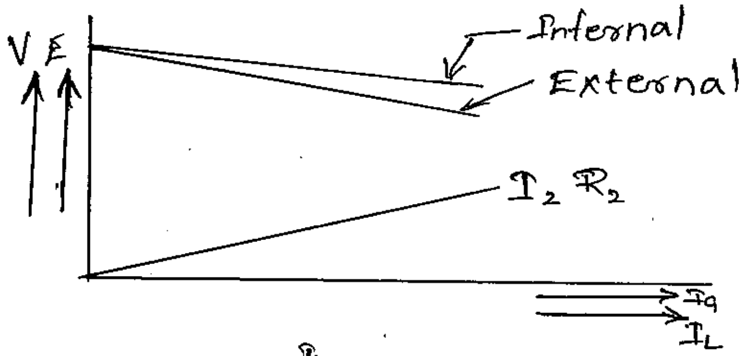
→ In this Circuit, the armature, field and load are Connected in parallel. To measure the terminal voltage a voltmeter is connected. To measure the field Current and load Currents two ammeters are Connected.

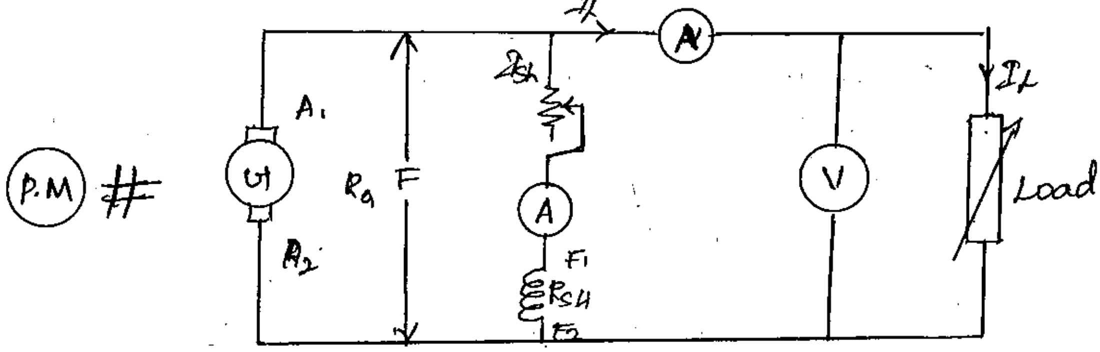
In shunt generator $I_a = I_L + I_{sh}$

$E = V + I_a R_a$.

→ The generator is started with the help of prime Mover and is run at rated speed. Adjust the field rheostat, so that the voltmeter reads the rated voltage. Then by keeping the field Current Constant, Vary the load Current, & note the terminal voltage for each value of load Current.

→ For each value of terminal voltage the induced emf and armature Current are calculated.





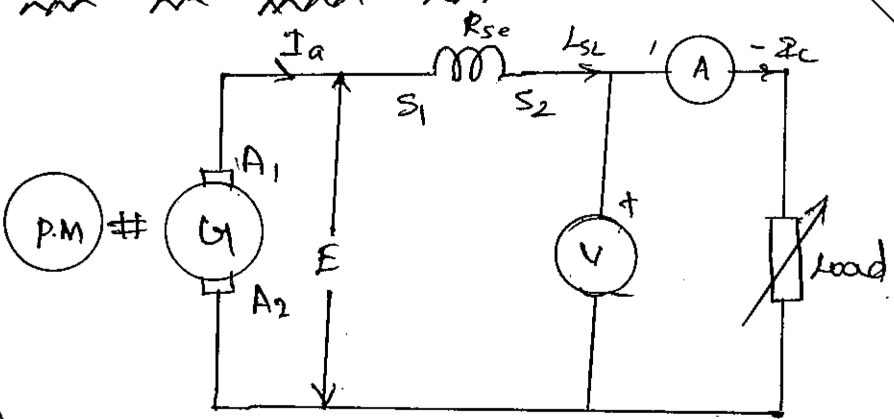
→ Then plot the load current on X-axis & terminal voltage on Y-axis in the graph. We get the external characteristics.

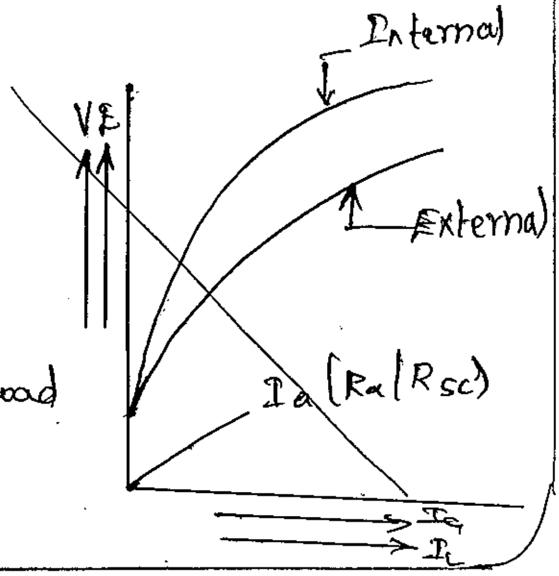
→ Then plot the armature current in X-axis & induced emf in Y-axis, we get the internal characteristics.

→ From the characteristics, when the current increases, the terminal voltage decreases. The voltage is reduced due to armature resistance drop and armature reaction effect.

→ When the current increases above the full load current, the voltage is reduced and becomes zero. Hence ~~Gen~~ shunt generator has drooping characteristics.

For DC Series Generator:





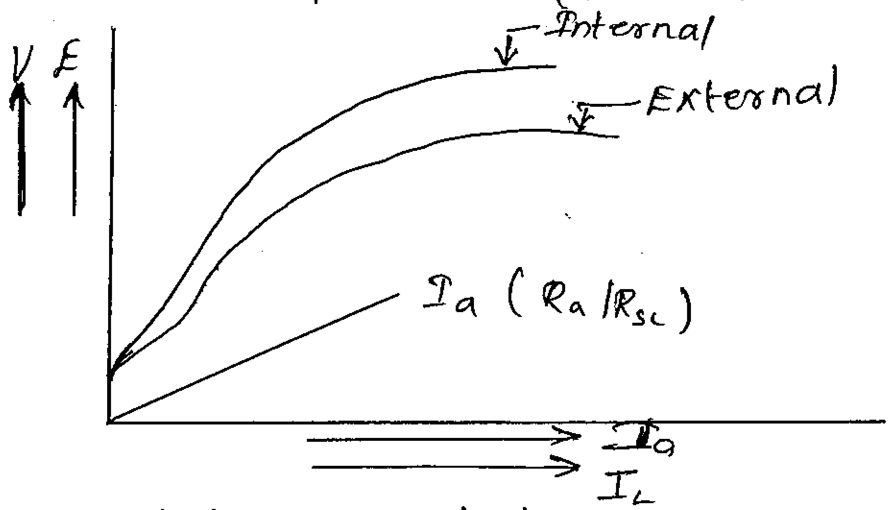
→ Using this Circuit diagram, the load characteristics are drawn. Since the armature and series field are connected in series, the Current through the armature, series field winding and the load current are same.

$$I_a = I_{se} = I_L .$$

→ To Measure terminal voltage a voltmeter is Connected. An ammeter is Connected to measure the load Current. The Generator is started with the help of a prime Mover and is allowed to run at its rated speed. Adjust the load step by step and also note terminal voltage and load current for every step.

→ For each reading Calculate the emf induced in the generator by using the formula.

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



→ plotting the load Current, armature Current in x-axis and terminal voltage, and induced emf on y-axis. Since the field winding is in series with the load, at no load ($I_L = 0$) the induced emf is zero. When $I_L = 0$, $I_{se} = 0$. Hence emf is zero. When the load current increases, the field current also increases, Which in turn increases the flux. So the terminal voltage and emf are also increased. Hence the series Generator has rising characteristics.

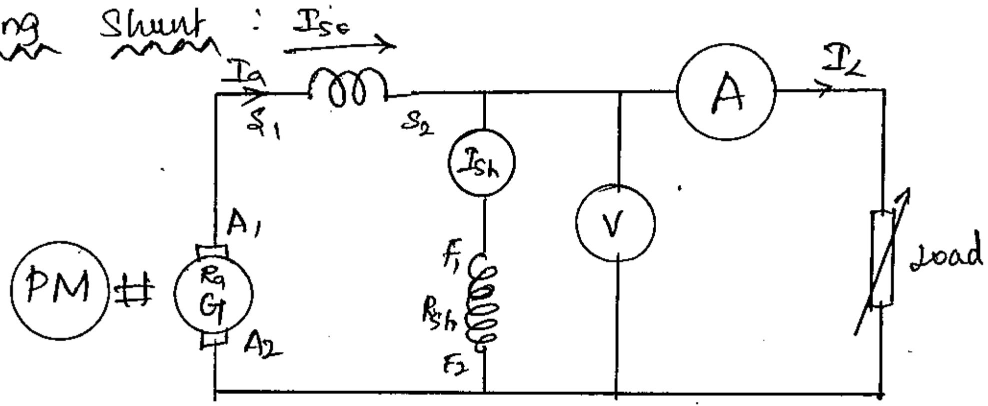
→ But after the saturation of field, the voltage is not increased, even though the load current increases.

→ After the saturation, when the load current increases, the voltage is reduced due to the armature reaction effect and armature resistance drop.

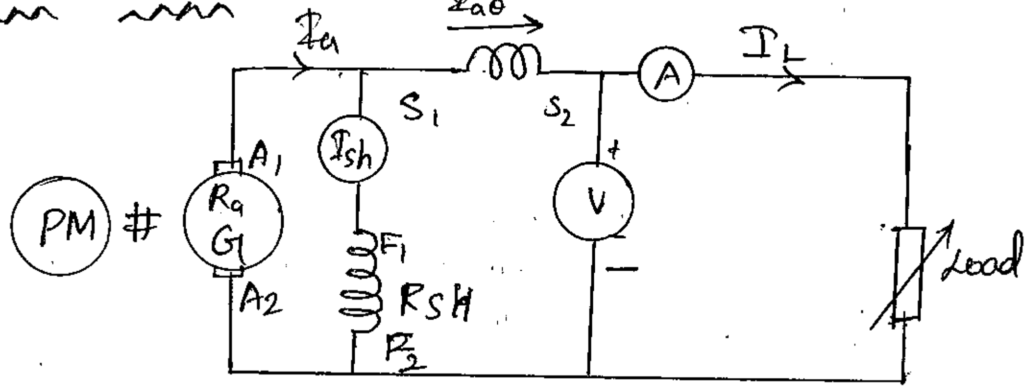
For Compound generator:

→ In this, both series and shunt windings are combined. The shunt winding can be connected either across the armature only (short shunt) (or) across the armature plus series field (long shunt).

Long Shunt:



Short Shunt:

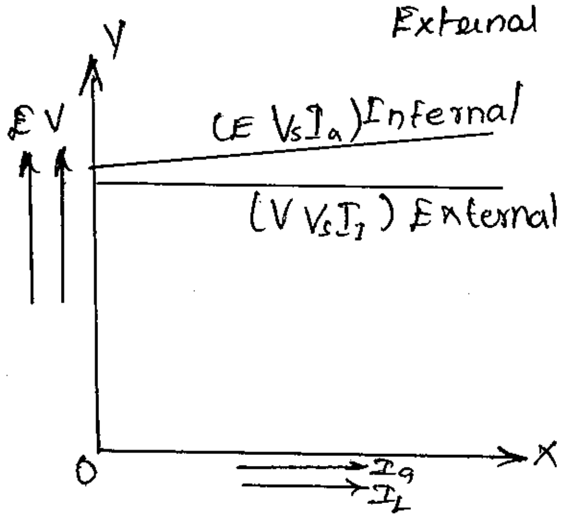


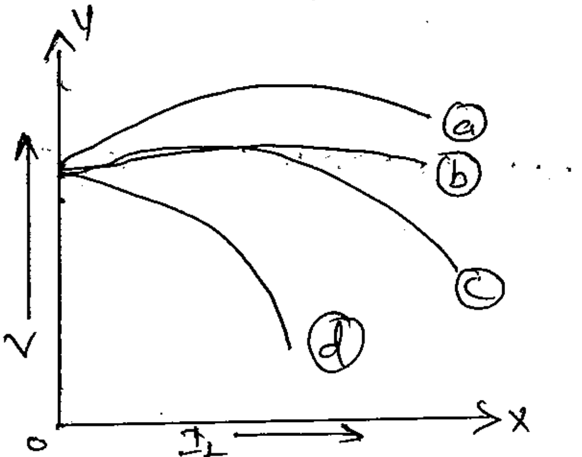
→ The generator is started with the help of a prime mover and is allowed to run at its rated speed. Adjust the load step by step and also note terminal voltage load current & field current for every step.

→ For each reading calculate the emf induced in the generator by using the formula

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

→ plotting the load current, armature current in x axis and terminal voltage, and induced emf on Y-axis. Now plot the internal characteristics (E Vs I_a) and External characteristics (V Vs I_L).





→ The external characteristics of DC shunt Generators are drooping characteristics and series generators are rising characteristics. Therefore in cumulative compound generator the drop in terminal can be compensated either in full (or) part by appropriately selecting a no. of turns in the series field winding.

→ If the series flux aids the shunt field flux then the generator is said to be cumulative compound generator. If the no. of turns in the series field winding is increased, the terminal voltage rises with increase in load and such generators are called over compound (or) cumulative compound generators. They are used to compensate the voltage in long feeders.

→ If the No. of turns in the series field winding is reduced, it is possible to get an external characteristics by the curve C, where the terminal voltage decreases when the generator is loaded. Such generators are called under compounded generator.

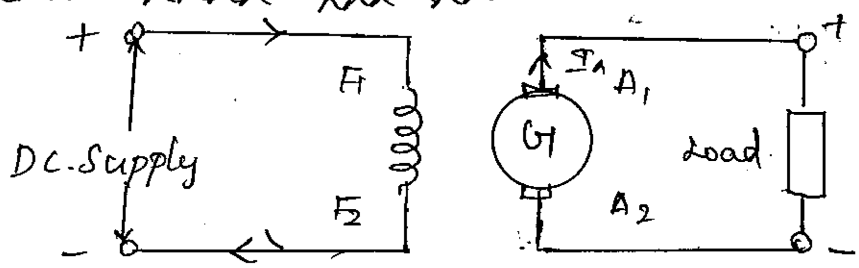
→ If the No. of turns in the series field winding are chosen such that, the generator delivers an almost constant terminal voltage from no load to full load by the curve b. It is called level of flat compound.

→ In differential compound generators the series field flux opposes the shunt field flux. Therefore when the generators is loaded the terminal voltage of the generator falls to zero, shown in the curve d.

TYPES OF DC GENERATORS:

* Separately Excited DC generator
* Self Excited DC generator.

* Separately Excited DC generator:



→ In this, the exciting field current is supplied by a separate source.

* Self Excited DC Generator:

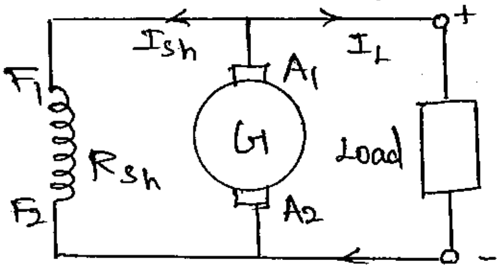
→ In this, the EMF induced in the armature ~~was~~ supplies, the exciting field current.

→ The self excited DC generators are classified as,

* DC Shunt Generator
* DC Series Generator
* DC Compound generator.

* DC Shunt Generator :

→ In shunt generator the field winding is connected in parallel with armature windings.

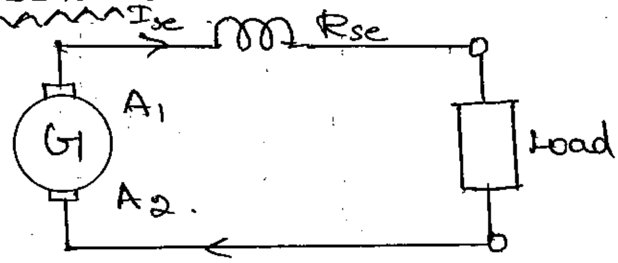


→ The shunt generator field winding has many turns of fine wire having high resistance. In DC shunt generator the armature current I_a will be the sum of load current I_L and the field current I_{sh}.

$$I_a = I_L + I_{sh}.$$

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

DC Series Generator :



→ In this the field winding is connected in series with armature and the external load circuit. In this type of DC series generator the armature current I_a, the field current I_{se} and load current I_L are same.

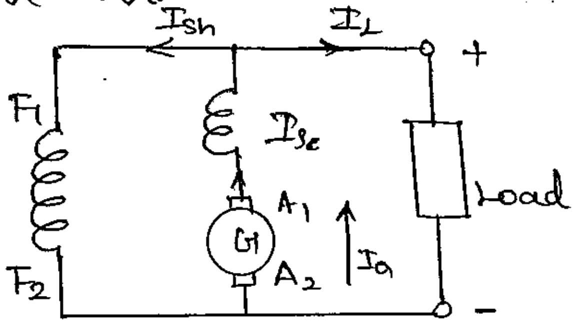
$$I_a = I_{se} = I_L.$$

DC Compound Generator :

Long Shunt DC Generator

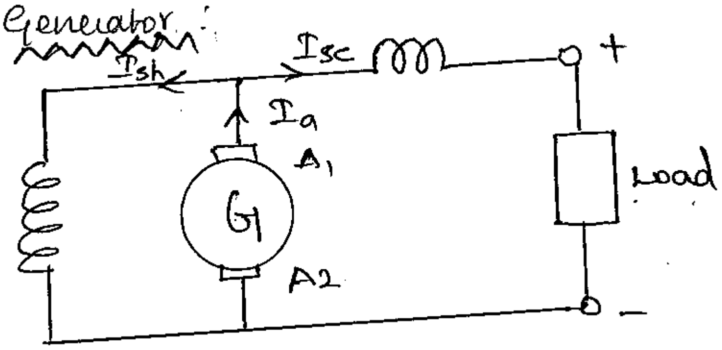
Short Shunt DC Generator.

Long shunt Generator :



→ In this, the shunt field winding is in parallel with both series field and armature winding.

Short shunt Generator :



→ In this, only shunt field winding is in parallel with the armature winding.

$$I_{se} = I_L$$

$$I_{se} = I_L + I_{sh}$$

$$I_a = I_{se} + I_{sh}.$$

→ Depending upon the way in which shunt field flux and series field flux act with respect to each other, DC Compound Generators are classified as

1. Cumulative Compound DC generator
2. Differentially Compound DC Generator.

Losses in DC Generator:

Copper losses
Iron (or) Core losses
Mechanical losses.

Copper losses:

→ These losses occur due to currents in the various windings of the Machine.

i) Armature Copper losses - $I_a^2 R_a$

ii) Shunt field Copper losses - $I_{sh}^2 \cdot R_{sh}$

iii) Series field Copper losses - $I_{se}^2 R_{se}$.

Iron (or) Core loss:

→ These losses occur in the armature of a DC Machine, due to the rotation of armature in the Magnetic field of the poles.

→ They are two types.

Hysteresis loss
Eddy Current loss.

Hysteresis loss:

→ When the armature rotates in the Magnetic field it crosses all the north pole & south pole. Therefore inside the armature Core, the reversal of Magnetic flux takes place, while the armature Core passes from one pole to another pole in each time. The reversal of Magnetic flux in the armature Core causes 'Hysteresis loss'.

$$W_h = \eta B_m^{1.6} f V \text{ Watts}$$

→ To Minimise the Hysteresis loss silicon steel is used for the armature Core.

Eddy Current loss :

→ When armature rotates in the Magnetic field the poles, an emf is induced in it, which circulates eddy Current in the armature Core. The power loss due to the eddy current is Called eddy Current loss.

→ To Minimise the eddy current loss, the armature Core is build up of thin laminations insulated from each other by a thin layer of varnish.

$$W_e = K_e B^2_{max} \cdot f^2 t^2 V \text{ Watts}$$

DC MOTOR :

→ Dc Motor Converts Electrical energy into Mechanical energy.

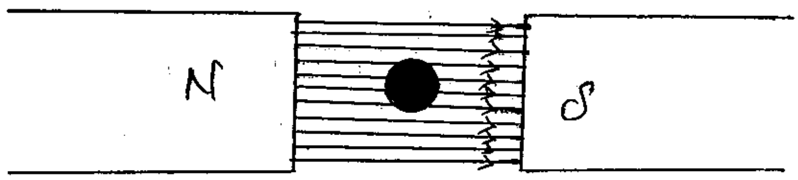
Construction of Dc Motor :

→ Construction of Dc Motor is same as that of Dc Generator.

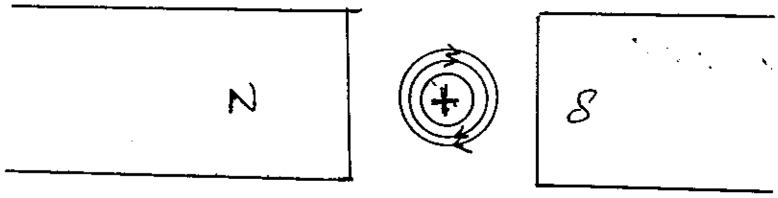
Principle of Operation of Dc Motor :

→ Whenever a Current Carrying Conductor is placed in a Magnetic field, a Mechanical force is produced on the Conductor. The direction of force is Given by Flemings left hand rule.

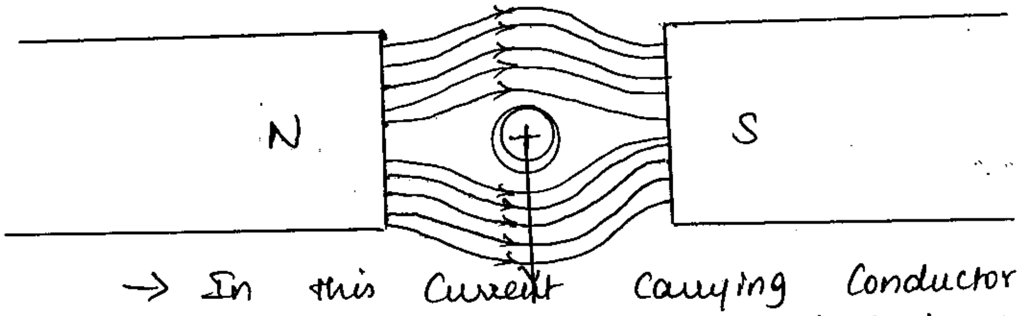
$$F = BLI \text{ Newton.}$$



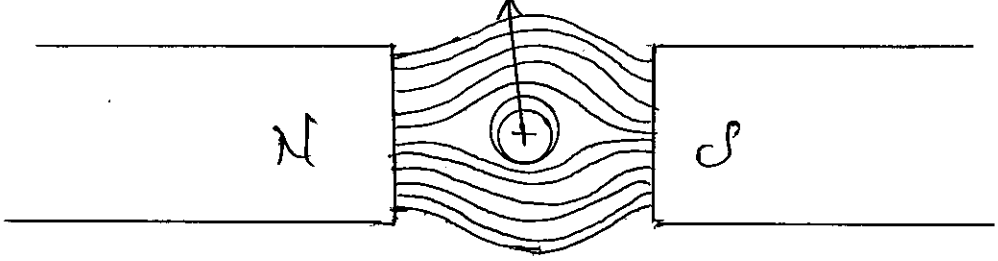
→ In an uniform Magnetic field in which a straight Conductor Carrying no Current is placed. The direction of Magnetic flux line is from North to South pole.



→ Now assume there is no exciting current flow through the field winding & DC current is sent through the conductor. Let the conductor carry the current away from the observer. It produces a magnetic flux lines around that in clockwise direction. There is no movement of the conductor during the above two conditions.



→ In this current carrying conductor is placed in the magnetic field. The field due to the current in the conductor aids the main field above the ~~abo~~ conductor, but opposes the main field below the conductor. Hence the flux strengthens above the conductor & weakens below the conductor. It is found that a force acts on the conductor, trying to push the conductor downwards.



→ If the current in the conductor is reversed, the strengthening of flux lines occurs below the conductor & the conductor will be pushed upward.

EMF Equation OF DC MOTOR :

→ Back emf induced in the armature of a DC Motor

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

ϕ - flux per pole in Wb

Z - No. of Conductors in the armature

P - No. of poles

A - No. of parallel paths

V - Supply voltage to the Motor

I_a - Armature Current.

R_a - Armature resistance in Ω

$$E_b = V - I_a R_a.$$

→ Voltage drop in the armature Circuit

$$I_a R_a = V - E_b.$$

→ Armature Current $I_a = \dfrac{V - E_b}{R_a}$.

Torque Equation :

→ Torque is the turning Moment of a force about an axis and is measured by the product of force (F) and radius (r) at right angle to which the force acts.

$$T = F \times r \text{ Newton metre}.$$

→ Consider a pully of radius R metre acted upon by Circumferential force of F newton which causes it to rotate at N rpm.

→ Torque produced on the pulley (T)

$= F \times r$ Newton metre.

→ Assume T_a be the torque developed by the armature and rotate at a speed N rpm.

Electrical power developed $= E_b I_a$ watts — ①

Mechanical power developed in the armature

$$\frac{2\pi N T_a}{60}.$$

→ The electric power which converts mechanical power in the armature.

$$\frac{2\pi N T}{60} = E_b I_a \text{ Watts} \quad — ②$$

① = ②

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

$$2\pi N T_a = 60 \times E_b I_a.$$

$$T_a = \frac{60 \times E_b I_a}{2\pi N} \text{ N.m}.$$

Back Emf $E_b = \dfrac{\phi Z N P}{60 A}$.

$$T_a = \frac{60 \times \phi Z N P \times I_a}{2\pi N \times 60 A} \text{ N.m}.$$

$$T_a = \frac{1}{2\pi} \phi Z P \frac{I_a}{A}.$$

$$T_a = 0.159 \phi Z P \frac{I_a}{A} \text{ N.m}.$$

9.81 Newton = 1 Kilogram.

$$T = \frac{0.159}{9.81} \phi Z P \times \frac{I_a}{A} \text{ kgm}.$$

$$T = 0.0162 \phi Z P \frac{I_a}{A} \text{ kgm}.$$

$$T \propto \phi I_a.$$

Armature Torque and Shaft torque:

→ The torque developed by the armature is called armature torque denoted as T_a. The full armature torque is not available for doing useful work. Some amount of torque is used for supplying iron and friction losses in the Motor. This torque is called torque lost denoted as T_f. The remaining torque is available in the shaft. This torque is known as shaft torque (or) useful torque denoted as T_{sh}.

→ The armature torque is sum of the torque lost and Shaft torque.

$$T_a = T_f + T_{sh}.$$

TYPES OF DC MOTOR:

DC Shunt Motor

DC Series Motor

DC Compound Motor.

DC Shunt Motor:

→ In this, the field winding is connected in parallel with the armature. The field winding has a large no. of turns and smaller crosssection area. Since the field current is small, the field power loss is also small.

$$V = E_b + I_a R_a + \text{brush drop}$$

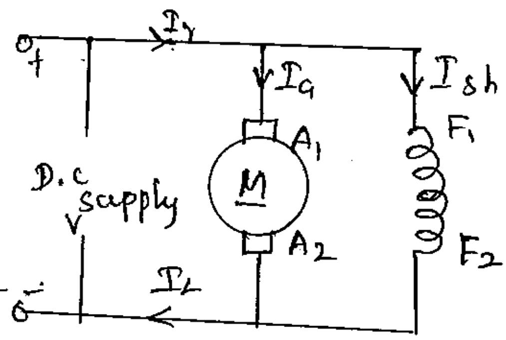
$$I_a = I_L - I_{sh}.$$

E_b – Back Emf of Motor

V – Applied voltage

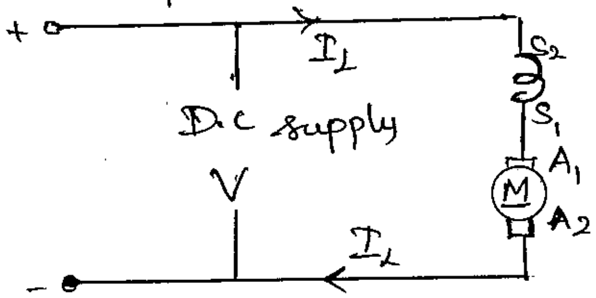
I_a – Armature Current

R_a – Armature resistance



DC Series Motor :

→ In this, the field winding is connected in series with the armature. The series field winding carries the input current. $I_L = I_a = I_{se}$. The series field winding has large cross-sectional area and few No. of turns.



$$V = E_b + I_aR_a + I_{se}R_{se} + \text{brush drop}.$$

$$I_a = I_{se} = I_L$$

$$V = E_b + I_a(R_a + R_{se}) + \text{brush drop}.$$

I_{se} = series field current.

I_a = Armature current

R_a = Armature Resistance in Ω

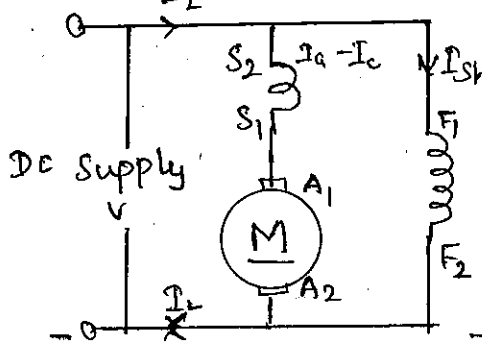
R_{se} = series field resistance in Ω

V = Applied Voltage.

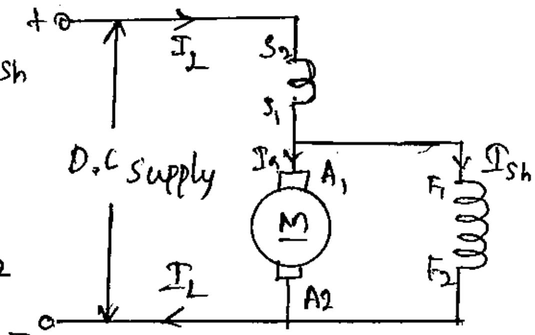
E_b = Back EMF induced.

DC Compound Motor :

→ In Compound Motor, both series field and shunt field windings are connected with the armature.



Long shunt DC compound motor



Short shunt DC compound motor.

→ The shunt field winding is connected across the series combination of armature and series field windings and this arrangement is connected across the supply. It is called long shunt DC compound motor.

→ The series field winding is connected in series with the parallel combination of shunt field winding and armature winding, and this arrangement is connected across the supply. It is called short shunt DC compound motor.

$$V = E_b + I_a R_a + I_{se} R_{se} + \text{Brush drop}$$

Long shunt compound motor

$$I_a = I_{se}$$

Short shunt compound motor

$$I_{se} = I_L$$

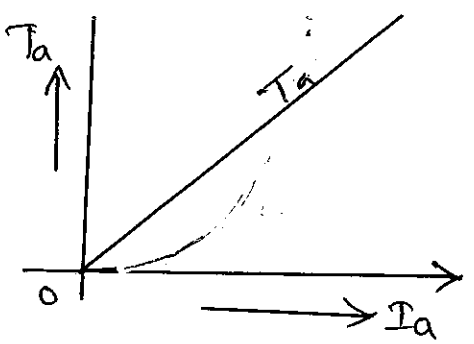
$$I_a = I_L - I_{sh}$$

~~Ta Vs~~

CHARACTERISTICS OF DC MOTOR:

Characteristics of DC Shunt Motor:

a) Torque Vs Armature Current characteristics:



$$T = 0.159\, \phi Z P \frac{I_a}{A}$$

Where Z, P, Ia, A are constant.

→ In any DC Motor $T \propto \phi I_a$.

→ The field current in shunt motor is constant, since the field winding is directly connected to the supply voltage V, which is assumed to be constant. Hence the flux in a shunt motor is constant. Therefore torque developed in a DC motor will be directly proportional to armature current.

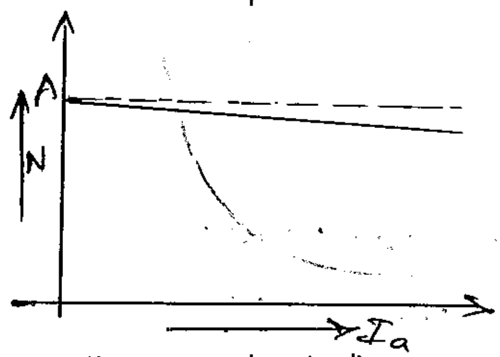
b) Speed Vs Armature Current Characteristics:

$$E_b = \frac{\phi Z N P}{60A} = V - I_a R_a$$

$$N = \frac{(V - I_a R_a)}{\phi Z P} \times 60A$$

$$= \frac{K(V - I_a R_a)}{\phi}$$

$$K = \frac{60A}{ZP}$$



→ When the supply voltage V is kept constant, the flux ϕ will also be constant. Hence in DC shunt motor $N \propto V - I_a R_a$. This indicates that speed of DC shunt motor decreases with increase in armature current due to loading.

→ The variation of speed with armature current characteristics is drooping slightly. The percentage of speed change will be about 5% at full load due to armature resistance drop. But due to armature reaction, the flux is weakened. Hence the speed will increase. This increase in speed compensates the drop in speed due to $I_a R_a$ drop.

c) Speed Vs Torque Characteristics:

$$N \propto \frac{E_b}{\phi} \text{ (i,e) } N \propto \frac{V - I_a R_a}{\phi}$$

Since ϕ is constant $N \propto V - I_a R_a$ — ①

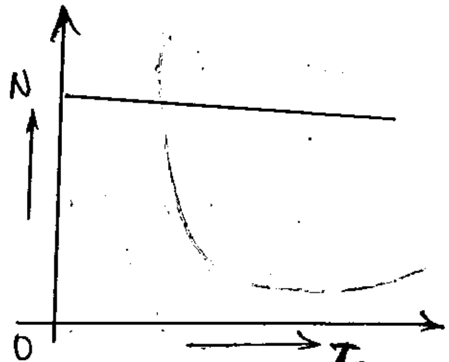
$$T \propto \phi I_a$$

Since ϕ is Constant $T \propto I_a$

$$I_a = KT \quad \text{— ②}$$

Sub eqn ② in eqn ①

$$N \propto V - (KT) R_a$$



→ When the torque increases, the speed decreases.

Characteristics of DC Series Motor:

a) Torque Vs Armature Current Characteristics:

→ In any DC Motor

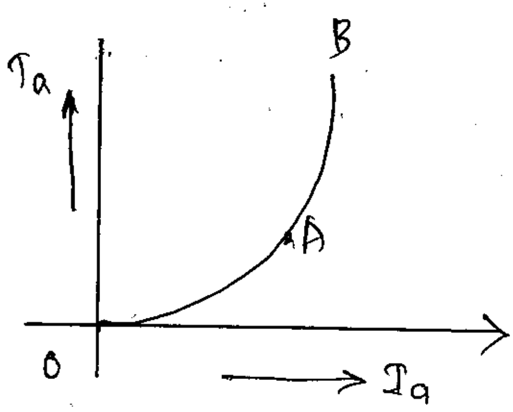
$$T \propto \phi I_a$$

upto Magnetic saturation $\phi \propto I_a$

$$T \propto I_a^2$$

After Magnetic saturation ϕ is Constant

$$T \propto I_a$$



→ Therefore upto Magnetic Saturation the torque is directly proportional to square of the armature current. Therefore torque Vs armature current characteristics is parabola at low value of armature current the torque Vs I_a characteristics is a straight line.

b) Speed Vs Armature Current Characteristics:

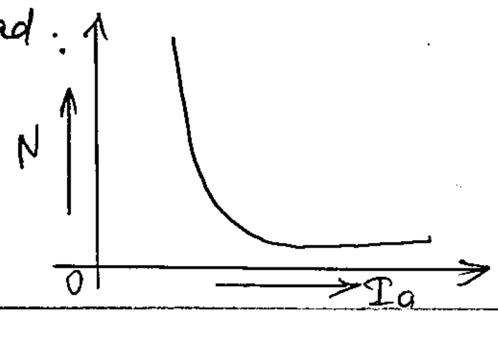
$$N = \frac{K(V - I_a R_a)}{\phi} = \frac{E_b K}{\phi}.$$

→ When supply voltage V is kept constant, the speed of the Motor will be inversely proportional to flux ($N \propto 1/\phi$).

→ On light loads, the flux produced will be weak and therefore the speed will be dangerously high. For small value of flux ϕ, the speed will be very high. Hence the shape of the curve will be hyperbolic. When the load current increases, the flux also increases, after saturation the flux remains constant.

→ At no load, the armature current is very small and hence the flux is low. Hence the speed is dangerously high at no load. This high speed develops high centrifugal forces, which may tear the armature conductors from the slots and damage the Machine.

→ Therefore a series Motor should never be started on no load & it should be started with the load.



c) Speed - Torque Characteristics:

$$N \propto \frac{V - I_a R_a}{\phi}$$

If $I_a R_a$ drop is negligible

$$N \propto \frac{V}{\phi} \quad \text{--- (1)}$$

$$T \propto \phi I_a$$

$$T \propto \phi \cdot \phi \qquad (I_a \propto \phi)$$

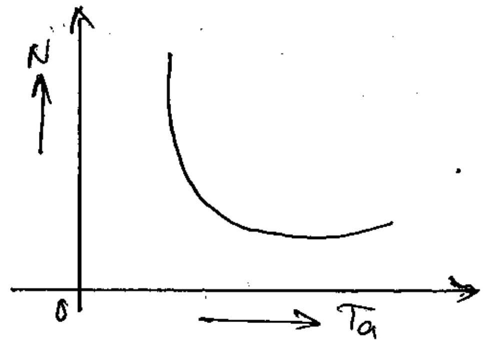
$$T \propto \phi^2$$

$$\phi^2 = T$$

$$\phi = \sqrt{T} \quad \text{--- (2)}$$

Sub eq^n (2) in eq^n (1)

$$N \propto \frac{V}{\sqrt{T}}$$



→ From the equation, speed is inversely proportional to torque. Hence the characteristic curve is hyperbolic in shape.

Characteristics of DC Compound Motor:

→ A compound motor has both series field & shunt field. Compound motors are of two types.

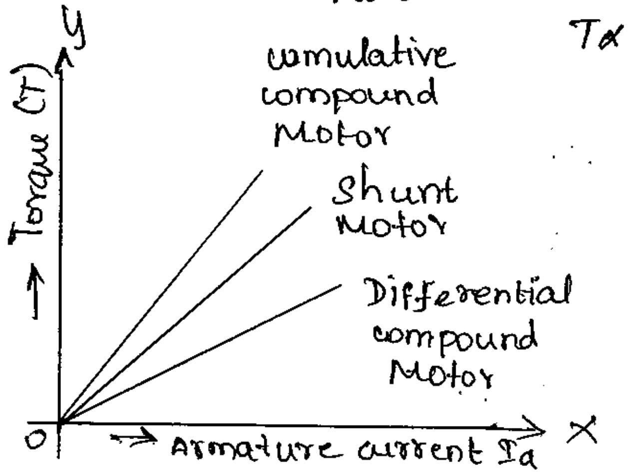
→ If the series field flux & shunt field flux add each other, it is called cumulative compounding.

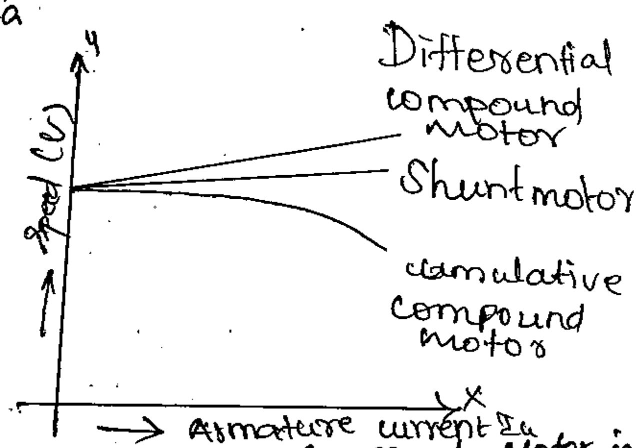
→ If the series field flux opposes the shunt field flux it is called differential compounding.

→ In the cumulative compounded, the series field mmf increases with increase in armature current

→ Hence It has More flux than that of Shunt Motor.

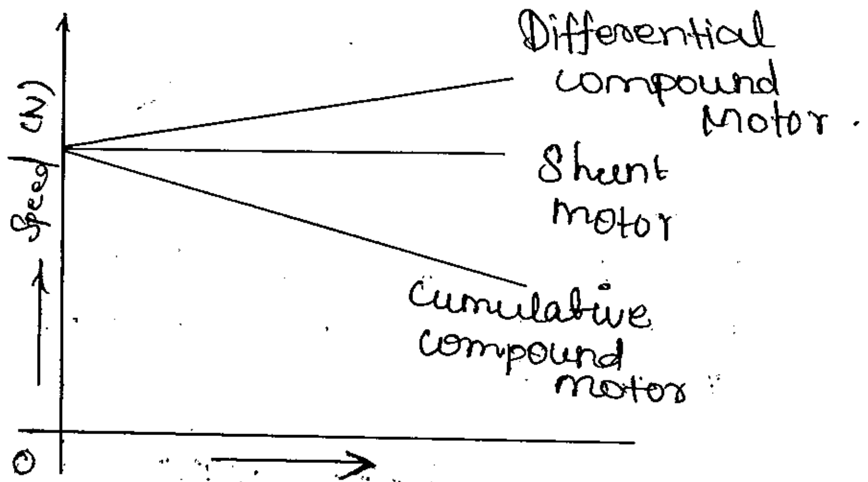
$T \propto \phi I_a$





→ Hence torque of Cumulative Compound Motor is greater than the shunt Motor. Since the speed is inversely proportional to flux.

→ In the case of differential Compounded Motor the field flux decreases when the armature current increases, Which reduces the torque. But the speed increases with reduction flux Hence the speed is greater ~~that~~ When Compared to Shunt Motor.



SINGLE PHASE TRANSFORMER:

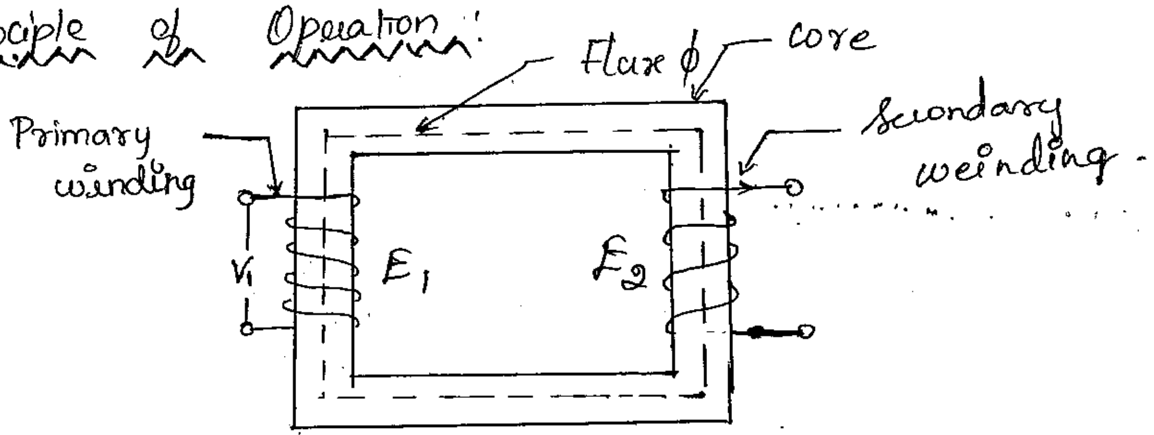
→ A transformer is a static electric Machine Which transfers electrical energy from one circuit to another Circuit without change in its frequency. Due to electro magnetic induction principle the transfer of energy takes place.

→ It Consists of three essential parts.

Primary winding
Secondary winding
Laminated iron Core.

→ The AC supply given to the winding is known as primary winding. The winding from which electric supply is taken is called secondary winding.

Principle of Operation:



→ The transformer works on the principle of Mutual Induction. When an AC supply is given to primary winding an alternating flux is set up in the Core. This alternating flux Cuts both the primary and secondary winding. An emf is induced in the primary winding according to self induction principle.

→ According to Faraday's Mutual Induction Principle an emf is induced in the secondary winding. If we connect a load to the secondary winding Current will flow through the load.

→ In this way electrical energy is transferred from Primary Circuit to secondary Circuit.

→ If the no. of turns in the secondary winding is more than that of the primary winding, the emf induced in the secondary winding will be higher than the voltage applied to the primary winding. This type of transformers are said to be step up transformers.

→ If the No. of turns in the secondary winding is less than that of the primary winding, the emf induced in the secondary winding will be less than the voltage applied to the primary winding. This type of transformers are said to be step down transformer.

Construction of Transformer:

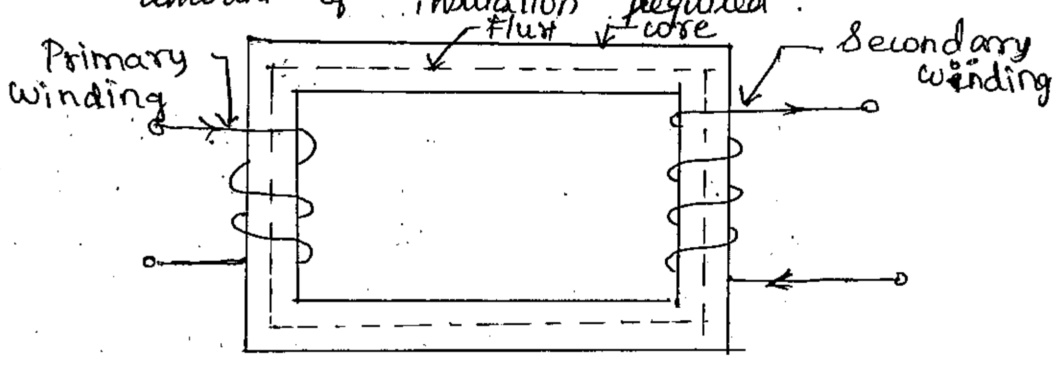
→ The transformers are classified into

Core Type Transformer
Shell type Transformer

Core Type Transformer:

→ In Core type transformer, the winding surround the core. The coils are wound around the two limbs of a rectangular magnetic core. Each limb carries one half of the primary winding and one half of the secondary winding so as to reduce the leakage reactance.

→ Insulations are provided between this primary and secondary windings. The LV winding is wound next to the insulated core and HV winding is wound over the LV winding inorder to reduce the amount of insulation required.

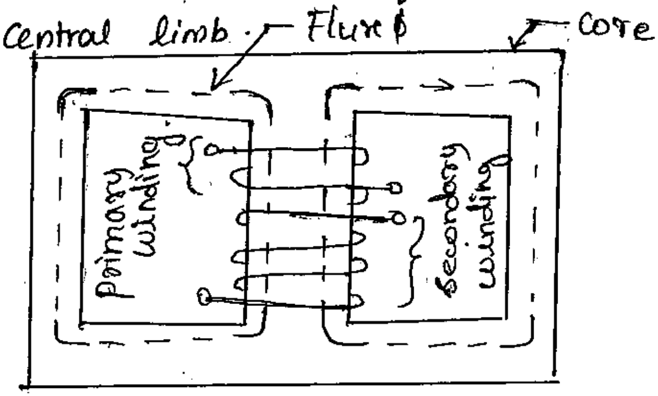


→ Small transformers may have cores of rectangular (or) square cross section, with rectangular (or) circular coils, In case of large size Transformer, stepped cruciform core with circular coil is employed. This type of cores are built with different sizes of laminations.

→ The circular coils with cruciform core provide more mechanical strength, especially when short circuit occurs. Other advantage of using cruciform core are reduced mean length of turns resulting in reduced copper loss.

Shell Type Transformer:

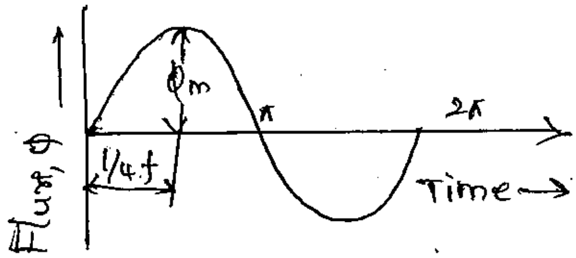
→ In shell type, the core surrounds the windings. The coils are wound on the central limb of a three limb core the entire flux passes through the central limb & divides into two parts going to inside limbs. The size of the outer limb is half of the central limb.



→ In this type, sandwich winding is used. The shell type transformer is built up with E and I shape cores. The laminated E & I cores are assembled to form the magnetic circuit. It consists of three limbs. One limb is at the centre and the two limbs are outer.

→ The HV windings & LV windings are placed over the central limb. The windings are covered on both sides by cores.

EMF Equation of a Transformer:



Consider a transformer having

N_1 - Primary turns

N_2 - Secondary turns

ϕ_m - Maximum flux

f - Frequency of AC voltage applied.

→ The flux in the core will vary sinusoidally. The flux increases from zero value to Maximum value ϕ_m in $1/4f$ seconds.

→ The change of flux that takes place in $1/4f$ seconds

$$\phi_m - 0 \text{ Wb}.$$

$$\text{Average emf} = \frac{d\phi_m}{dt}.$$

→ Rate of change of flux in one second $= \dfrac{\phi_m}{1/4f}$

$$= 4f\phi_m \text{ Wb/ second}.$$

→ Average emf induced per turn = Average rate of change of flux in one second

$$= 4f\phi_m \text{ volts}.$$

$$\text{Form factor of sine wave} = \frac{\text{RMS value}}{\text{Average value}} = 1.11.$$

→ RMS value of emf induced in one turn $= 4f\phi_m \times 1.11$

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

→ R.M.S value of emf induced in primary winding

$$E_1 = 4.44 f \phi m N_1$$

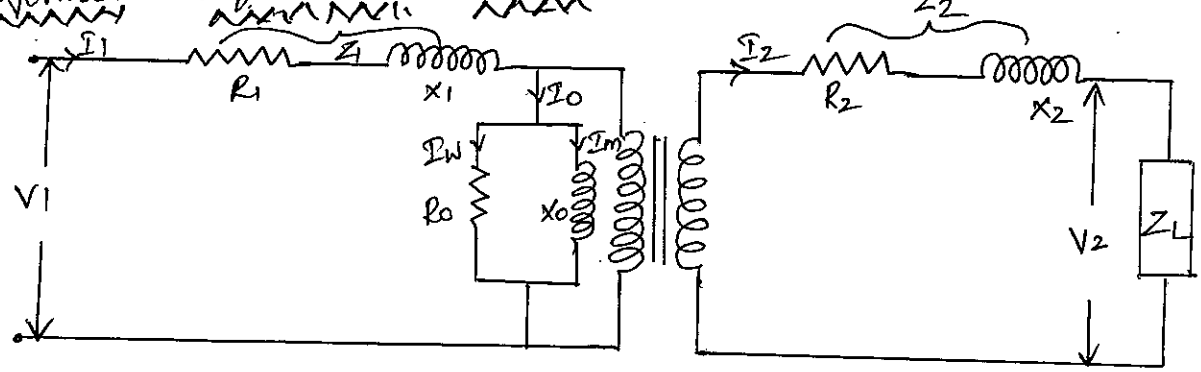
→ R.M.S value of emf induced in secondary winding

$$E_2 = 4.44 f \phi m N_2 .$$

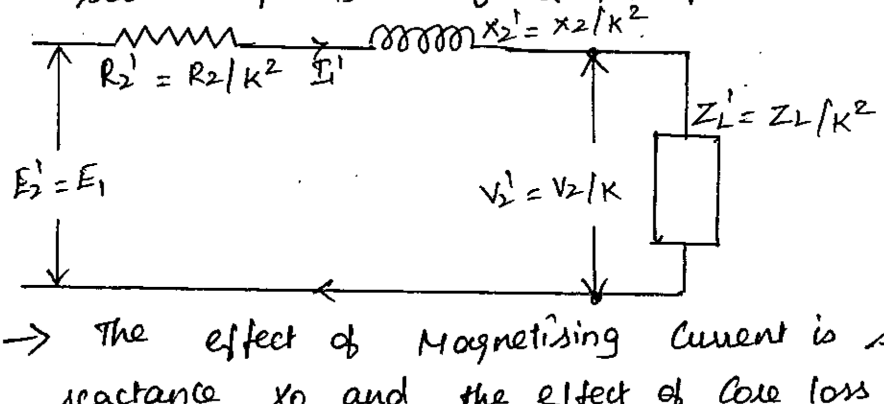
$$\frac{E_2}{E_1} = \frac{N_2}{N_1} = \frac{I_1}{I_2} = K .$$

Where K = transformation ratio. (or) turns ratio

Transformer Equivalent Circuit :



→ If the resistance & Inductive reactance of the primary and the secondary windings are considered to be in series with those windings. We get the electrical circuits representing the primary & secondary sides of a transformer.



→ The effect of Magnetising current is shown by a reactance X_0 and the effect of core loss is indicated by a pure resistance R_0. Both of them assumed to be in parallel across the primary circuit. This circuit is called no load circuit.

→ Primary Equivalent of Secondary induced voltage

$$E_2' = \frac{E_2}{K} \; ; K = \frac{N_2}{N_1}$$

→ The primary equivalent of secondary terminal voltage

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

$$= V_2 \times \frac{N_1}{N_2}$$

→ The primary equivalent of secondary current

$$I_2' = K \cdot I_2$$

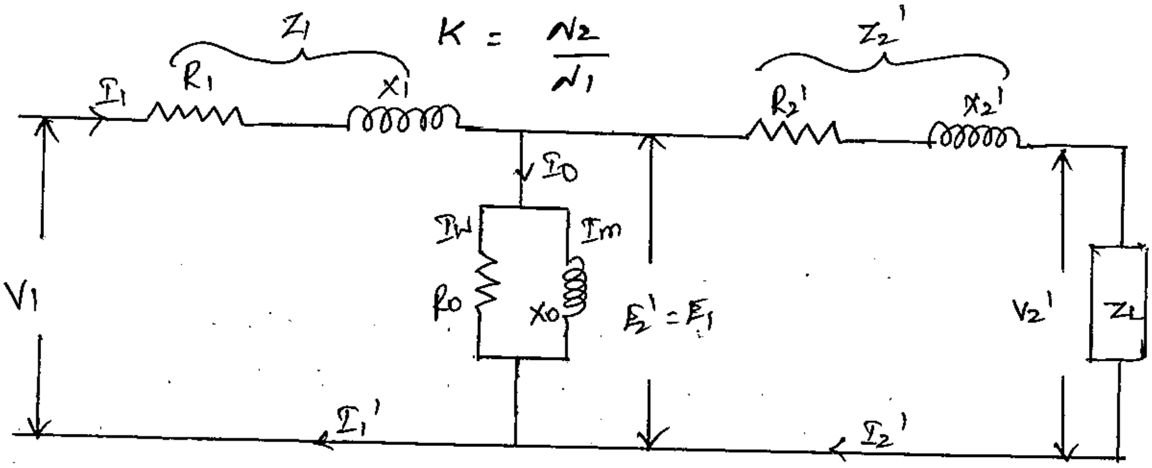
$$= \frac{N_2}{N_1} \cdot I_2 .$$

→ For transferring secondary impedance to primary K^2 is used

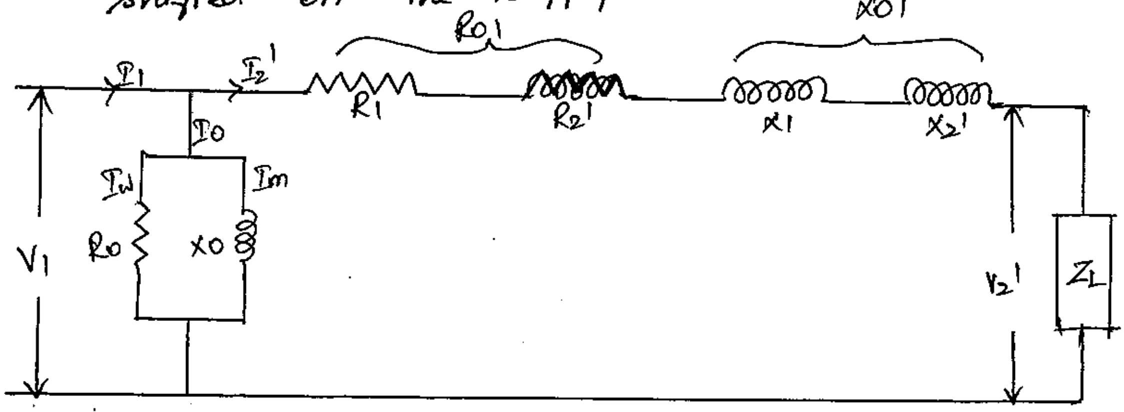
$$R_2' = \frac{R_2}{K^2} ; \quad X_2' = \frac{X_2}{K^2} ; \quad Z_2' = \frac{Z_2}{K^2}$$

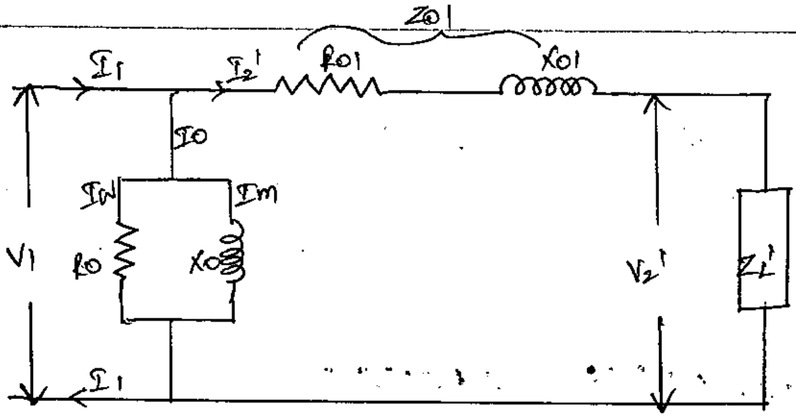
$$Z_L' = \frac{Z_L}{K^2} .$$

$$K = \frac{N_2}{N_1}$$



→ To simplify the circuit, the no load circuit is shifted on the supply side.





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

$$X_{01} = X_1 + X_2'$$

R_{01} => Total equivalent resistance referred to primary

X_{01} => Total equivalent reactance refered to ~~secon~~ primary.

THREE PHASE TRANSFORMER:

→ In a 3φ system the voltage is lowered (or) raised either by a bank of 3 1φ transformer (or) by 3φ transformer. The windings may be connected in

Y-y, Δ-d, Y-d, Δ-y.

→ When compared to a group of 3 1φ transformer, a single 3φ transformer has the advantages.

* It occupies less space
* The weight of 3φ transformer is less.
* The cost of 3φ transformer is usually 15% less than that of three 1φ transformer bank.

→ The drawback in using a 3φ transformer is that if any transformer windings becomes disabled, then have to remove the whole transformer. But in 1φ transformers, if one transformer goes out; then the faulty transformers can be replaced by a single one.

→ The 3φ transformers are classified as,

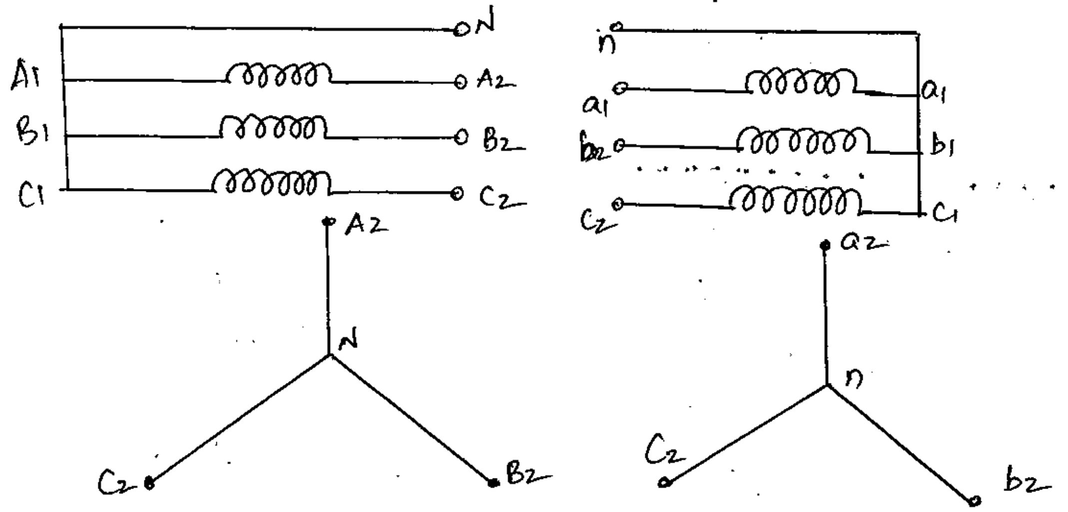
* Core type
* Shell type.

→ When the supply is given to 3ϕ primary winding, a 3ϕ magnetic field is set up. According to the mutual induction principle an emf is induced in the secondary winding.

Three Phase Transformer Connections:

a) Star - Star Connection:

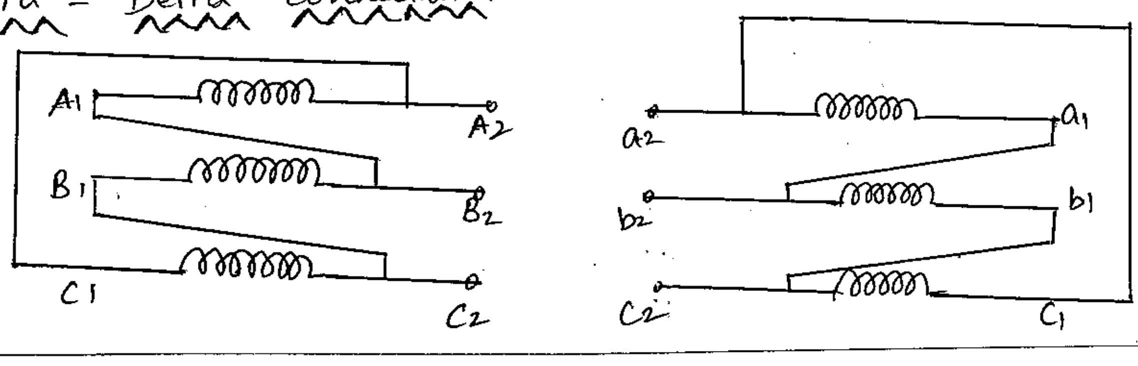
→ In a 3ϕ four wire system a 3ϕ transformer connected in Y - Y. There is a phase relationship between the terminal voltages of the high voltage side and low voltage side for these connections.

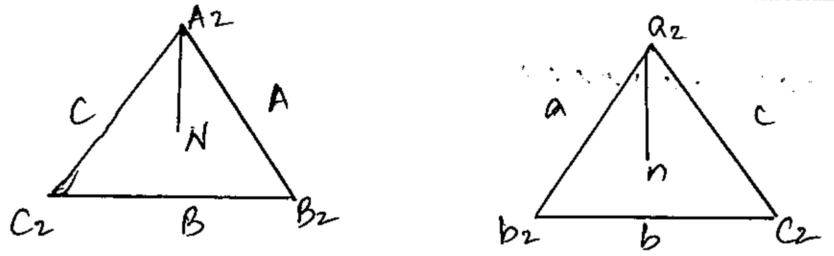


→ Suppose the terminals a_2, b_2, c_2 are connected to neutral n and a_1, b_1 and c_1 taken out as phase terminals. This arrangement will produce 180° phase displacement between primary & secondary.

→ When two such transformers are to be connected in parallel, the two should be connected either for zero phase displacement (or) 180° phase displacement.

b) Delta - Delta Connection:



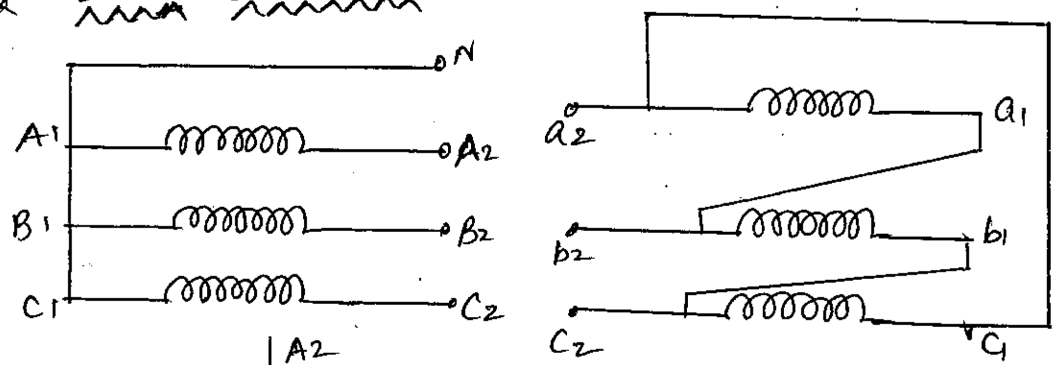


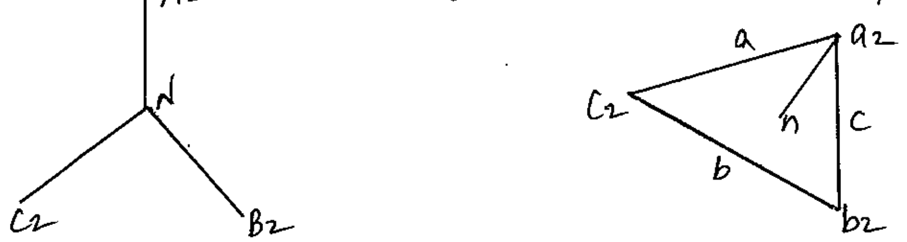
→ The voltage in each phase winding is line voltage ($V_P = V_L$). The current in each phase is the line current divided by $\sqrt{3}$ ($I_P = \frac{I_L}{\sqrt{3}}$).

→ No. of turns per phase are more and area of cross section of conductor is less. For large, low voltage transformers this connection is economical. Unbalancing of loads, is no problem. Star point is not available.

→ For parallel operation, of two Δ-Δ transformers, both must be connected for the same phase displacement.

c) Star - Delta Connection:

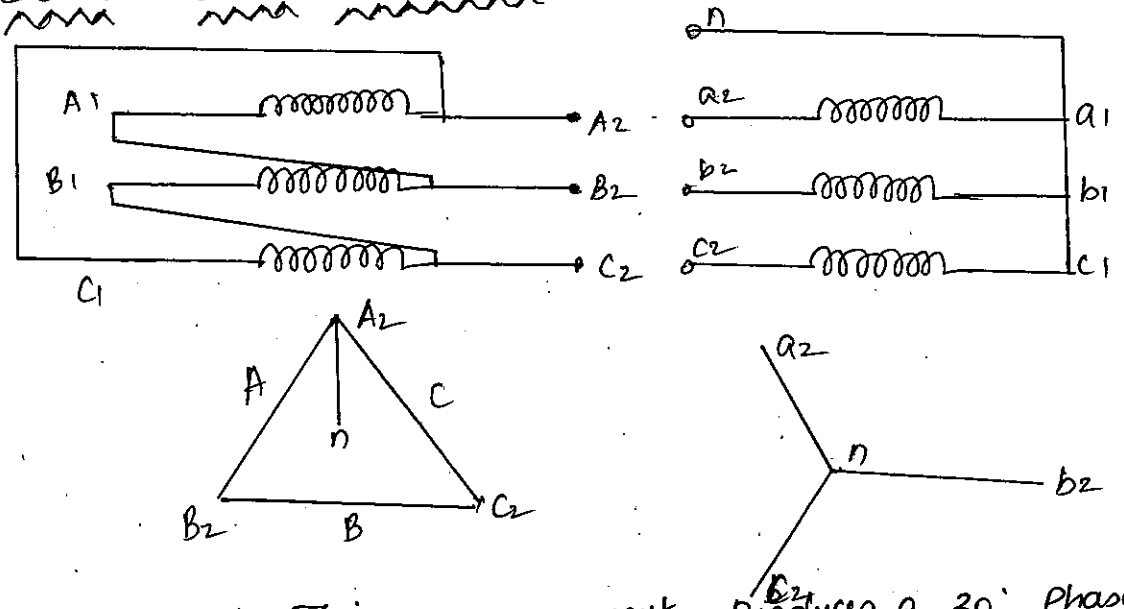




→ There is a 30° phase shift between primary and secondary voltages. If the primary line voltage is V_P and the secondary line voltage is V_S, then the primary phase winding must be designed for $V_P/\sqrt{3}$ & secondary phase winding must be designed for ~~$V_P/\sqrt{3}$~~ V_S.

→ The primary supply may be 3 wire (or) 4 wire. The high voltage winding is usually star connected side.

d) Delta - Star Connection:



→ This arrangement produces a 30° phase displacement between primary & secondary voltages. If the primary line voltage is V_P & the secondary line voltage is V_S, then the primary phase winding must be designed for V_P and the secondary phase winding must be designed for $V_S/\sqrt{3}$.

→ For step up power transformers in Generating stations this connection is normally used. The Generator terminals are connected to the delta winding while the star terminals are connected to the high voltage transmission lines.

SYNCHRONOUS GENERATOR:

→ A Machine which produces 3ϕ power from Mechanical power is called an alternator (or) Synchronous Generator.

→ In any Alternator, consists of armature winding Mounted on a stationary element called stator & field winding on a rotating element called Rotor

→ The frequency of output ac voltage of a syn. Generator is directly proportional to the rotor speed. To Maintain constant frequency, the Rotor must always move at syn. speed.

Construction of Alternator:

Stator:

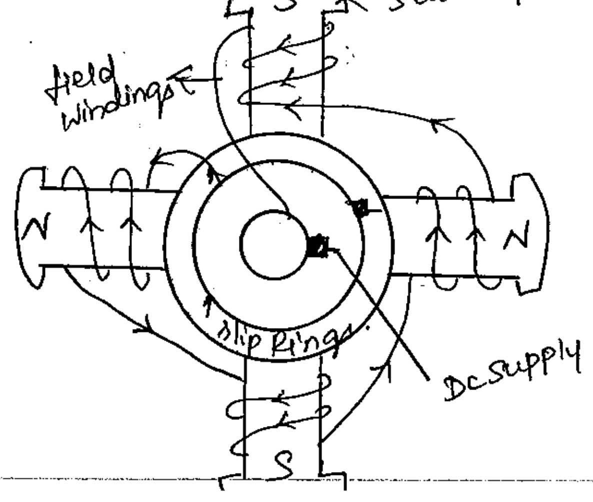
→ It is the stationary part of the Machine and is built up of sheet-steel laminations having slots on its inner periphery. A 3ϕ winding is placed in these slots and serves as the armature winding of the alternator. The alternator winding is always connected in star & the neutral is connected to ground.

Rotor:

→ The Rotor carries a field winding which is supplied with direct current through two slip rings by a separate dc source. Rotor construction is of two types,

* Salient (or) projecting pole type
* Non-salient (or) cylindrical type.

Salient pole Type:



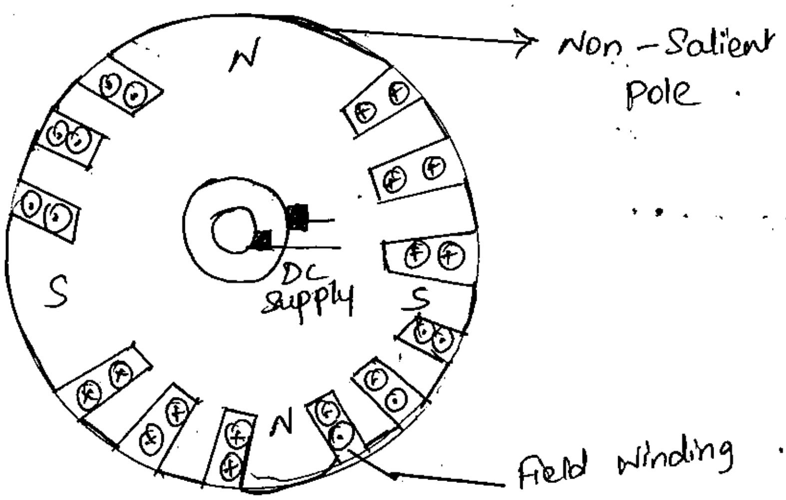
→ The Rotor of this type is used almost entirely for slow & Moderate Speed alternators, since it is least expensive and provides ample space for the field ampere turns. Salient poles cannot be employed in high speed generators on account of very high peripheral speed and the difficulty of obtaining sufficient Mechanical strength.

→ The salient poles are made of thick steel laminations riveted together and are fixed to Rotor by a dove-tail joint. The pole faces are usually provided with slots for damper windings. These dampers are useful in preventing hunting.

→ The pole faces are so shaped and the radial air gap length increases from the pole centre to the pole tips so that the flux distribution over the armature is sinusoidal & waveform of generated emf is sinusoidal.

→ The field coils are placed in the pole-pieces and connected in series. The ends of the field windings are connected to a dc source through slip-rings carrying brushes & mounted on the shaft of the field structure.

Smooth Cylindrical (or) Non-Salient Pole Type:



→ The Rotors of this type are used in very high speed alternators driven by steam turbines. To reduce the peripheral velocity, the diameter of the rotor is reduced and axial length is increased. Such rotors have two (or) four poles.

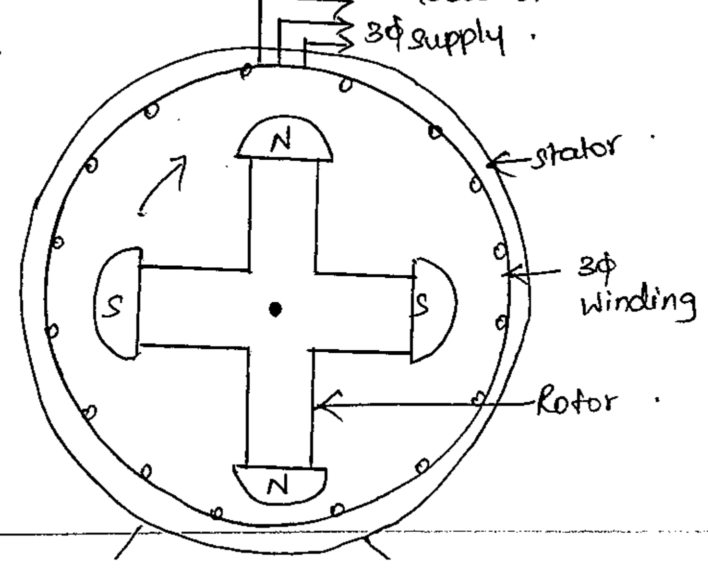
→ It Consists of a Cylindrical steel forging which is suitably fabricated Mechanically & treated thermally. The forging has radial slots in Which the field Copper, usually in strip form is placed. The coils are held in place by steel (or) bronze wedges and the Coil ends are fastened by metal rings. The slots over certain portions of the Core are ommitted to form pole faces. The regions forming the poles are usually left unslotted.

Working OF Alternator:

→ The field Magnets are Magnetised by applying 125V (or) 250V through slip rings. The field windings are Connected such that, alternate N & S poles are produced. The rotor & hence the field magnets are driven by the prime Mover.

→ As the rotor rotates, the armature Conductors are Cut by the Magnetic flux. Hence an emf is induced in the armature Conductors. As the Magnetic poles are alternately N & S poles, this emf acts in one direction & then in the other direction.

→ Hence an alternating emf is induced in the stator Conductors. The frequency of induced emf depends on the No. of N & S poles Moving past an armature conductor in one second.



→ The direction of induced emf can be ~~forme~~ found by Fleming's right hand rule & frequency is given by

$$f = \frac{PN}{120}$$

Where N = Speed in rpm

P = No. of rotor poles.

EMF Equation of An Alternator:

Let,

Z_{ph} – No. of Conductors (or) Coil sides in series / phase.

$Z_{ph} = 2T_{ph}$, T_{ph} – No. of Coils

P – No. of poles

f – Frequency of induced emf in Hz.

ϕ – flux / pole in wb.

K_d – distribution factor $= \dfrac{\sin m\beta/2}{m \sin \beta/2}$.

K_c (or) K_p – pitch factor (or) Coil span factor $= \cos \alpha/2$

K_f – form factor = 1.11

N – Rotor speed in r.p.m.

→ For one revolution of the Rotor each stator Conductor is cut by a flux of ϕP Wb.

$d\phi = \phi P$

$dt = 60/N$ second.

→ Average emf induced per Conductor

$$\frac{d\phi}{dt} = \frac{\phi P}{60/N} = \frac{\phi P N}{60}.$$

$$f = \frac{PN}{120} \text{ (or) } N = \frac{120f}{P}$$

Sub this value of N, we get

$$= \frac{\phi P}{60} \times \frac{120f}{P} = 2f\phi \text{ volt}.$$

→ If there are Z_{ph} conductors in series/phase, then

Average emf / phase = $2f\phi Z_{ph}$ volts = $4f\phi T_{ph}$ volts

RMS value of emf / phase = $1.11 \times 4f\phi T_{ph}$

$= 4.44 f \phi T_{ph}$ volts.

→ Actually available voltage / phase = $4.44 K_p K_d f \phi T_{ph}$

$K_d K_p = K_w$ = Winding factor.

SYNCHRONOUS MOTOR:

→ It is one type of 3ϕ AC Motors which operate at a constant speed from no load to full load. It is similar in construction to 3ϕ AC generator in that it has a revolving field which must be separately excited from a DC source. By changing the DC field excitation, the power factor of this type of motor can be varied over a wide range of lagging & leading values.

→ This motor is used in many applications because of its fixed speed from no load to full load, its high efficiency & low initial cost. It is used to improve the p.f of 3ϕ AC industrial circuits.

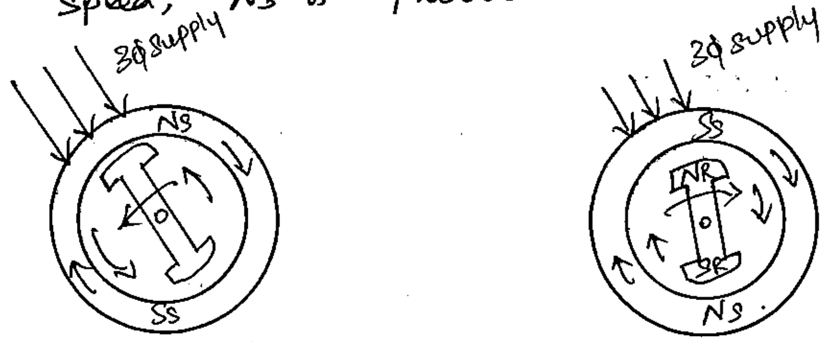
Principle of Operation:

→ When a sinusoidal voltage is applied to a winding, the magnetic field produced by a resultant current flow will also be sinusoidally varying with respect to time. This means that the field is pulsating. Now when a 3ϕ voltage is applied to a three phase winding, the flux produced will be the resultant of all the three pulsating fields.

→ It can be shown that the resultant field has a magnitude of $1.5\,\phi_m$ where ϕ_m is the maximum value of the flux due to a single phase current. Further it can also be shown that the direction of the field changes continuously (i.e) the field is rotating in space at a speed given by,

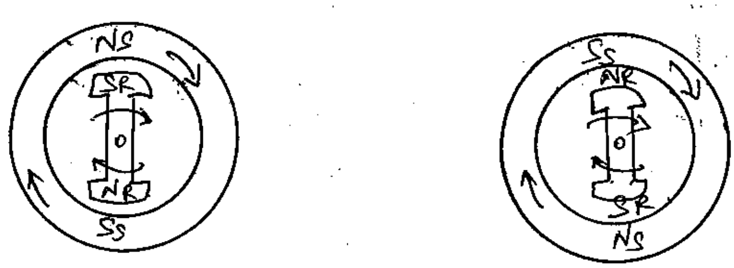
$$N_s = \frac{120 \times f}{P}.$$

→ This speed is called the synchronous speed. Hence it is to be remembered that when a 3ϕ supply is given to a 3ϕ winding a magnetic field of constant magnitude but rotating at a constant speed, N_s is produced.



→ The two fictitious stator poles marked N_s & S_s assumed to rotate clockwise at a synchronous speed N_s. The Rotor poles N_R & S_R are formed by the dc excitation. When N_s & N_R are together like poles repel each other. Since N_s & S_s are moving in the clockwise direction.

→ Half a cycle later, the stator poles have moved, whereas the rotor poles have moved significantly. N_s & ~~S~~ S_R & similarly S_s & N_R get attached and the rotor tries to rotate in clockwise direction. This implies that the rotor experiences torque in different directions every half a cycle. As a result, the Rotor is at standstill due to its large inertia.



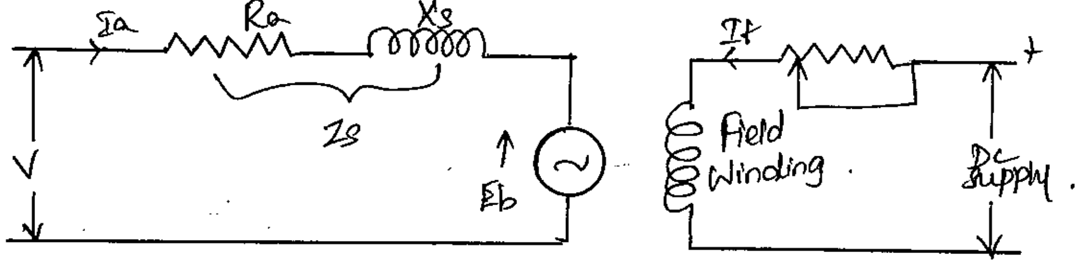
→ This explains why a synchronous motor has no starting torque & cannot start by itself.

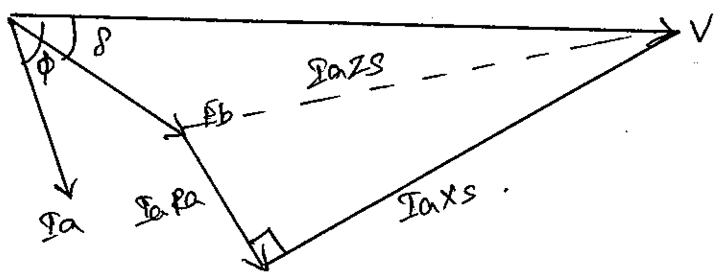
→ However if the rotor is now rotated separately by a prime mover in the same direction as the synchronously rotating stator field, and at a speed near N_s then it is possible that at some instant of time, N_s & S_R and similarly S_s and N_R get attracted and locked to one another.

→ Hence a synchronous motor, though not self starting, starts working as a motor if it is started up by some means.

→ It needs two separate supplies - one a dc source for excitation of the rotor & other, a 3ϕ supply for the stator. Because of the interlocking between the stator & rotor poles, the motor runs only at one speed, the synchronous speed.

Equivalent Circuit and phasor diagram of Synchronous Motor:

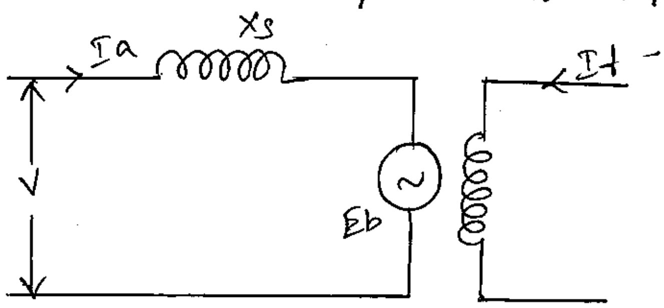




→ It shows the equivalent circuit model for one armature phase of cylindrical rotor synchronous motor.

→ The applied voltage V is the vector sum of reversed back emf (i.e) $-E_b$ and impedance drop $I_a Z_a$. $V = -E_b + I_a Z_s$. The angle between the phasors V & E_b is called the load angle (or) power angle of the synchronous motor.

→ Except for very small machines, the armature resistance of a synchronous motor is negligible as compared to its synchronous reactance.



$$AB = E_b \sin\delta$$

$$\cos\phi = \frac{AB}{I_a X_s}$$

$$AB = I_a X_s \cos\phi$$

$$\therefore E_b \sin\delta = I_a X_s \cos\phi = I_a \cos\phi = \frac{E_b \sin\delta}{X_s}.$$

$$P = V I_a \cos\phi$$

$$P = \frac{V E_b \sin\delta}{X_s}$$

$$P_{in} = \frac{3 E_b V}{X_s} \sin\delta \text{ for 3 phases.}$$

→ Since stator copper loss has been neglected, P_{in} also represents the gross mechanical power (P_m) developed by the motor.

$$P_m = \frac{3 E_b V}{X_s} \sin\delta$$

→ Gross torque developed by the motor.

$$T = \frac{P_m}{\omega_m}$$

$$T = \frac{3 E_b V}{\omega_m X_s} \sin\delta \qquad \left(\omega_m = \frac{2\pi N}{60}\right)$$

$$T = \frac{9.55 P_m}{N} \text{ Nm}.$$

Torque Equation of the Synchronous Motor:

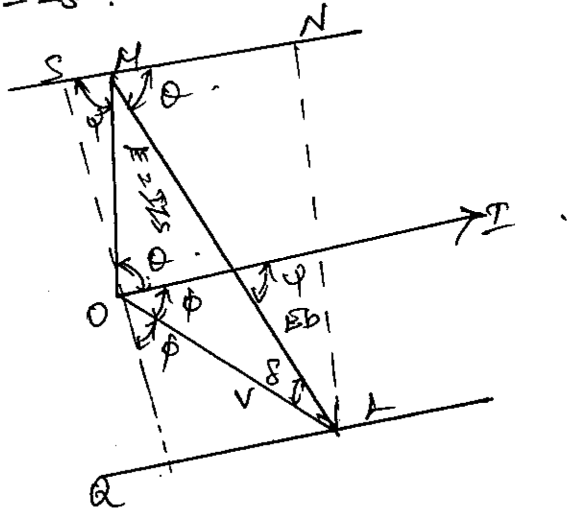
OL – Supply Voltage / phase

I – Armature Current

LM – Back EMF at a load angle of δ

OM – Resultant voltage ER

$E_r = IZ_s$.



→ I lags / leads V by an angle ϕ & lags behind E_r by an angle θ.

$$\theta = \tan^{-1}\left(\frac{X_s}{R_a}\right)$$

Line NS is drawn at angle θ to LM

LN and QS are perpendicular to NS.

→ Mechanical power developed per phase in the rotor.

$$P_{mech} = E_b I \cos\psi$$

Δ OMS, $MS = IZ_s \cos\psi$

$$MS = NS - NM = LQ - NM$$

$$IZ_s \cos\psi = V\cos(\theta-\delta) - E_b\cos\theta$$

(or)

$$I\cos\psi = \frac{V}{Z_s}\cos(\theta-\delta) - \frac{E_b}{Z_s}\cos\theta.$$

→ $P_{mech}/\text{phase} = E_b\left(\frac{V}{Z_s}\cos(\theta-\delta) - \frac{E_b}{Z_s}\cos\theta\right)$

$$P_{mech}/\text{phase} = \frac{E_b V}{Z_s}\cos(\theta-\delta) - \frac{E_b^2}{Z_s}\cos\theta.$$

→ This is the expression for the Mechanical power developed in terms of load angle (α) and the internal angle θ of the

Motor for a constant voltage V & E_b.

Maximum Power developed:

→ Condition for Maximum power developed can be found by differentiating the above expression with respect to load angle & then equating it to zero.

$$\frac{dP_{mech}}{d\alpha} = \frac{-E_b V}{Z_s} \sin(\theta - \delta) = 0 .$$

$\therefore \sin(\theta - \delta) = 0$ (or) $\theta = \delta$.

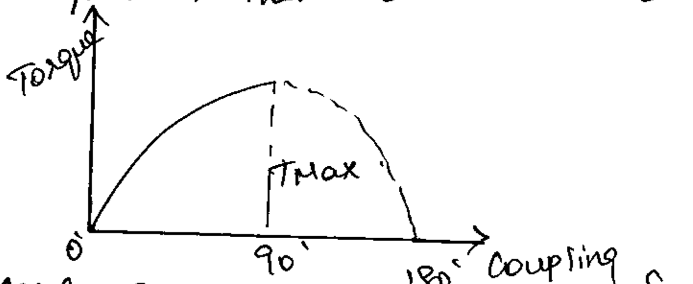
$\therefore$ value of Maximum power,

$$(P_{mech})_{max} = \frac{E_b V}{Z_s} - \frac{E_b^2}{Z_s} \cos\delta$$

$$= \frac{E_b V}{Z_s} - \frac{E_b^2}{Z_s} \cos\theta .$$

→ This shows the Maximum power & hence torque depends on V & E_b that is excitation. Maximum value of θ and hence α is $90°$. For all values of V & E_b, this limiting value of α is the same but Maximum torque will be proportional to the Maximum power developed.

→ If R_a is neglected, then $Z_s = X_s$ and $\theta = 90°$.



$\cos\theta = 0$.

$$P_{mech} = \frac{E_b V}{X_s} \cos(90° - \delta)$$

$$P_{mech} = \frac{E_b V}{X_s} \sin\delta .$$

→ This gives the value of Mechanical power developed in terms of δ - the basic variable of a Synchronous Machine.

$$P_{mech}(Max) = \frac{E_b V}{X_s} \quad \text{when } (\delta = 90^\circ)$$

This corresponds to the 'pull out torque'.

→ To determine the value of excitation (or) induced emf E_b to give maximum power developed possible, differentiate with respect to E_b and equate to zero.

$$\frac{dP_{mech}(max)}{dE_b} = \frac{V}{Z_s} - \frac{2E_b}{Z_s}\cos\theta = 0$$

(or)

$$E_b = \frac{V}{2\cos\theta}.$$

Sub $E_b = \frac{V}{2\cos\theta}$ in $(P_{mech})_{max}$

$$(P_{mech})_{max} = \frac{V^2}{2Z_s\cos\theta} - \frac{V^2}{4Z_s\cos\theta} = \frac{V^2}{4Z_s\cos\theta} = \frac{V^2}{4R_a}$$

R_a = Effective Resistance of the Motor.

Hence $(P_{mech})_{max} = \frac{V^2}{4R_a}$.

Power Flow in a Synchronous Motor:

Let,

R_a = armature resistance / phase

X_s = Synchronous reactance / phase

Z_s = Synchronous impedance.

$Z_s = R_a + jX_s$

$$I_a = \text{Armature current} = \frac{E_R}{Z_s} = \frac{V - E_b}{Z_s}.$$

θ = Internal angle = $\tan^{-1}\left(\frac{X_s}{R_a}\right)$.

If R_a is negligible, then $\theta = 90^\circ$

Input power to the motor (per phase) = $V I_a \cos\phi$.

→ Total input power for a star connected 3ϕ synchronous Motor $= \sqrt{3}\, V_L I_L \cos\phi$.

P_m = Back Emf × armature current × cosine of the angle between the two.

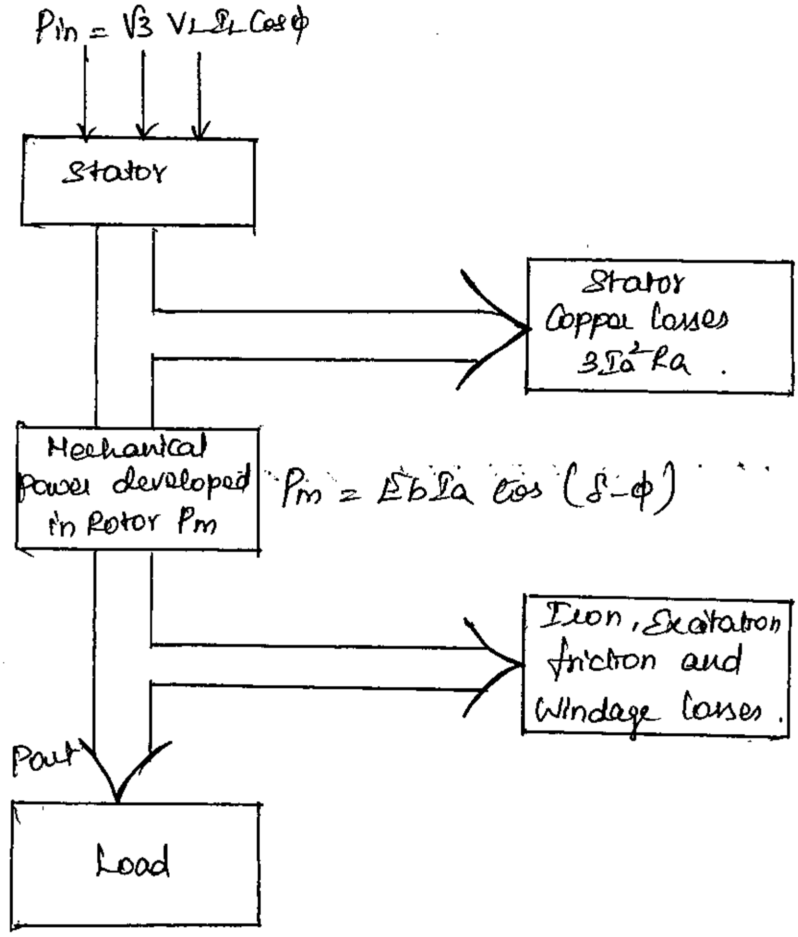
$= E_b I_a \cos(\delta - \phi)$ per phase.

→ power wasted in the armature $= I_a^2 R_a$

Input power per phase $= P_{in} = P_m + I_a^2 R_a$

Mechanical power in the Rotor $P_m = P_{in} - I_a^2 R_a$

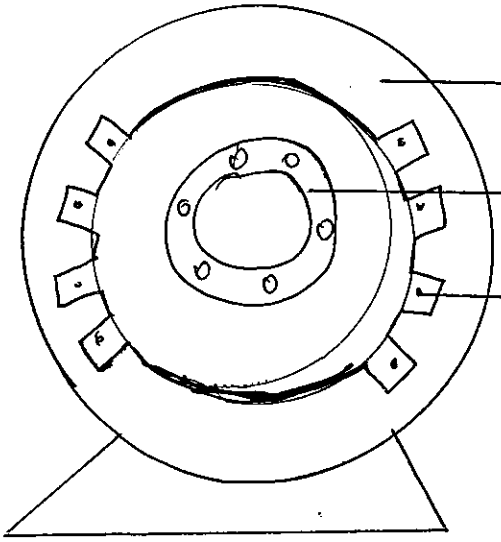
For three phases $P_m = \sqrt{3}\, V_L I_L \cos\phi - 3 I_a^2 R_a$.



SINGLE PHASE INDUCTION MOTOR:

Construction of Single phase Induction Motor:

→ It Consists of two parts. One is stator and another one is rotor. The air gap between stator and Rotor is uniform. There is no external Connection between stator and Rotor.

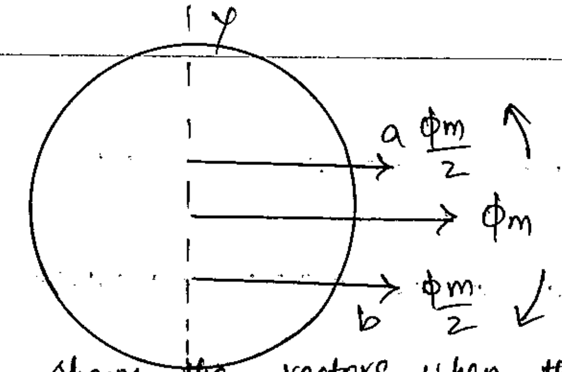


→ From the principle of operation, the 1ϕ Induction Motor has no self-starting torque. This can be explained in two ways.

* Two field (or) Double revolving field theory
* Cross field theory.

Double Revolving Field Theory:

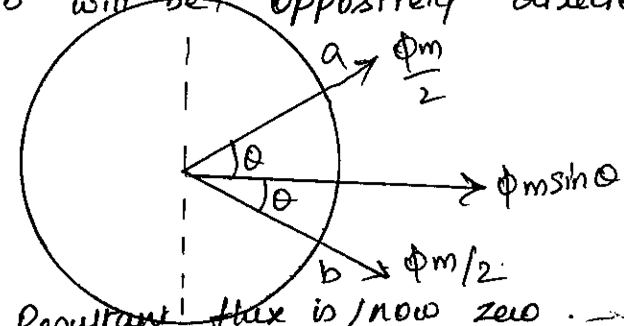
→ From Fundamental Principle (i.e) any alternating quantity can be resolved into two quantities which rotate in opposite directions and have half of the Magnitude. The alternating flux (ϕm) produced in the $1-\phi$ Induction Motor can be represented by two revolving fluxes, equal to half of the value of $\left(\frac{\phi m}{2}\right)$ the alternating flux and each rotating synchronously $\left(N_s = \frac{120f}{P}\right)$ in Opposite directions.



→ This shows the vectors when they have been rotated by an angle $+\theta$ and $-\theta$.

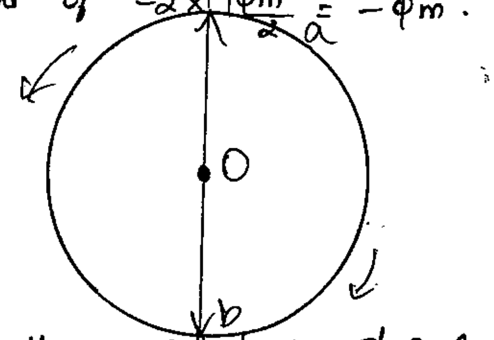
→ The resultant flux would be $2 \times \frac{\phi m}{2} \frac{\sin 2\theta}{2} = \phi m \sin\theta$.

After a quarter cycle of rotation, fluxes a & b will be oppositely directed.

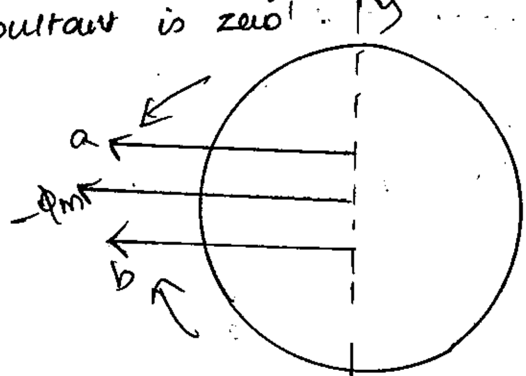


The Resultant flux is now zero.

→ After half cycle, fluxes a & b will have resultant of $-2 \times \frac{\phi m}{2} = -\phi m$.



→ After three quarters of a cycle, again the resultant is zero.



→ So the flux variation is $\phi m, 0, -\phi m, 0$. Thus an alternating flux can be looked upon as composed of two revolving fluxes each of half the values & revolving synchronously in opposite direction.

The slip of the Rotor is given by

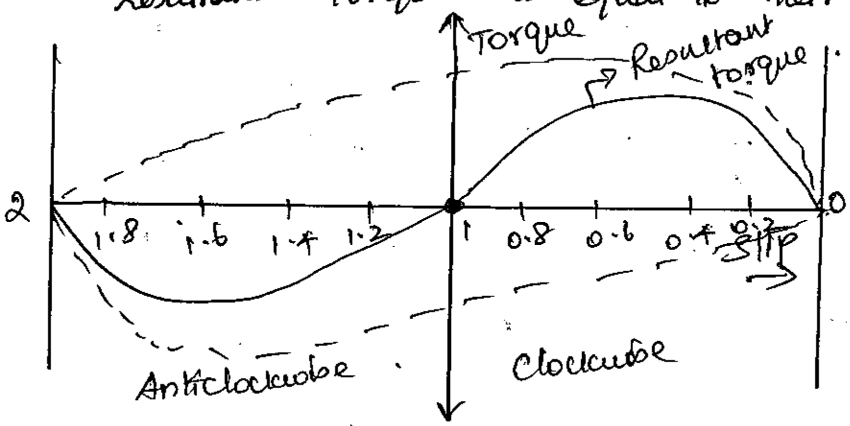
$$S_f = \frac{N_s - N}{N_s}$$

→ With respect to the forward rotating flux. The slip with respect to the backward rotating flux is

$$S_b = \frac{N_s - (-N)}{N_s} = 1 + \frac{N}{N_s} = 1 + 1 - S = 2 - S$$

$$\therefore S_b = 2 - S.$$

→ Each of the two component fluxes while revolving round the stator cuts the rotor, induces an emf and thus produces its own torque. Obviously two torques (called forward & backward torques) are oppositely directed so that the net torque (i.e) resultant torque is equal to their differences.



Operation of Single - Phase Induction Motor:

→ The stator winding of a 1φ induction Motor is connected to 1φ AC supply. Then a Magnetic field is developed in the stator whose axis is always along the axis of stator windings. With alternating current in the fixed stator coil the mmf wave is stationary in space but pulsates in magnitude & varies sinusoidally with time.

→ Due to the transformer action, currents are induced in the rotor conductors. The direction of the current is to oppose the stator MMF. Thus the axis of rotor mmf wave coincides with the axis of stator mmf wave. Therefore the torque angle is zero and so no starting torque is developed in the Motor.

→ However if rotor is initially given a starting torque by some means, the motor will pick up the speed and continue to rotate in the same direction. Thus the 1ϕ Induction Motor is not a self starting Motor.

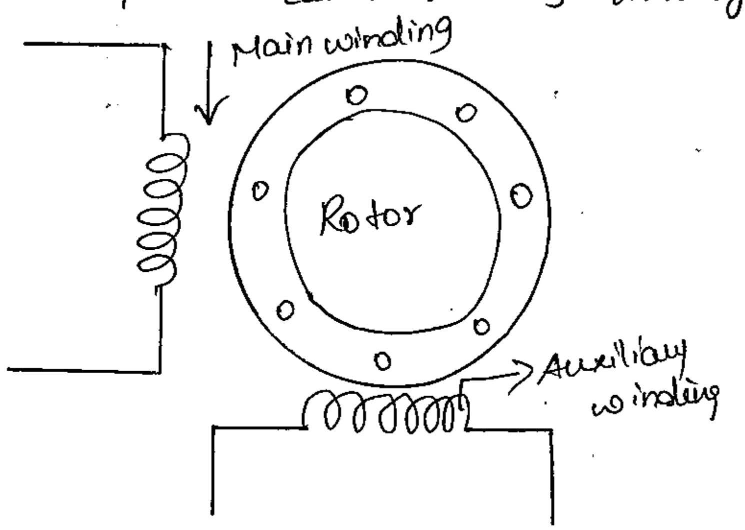
Starting of 1ϕ Induction Motor:

→ The starting Method of 1ϕ Induction Motor is very simple. An auxiliary winding in the Stator is provided in addition to the Main winding. Then the induction Motor starts as a two phase Motor.

→ The Main winding axis and auxiliary winding axis are displaced by 90 electrical degree. The impedances of the windings differ and currents in the main and auxiliary winding are phase shifted from each other. As a result of this, a rotating stator field is produced and the rotor rotates.

→ When the Motor speed is about 75% of Syn. Speed, the auxiliary winding is disconnected from the Circuit. This is done by connecting a Centrifugal switch in the auxiliary winding which is used for starting purpose only. That is why it is called starting winding.

→ Under running Condition, a 1ϕ Induction Motor Can develop torque only with Main winding. That is why it is called running winding.



THREE PHASE INDUCTION MOTOR:

Construction:

→ The Induction Motor consists of two main parts

Stator

Rotor

Stator:

→ The stator is made up of a No. of stampings with alternate slot and tooth. Stampings are insulated from each other. Each stamping is 0.4 to 0.5 mm thick. No. of stampings are stamped together to build the stator core. The stator core is then fitted in a casted (or) fabricated steel frame. The slot house the 3ϕ winding just like the 3ϕ alternator. The 3ϕ winding is called stator winding. It may be connected either in star (or) delta. The stator winding is made for a fixed no. of poles.

Rotor:

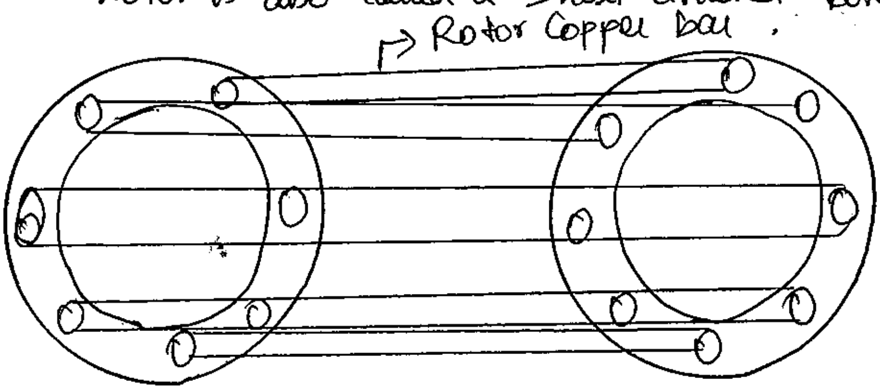
→ There are two types of Rotors used in induction Motors.

Squirrel cage Rotor

Slip ring (or) wound Rotor.

Squirrel cage Rotor:

→ This is made up of a cylindrical laminated core with slots to carry the Rotor Conductors. The Rotor Conductors are heavy bars of Copper (or) aluminium. Short circuited at both ends by end rings. Hence this rotor is also called a Short Circuited Rotor.

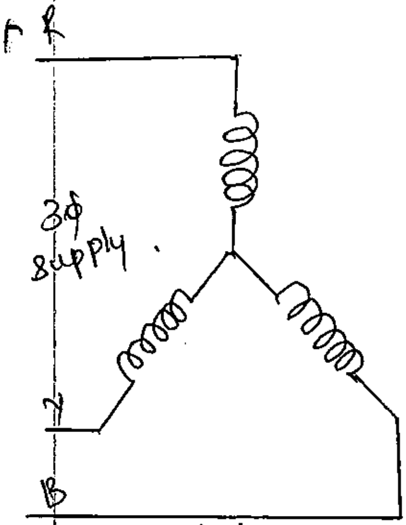


→ The entire rotor Resistance is very small. External resistance cannot be connected in the rotor circuit. Such Motors are extremely rugged in construction. Motors using such rotors are called squirrel cage Induction Motors.

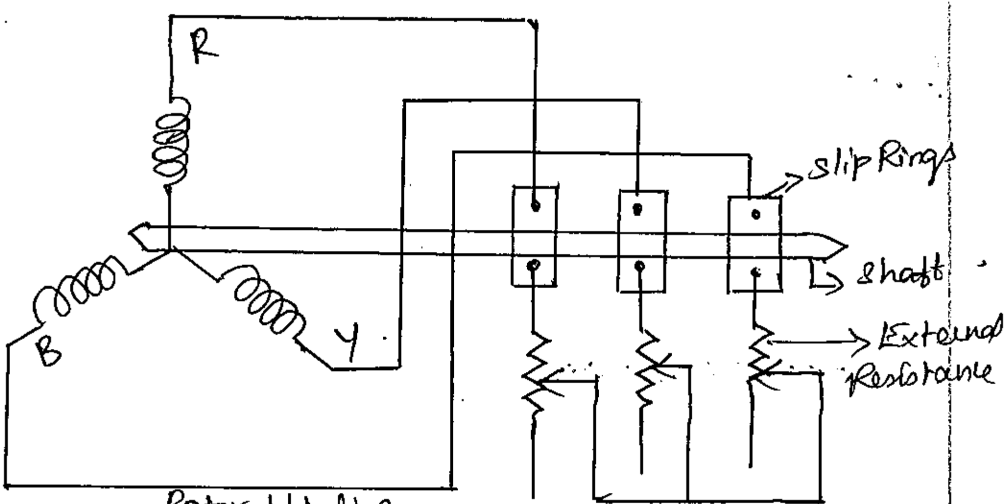
Slip Ring (or) wound Rotor:

→ In this type of Rotor, rotor windings are similar to the stator winding. The rotor winding may be star (or) delta connected, distributed winding wound for as many no. of poles as the stator. The three phases are brought out & connected to slip rings mounted on the rotor shaft.

→ Variable external resistance can be connected in the rotor circuit, with the help of brushes and slip ring arrangements. By varying the external resistance in the rotor circuit, the Motor speed and torque can be controlled. This Motor is called Slip Ring Induction Motor (or) wound Rotor Induction Motor.



Stator Winding



Rotor Winding

Principle of Operation:

→ 3ϕ supply is given to the stator winding. Due to this, current flows through the stator winding. This current is called stator current. It produces a rotating Magnetic field in the space between stator and rotor. The Magnetic field rotates at syn. speed given by,

$$N_s = \frac{120f}{P}$$

→ As a result of the rotating Magnetic field Cutting the rotor Conductors, an emf is induced in the rotor. If the rotor winding is shorted then the induced emf produces Current. This Current produces a rotor field.

→ The interaction of stator & Rotor fields develops torque. Then the rotor rotates in the same direction as the rotating Magnetic field. When the rotor is at standstill, the frequency of rotor emf is equal to the supply frequency.

→ As the Rotor speed picks up, the frequency of rotor emf and the Magnitude of Rotor emf decrease. The rotor tries to Catch up with the rotating magnetic field. However, the rotor Cannot really catch up and rotate at the syn. speed because if it does so, the relative speed would become zero and then there is no rotor induced emf, no Current and hence no torque.

→ Therefore, the Rotor runs at a speed slightly less than the syn. Speed. In an Induction Motor, the rotor speed is always less than the Syn. Speed. Therefore this Machine is called an Asynchronous Machine.

→ The difference between synchronous Speed and Rotor speed is called slip Speed.

$$\text{Slip Speed} = N_s - N$$

$$S = \frac{N_s - N}{N_s}$$

$$N = N_s(1-s)$$

$$\%\,\text{slip} = \frac{N_s - N}{N_s} \times 100.$$

→ At no load, the difference between Syn. Speed & Rotor Speed is only about 1%. At loaded Condition, the Rotor slows down. The emf induced in the Rotor and hence the rotor Current increase. Due to this, torque also increases.

→ Under steady state Conditions, the electromagnetic torque is equal to the load torque. At full load Conditions the difference between Syn. Speed and Rotor speed is about 3 to 5%.

→ The variation of speed from no-load to full load is very small. Thus a 3ϕ Induction Motor is also called a constant speed Motor.

→ Variation of speed is possible, but such variation is accompanied by loss of efficiency.

Torque - slip characteristics:

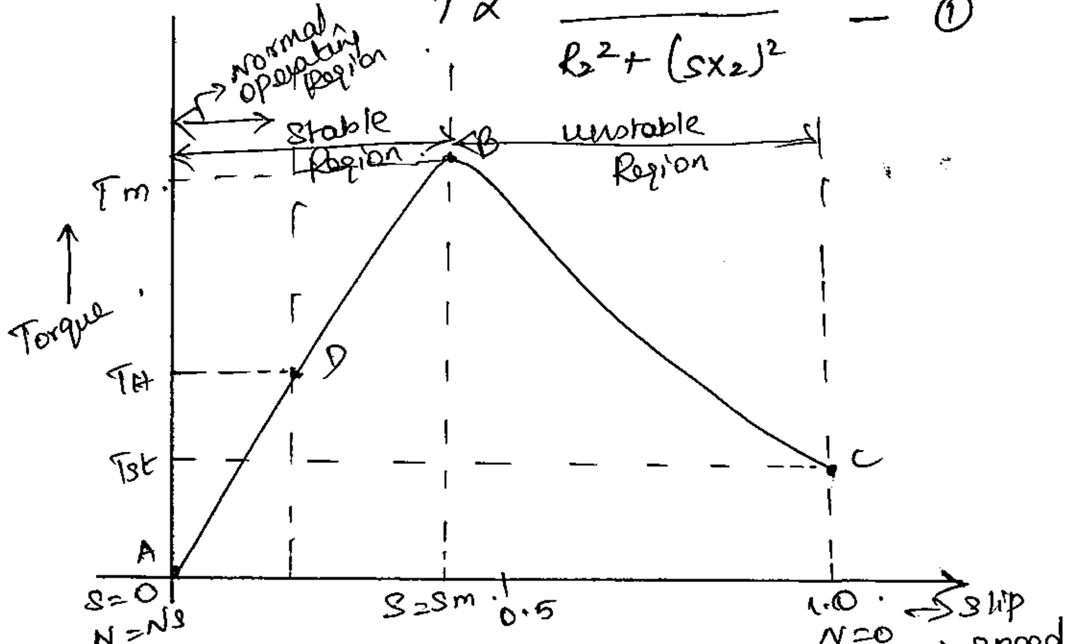
→ The curve drawn between torque & slip from $s=1$ to $s=0$ is called torque-slip characteristic of the Induction Motor.

→ The torque equation for 3ϕ Induction Motor is given by,

$$T \propto \frac{sE_2^2 R_2}{R_2^2 + (sX_2)^2}$$

Here, the input voltage is constant (i.e) E_2 is also constant. So the above equation becomes,

$$T \propto \frac{sR_2}{R_2^2 + (sX_2)^2} \quad - (1)$$



→ It consists of three regions

* Stable operating Region
* Unstable Operating Region
* Normal operating Region

Stable Region:

→ In stable Region, the slip value 'S' is very small (i,e) the term $(SX_2)^2$ is very small as compared to R_2^2. Hence neglecting $S^2X_2^2$ in equation ① -

$$T \propto \frac{SR_2}{R_2^2} \propto S \text{ as } R_2 \text{ is constant}$$

$$T \propto S.$$

→ The slip value is directly proportional to the torque. In this Region, as the load increases speed decreases (or) the slip increases

$$T\uparrow, S\uparrow$$

→ So the characteristic is approximately a stright line. It is indicated in curve AB.

Unstable Region:

→ When the slip is further increased from Sm, the region is unstable region. Here, the slip value is high (i,e) the values between Sm and 1. The term R_2^2 may be neglected as compared to $S^2X_2^2$ in eq ①

$$T \propto \frac{S}{(SX_2)^2} \propto \frac{1}{S}$$

$$T \propto \frac{1}{S}.$$

→ In this region, torque is inversely proportional to slip (i,e) slip increases and torque decreases.

$$S\uparrow, T\downarrow.$$

→ The torque - slip curve is similar to a rectangular ~~para~~ hyperbola.

Normal Operating Region:

→ The region (AD) is also called low slip region & the operating Region.

→ The Motor is Continuously operated in this region. From this curve, we can understand the following terms.

* Starting torque (T_{st})
* Maximum torque (or) pull out torque (T_m)
* Full load torque (T_{FL}).

Starting torque (T_{st}):

→ When the slip is 1, the speed is zero. At this condition the motor produces a torque called starting torque.

Maximum torque (T_m):

→ The torque which the Motor produces at slip $s = s_m$ is called Maximum torque. s_m = slip at which Maximum torque occurs. This Maximum torque is also called the breakdown torque (or) pull out torque.

Full load torque (T_{fl}):

→ The point D corresponds to full load torque of the Motor. Normally full load torque is less than the Maximum torque.

UNIT – III
ELECTRICAL MACHINES

1. How will you find the direction of emf using Fleming's Right Hand Rule?

The thumb, the forefinger and the middle finger of the right hand are held so that these fingers are mutually perpendicular, then Forefinger - Field Thumb - Motion Middle finger- I, current

2. **How will you find the direction of force produced using Fleming's Left Hand Rule?**

The thumb , forefinger and middle finger of the left hand are held so that those fingers are mutually perpendicular then Forefinger - Field Thumb - Motion(due to force) Middle finger - I, current

3. **How are armature windings classified based on the placement of the coil inside the armature slots?**

Single layer winding and Double layer winding

4. **Write down the emf equation for d.c generator.**

$E = (\phi NZ / 60)(P/A)$ V Where P= number of poles Z= Total number of conductors A= number of parallel paths Φ= flux per pole N= speed in rpm

5. **Why the armature core in d.c machines is constructed with laminated steel sheets instead of solid steel steel?**
Steel sheets offer low relutance path for the magnetic field , laminated sheets reduce eddy current loss.

6. **Why is commutator employed in d.c machines?**
• Conduct electricity between armature and fixed brushes
• Converts altenatingemf into unidirectional emf and vice versa

7. **Distinguish between shunt and series field coil constructions.**
Shunt field coils are wound with wires of small cross section and have more number of turns. Series field coils are wound with wires of larger cross section and have less number of turns.

8. **How does a d.c motor differ from d.c generator in construction?**
Generators are normally placed in closed room , accessible only to skilled operators. Therefore on ventilation point of view they may be constructed with large opening in the frame. Motors on the other hand , have to be installed right in the place of use which may have dust, dampness,inflammable gases, chemical fumes etc . To protect the motors against these elements , the motor frames are made either partly closed or totally closed or flame proof etc.

9. How will you change the direction of rotation of a d.c motor?
Either the direction of the main field or the direction of current through the armature conductors is to be reserved.

10. **What is back emf in d.cmotors** ?
As the motor armature rotates , the system of conductor come across alternate North and South pole magnetic fields causing an emf induced in the conductors. The direction of the emf induced in the conductors . The direction of the emf induced is in the direction opposite to the current .As this emf always opposes the flow of current in motor operation it is called back emf.

11. **Enumerate the factors on which the speed of a dc motor depends. $N = (V\text{-}IaRa)/\phi$**
The speed of dc motor depends on three factors.
• Flux in the air gap
• Resistance of the armature circuit
• Voltage applied to the armature

12. **How can one differentiate between long shunt compound generator and short shunt compound generator?**
In a short shunt compound generator the shunt field circuit is shorter i.e. across the armature terminals. In a long shunt compound generator the shunt field circuit is connected across the load terminals.

13. **Why is the emf not zero when the field current is reduced to zero in a dc generator ?**
Even after the field current/magnetizing force is reduced to zero the machine is left out with some flux as residue. Emf due to this residual flux is available when field current is zero
.

14. **On what occasions dc generators may not have residual flux?**
• The generator may be put for its first operation after its construction.
• In previous operation the generator would have been fully demagnetized.

15. **What are the conditions to be fulfilled for a dc shunt generator to build up emf?**
• The generator should have residual flux • The field winding should be connected in such a manner that the flux set up by the field winding should be in the same direction as that of residual flux
• The field circuit resistance should be less than critical field resistance
• Load circuit resistance should be above its critical load resistance

16. How the critical field resistance of a dc shunt generator is estimated from its OCC?
Critical field resistance can be obtained from OCC by drawing a straight line passing through the origin and tangent to the initial straight line portion of OCC. The slope of this line gives the value of critical field resistance for the given speed at which OCC is obtained.

17.What is the function of carbon brush used in D.C generator?
The function of carbon brush is to collect current from the commutator and supply to the external load circuit and to the field circuit.

18.Write the number of parallel paths in a lap and wave connected windings
In a lap wound machine, the number of parallel paths is equal to the number of poles. But in wave wound machine, the number of parallel paths is always two irrespective of number of poles.
19. What is the basic difference between dc generator and dc motor
Generator converts mechanical energy into electrical energy. Motor converts electrical energy into mechanical energy. But there is no constructional difference between the two.

20. Mention the difference between core and shell type transformers.
In core type, the windings surround the core considerably and in shell type the core surround the winding.

21. What is the purpose of laminating the core in a transformers?
To reduce eddy current loss.

22. Give the emf equation of a transformer and define each term
Emf induced in primary coil $E1 = 4.44\ f\Phi\ mN1$ volt Emf induced in secondary coil $E2 = 4.44 f\Phi\ mN2$ volt Where f is the frequency of AC input Φ m is the maximum value of flux in the core N1, N2 are the number of primary and secondary turns

23. Does the transformer draw any current when secondary is open ?Why ?
Yes,it (primary) will draw the current from the main supply in order to magnetize the core and to supply iron and copper losses on no load . There will not be any current in the secondary since secondary is open.

24.why transformers are rated in kVA ?
Copper loss of a transformer depends on current and iron loss on voltage. Hence total Losses depend on Volt- Ampere and not on the power factor. That is why the rating of Transformers are in kVA and not in Kw

25. How transformers are classified according to their construction ?
Or Mention the difference between "CORE" and "SHELL" type transformers.
Or
What are the two types of cores used ? Compare them.
Transformers are classified according to their construction as ,
(i)Core type (ii) Shell type (iii)Spiracore type.
Spirakore type is a latest transformer and is used in big transformers.
In "core" type, the windings (primary and secondary)surround the core and in "shell" type, the core surround the windings.

26.. Explain on the material used for core construction.
The core is constructed of transformer sheet steel laminations assembled to provide a Continuous magnetic path with a minimum of air gap included. The steel used is of high silicon content sometimes heat treated to produce a high permeability and a low hysteresis loss at the usual operating flux densities. the eddy current loss is minimized by laminating the core, the

laminations being insulated from each other by light coat of core-plate vanish or by an oxide layer on the surface .the thickness of laminations varies from 0.35 mm for a frequency of 50 Hz and 0.5 mm for a frequency of 25 Hz.

27. How does change in frequency affect the operation of a given transformer?
With a change in frequency, iron loss, copper loss, regulation, efficiency and heatingvaries and thereby the Operation of the transformer is affected.

28. What is the angle by which no-load current will lag the ideal applied voltage?
In an ideal transformer, there are no copper loss and no core loss, (i.e. loss free core).
The no load current is only magnetizing current. Therefore the no-load current lags behind by an angle of 90°. However the windings possess resistance and leakage reactance and therefore the no-load current lags the applied voltage slightly less than 90°.

29. List the advantages of stepped core arrangement in a transformer

(i) To reduce the space effectively.
(ii) To obtain reduced length of mean turn of the windings.
(iii) To reduce I2R loss.

30. What are the functions of no-load current in a transformer ?
No-load current produces flux and supplies iron loss and copper loss on no-load.

31. Can the voltage regulation of a transformer go to negative? If so under what condition?
Yes. If the load has leading power factor.

32. What is prime mover?
The basic source of mechanical power which drives the armature of the generator is called prime mover.

33. Write down the equation for frequency of emf induced in an Altenator.
Frequency of emf induced in an Alternator,f ,expressed in cycles persecond or Hz, is given by the following equationF = (PN)/120 Hz Where P- Number of poles N-Speed in rpm

34. How are alternators classified?
According to type of field systemStationary field system type Rotating field system type
According to shape of field systemSalient pole type Smooth cylindrical type

35. Name the types of Alternator based on their rotor construction.
Alternators can be classified into the following two types according to its rotor constructionSmooth cylindrical type alternator Salient pole alternator

36. What are the advantages of salient pole type construction used for Synchronous machines?
Advantages of salient-pole type construction are: They allow better ventilation The pole faces are so shaped that the radial air gap length increases from the pole center to the pole tips so that

the flux distribution in the air-gap is sinusoidal in shape which will help the machine to generate sinusoidal emfDue to the variable reluctance the machine
develops additional reluctance power which is independent of excitation

37. Why are Alternators rated in kVA and not in kW?
The continuous power rating of any machine is generally defined as thepower the machine or apparatus can deliver for a continuous period so thatthe losses incurred in the machine gives rise to a steady temperature risenot exceeding the limit prescribed by the insulation class.Apart from the constant loss incurred in Alternators is the copper loss, occurring in the 3 –phase winding which depends on I2 R, the square of the current delivered by the generator. As the current is directly related toapparent – power delivered by the generator , the Alternators have only their apparent power in VA/kVA/MVA as their power rating.

38. What are the causes of changes in voltage in Alternators when loaded?
Variations in terminal voltage in Alternators on load condition aredue to the following three causes:
· Voltage variation due to the resistance of the winding, R
· Voltage variation due to the leakage reactanceof the winding, Xt
· Voltage variation due to the armature reaction effect, Xa

39. What is meant by synchronous impedance of an Alternator?
The complex addition of resistance, R and synchronous reactance ,jXs, can be represented together by a single complex impedance Zs called synchronous impedance.In complex form Zs = (R + jXs)

40.Why a synchronous motor is a constant speed motor?
Synchronous motor work on the principle of force developed due to the magnetic attraction established between the rotating magnetic field and the main pole feed. Since the speed of rotating magnetic field is directly proportional to frequency the motor operates at constant speed.

UNIT – IV
ELECTRONIC DEVICES & CIRCUITS

UNIT - IV

ELECTRONIC DEVICES & CIRCUITS.

ATOMIC STRUCTURE :

→ All Matters Consist of Atoms. An atom Consists of three particles namely electron, Proton & neutron.

→ The Proton is positively charged particle, the electron is negatively charged particle and the neutron is an electrically neutral particle.

→ The protons & neutrons are clustered together, to form a hard central area, Called nucleus (+ve charge).

→ The electrons revolve around the nucleus, in a well defined path called Orbit.

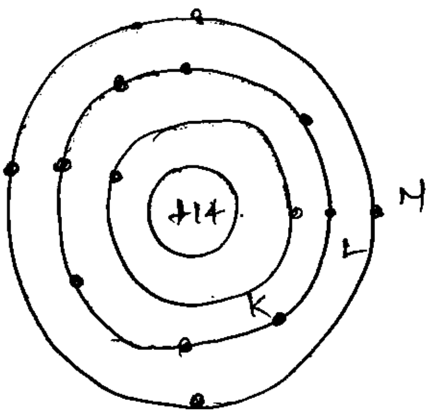
Atomic number = Number of electrons

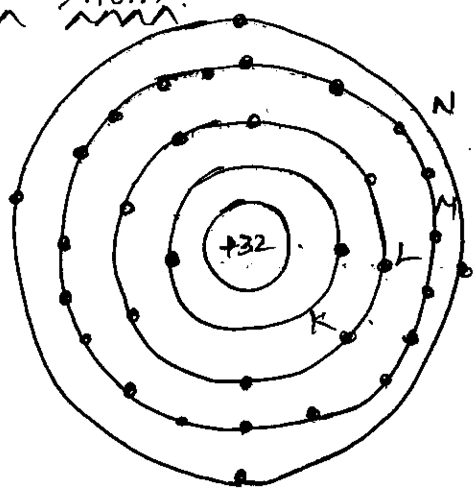
= Number of protons.

Atomic Weight of an atom

= Number of protons + Number of neutrons.

Arrangement of Electrons in Atom :





Silicon (Si) :

→ The atomic number of silicon is 14. In Si atom, the electrons are arranged in the following manner.

Si(14); K(=2), L(=8), M(=4).

→ The Maximum number of electrons to be placed in the M shell is 18. But in Si, it contains only 4 electrons.

Germanium (Ge) :

→ The atomic number of Germanium is 32. In Ge atom, the electrons are arranged as,

Ge(32); K(=2), L(=8), M(=18), N(=4).

→ The outer shell contains only 4 electrons irrespective of 32 electrons.

ENERGY LEVELS :

Valence band :

→ The energy band occupied by valence electrons is called Valence band.

Conduction band :

→ During Conduction, the electrons are moved from one orbit to another, (or) from one atom to another atom. This energy band is called Conduction band.

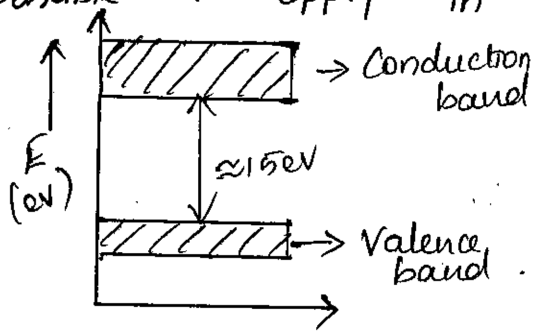
Forbidden energy gap :

→ The energy gap between Valence band & Conduction band is called forbidden energy gap.

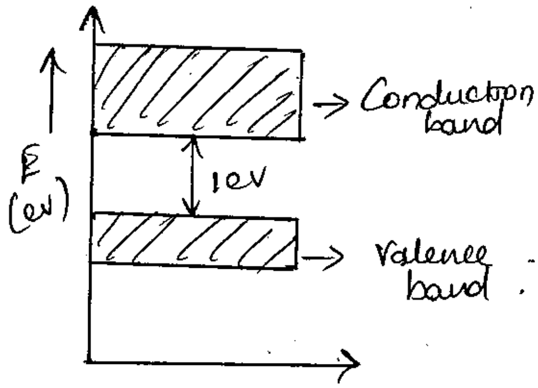
Insulator :

→ In insulators (wood, glass), the forbidden energy gap is very high ($\simeq 15eV$). If the energy applied to the insulator is more than 15eV, the electrons are moved from valence band to conduction band.

→ But this energy will destroy the insulators, not possible to apply in insulators.

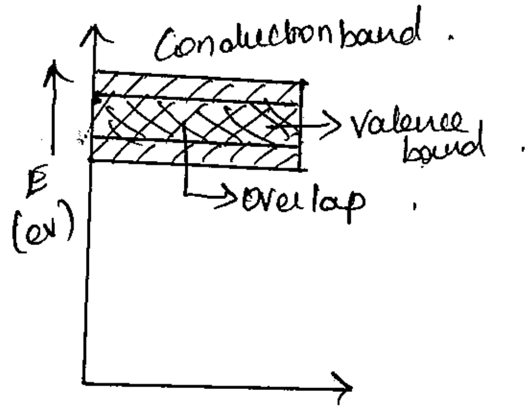


Semiconductors :



→ In semiconductors (Silicon, Germanium) the forbidden energy gap is only 1eV. Therefore, a small amount of energy is required for moving the electrons from valence band to conduction band.

Conductors :



→ In Conductors (Aluminium, Copper), the Valence band & Conduction band are overlapped with each other.

→ Hence without applying any energy, large number of free electrons are available in the Conduction band. Hence large current flows in Conductors.

SEMI CONDUCTOR :

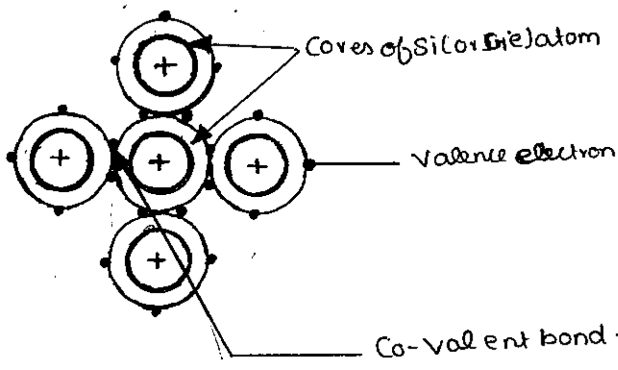
→ The Substances (Si, Ge) whose electrical Conductivity lies in between the Conductors and insulators are called as Semi Conductors.

→ The SemiConductor behave like insulators at 0 K, because no electrons are available in the Conduction band.

Types of SemiConductor :

- Semi Conductor
  - Intrinsic Semiconductor
  - Extrinsic Semiconductor
    - N-type
    - P-type

Intrinsic Semiconductor :

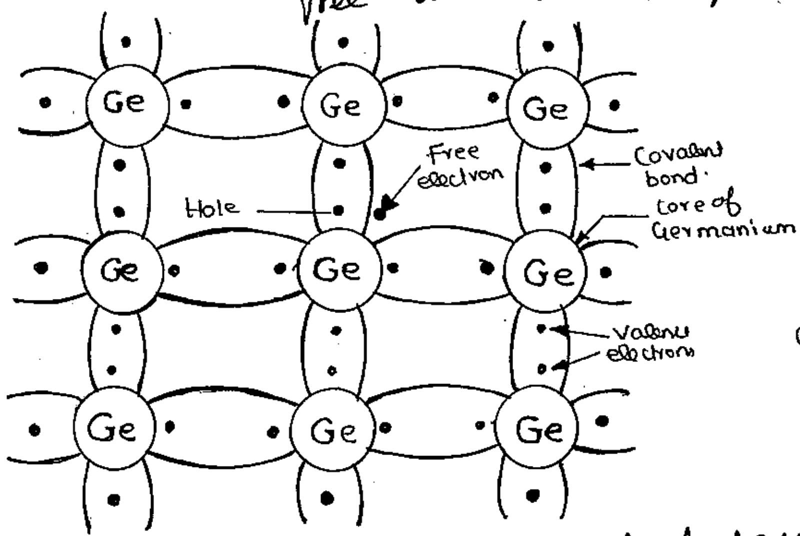


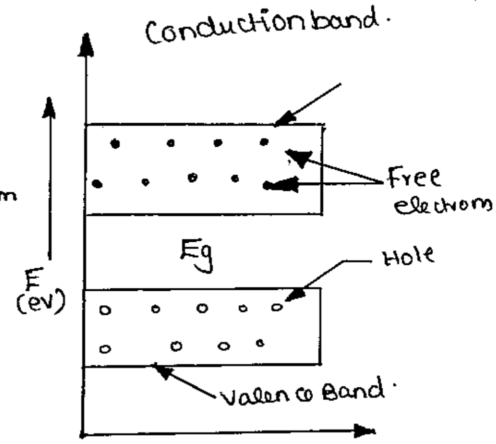
→ A pure semiconductor is called Intrinsic semiconductor.

→ The silicon & germanium atom contains only four electrons in the ~~LLO~~ outermost orbit. They are called tetravalent atoms.

→ At low temperature (0°K), the semiconductor behaves as a perfect insulator. Now no electrons get away from the co-valent band. So the current flow is zero.

→ At room temperature, some of the valence electrons may acquire sufficient energy. The bonds may be broken, the electrons become free and are shifted to the conduction band.





→ The motion of electrons constitutes electron current. The vacancy created by this electron in the valence band is known as holes, and acquires a positive charge.

→ The combination of electron & hole is known as electron - hole pair.

→ In the intrinsic semiconductors, the number of electrons is equal to the number of holes.

→ The amount of current flow depends upon the number of electron - hole pairs broken, depends upon the applied electric field.

→ When an external electric field is applied across the this, more no. of electron - hole pair combinations will be broken.

→ According to the amount of electric field, many free electrons are generated in the valence band. The free electrons are moved to the positive potential through holes, called electron current.

→ Now the holes are moved towards the negative potential, called hole current. The sum of electron current and hole current is known as electric current.

Extrinsic Semiconductors:

→ The electrical conductivity of pure semiconductor is increased by adding some impurities in it. The resultant semiconductor is called Extrinsic semiconductor.

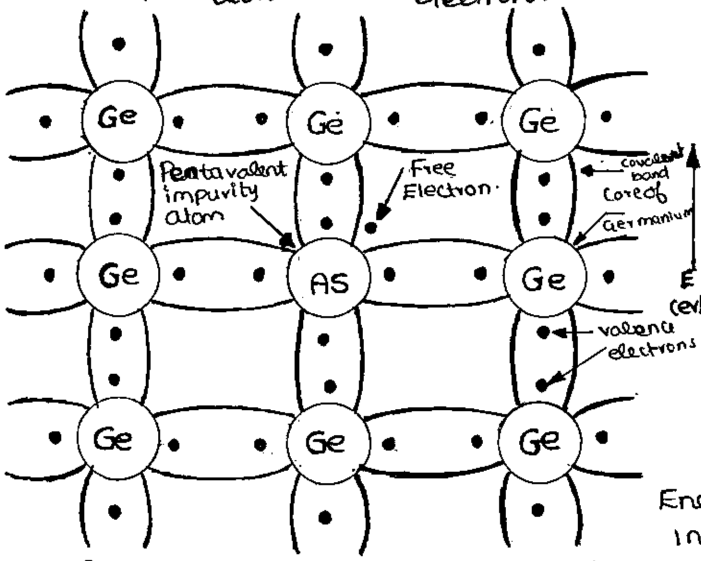
→ The process of adding impurities to a pure semiconductor is known as doping. The purpose of adding impurities in the pure semiconductor is to increase the number of free electrons (or) holes, for increasing their conductivity.

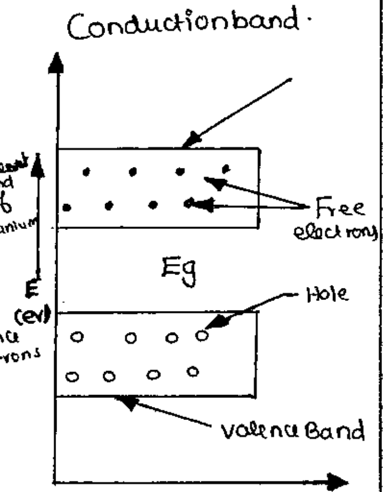
→ The extrinsic semiconductors are divided into two types.

* N - type semiconductor
* P - type semiconductor.

N-type Semiconductor:

→ It is formed by adding a small amount of pentavalent impurities to a semiconductor Material. The added impurities are called donar impurities because they will donate electrons.





Energy band diagram of intrinsic semiconductor.

→ Germanium atom has four valence electrons and antimony has five valence electrons.

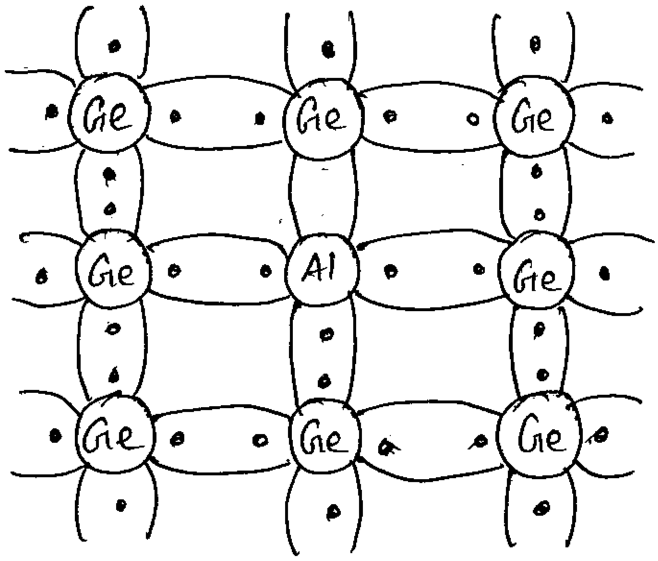
→ The Antimony atom forms Co-valent bonds with their surrounding four germanium atoms. The four valence electrons of antimony atom form Co-valent bonds with four valence electrons of individual germanium atom. The fifth valence electron of antimony is left free, loosely bound to the antimony atom.

→ This loosely bound electron can be easily excited from the valence band to the Conduction band by the application of small electric field. The extra electron creates impurity because it can donate one electron for Conduction.

→ Thus the addition of pentavalent Impurities increases the no. of electrons in the Conduction band, thereby increasing the Conductivity of the SemiConductor.

→ Now the semiconductor contains more electrons and less holes. Hence it is called N-type semiconductor.

P-type Semiconductor :



→ It is formed by adding a small amount of trivalent impurities to a pure semiconductor material. Three valence electrons in aluminium form co-valent bond with four surrounding atoms of Ge.

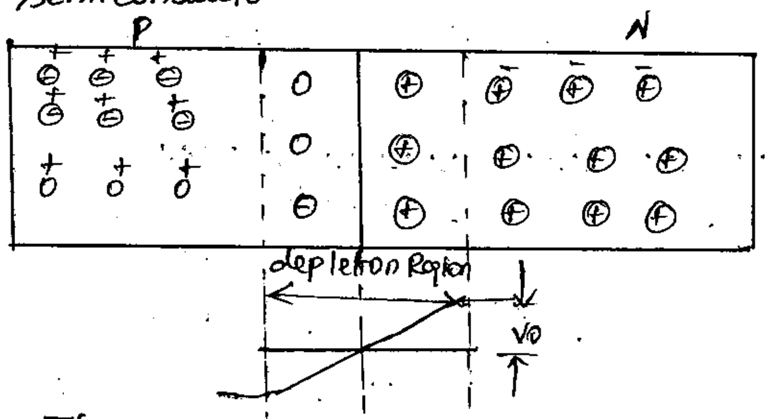
→ Now one co-valent bond is incomplete, which gives rise to a hole. ~~The Co-valent bond~~

→ For this, more no. of holes are generated. The holes increase the conductivity of P-type semiconductor. This impurities are known as acceptor impurities, because the holes created can accept electrons. The no. of holes is more than the no. of electrons.

→ In P-type semiconductors holes are majority carriers and electrons are minority carriers.

PN JUNCTION DIODE:

→ A PN Junction is formed by suitably joining a P-type and a N-type semiconductor.



→ The P-type semiconductor has more holes and less electrons. The N-type has more electrons and less holes. Therefore, at the junction, the electrons in the N-side have a tendency to move towards the P-side.

→ Similarly, the holes on the P-side have a tendency to move towards the N-side.

→ According to that, the electrons & holes recombine with each other, to form a region at the junction. It is called "depletion region".

→ When the free electrons move from N-type to P-type, the donar ions become positively charged. Similarly when the holes move from P-type to N-type, the acceptor ions becomes negatively charged. These two charges, on either sides, make a potential across the depletion region called "barrier potential".

→ The barrier potential opposes the flow of carriers through the junction, maintains an equilibrium level.

→ The barrier potential aids the flow of minority Carriers & opposes the flow of majority carriers through the junction.

→ For both these opposite effects, no charge Carriers are flow through the junction at normal Conditions.

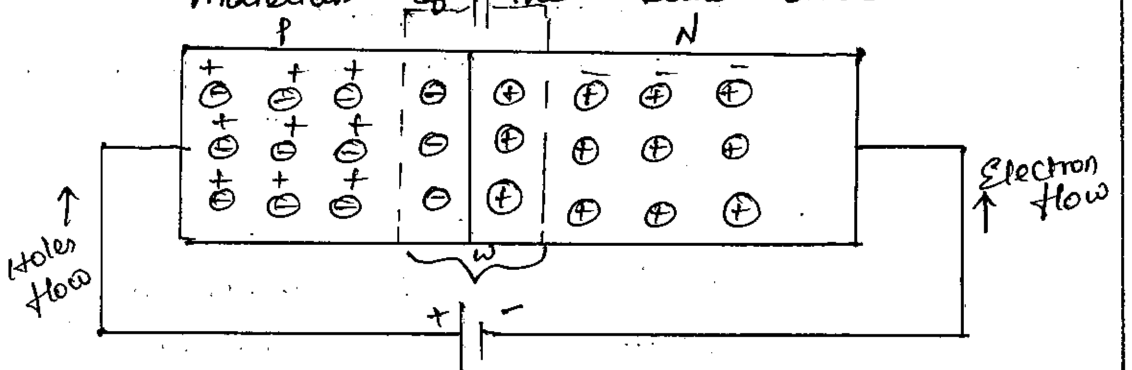
Working of a PN Junction Diode:

→ The Conduction of any diodes, depends on their biasing. There are two types of biasing, known as

* Forward biasing
* Reverse biasing.

Forward Biasing:

→ In forward biasing, the positive terminal of the battery is Connected to the p-type and the negative terminal of the battery is Connected to the N-type materials of the ~~batter~~ diode.



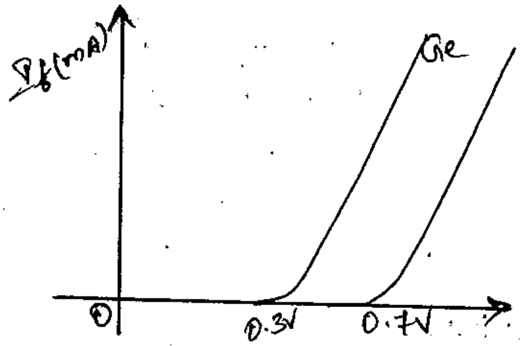
→ Under the forward bias Condition, the applied positive potential repels the holes in p-type region. The negative potential repels the electrons in N-type region.

→ Now the electrons in N-type region & the holes in the p-type region move towards the junction. This reduces the width of the depletion region & also the barrier potential.

→ If the applied potential is greater than barrier potential, the majority carriers on both regions move towards the junction. It makes current flow through the junction. The amount of current flow depends upon the magnitude of applied potential.

V-I Characteristics :

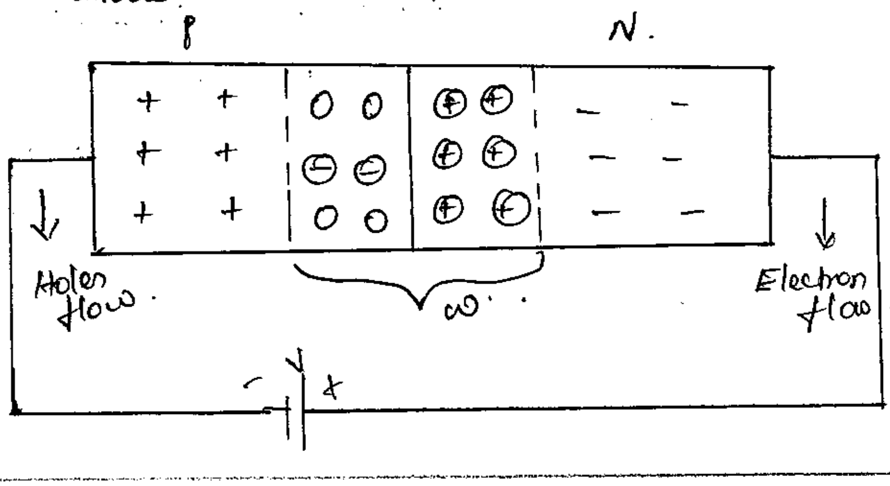
→ When the applied potential is less than cut-in (or) threshold voltage, the current flow is very low. The cut-in voltage is generally 0.3V for Ge and 0.7V for Si.



→ At the cut-in voltage, the applied potential overcomes the barrier potential, increases the current rapidly.

Reverse Biasing :

→ In Reverse biasing, the positive terminal of the battery is connected to the N-type & the negative terminal of the battery is connected to the P-type materials of the diode.

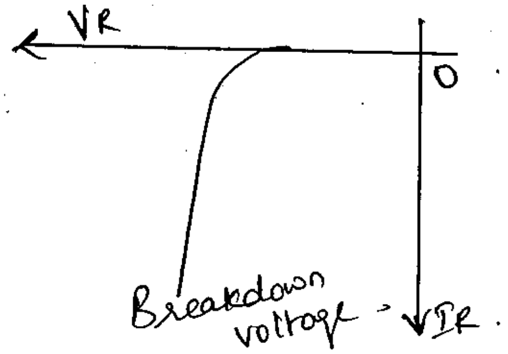


→ Under reverse bias condition, the majority carriers with P & N regions are moved towards the battery.

→ The holes in P type & the electrons in N type regions move to the negative & positive terminals of the battery. Hence the width of the depletion region is increased, which prevents the flow of majority carriers through the junction.

→ When the applied voltage is slowly increased, the minority carriers in P region and the minority carriers in N region make a small amount of current flow through the junction. This current is called " Reverse Saturation Current.

V-I Characteristics:



→ When the applied reverse voltage is further increased, breakdown occurs in the junction. Now large reverse current flows through the junction. The Minimum voltage that needs to breakdown occurs in the junction is called breakdown voltage.

Diode specifications :

1) **Peak inverse voltage (PIV) :**

→ It is the Maximum allowable reverse voltage that can appear across the diode without causing it any damage. It may be in between 10V and 10kV depending on the type of diode.

2) **Reverse Recovery Time (t_{rr}) :**

→ It is the time that elapses before a forward biased diode returns to the reverse biased state after an input signal abruptly reverses the bias voltage.

3) **Peak forward Current (or) Surge Current :**

→ It is the Maximum forward current that the diode can withstand without getting damaged.

4) **I^2t Rating :**

→ It is the one cycle peak surge current rating of the diode.

5) **Forward Current :**

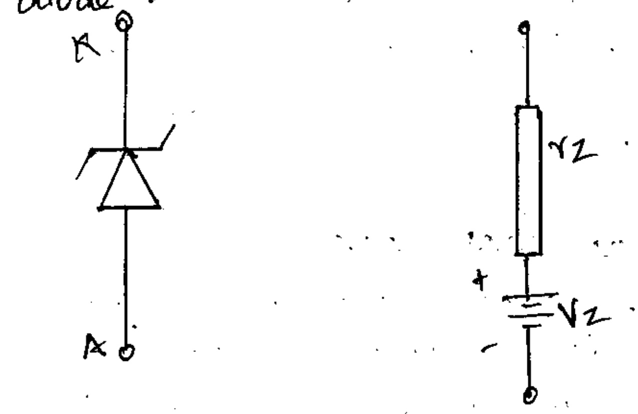
→ It is the current flowing through a forward biased diode. If this current is exceeded, the diode may be destroyed due to excessive heat.

6) **Reverse leakage Current :**

→ It is the current that flows through a reverse biased diode. This current is due to minority carriers.

ZENER DIODE :

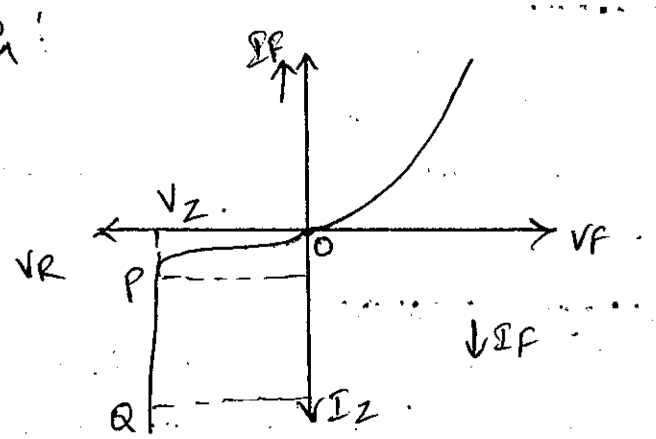
→ It is a specially designed PN junction diode. It is a heavily doped PN junction diode.



→ The operation of the zener diode is same as that of an ordinary PN junction diode in forward biased condition. But in Reverse biased condition, breakdown may occur in the junction of the diode. The breakdown voltage depends upon the amount of doping.

→ Heavily doped diodes breakdown at low voltage levels. Similarly lower doped diodes breakdown at high voltage levels.

V - I Characteristics :



→ In forward biasing, the current is linearly increased with respect to applied voltage. Now the conduction depends upon the majority carriers.

→ In Reverse biasing, the current is very low before breakdown levels.

→ After breakdown the current increases rapidly. The Reverse breakdown of the zener diode may occur due to the following Mechanism.

* Avalanche breakdown
* zener breakdown.

Avalanche breakdown:

→ This breakdown occurs at lightly doped zener diodes, the width of the depletion layer is large. When reverse bias voltage is increased, the accelerated free electrons Collide with the immobile ions in the depletion region.

→ Due to Collision Co-valent bonds are broken and electron-hole pairs are generated. These new carriers again acquire sufficient energy and Collide with other ions, thereby Generating further electron-hole-pairs. This process is Cumulative in nature and results in Generation of an avalanche charge carriers a short time. This breakdown occurs at higher reverse voltage levels.

Zener breakdown:

→ Zener breakdown takes place at heavily doped thin depletion layer diodes. A small reverse voltage, produces strong electric field across the depletion layer.

→ This electric field breaks a large no. of Co-valent bonds and produces large current. This process is called zener breakdown.

BIPOLAR JUNCTION TRANSISTOR:

→ Transistor is a semiconductor device, containing three layers & two junctions. There are two types of transistors.

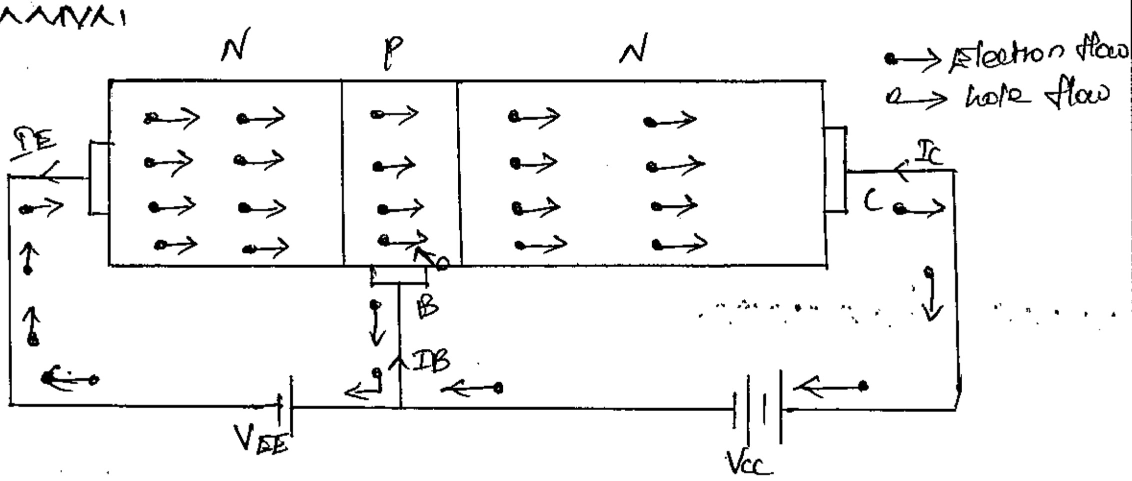
* NPN transistor
* PNP transistor.

→ In NPN, a thin layer of P-type is sandwiched between two N type layers.

→ In PNP, a thin layer of N-type is sandwiched between two P type layers.

→ The three portions of the transistor are emitter (E), Collector (C) and base (B). An arrow is marked in the emitter terminal, specifies the direction of current.

NPN Transistor:



→ The Emitter - base junction is forward biased by the potential V_{EE}. The Collector - base junction is reverse biased by the potential V_{CC}.

→ The forward bias potential V_{EE}, causes a lot of the electrons from the emitter region to cross over the base region. This produces the emitter current I_E.

→ The base is lightly doped, hence few no. of electrons from the emitter, recombine with the holes in the base region, producing the base current I_B. The remaining electrons move towards the Collector region by the Collector - base potential Vcc, which produces Collector current I_C.

→ According to the reverse bias voltage Vcc, between the Collector & base, a small reverse current flows through the region. Now Collector current consist of majority carriers and minority carriers, so the transistor is called BJT. The Emitter current is approximately equal to the sum of base current & Collector current.

→ According to the biasing, the transistor operates in three regions.

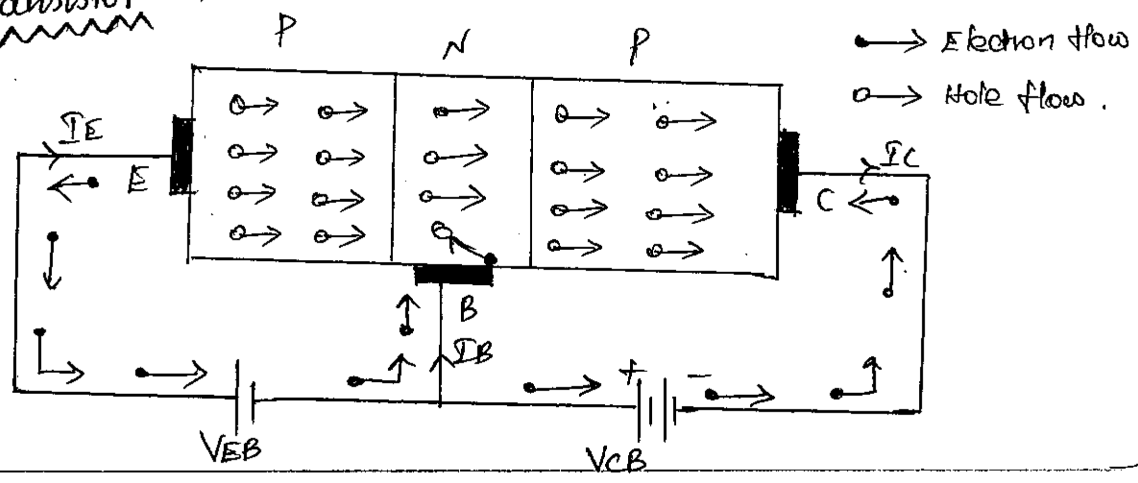
* Active
* Cut off
* Saturation.

→ During Active region, the input is in forward biasing and the output is reverse biasing.

→ In Saturation region, both input & output are in forward biasing.

→ In Cut-off region, both the input & output are in reverse biasing.

PNP Transistor



→ The operation of PNP is identical with the operation of NPN. Here the current flow depends upon the holes in the P-type emitter region.

→ The forward bias is applied in between base & emitter, and reverse bias is applied in between base & collector junction of the transistor.

→ The forward bias V_{EE} causes a lot of holes from the emitter region & constitutes the emitter current, to cross into the base region.

→ The base is lightly doped with N type impurity, therefore only a few holes combine with the electrons, constitute a base current I_B. The remaining holes cross into the collector region to constitute the collector current I_C.

→ $I_E = I_C + I_B$

Transistor Biasing:

→ The amplifiers which are used to magnify the weak signal without change in its wave shape & frequency are called faithful amplifiers.

→ For faithful amplifications, the transistor amplifier must satisfy three basic conditions.

* Proper zero signal collector current.
* Proper base to emitter voltage at any instant.
* Proper collector to emitter voltage at any instant.

→ 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.

→ The basic purpose of transistor biasing is to keep the base emitter junction properly forward biased & collector-emitter junction is reverse biased during the application of signals.

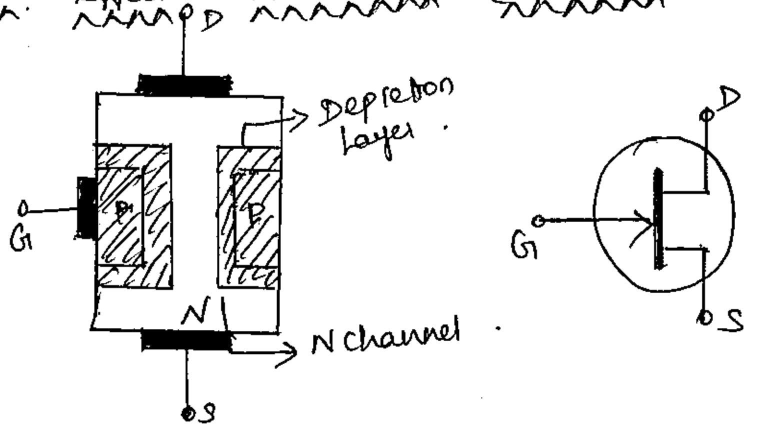
→ That means the transistor must operate only in active region. This can be achieved by using bias battery (or) resistor circuit with the transistor.

FIELD EFFECT TRANSISTORS:

→ Field effect transistor (FET) is a unipolar semiconductor device. The flow of current through it is controlled by an electric field. The flow of current only depends on the majority carriers, so the FET is called unipolar device.

- FET
  - JUNCTION FET JFET
    - N Channel JFET
    - P Channel JFET
  - MOSFET
    - DE-MOSFET
      - N channel
      - P channel
    - E-MOSFET
      - N channel
      - P channel.

Junction Field Effect Transistor (JFET):

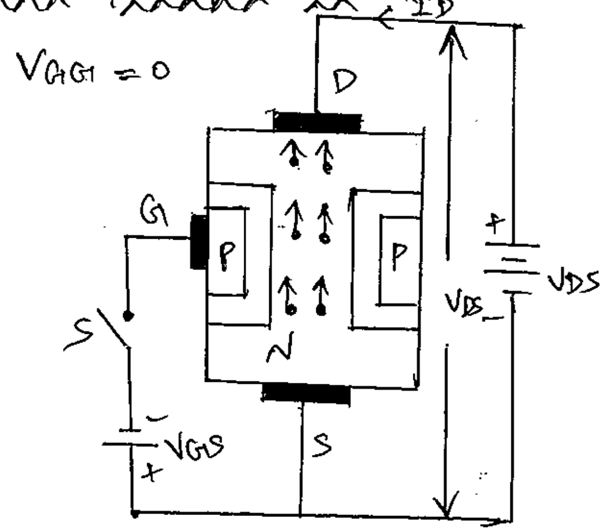


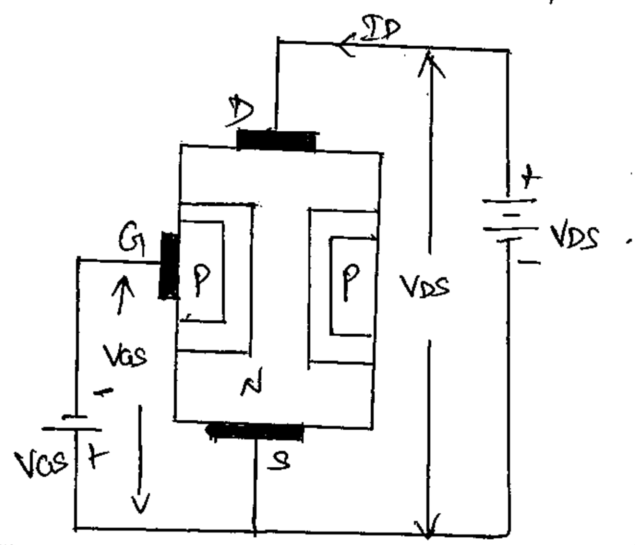
→ It consists of an uniformly doped N-type semiconductor bar. On both sides of the semiconductor bar, two heavily doped P-type regions are formed by diffusion. The two P-regions are internally connected, and a single lead is taken out. This terminal is called " Gate".

→ Ohmic contacts are made at the two ends of the N-type semiconductor bar. One terminal is called " source" and the other is called "Drain"

→ The source is a terminal, where majority carriers enter the bar. The drain is a terminal where majority carriers leave the bar. The region between source and drain is called channel. The majority carriers move from source to drain through this channel. The gate terminal controls the flow of majority carriers from source to drain.

Working Principle of JFET:

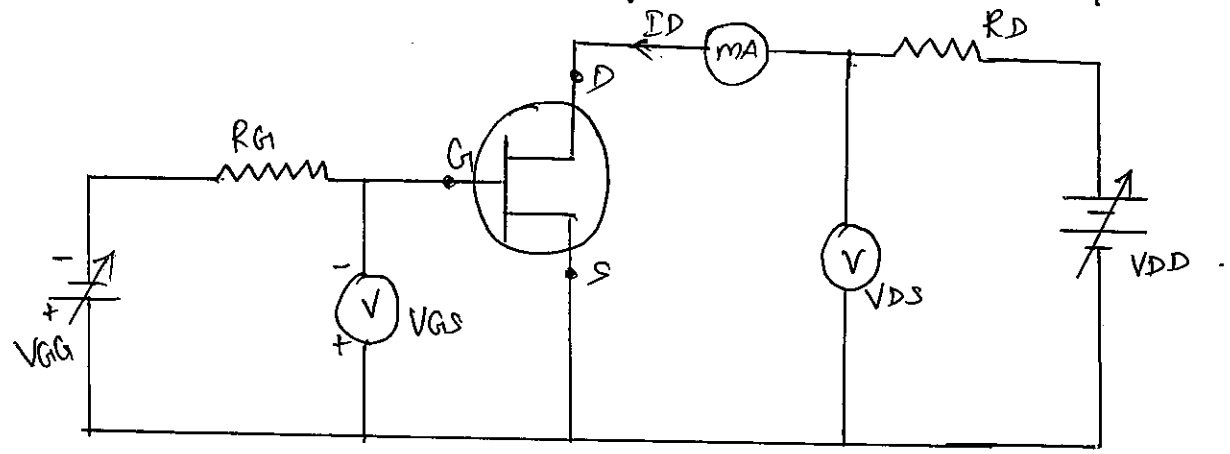




→ The N-channel JFET is normally biased by applying negative potential to the gate with respect to source. A positive potential is applied to the drain terminal with respect to source. The drain characteristics are obtained by taking the readings in between V_{DS} and I_D, with a constant variation of V_{GS}.

→ When $V_{GS} = 0$, the two p-n junctions established a very thin & uniform depletion layer. Thus a large amount of electrons will flow from drain to source through a wide channel, in between the depletion region. This constitutes drain current I_D.

→ When the reverse voltage V_{GS} is increased, it increases the width of the depletion region. This reduces the width of the channel. So the current flow is also reduced. The channel width is larger in the source region than the drain region.



→ Thus the current flowing through the channel is controlled by the reverse potential applied to the gate. Three regions are formed in the drain characteristics.

i) Linear region:

→ Initially as the drain to source voltage V_{DS} is increased, drain current I_D also increases. Such that I_D is directly proportional to V_{GS}. This region is called linear region (or) channel ohmic region.

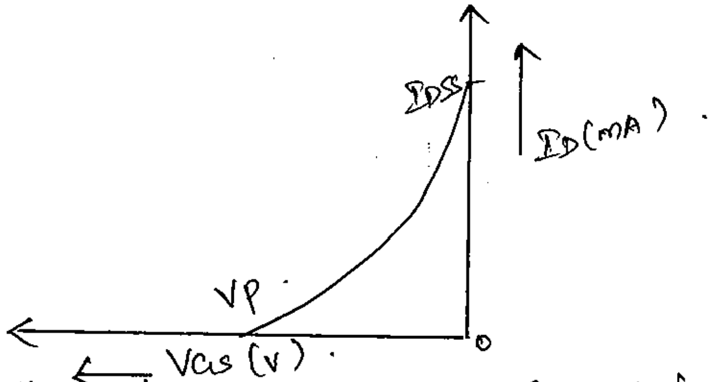
ii) Satuation Region:

→ After a certain drain to source voltage V_{DS}, the drain current becomes almost constant. Now the channel becomes very narrow. Therefore, the variation of drain current with the increasing of V_{DS} is constant. This region is called saturation region (or) pinch-off region.

iii) Breakdown Region:

→ After a certain increase of V_{DS}, the drain current increases to a very high value, with a slight increase of V_{DS}. Now the depletion region at the PN junction. undergo avalanche breakdown. This region is known as breakdown region.

→ The graph between I_D & V_{GS} at constant V_{DS} is called transfer (or) Mutual characteristics.



→ When $V_{GS} = 0$, the drain currents is in higher value. The increasing of V_{GS}, increase the width of depletion region, also reduces the drain current I_D.

From the graph,

i) Drain resistance $(r_d) = \dfrac{\Delta V_{DS}}{\Delta I_D}$ at constant V_{GS}.

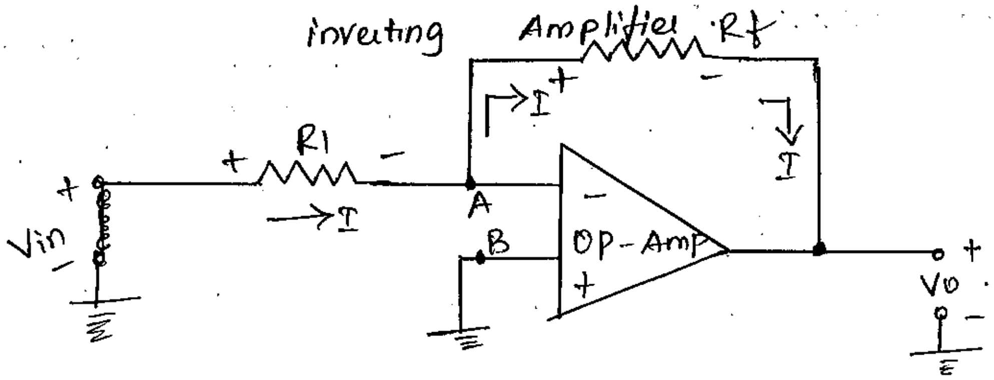
ii) Transconductance $(g_m) = \dfrac{\Delta I_D}{\Delta V_{GS}}$ at V_{DS}

iii) Amplification factor $(\mu) = \dfrac{\Delta V_{DS}}{\Delta V_{GS}}$ at I_D.

Inverting Amplifier :

→ The output of an amplifier is inverted as compared to the input signal. The inverted output signal means having a phase shift of 180° as compared to the input signal.

→ So, an amplifier which provides a phase shift of 180° between input and output is called inverting Amplifier.



Closed loop Gain :

→ As node B is grounded, node A is also at ground potential, from the concept of virtual ground, so $V_A = 0$.

$$I = \frac{V_{in} - V_A}{R_1}$$

$$I = \frac{V_{in}}{R_1} \quad \text{— (1)}$$

→ From the output side,

$$I = \frac{V_A - V_o}{R_f}$$

$$I = -\frac{V_o}{R_f} \quad \text{— (2)}$$

→ Entire current I passes through Rf as op-amp input current is zero.

(1) = (2) $\quad \frac{V_{in}}{R_1} = -\frac{V_o}{R_f}$.

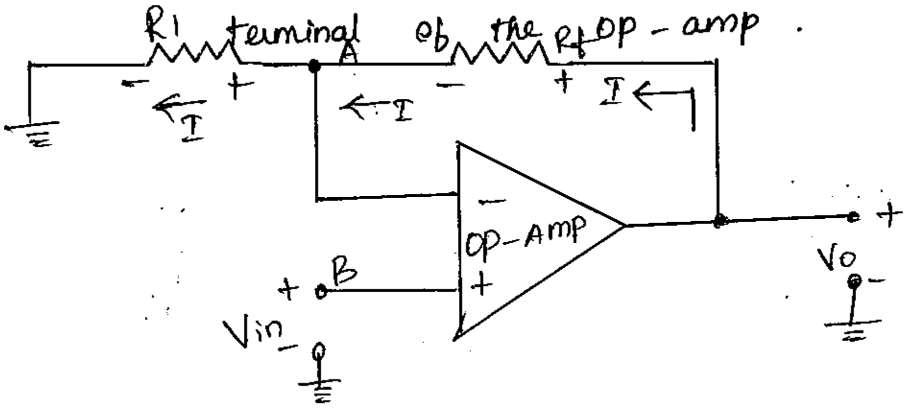
$$A_{vf} = \frac{V_o}{V_{in}} = -\frac{R_f}{R_1} \quad \text{(Gain with feedback)}.$$

→ The $\frac{R_f}{R_1}$ is the gain of the amplifier while negative sign indicates that the polarity of output is opposite to that of input.

Non-Inverting Amplifier:

→ An amplifier which amplifies the input without producing any phase shift between input and output is called Non-inverting amplifier.

→ The input is applied to the non inverting input terminal of the op-amp.



Closed Loop Gain:

→ The node B is at potential Vin, hence the potential of point A is same as B which is Vin, from the concept of virtual short.

$$V_A = V_B = V_{in}. \quad — (1)$$

→ From the output side,

$$I = \frac{V_o - V_A}{R_f}.$$

$$I = \frac{V_o - V_{in}}{R_f} \quad — (2)$$

→ At the inverting terminal,

$$I = \frac{V_A - 0}{R_1}$$

$$I = \frac{V_{in}}{R_1} \quad \text{--- (3)}$$

→ Entire current passes through R_1 as input current of op-amp is zero.

(2) = (3)

$$\frac{V_o - V_{in}}{R_f} = \frac{V_{in}}{R_1}$$

$$\frac{V_o}{R_f} = \frac{V_{in}}{R_f} + \frac{V_{in}}{R_1}$$

$$\frac{V_o}{R_f} = V_{in}\left[\frac{(R_1+R_f)}{R_1R_f}\right]$$

$$\frac{V_o}{V_{in}} = \frac{(R_1+R_f)R_f}{R_1R_f} = \frac{R_1+R_f}{R_1}$$

$$A_{vf} = \frac{V_o}{V_{in}} = 1 + \frac{R_f}{R_1}.$$

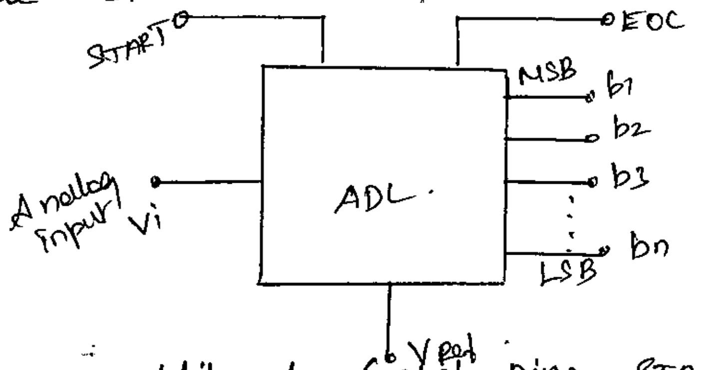
A/D CONVERTERS:

→ An A/D converter does ~~not~~ the inverse function of a D/A converter. It converts an analog signal into its equivalent n-bit binary coded digital output signal. The analog input is sampled at a frequency much higher than the maximum frequency component of the input signal. The digital output from an A/D converter can be in serial (or) parallel form.

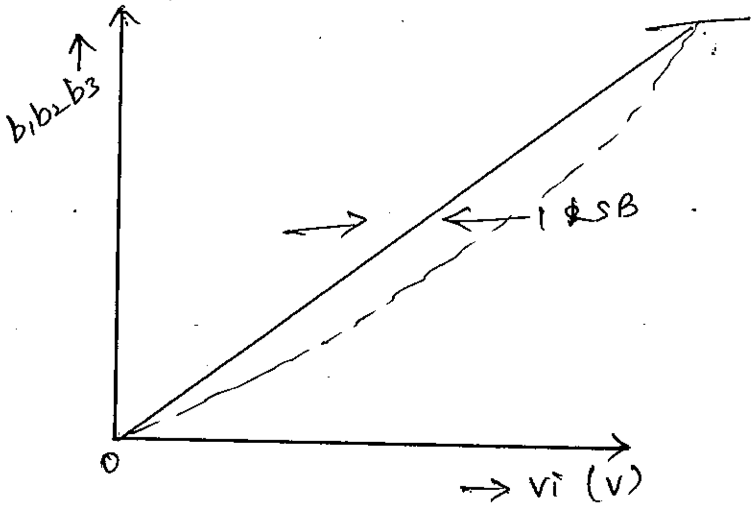
→ The A/D converter accepts an analog input V_i and produces an output binary word $b_1, b_2 \ldots b_n$ of fractional value D such that

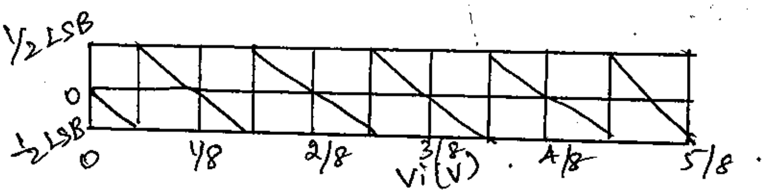
$$D = b_1 2^{-1} + b_2 2^{-2} + \ldots + b_n 2^{-n}.$$

Where b_1 is the MSB and b_n is the LSB.



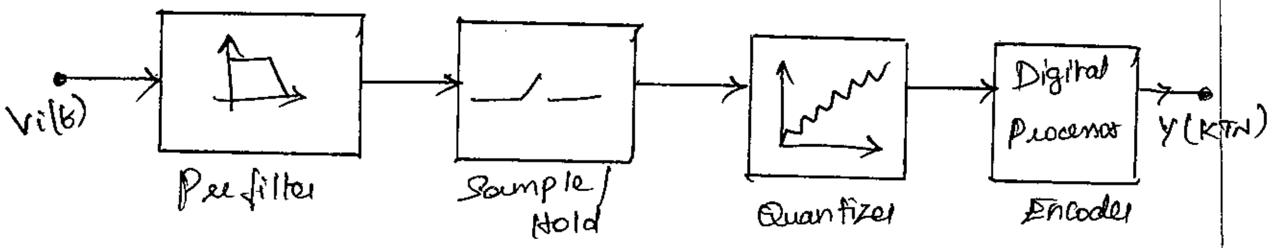
→ Two additional control pins START input and End of Conversion (EOC) output are provided with A/D converters. The START input initiates the conversion and the EOC announces when the conversion is complete. The output can be of parallel (or) serial form. Usually latches, control logic and buffers are provided to enable interfacing of the A/D converter to microprocessor (or) LCD/LED displays directly.





→ Shows the ideal characteristics of a 3 bit A/D converter with $V_{FS} = 1.0V$ where V_{FS} is the full scale analog voltage.

→ The A/D conversion process divides the analog input to 2^n intervals. These intervals are called code ranges and all the values of V_i falling within a code range are represented by the particular code.



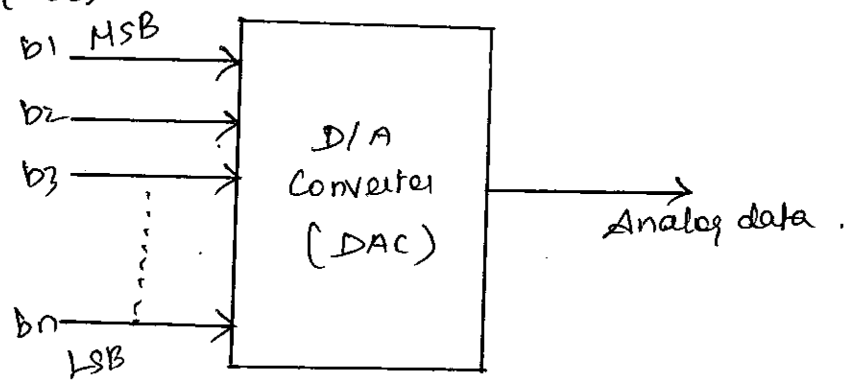
→ Shows the general block diagram of an A/D Converter. It Consists of an antialiasing filter (or) Prefilter, Sample and hold amplifier, a quantizer and an encoder. The prefilter avoids the aliasing of high frequency signals.

→ The Sample and Hold Circuit holds the input analog signal into an A/D Converter at a Constant value during the Conversion time. The quantizer segments the reference voltage signal into subranges. Typically, for an n-bit digital output Code, there are 2^n subranges.

→ The digital processor forms the encoder Circuit Which encodes the subrange into the corresponding digital bits. Therefore, the analog input signal is converted into an equivalent digital output Code within the Conversion time.

D/A CONVERTER:

→ The D/A Converter Converts digital (or) binary data into its equivalent analog value. The input digital data for a D/A Converter is an n-bit binary word D. The bit b_1 is called the Most significant bit (MSB) & bit b_n the least significant bit (LSB).



→ Then the quantity D can be represented by

$$D = b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \dots + b_n 2^{-n}.$$

→ The D/A converter accepts the binary input D and produces an analog output, which is proportional to D using a reference voltage V_R. The converted analog value is either in voltage (or) current form.

→ For a voltage output D/A converter, the conversion characteristic may be expressed as,

$$V_o = kV_{FS} = K\,V_{FS}\left(b_1 2^{-1} + b_2 2^{-2} + b_3 2^{-3} + \dots + b_n 2^{-n}\right)$$

V_o – output voltage.

V_{FS} – Full scale range of voltage

k – Scaling factor.

b_1 – MSB of weight $V_{FS}/2$

b_n – LSB of weight $V_{FS}/2^n$.

UNIT – IV

ELECTRON DEVICES & CIRCUITS

1. Mention the disadvantages of FET compared to BJT.

1. FET is a voltage controlled device 2. Less sensitivity to changes in applied voltage

2. Define pinch off voltage of a FET

The substrate is of p-type material on to which an n-type channel is epitaxially grown. A ptype gate is then diffused into the n-type channel.

3. Why FET is called as "Voltage operated device"?

The voltage applied between gate and source (VGS) controls the drain current ID Therefore, FET is a voltage controlled device

4. Define : Amplification factor in JFET

VDS

Amplification factor ---------- ID Constant = rd x gm SRI

VQS

5. What are power transistors? List it's applications.

Power transistors are designed for power amplification which means that the operating voltage and must be large.

Applications: 1. They are used in switching power supplies. 2. They are used in audio power amplifiers

6. Name the operating modes of a transistor?

1.Cut off 2.Active 3.Saturation

7. When does a transistor acts as a switch?

The transistor acts as a switch when it is operated at either cutoff region or saturation region.

8. Differentiate drift and diffusion current

When a voltage is applied to a material, the free electrons move towards the positive of the battery. While moving them collide with the adjacent atoms and keep changing their directions randomly. In case of diffusion current, the external voltage is not required.

9. What is a PN Junction diode

There are two electrodes each from p-type and n-type materials and due to these two electrodes; the device is called a diode. It conducts only in one direction.

10. What is meant by dynamic resistance of diode

The resistance offered by the p-n junction diode under a.c condtions is called dynamic resistance of diode.

11. What is depletion region in PN junction?

The region around the junction from which the mobile charge carriers (electrons and holes) are depleted is called as depletion region. Since this region has immobile ions, which are electrically charged, the depletion region is also known as space charge region.

12. Give the other names of depletion region?

i. Space charge region ii. Transition region 3. What is barrier potential? The oppositely charged ions present on both sides of PN junction an electric potential is established across the junction even without any external voltage source which is termed as barrier potential.

13. What is meant by biasing a PN junction?

Connecting a PN junction to an external voltage source is biasing a PN junction.

14. What are the types of biasing a PN junction?

1. Forward bias 2. Reverse bias

15. What is forward bias and reverse bias in a PN junction?

When positive terminal of the external supply is connected to P region and negative terminal to N region, the PN junction is said to be forward biased. Under forward biased condition the PN region offers a very low resistance and a large amount of current flows through it.

16. What is reverse bias in a PN junction?

When positive terminal of the external supply is connected to N type and negative terminal to P type then the PN junction is said to be in reverse bias. Under reverse biased condition the PN region offers a very high resistance and a small amount of current flows through it.

17. What is Reverse saturation current?

The current due to the minority carriers in reverse bias is said to be reverse saturation current. This current is independent of the value of the reverse bias voltage.

18. What is an amplifier?

An amplifier is a device which produces a large electrical output of similar characteristics to that of the input parameters.

19. Why contact differences of potential exist in PN junction?

When a PN junction is formed by placing a p-type and n-type material in intimate contact, the Fermi level throughout the newly formed specimen is not constant at equilibrium. There will be transfer of electron and energy until Fermi levels in the two sides did line up. But the valence and conduction band in p side cannot be at the same level as in n side .this shift in energy level results in contact difference of potential.

20. What is the static resistance of a diode?

Static resistance R of a diode can be defined as the ratio of voltage V across the diode to the current flowing through the diode. R = V/ I Where R - Static resistance of a diode V - Voltage across the diode I - current across the diode

21. Define dynamic resistance.

Dynamic resistance of a diode can be defined as the ratio of change in voltage across the diode to the change in current through the diode. r = V / I Where r - Dynamic resistance of a diode V - Change in voltage across the diode I - Change in current through the diode

22. What is biasing?

To use the transistor in any application it is necessary to provide sufficient voltage and current to operate the transistor. This is called biasing

23. Define an operational amplifier.

An operational amplifier is a direct-coupled, high gain amplifier consisting of one or more differential amplifier. By properly selecting the external components, it can be used to perform a variety of mathematical operations.

24. Mention the characteristics of an ideal op-amp.

* Open loop voltage gain is infinity. * Input impedance is infinity.

* Output impedance is zero. * Bandwidth is infinity.

* Zero offset.

25. What is piezo electric effect?

The piezo electric Crystals exhibit a property that if a mechanical stress is applied across one face the electric potential is developed across opposite face. The inverse is also live. This phenomenon is called piezo electric effect.

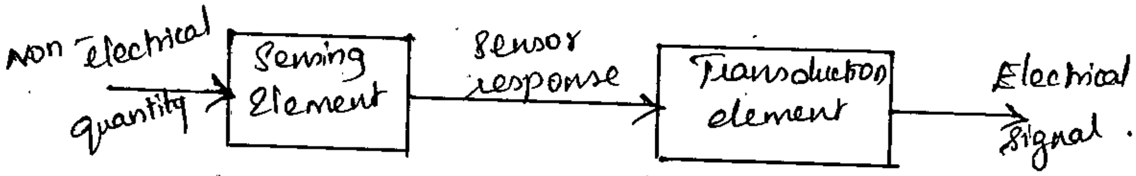
UNIT – V
MEASUREMENTS
& INSTRUMENTATION

UNIT – V

MEASUREMENTS & INSTRUMENTATION

TRANSDUCER :

→ A device which Converts a physical quantity into the proportional electrical signal is called a transducer.



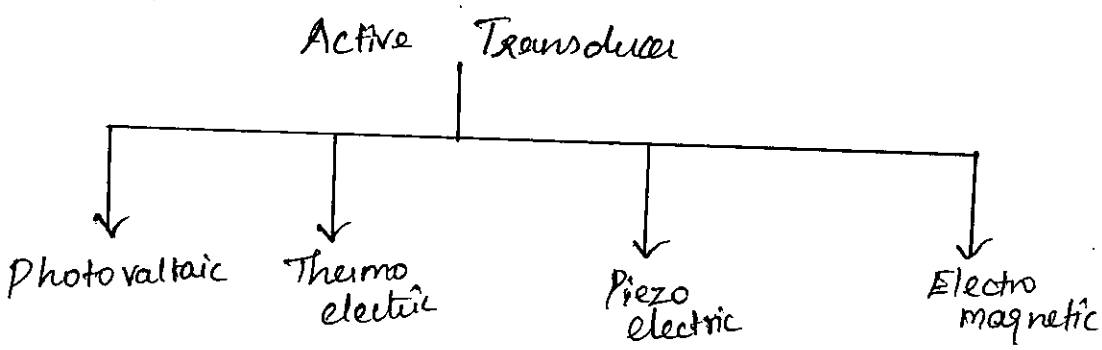
Classification of Transducers :

* Active Transducer
* Passive Transducer.

Active Transducer :

→ These are self generating type of transducers. these transducers develop an electrical parameter which is proportional to the quantity under measurement.

→ Do not require any external source (or) power for their operation.



Passive Transducer :

→ Do not Generate any electrical signal by themselves. To obtain an electrical signal from such transducers, an external source of power is essential.

Passive Transducer

- Variable Resistance
  - Photo Conductors
  - Strain gauge
  - Thermistor
- Opto electronic
  - Photo emissive
  - Photo Junctions.
- Variable reactance
  - Inductive
    - Variable reluctance
    - Variable Permeability
    - LVDT
    - Eddy Current.
  - Capacitive
    - Variable area
    - Variable separation
    - Variable Permittivity

RESISTIVE TRANSDUCERS:

→ The Resistance of a metal Conductor is Given by,

$$R = \frac{\rho L}{A}.$$

ρ => Resistivity of Conductor (Ωm)

L => Length of Conductor (m)

A => Area of Cross - section of Conductor (m^2).

→ The electrical resistive transducers are designed on the basis of the methods of Variation of any one of the quantities in above equation. such as change in length, Change in area of cross - section and change in resistivity.

→ The Resistive transducers can be used either as primary transducers or secondary transducers. The Methods based on measurement of the resistance change are most widely used in various industrial applications as,

i) Both ac and dc voltage and current are suitable for the measurement of resistance change.

ii) The speed of response of the resistive transducers is high.

iii) They are available in various sizes with wide range of resistance value.

iv) High resolution in measurement can be achieved as large variety of electrical Circuits are available.

→ The Resistance change due to the change in the length of the Conductor is used in translational (or) rotational potentiometers to measure linear (or) rotational displacement.

→ The change in resistance of Conductor or semiconductor due to the strain applied is the working principle of the strain gauge which is used to measure various physical quantities such as pressure, displacement and force.

→ The change in resistivity of Conductor due to the temperature variations causes change in resistance. This principle is used to measure temperature.

INDUCTIVE TRANSDUCER:

→ It is a simple & most popular type of displacement transducer in which variation of inductance as a function of displacement is achieved by variation in self inductance (or) mutual inductance.

→ In general, the value of self inductance of an inductor is given by,

$$L = \frac{N^2}{S}$$

N = Number of the coil.

S = Reluctance of the coil (A/Wb).

→ But the reluctance S is given by,

$$S = \frac{l}{\mu a}$$

→ Hence self inductance L is given by,

$$L = \frac{N^2 \mu a}{l}$$

N = Number of turns of coil.

μ = Permeability of core (H/m)

a = Area of magnetic circuit through which flux is passing (m^2)

l = Length of the magnetic circuit (m).

→ Thus the variation in the self inductance may be due to

i) change in number of turns
ii) change in reluctance.
iii) change in permeability.

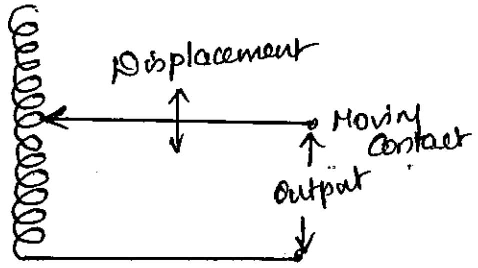
→ The Mutual Inductance between the two coils is given by,

$$M = K\sqrt{L_1 \cdot L_2}$$

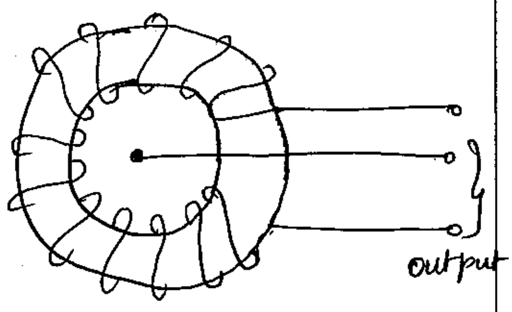
→ The Mutual Inductance between two coils can be varied by varying either self inductances of the coils or coefficient of coupling.

Transducer Inductance **Based on Principle of change in self with number of Turns.**

→ L is directly proportional to N^2 (i.e) square of the number of turns. This property can be used to measure linear as well as angular displacement.



Linear displacement

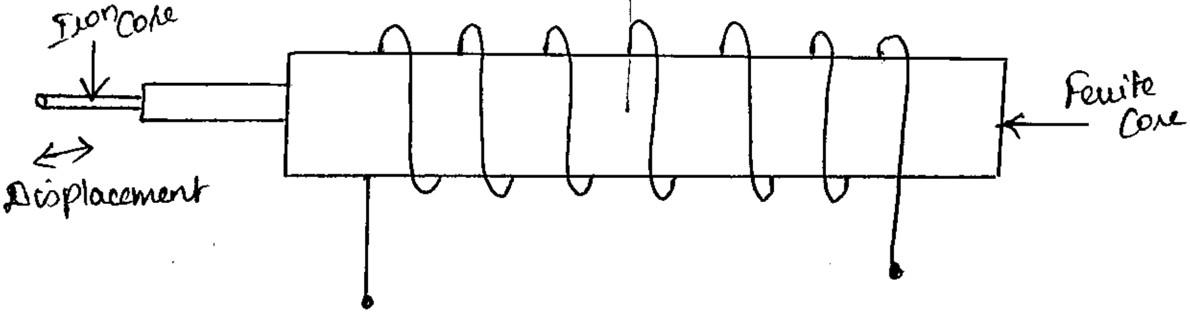


Angular displacement.

→ In both the cases, as no. of turns changes, the value of self Inductance changes and hence the output voltage also changes.

Variable Permeability Inductive Transducer:

→ The value of self inductance of a coil also depends on the permeability μ

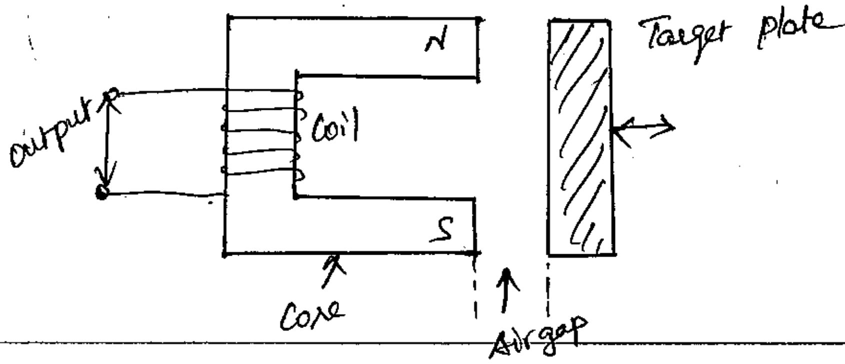


→ In this transducer, the displacement to be measured is applied to the rod which moves in and out of ferrite core according to the direction of the displacement.

→ When iron core moves in, the effective permeability increases, while when iron core moves out, the effective permeability decreases and accordingly output voltage changes.

Variable Reluctance Inductive Transducer:

→ The self Inductance L is inversely proportional to the reluctance S. It is a self generating type transducer.



→ A Coil is wound by C shaped Ferromagnetic core with a target plate placed above core with a small air gap.

→ The size of this air gap determines the reluctance of the magnetic circuit, which inturn decides the self Inductance.

→ The displacement to be measured is applied to the target plate. According to the displacement, the target plate moves which changes the air gap & hence the self inductance. Thus for different air gaps will get different values of inductance hence will get different output voltage.

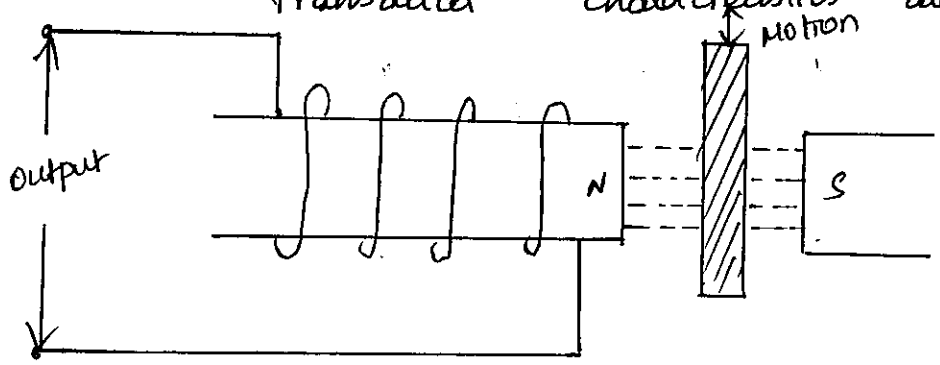
Eddy Current Type Inductive Transducer:

→ It is a self generating type transducer. A non-ferrous plate moves in a direction perpendicular to the lines of flux of a magnet

→ The eddy currents are generated in a plate which are proportional to the velocity of the plate.

→ These currents set up a magnetic field in a direction opposing the magnetic field producing these currents. Thus the output is proportional to the change in eddy current or the acceleration of the plate.

→ As the air gap between the magnet and the plate remains constant, the transducer characteristics are linear.



CAPACITIVE TRANSDUCER :

→ It works on the fundamental principle of electrical capacitance. The capacitance C of a system depends on the dielectric medium used and properties of a capacitive system.

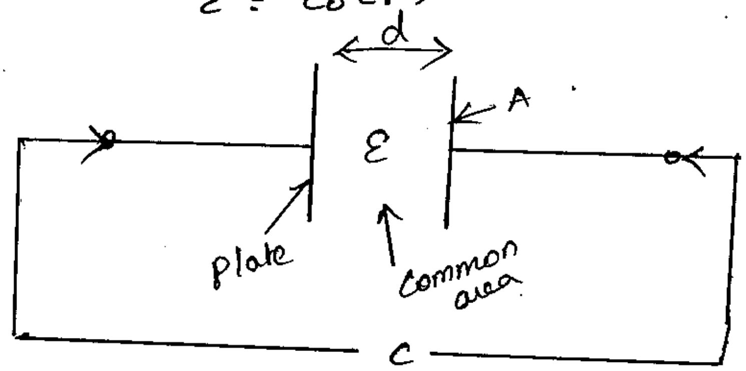
→ The important capacitances used in the capacitive transducers are,

i) Parallel plate capacitor :

→ The capacitance of a parallel plate capacitor is given by,

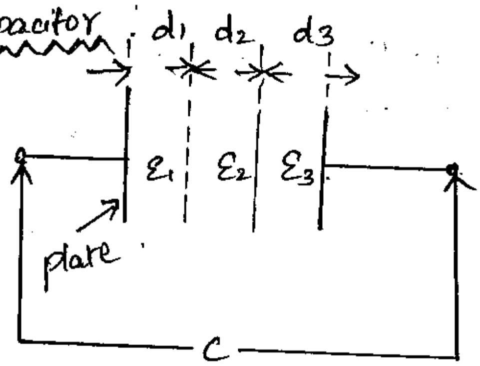
$$C = \frac{\varepsilon A}{d} F.$$

$$\varepsilon = \varepsilon_0 \varepsilon_r, \quad \varepsilon_0 = 8.85 \times 10^{-12} \text{ F/m}.$$



→ By using simple methods, the capacitance of the capacitor can be varied and change in its value can be used for transduction in a transducer

ii) Composite Capacitor :



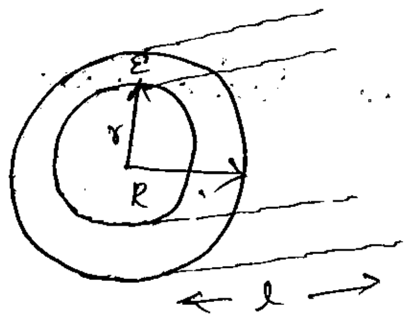
→ This capacitance consists of more than one dielectric medium in between the plates.

→ It consists of three layers of dielectrics having relative permittivities ε_1, ε_2 & ε_3. The layers having thicknesses d_1, d_2 & d_3.

→ The capacitance is given by,

$$C = \frac{\varepsilon_0 A}{\frac{d_1}{\varepsilon_1} + \frac{d_2}{\varepsilon_2} + \frac{d_3}{\varepsilon_3}}.$$

iii) Cylindrical Capacitor :



→ In this system, the plates are cylindrical separated by a dielectric.

$$C = \frac{2\pi\varepsilon l}{\ln(R/r)} \text{ F}.$$

r → outer radius of inner cylinder.

R → Inner radius of outer cylinder.

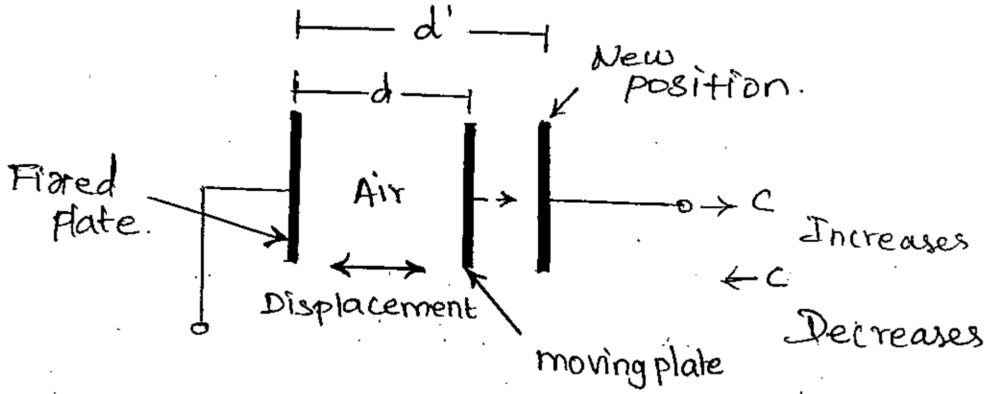
l → length of the cylinders.

Variation in Capacitance :

→ Variation of capacitance is achieved in four ways.

a) Change of distance :

→ The capacitance C depends on separation between the plates.

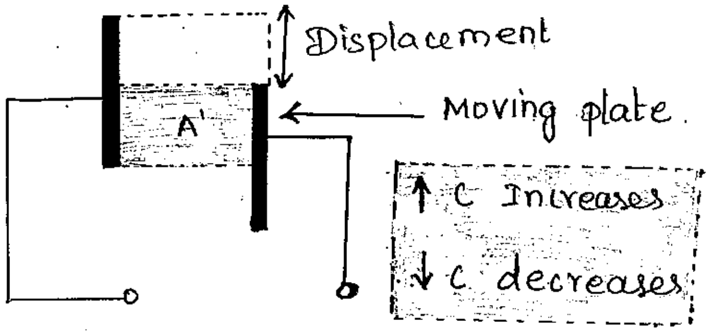


→ Thus by varying the distance of separation, C can be varied. The System in which distance is varied by keeping one plate fixed and other plate Moving.

→ As the distance increases from d to d' the capacitance decreases from C to C'.

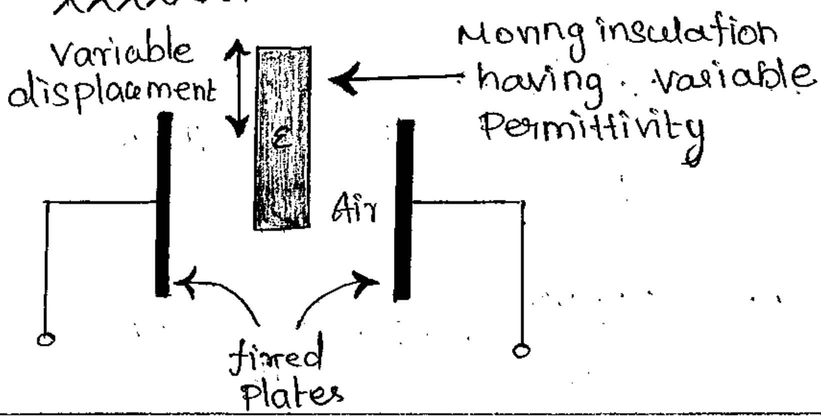
b) Change in Common plate area:

→ By keeping the one plate Moving and changing its position parallel to the other plate, Common plate area can be varied.



→ This Method is suitable in the measurement of rotational displacement.

c) Change in Dielectric:

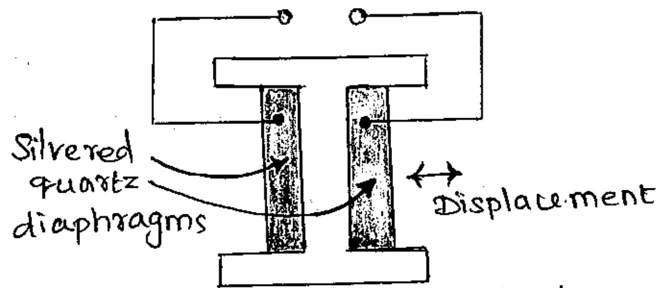


→ By inserting a slab of variable Permittivity, the Capacitance can be varied.

→ Introduction of slab of variable Permittivity gives rise to a Composite Capacitor

→ This Method is used in capacitance type level meter.

d) Using quartz diaphragms:

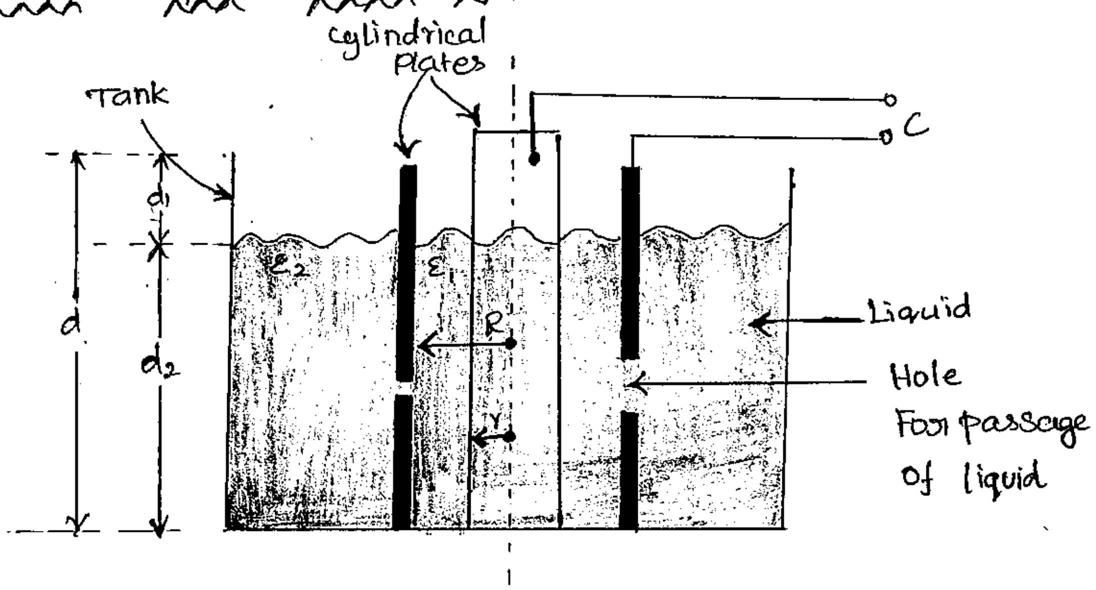


use of quartz disphragms.

→ In some cases the two silvered quartz diaphragms are used.

→ Depending upon the Pressure the displacement of these diaphragms vary and hence the capacitance of the System gets varied. This Method is used in capacitive Pressure transducers.

Capacitance Type Level Meter:



→ The capacitive transducer using the Method of change in dielectric is used for measurement of the liquid levels.

→ It uses Concentric Cylindrical capacitor. Two plates are Cylindrical using the dielectric Material with a permittivity ε_1.

→ When dielectric is an air $\varepsilon_r = 1$ & $\varepsilon = \varepsilon_0$.

→ The outer cylindrical plates have holes at the bottom through which passage of liquid is possible between the plates.

→ Let,

r = Outer radius of inner cylinder.
R = Inner radius of outer cylinder.
d = Height of tank.
d_2 = Level of liquid in tank.
ε_2 = Permittivity of liquid.

→ As the liquid level d_2 changes, the Composite capacitor formed experiences Change in its value.

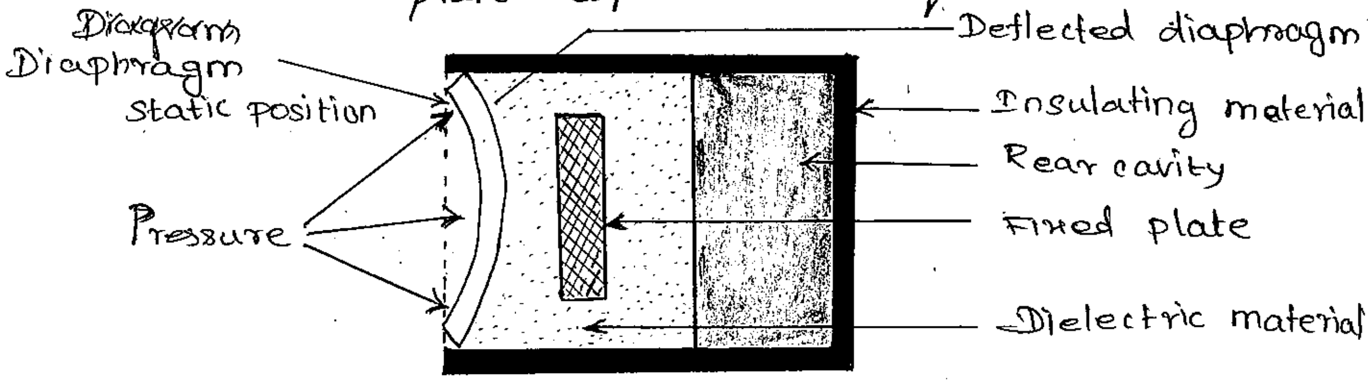
→ The value of capacitance is given by,

$$C = \frac{2\pi\varepsilon_0\left[\varepsilon_1 d_1 + \varepsilon_2 d_2\right]}{\ln\left(R/r\right)}.$$

→ This Change in Capacitance is detected by some other Circuit with which the electrical signal proportional to the liquid level can be obtained.

Capacitive Pressure Transducer

→ It is based on the principle that when the distance between the two parallel plate changes, capacitance of the parallel plate capacitor changes.



→ In this diaphragm acts as one of the plates of a two plate capacitor while other plate is fixed. The fixed plate and the diaphragm are separated by a dielectric material.

→ When the force is applied to the diaphragm it changes its position from initial static position obtained with no force applied.

→ Due to this, the distance of separation between the fixed plate & the diaphragm changes, hence the capacitance also changes.

→ The change in the capacitance can be measured by using any simple ac bridge. But practically the change in capacitance is measured using an oscillator circuit where capacitive transducer is part of that circuit. Hence when capacitance changes, the oscillator frequency changes.

Advantages of Capacitive Transducer:

The force requirement is very small, hence the power required to operate is small & very useful in small systems.

They are highly sensitive.

They have good frequency response & very high input impedance, so loading effects are minimum.

They are useful in the applications where stray magnet fields affect performance of the Inductive transducers.

Disadvantages:

Proper insulation is required between the metallic parts of the capacitive transducers.

The stray capacitances affect the performance of the transducer. It can be overcome by properly earthing the frame of the transducer.

They show non-linear behaviour due to edge effects and stray electric fields. These can be eliminated by using guard rings.

Due to long leads and the cables used, loading effect makes low frequency response poor & reduces sensitivity.

PIEZOELECTRIC TRANSDUCER:

→ When two opposite faces of a thin slice of certain crystals are subjected to a mechanical force, then opposite charges are developed on the two faces of the slice.

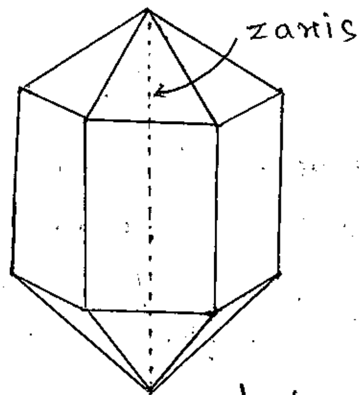
→ The magnitude of the electric potential between the two faces is proportional to the deformation produced.

→ The polarity of the potential produced across the faces gets reversed if the direction of deformation is reversed.

→ If varying potential is applied to the axis of the crystal, the dimensions are changed, and the crystal deforms. This phenomenon is called piezoelectric effect and the materials exhibiting this effect are called piezoelectric materials.

→ The main substances exhibiting piezo-electric effect are quartz, Rochelle salts and tourmaline.

Quartz Crystal:



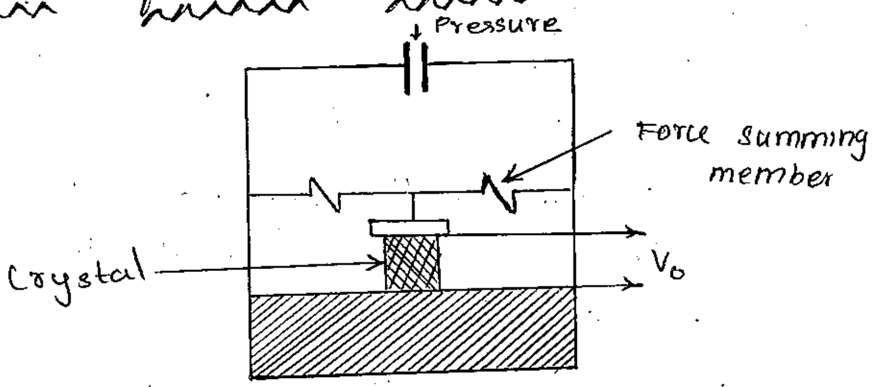
Diamond shaped

→ A piezo electric quartz crystal is hexagonal prism shaped crystal, which has pyramids at both ends. The marking of co-ordinate axes are fixed for such crystals.
→ The axis passing through the end points of pyramids called optic axis (or) z axis.

→ The axis passing through Corners is called electrical axis (or) x axis.

→ The axis passing through Midpoints of opposite sides is called Mechanical axis.

Piezo electric pressure transducer:



→ A crystal is placed between solid base and force summing member. Metal electrodes plated on to faces of piezo electric crystal are taken out to measure output.

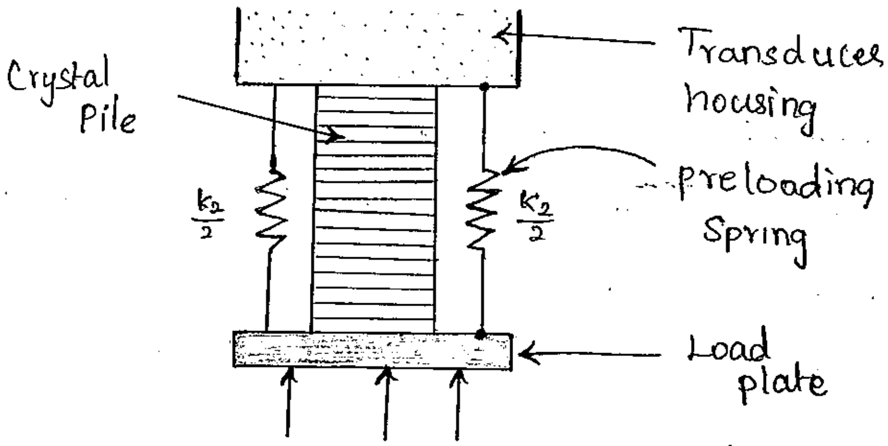
→ The electrodes become plates of the parallel plate capacitor. Thus it can be considered as charge generator.

→ The output voltage is given by,

$$V_0 = \frac{Q}{C}.$$

→ The output is very high and 1 to 30mV. No external power supply is required. High frequency response is excellent. Its size is small & construction is simple.

→ Practically the sensitive piezoelectric element of a piezoelectric pressure transducer is in the form of pile of pairs of quartz discs.



→ These discs are held in such a way that their optically flat faces are between a flat metal face called load Plate on one side and transducer housing on other side.

→ For this purpose preloading spring of stiffness K_2 is used. The stiffness of crystal is denoted as K_1.

→ Let P be the force produced by the external pressure. This gets split into two parts. The force P_1 in the crystal pile while the force P_2 in the preloading thin walled tube (or) a diaphragm.

→ The pile is compressed by say Δx then we can write,

$$P = P_1 + P_2 = K_1 \Delta x + K_2 \Delta x = (K_1 + K_2)\Delta x.$$

$$\frac{P_1}{P} = \frac{K_1 \Delta x}{(K_1+K_2)\Delta x} = \frac{K_1}{K_1+K_2} = \frac{1}{1+\frac{K_2}{K_1}}$$

Advantages:

* Rugged Construction & small size.
* High output with negligible phase shift.
* Excellent frequency response.

Limitations :

* Piezoelectric crystals are water soluable. Hence in a high humidity environment gets dissolved.
* Temperature sensitive.
* It can be used for dynamic measurements only.

PHOTO ELECTRIC TRANSDUCERS :

-> The photo electric transducers are used for producing photo electric effect which is the effect of visible radiations.

-> It include photo-emissive, photo conductive and photo-voltaic transducers.

Photo Emissive Transducer :

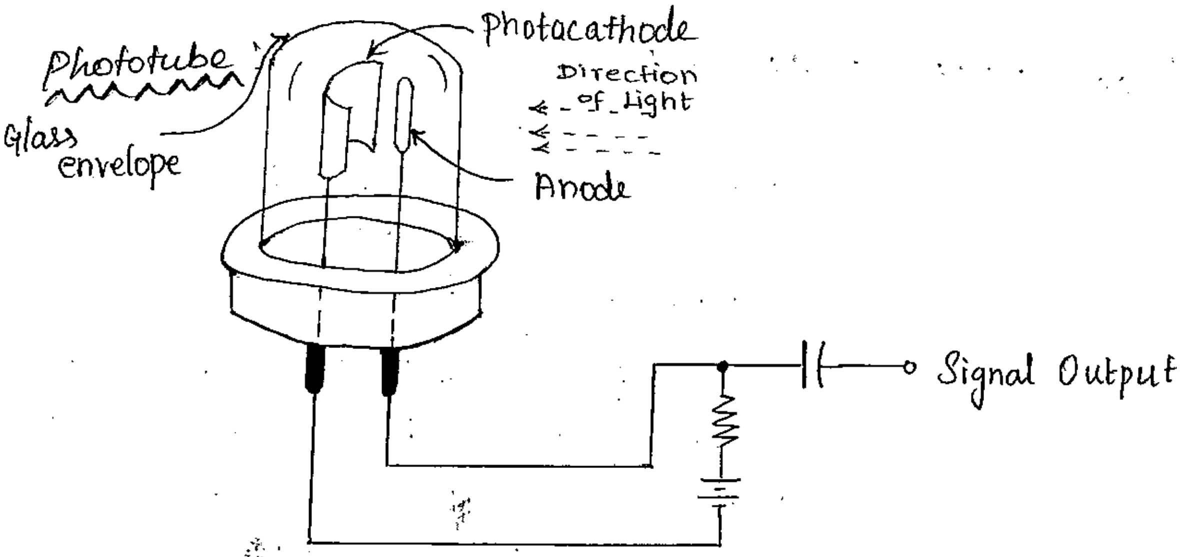
-> When the photons of the incident light with sufficient energy incident on the surface, the electrons break their atomic bonds as well as the forces of the entire material lattice. This effect is called photo emissive effect.

-> The common photo emissive material is Cesiom-antimony.

-> The photo emissive devices are also called photo tubes. Types of photo tubes are.

* Vacuum phototube
* Gas-filled phototube
* photomultiplier Tube.

Vacuum Phototube



→ A surface of specially shaped cathode is coated with some photoemissive material. This photocathode is housed in a sealed glass tube along with another electrode called anode.

→ A vacuum exists within the glass tube. A voltage is created between the photocathode and anode with anode having positive voltage level with photocathode having negative voltage level.

→ When light strikes the photocathode, the photons impart sufficient energy to the electrons, the electrons are emitted from the photocathode and collected by the positive anode. If the intensity of light incident is stronger, more no. of electrons are emitted.

→ Hence the magnitude of the current flowing in the circuit is directly proportional to the intensity of the light incident on the photocathode.

→ The response time of phototubes to the incident light is so rapid they are used in the applications where short duration light pulses are to be observed.

Gas - Filled Phototubes:

→ In this, the tube enclosing photocathode and anode is filled with an inert gas such as argon. The basic Construction of phototube remains same.

→ When light strikes the photo cathode, the electrons are emitted and they are accelerated towards the anode due to the voltage difference. The emitted electrons Collide with the argon gas atoms.

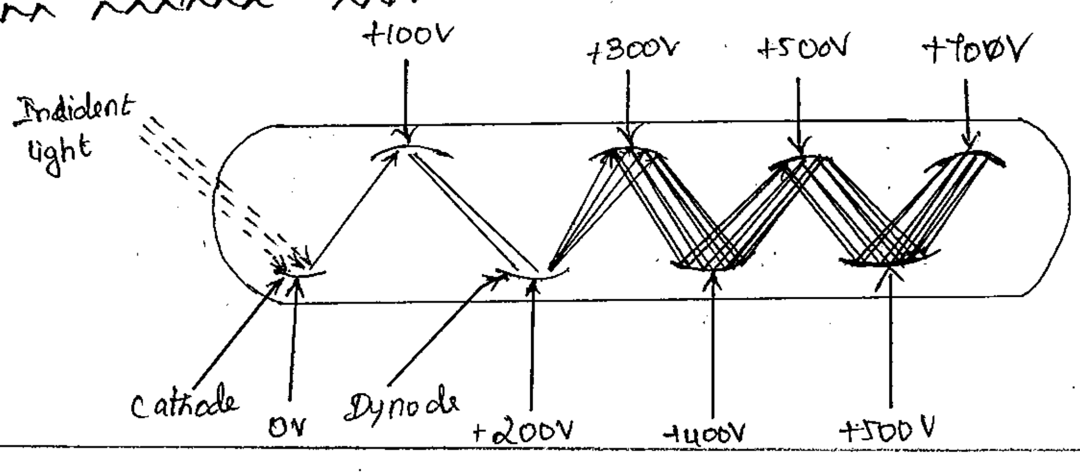
→ If the energy of the electron is high, it ionises argon atom during Collision. Hence Collision gives positive ions and additional free electrons.

→ As a result cathode attracts positive ions while anode collects free electrons. Hence Current in the external circuit increases.

→ Thus due to collisions of emitted electrons with an argon atoms, large Current flows in the Circuit.

→ The response time of the gas filled photo tubes is slow as compared to the Vacuum photo tubes as positive ions move relatively slowly towards the photocathode.

Photo Multiplier Tube:



→ The photo multiplier tube is actually amplifying device.

→ The beam of incident light is first made to strike a photo emissive material coated photo cathode similar to the ordinary vacuum photo tube. As a result, the electrons are emitted. But the emitted electrons are not immediately drawn to the anode. Instead, they are attracted to another electrode called dynode.

→ When the electron beam strikes dynode, it emits secondary electrons. Thus each individual photo electron is accelerated by an electric field externally applied and strikes several secondary electrons out of the dynode.

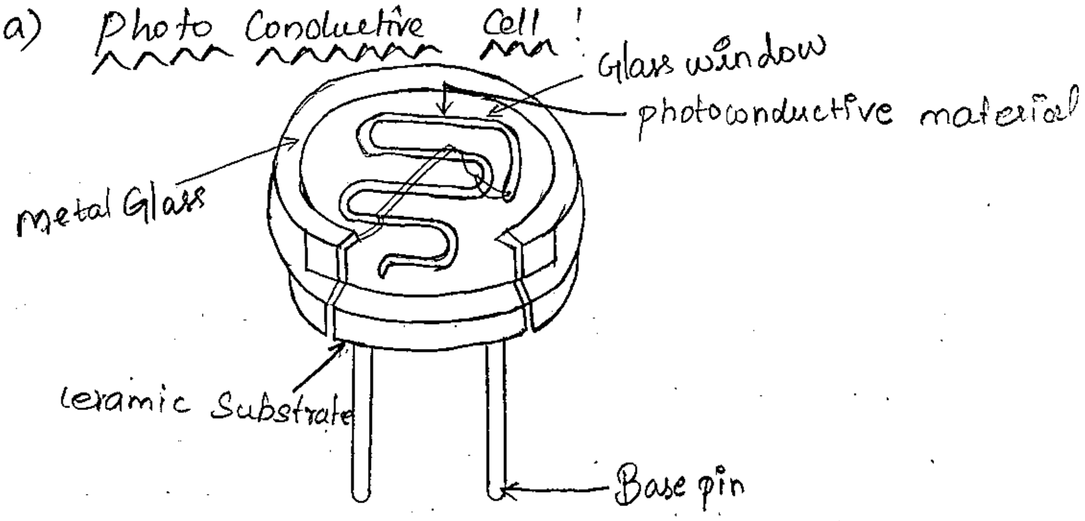
→ If dynode is designed such that it forms electric field lines which direct the emitted secondary electrons of previous dynode to itself.

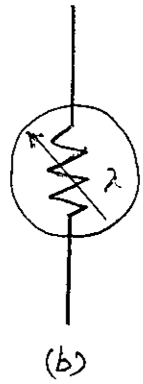
→ Thus at each dynode, the electrons are multiplied in numbers and finally all are collected by anode. Thus a multiplication factor over 10^6 can be achieved in some at the commercial tubes.

Photo Conductive Transducer:

→ When light falls on a material, the energy in the radiation ionizes the covalent bonds. Thus the bonds are broken & large no. of electron-hole pairs are generated. This increases no. of current carrier & decreases the resistance of the material. The phenomenon called photo conductive effect.

a) Photo Conductive Cell :





→ It is the Commonly used photosensitive element in the relays & proximity switches.

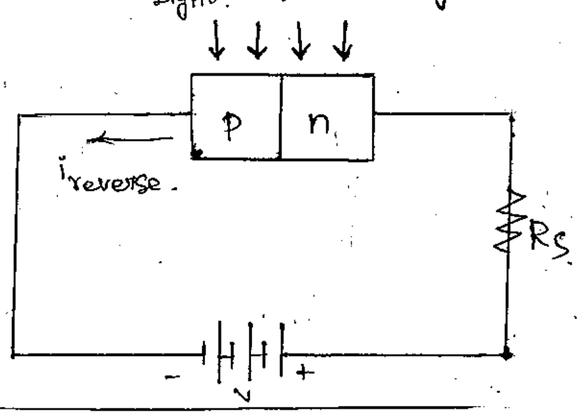
→ It is also used in intrusion alarms & a Counters as sensor. In this, light sensitive material is applied on disc in zigzag shape.

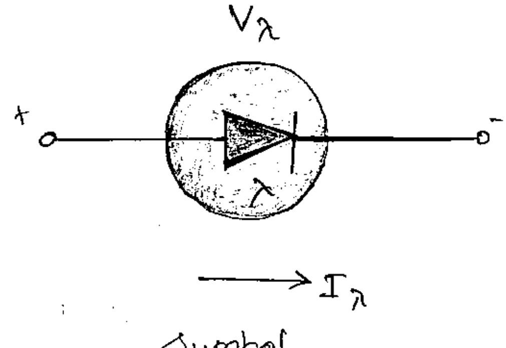
→ The Most Commonly used Materials are Cadmium sulphide (CdS) & Cadmium selenide (CdSe).

→ When the intensity of illumination increases, the no. of photons increases giving large no. of free electrons which inturns decreases resistivity.

b) photodiodes :

→ It is a diode which is used to detect light and its operation is limited in reverse bias region only.





Symbol

→ In a normal diode, under reverse biased condition, the reverse current is due to the minority charge carriers in p-type & n-type regions. This current is limited to few μA.

→ In photo diode, when light falls on it, the energy in the form of photons is transfer to the atomic structure. It results in increasing the no. of minority charge carriers in both the region and increasing reverse current level.

→ The variation in the reverse current with increase in light intensity. The rise & fall time in photo diodes is very small.

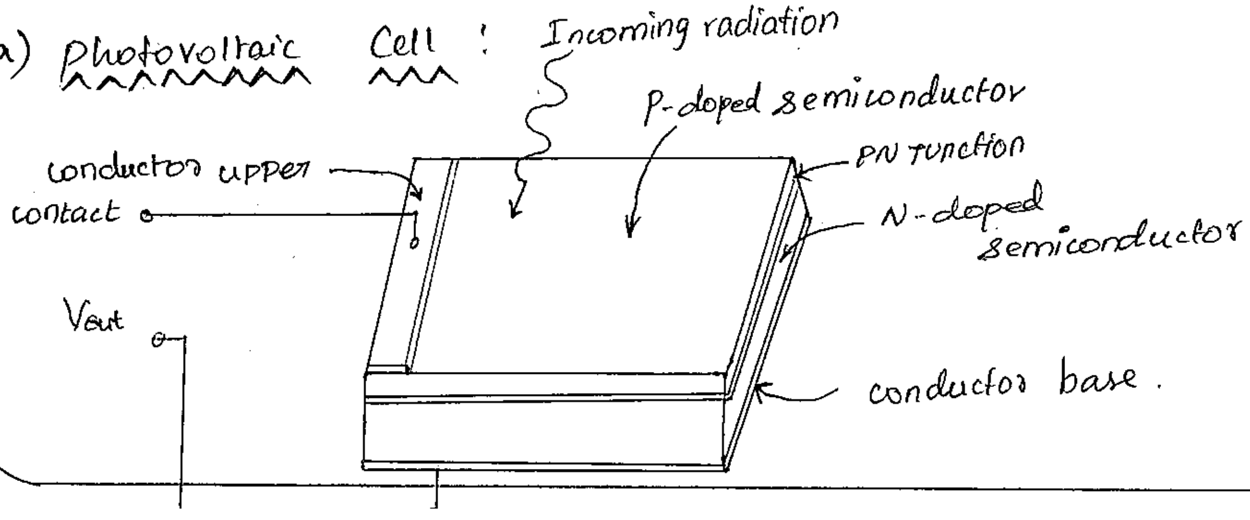
→ When a photodiode is illuminated without applying reverse biasing voltage, it acts as a voltage source with p-region positive & n-region negative. In this mode of operation it is called photovoltaic diode (or) solar cell.

Photovoltaic Transducer:

→ When an open circuited p-n junction is illuminated, large no. of electron-hole pairs are generated in the region near junction.

→ Typically, a small voltage appears across its terminals, hence acts as a voltage source. This phenomenon in which light energy is converted to electrical energy is called photovoltaic effect.

a) Photovoltaic Cell:

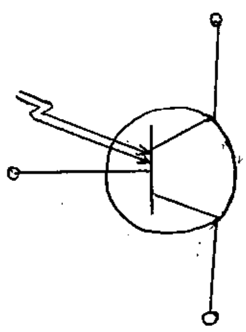


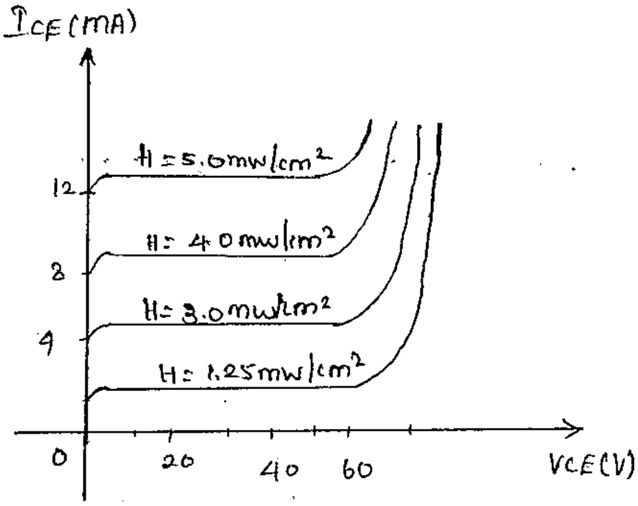
→ The Cell is actually a PN junction diode with appropriately doped semiconductor. When photons strike on the thin p-doped upper layer, they are absorbed by the electrons in the n-layer which causes formation of conduction electrons & holes.

→ These conduction electrons and holes are separated by depletion region potential of the pn-junction. When a load is connected across the cell, the depletion region potential causes the photo current to flow through the load.

b) Photo transistors :

(a)





→ In this, reverse biased collector base junction is nothing but photo diode. The reverse leakage current in the transistor is the diode current which increases with increase in intensity of light.

→ As base current increases, collector current also increases.

→ The phototransistor & infrared emitting diodes are used in combination to give optocoupler (or) opto isolator.

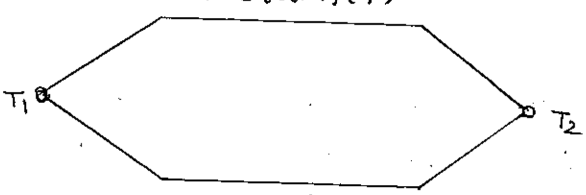
Thermo Electric Transducer:

→ It is a temperature transducer which converts thermal energy into an electrical energy. The Most Commonly used thermoelectric transducer is thermo couple.

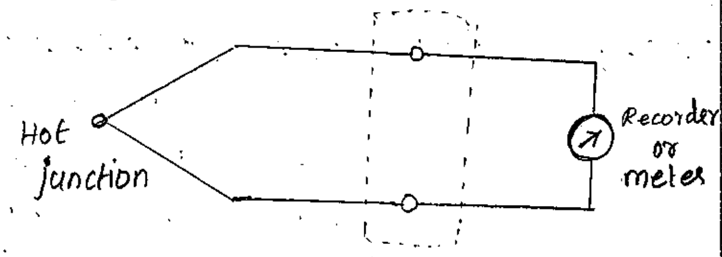
Construction of Thermo Couple:

→ A thermo couple is the most commonly used thermo electric transducer. It is made up of two wires of dissimilar metals joined together to form two junctions.

(a) Basic thermocouple circuit.



(b) Practical thermocouple circuit



→ Out of two junctions T_1 and T_2, T_2 is kept at constant reference temperature. Hence it is refered as cold junction.

→ While the temperature changes to be measured are subjected to the junction T_1 which is refered as hot junction.

→ When the hot junction temperature is greater as compared to the cold junction; emf is generated due to the temperature gradient. The Magnitude of the emf generated depends on the material used for the wires and temperature difference between the two junctions.

→ The hot junction is sometimes called measuring junction while the cold junction is called reference junction.

→ The two wires of the thermocouple are generally twisted + welded together.

→ In general a junction may be formed by two Methods, namely,

* twisted weld
* Butt weld

→ In twisted weld, two wires are twisted together in several turns and welded together. This type of welding is used for larger sized wires which gives Mechanical Strength.

→ In Butt weld, two wires of comparatively smaller sizes are fused into a round bend.

Materials Used for Thermocouples:

→ The thermocouples are made from a no. of different metals including copper - constant, iron - constantan, chromel - constantan, platinum - platinum - rhodium etc.

Thermo electric Laws:

* The application of heat to a single homogenous metal is in itself not capable of producing or sustaining an electric current.

* A thermo electric emf is produced when the junctions of two dissimilar homogeneous metals are kept at different temperatures. This emf is not affected by temperature gradients along the conductors. In other words, the emf is not affected by temperatures T_3 & T_4 along the conductors.

* In a thermocouple, having the junctions at different temperatures, the emf developed will not be affected when a third homogeneous metal is made a part of the circuit, provided that the temperatures of its two junctions are same. This is called law of intermediate metals.

CLASSIFICATION OF INSTRUMENTS :

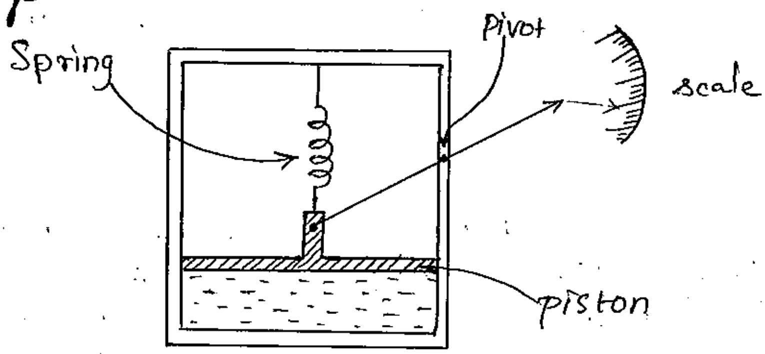
* Active / passive Instruments
* Null / deflection type Instruments
* Monitoring / Control Instruments
* Analog / digital Instruments
* Absolute / secondary Instruments.

Active / Passive Instruments :

Passive Instruments :

→ The Instruments in which the output is produced entirely by the quantity being measured, are called passive Instruments.

→ The example of such an Instrument is pressure gauge.



↳ pressure gauge.

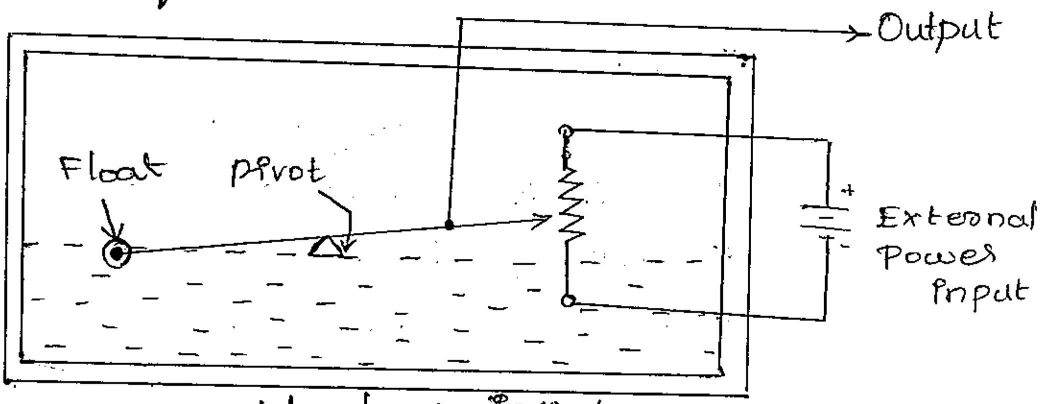
→ As the liquid pressure changes, the piston moves to which pointer is connected. Thus the liquid pressure, due to which piston and hence pointer moves, is solely responsible for the measurement

→ No other input energy source other than liquid pressure is used in this instrument.

Active Instruments :

→ The Instruments in which the quantity to be measured just activates the magnitude of some external power input source which inturn produces the measurement are called active Instruments.

→ The example of such an active instrument is liquid level indicator.



Liquide level Indicator

→ The potentiometer & the external power input is used to sense the position of float which is proportional to the level of the liquid in a tank.

→ When the level changes, the float moves & hence slider of the potentiometer also moves. This derives the voltage, which is the part of the external power input, which produces the output. Thus the variable to be measured just modulates the magnitude of external power source.

S.NO	Passive Instruments	S.NO	Active Instruments.
1.	The output is produced entirely by the quantity being measured.	1.	The quantity to be measured activates some external power input source, which inturn produces the output.
2.	Additional energy input source not required.	2.	Additional external energy input source is required.
3.	The resolution is less	3.	The resolution is high.
4.	The resolution cannot be easily adjusted.	4.	The resolution can be adjusted.
5.	Simple to design	5.	Complicated to design.
6.	Cheaper	6.	It is Costlier.

Null / Deflection Type Instruments :

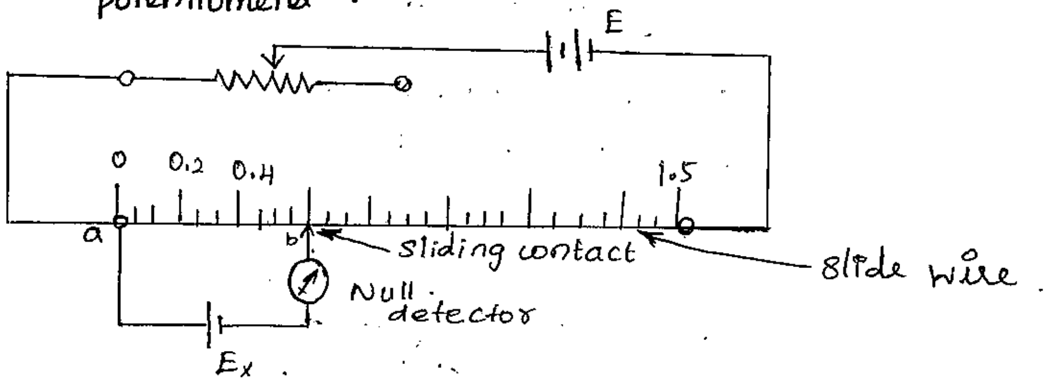
Null type Instruments :

→ The instruments in which a zero or null indication leads to the determination of the magnitude of the measured quantity are called null type Instruments.

→ A Null type Instruments requires,

* The effect produced by measured quantity.
* The opposite effect the value of which is known.
* The null detector.

→ The example of null type instrument is dc potentiometer.



→ In this, the slide wire is calibrated interms of emf with the help of standard emf source. The null detector is generally a galvanometer.

→ The deflection of galvanometer is proportional to the difference between the emf E_{ab} and unknown emf E_x.

→ When these two emfs are equal to the galvanometer shows null deflection. In such case E_x is equal to E_{ab}, where E_{ab} is known. Which is directly indicated on slide wire, Thus unknown emf E_x can be determined.

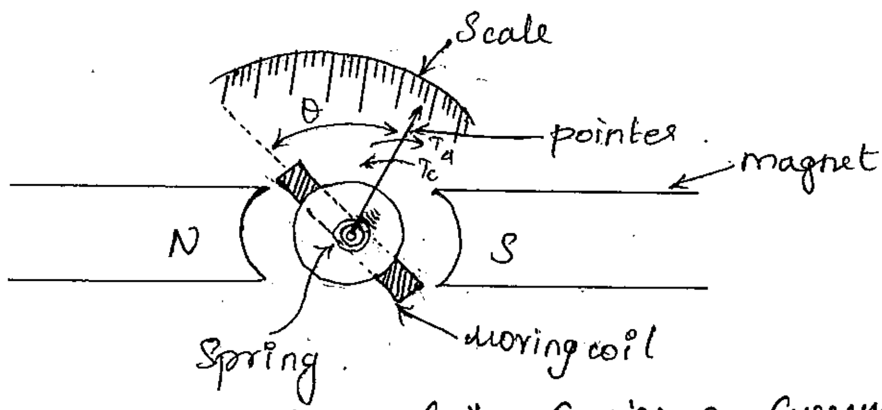
Deflection Type Instruments :

→ The instruments in which the quantity to be measured produces some effect due to which pointer deflects, are called deflection type instruments.

→ The pointer deflection is proportional to the quantity to be measured. The controlling torque which acts opposite to the pointer deflecting torque is provided in such instruments.

→ When the opposing torque is equal to deflecting torque, the pointer is in balanced condition showing the reading on the calibrated scale which is the value of the quantity to be measured.

→ The example is permanent Magnet Moving Coil ammeter.



→ The Moving Coil carries a current to be measured. It produces its own flux. It is placed under the Magnetic field of permanent Magnet.

→ Due to interaction the two fluxes, Coil moves. Hence the pointer deflects under the influence of the deflecting torque T_d. The controlling torque T_c is provided by spring.

→ When $T_d = T_c$, the pointer attains the steady position. The deflection θ is proportional to the current through the coil which is to be measured.

S.No	Null type Instrument	S.No	Deflection type Instrument
1.	It uses null detector, the effect produced by measured quantity and opposite effect to obtain null condition.	1.	In this, the quantity to be measured produces some effect which deflects the pointer against controlling torque.
2.	The accuracy is high	2.	The accuracy is less.
3.	Highly sensitive	3.	Less sensitive.
4.	Not suitable for dynamic and rapid measurements.	4.	Preferred for the dynamic measurements.

Monitoring / Control Instruments:

Monitoring Instruments:

→ The Instruments which are used to monitor the process, Indicating the value (or) condition of parameter under ~~steady~~ study are called the Monitoring Instrument.

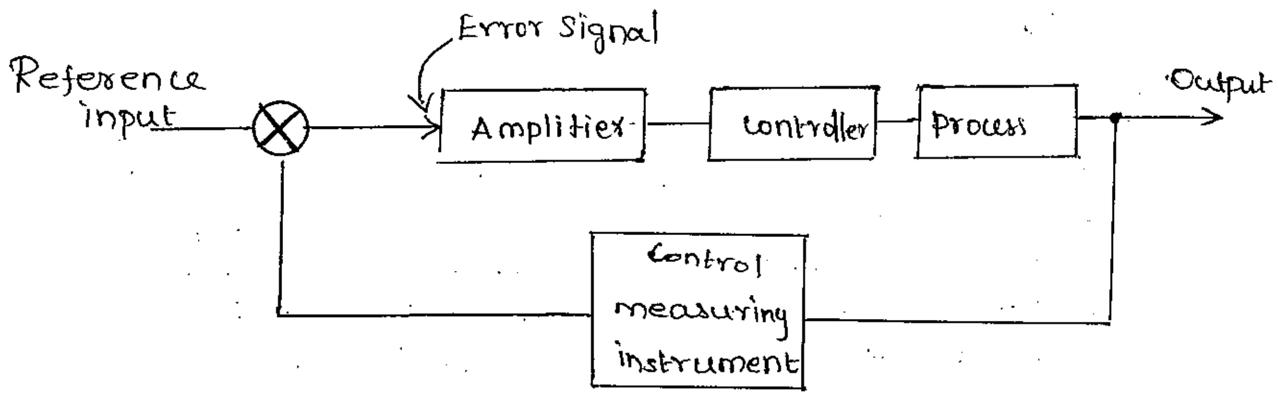
→ Such Instruments give as audio (or) visual Indication of the Magnitude of the quantity to be measured.

→ All the deflection type Instruments like voltmeter ammeter etc are all the null type Instruments, thermometers & passive transducers are the Monitoring Instruments.

Control Instruments:

→ The Instruments which are used in automatic control system are called control Instruments.

→ Generally such Instruments have an electrical output. Such Instruments used in the F/B path to measure the O/P and F/B the Information to the Controller.



→ The Control Instrument measures the o/p and sends it to the input side in the proper form. There it gets compared with the reference input to produce an error signal.

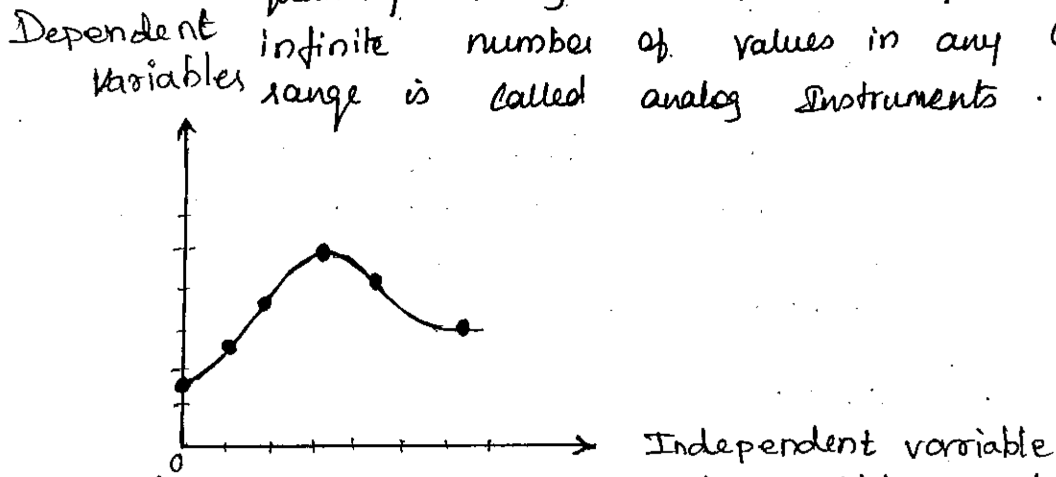
→ The error signal is amplified & given to the Controller. the Controller decides the proper controlling action and Controls the process.

→ This produces the required output which is a Controlled Variable.

Analog / Digital Instruments :

Analog Instruments :

→ The Instrument Which gives the output Which varies in Continuous fashion as the quantity being measured changes, takes infinite number of values in any Given range is called analog Instruments.



→ The voltmeter, ammeter which are deflection type instruments are the good examples of the analog Instruments.

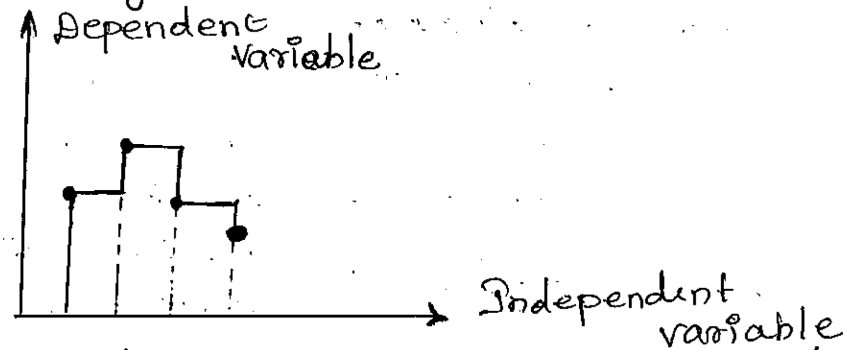
→ As the input value changes, the pointer immediately

Moves with a smooth continuous motion.

→ Thus the pointer can be in an infinite no. of positions within its range of movement.

Digital Instrument:

→ The instrument which gives the output which varies in discrete steps and thus take only finite different values in the given range is called digital instrument.



→ For example, if the value shown by analog instrument having a range of 0-10 is 3.5 unit, then the digital instrument with 10 equal parts show the same reading as 3.

→ The analog reading of 0.5 means a reading of zero of a digital instrument.

→ In digital instruments, the magnitude is measured only at the instant the reading is taken.

Absolute / Secondary Instruments:

Absolute Instrument:

→ The instrument which gives the magnitude of the quantity to be measured in terms of the physical constants of the instrument, is called an absolute instrument.

→ The galvanometer is the example of an absolute instrument.

Secondary Instrument:

→ The instrument in which the reading shown by the instrument gives directly the measurement of the quantity to be measured is called a secondary Instrument.

→ The ammeters, voltmeters, thermometers are the examples of the secondary instruments.

INSTRUMENT TRANSFORMERS:

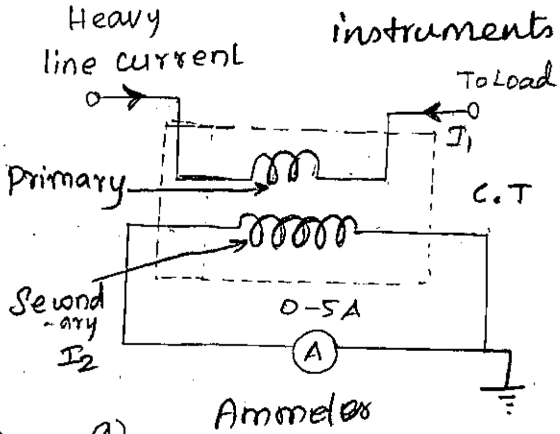
→ In heavy currents and high voltage ac circuits, the measurement cannot be done by using the method of extension of ranges of low range meters by providing suitable shunts. In such conditions, specially constructed accurate ratio transformers called instrument transformers.

→ These are generally classified as

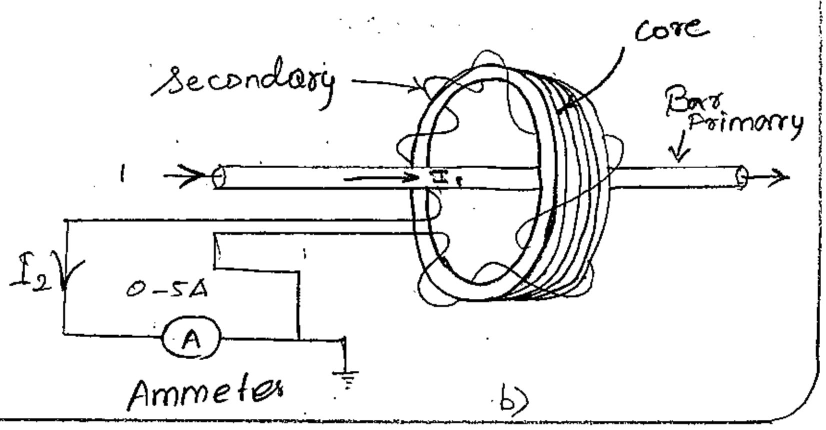
* Current transformer
* Potential transformer.

Current Transformer:

→ The large alternating currents which cannot be sensed or passed through normal ammeters and current coils of wattmeters, energy meters can easily be measured by use of current transformers along with normal low range instruments.



a)



b)

→ A transformer is a device which consists of two windings called primary and secondary. It transfers energy from one side to another with suitable change in the level of current (or) voltage.

→ A current transformer basically has a primary coil of one (or) more turns of heavy cross-sectional area. In some, the bar carrying high current may act as a primary.

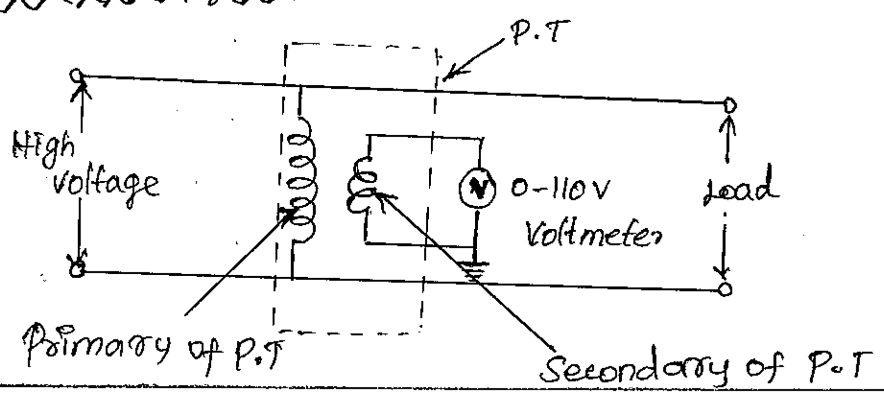
→ This is connected in series with the line carrying high current. The secondary of the transformer is made up of a large no. of turns of fine wire (i,e) having small cross-sectional area. This is usually rated for 5A current.

→ These transformers are basically step up transformers (i,e) stepping up a voltage from primary to secondary. Hence obviously current considerably gets stepped down from primary to secondary.

$$\frac{I_1}{I_2} = \frac{N_1}{N_2}$$

→ This is the current and no. of turns, relationship for the current transformer. Hence if current ratio of C.T is known and meter reading is known, the actual high line current value can be determined.

Potential Transformer (P.T):



→ The basic principle of these transformer is same as current transformers.

→ The high alternating voltages are reduced in a fixed proportion for the measurement purpose with the help of potential transformers.

→ These are extremely accurate ratio stepdown transformers. The windings are low power rating windings.

→ The primary winding consist of large no. of turns while secondary has less no. of turns and usually rated for 110V, irrespective of the primary voltage rating.

→ The primary is connected across the high voltage line while secondary is connected to the low range voltmeter coil.

→ One end of the secondary is always grounded for safety purpose.

→ As a normal transformer, it's ratio can be specified as,

$$\frac{V_1}{V_2} = \frac{N_1}{N_2}.$$

Advantages:

* The normal range voltmeter & ammeter can be used along with these transformers to measure high voltage and currents.

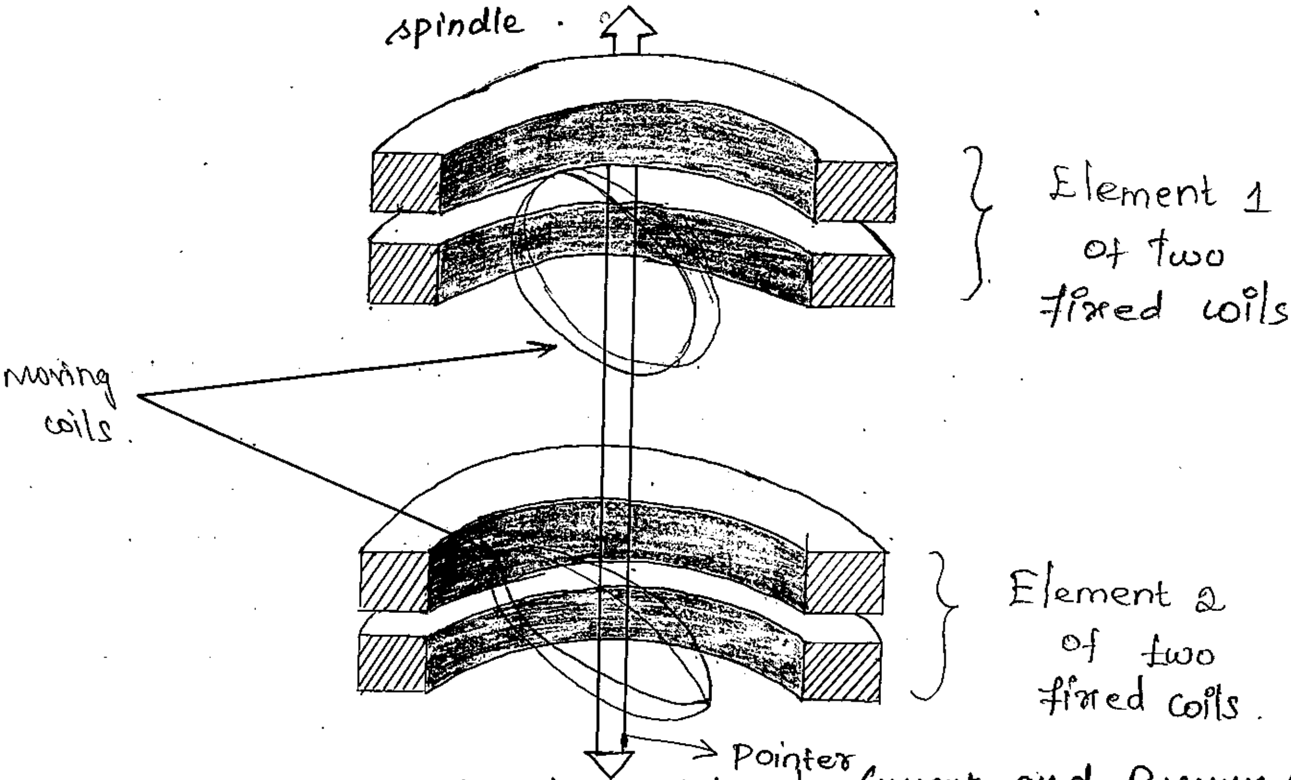
* The rating of low range meter can be fixed irrespective of the value of high voltage (or) current to be measured.

* These can be used for operating many types of protecting devices such as relays (or) pilot lights.

THREE PHASE POWER MEASUREMENT:

Three phase wattmeter:

- It consists of two sets of fixed and moving coils, mounted together in one case.
- The moving coils are placed on the same spindle.



- Due to two sets of current and pressure coils, its connections are similar to the connections of two single phase wattmeters to measure three phase power.
- Each element experiences a torque which is proportional to the power measured by that element.
- The net torque on the moving system is the sum of the deflecting torques produced on each of the two elements.

$$T_{d1} \propto W_1 \quad \& \quad T_{d2} \propto W_2 .$$

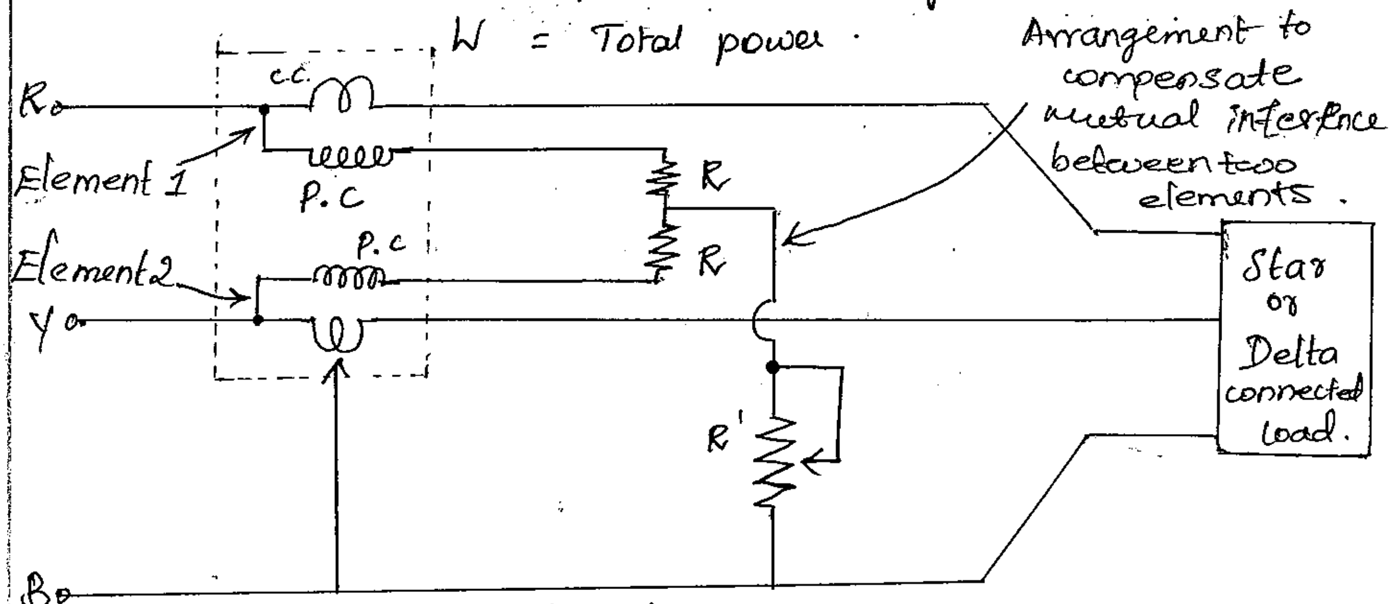
$$T_d \propto (T_{d1} + T_{d2}) \propto (W_1 + W_2) \propto W$$

$T_d \Rightarrow$ Total deflecting torque

$W_1 \Rightarrow$ power measured by element 1

W_2 = power measured by element 2

W = Total power.



Three phase wattmeter

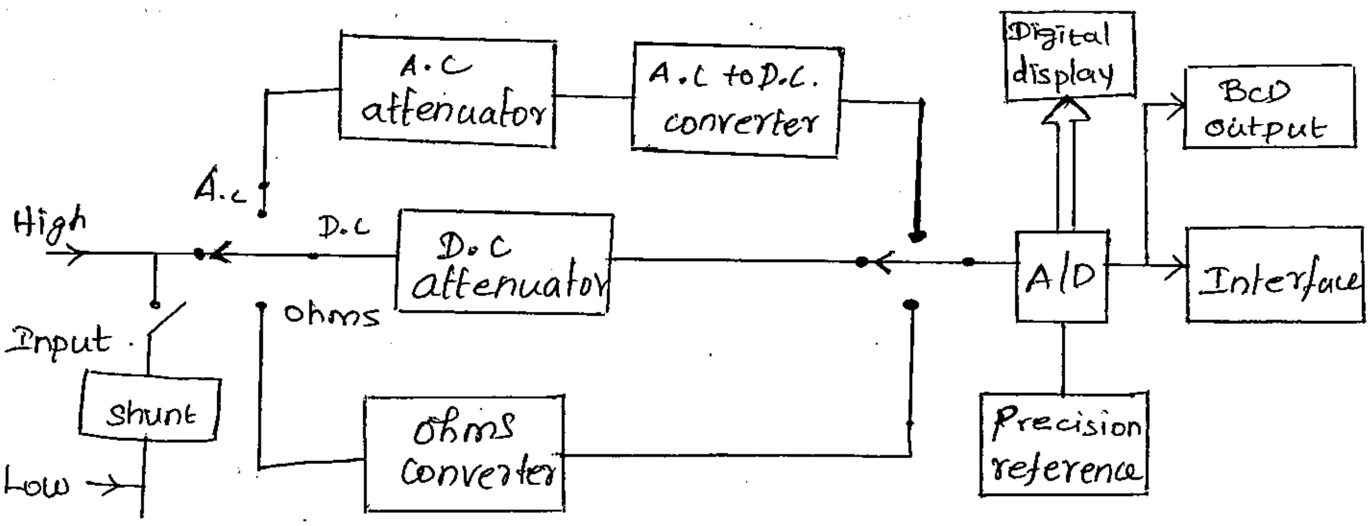
→ Thus the total deflecting torque is proportional to the total power.

→ As the coils are mounted very near each other, errors due to mutual interference are possible

→ To eliminate such errors, the laminated iron shield is placed in between the two elements.

MULTIMETERS:

→ The digital Multimeter is an instrument which is capable of measuring ac voltages, dc voltages ac and dc currents and resistances over several ranges.



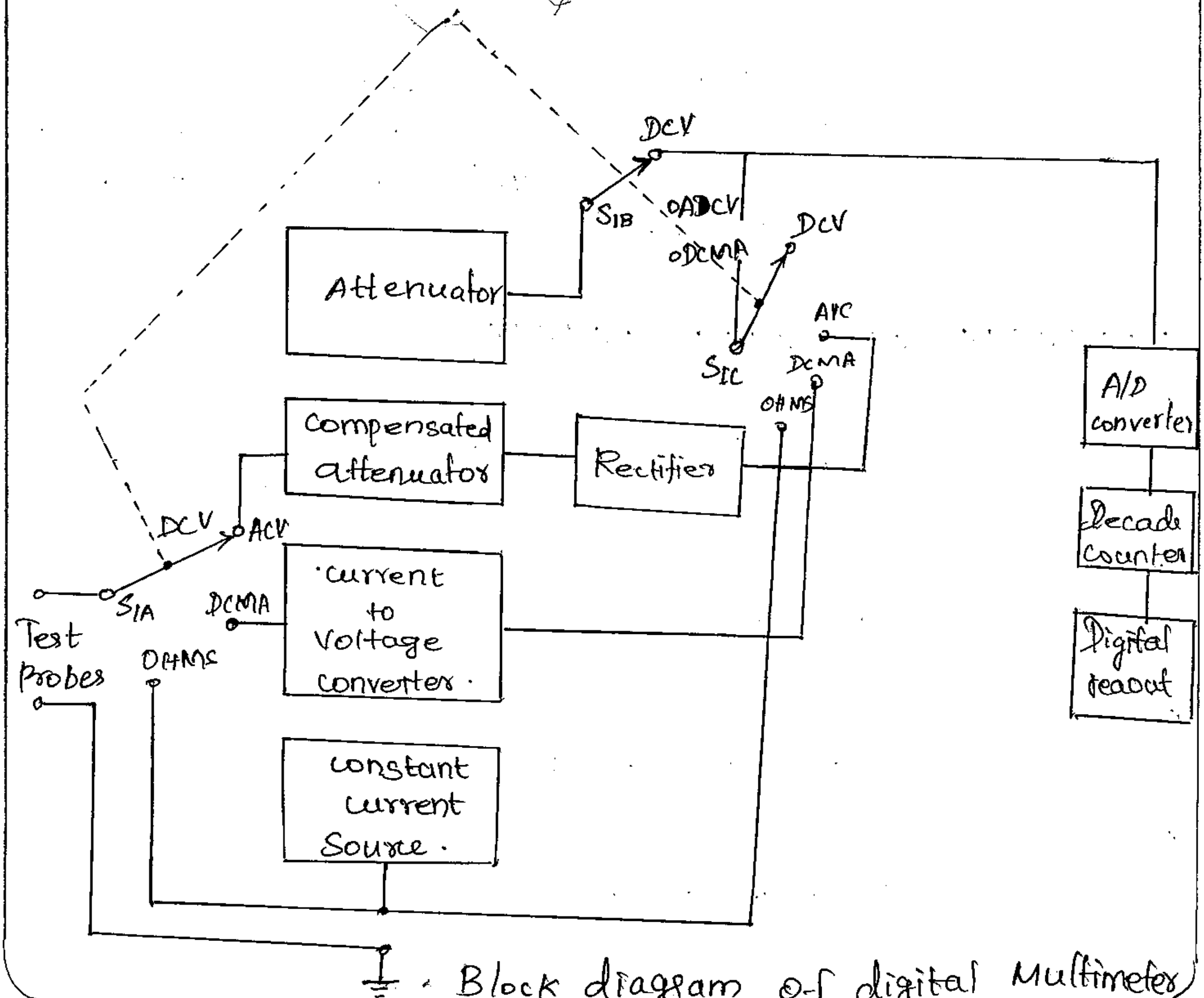
→ The current is converted to voltage by passing it through low shunt resistance.

→ The ac quantities are converted to dc by employing various rectifier & filtering circuits. While for the resistance measurements the meter consist of a precision low current source that is applied across the unknown resistance while gives dc voltage.

→ All the quantities are digitized using analog to digital converter and displayed in the digital form on the display.

~~The requirement of power supply, electric noise~~

→ The basic building blocks of digital Multimeter are several A/D converters, counting circuitry and an attenuation circuit.



Block diagram of digital Multimeter

→ The unknown current is applied to the summing junction Σi at the input of op-amp. As input current of op-amp is almost zero, the current I_R is almost same as I_i.

→ This current I_R causes a voltage drop, which is proportional to the current to be measured. This voltage drop is the analog input to the analog to digital converter, thus providing a reading that is proportional to the unknown current.

→ In order to measure the resistances, a constant current source is used. The known current is passed through the unknown resistance. The voltage drop across the resistance is applied to analog to digital converter hence providing the display of the value of the unknown resistance.

→ To measure the ac voltages, the rectifiers and filters are used. The ac is converted to dc and then applied to the analog to digital converter.

Specifications of Digital Multimeter:

* DC Voltage:

  $\pm 200mV$ to $\pm 1000V$.

* AC Voltage:

  200mV to 750V

* DC Current:

  $\pm 200\mu A$ to $\pm 2000mA$.

* AC Current:

  $200\mu A$ to $2000mA$.

* Resistance :

  200Ω to $20M\Omega$

* Input Impedance :

  $10M\Omega$.

OSCILLOSCOPES :

→ Signals which are functions of time, such signals may be periodic (or) non-periodic in nature.

→ The device which allows, the amplitude of such signals, to be displayed primarily as a function of time is called cathode ray oscilloscope commonly known as C.R.O.

→ The C.R.O gives the visual representation of the time varying signals.

→ The electron beam can be deflected in two directions the horizontal (or) x direction and the vertical (or) y-direction. Thus an electron beam producing a spot can be used to produce two dimensional displays.

→ Thus C.R.O can be regarded as a fast x-y plotter. The x axis & y axis can be used to study the variation of one voltage as a function of another.

→ Typically the x axis of the oscilloscope represent the time while the y-axis represents variation of the input voltage signal.

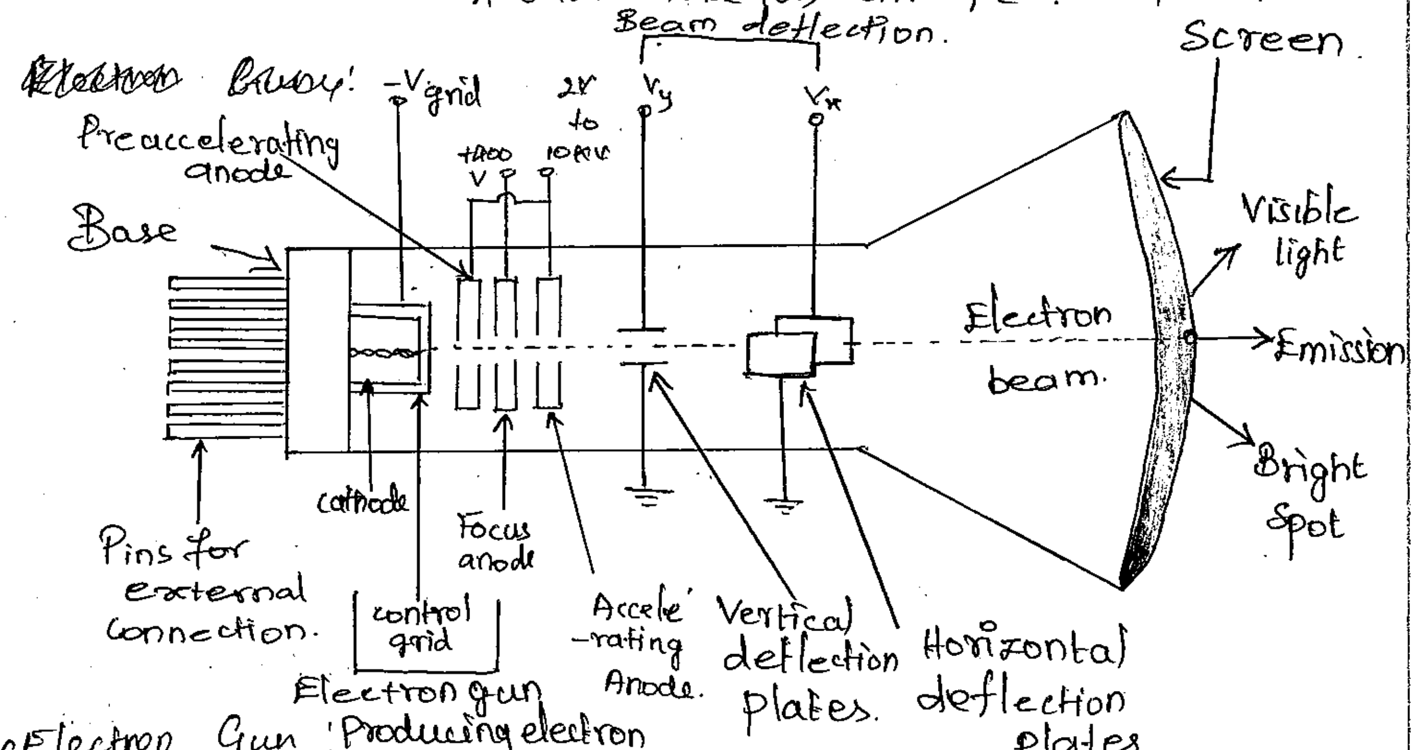
→ Thus if the input voltage signal applied to the y axis of C.R.O is sinusoidally varying and if x-axis represents the time axis, then the spot moves sinusoidally, & the familiar sinusoidal waveform can be seen on the screen of the oscilloscope.

Cathode Ray Tube (CRT):

→ It is the heart of the C.R.O. The CRT Generates the electron beam, accelerates the beam, deflects the beam & also has a screen where beam becomes visible as a spot.

→ The Main parts of the CRT are:

* Electron gun
* Fluorescent screen
* Base
* Deflection System
* Glass tube (or) envelope.



***Electron Gun:** Producing electron beam

→ The electron Gun section of the CRT provides a sharply focused electron beam directed towards the fluorescent - Coated screen. This section starts from thermally heated cathode, emitting the electrons. The control Grid is given negative potential with respect to cathode.

→ This grid controls the no. of electrons in the beam, Going to the screen.

→ The Momentum of the electrons determines the intensity, (or) brightness, of the light emitted from the fluorescent screen due to the electron bombardment.

→ The light emitted is usually of the green colour. Because the electrons are negatively charged, a repulsive force is created by applying a negative voltage to the control grid. This negative control voltage can be made variable. A More negative voltage results in less no. of electrons in the beam & hence decreased brightness of the beam spot.

→ Since the electron beam consists of many electrons, the beam tends to diverge. This is because the similar charges on the electron repel each other. To compensate for such repulsive forces, an adjustable electrostatic field is created between two cylindrical anodes, called the focusing anodes.

→ The variable positive voltage on the second anode is used to adjust the focus (or) sharpness of the bright beam spot.

→ The high positive potential is also given to the pre accelerating anodes & accelerating anodes, which results into the required acceleration of the electrons.

→ Both focusing & accelerating anodes are cylindrical in shape having small openings located in the centre of each electrode, co-axial with the tube axis.

→ The pre accelerating & accelerating anodes are connected to a common positive high voltage which varies between 2kV to 10kV. The focusing anode is connected to a lower positive voltage of about 400V to 500V.

*Deflection System:

→ When the electron beam is accelerated it passes through the deflection system with which beam can be positioned anywhere on the screen

→ The deflection system of the CRT consists of two pairs of parallel plates, referred to as the vertical & horizontal deflection plates. One of the plates in each set is connected to ground (0V).

→ To the plate of each set, the external deflection voltage is applied through an internal adjustable gain amplifier stage. To apply the deflection voltage externally, an external terminal, called the y input (or) the x-input is available.

→ The electron beam passes through these plates. A positive voltage applied to the y input terminal (V_y) causes the beam to deflect vertically upward due to the attraction forces, while a negative voltage applied to the y input terminal will cause the electron beam to deflect vertically downward, due to the repulsion forces.

→ Similarly, a positive voltage applied to x input terminal (V_x) will cause the electron beam to deflect horizontally towards the right, while a negative voltage applied to the x-input terminal will cause the electron beam to deflect horizontally towards the left of the screen. The amount of vertical (or) horizontal deflection is directly proportional to the applied voltage.

→ When the voltages are applied simultaneously to vertical & horizontal deflection plates, the electron beam is deflected due to the resultant of these two voltages.

→ The face of the screen can be considered as an x-y plane. The (x, y) position of the beam spot is thus directly influenced by the horizontal and the vertical voltages applied to the deflection plates V_x & V_y.

→ The horizontal deflection (x) produced will be proportional to the horizontal deflecting voltage V_x, applied to x - input.

$$X \propto V_x .$$

$$X = K_x V_x .$$

→ The deflection produced is usually measured in Cm (or) as no. of divisions, on the scale, in the horizontal direction.

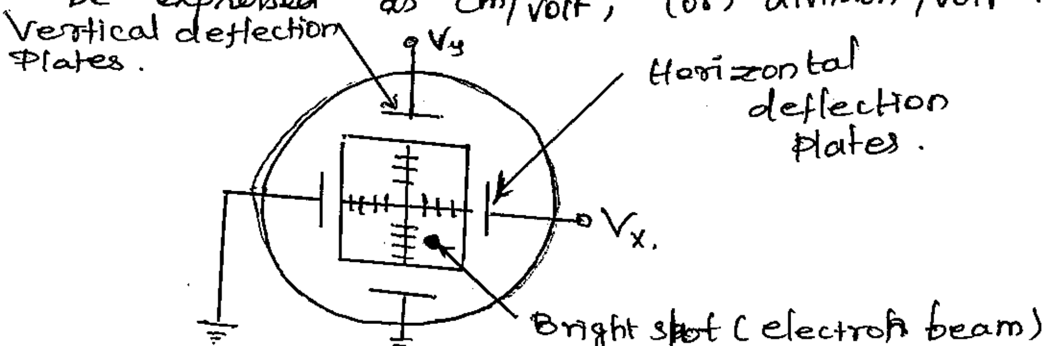
→ Then $K_x = \frac{x}{V_x}$ is called horizontal sensitivity of the oscilloscope.

→ Similarly, the vertical deflection (y) produced will be proportional to the vertical deflecting voltage, V_y applied to the y - input.

$$y \propto V_y$$

$$y = k_y V_y .$$

→ $k_y = y/V_y$ & k_y, the vertical sensitivity, will be expressed as cm/volt, (or) division/volt.



→ The values of vertical & horizontal sensitivities are selectable and adjustable through multipositional switches on the front panel that controls the gain of the corresponding internal amplifier stage.

→ The bright spot of the electron beam can thus trace the x-y relationship between the two voltages V_x & V_y.

*Glass Tube:

→ All the components of a CRT are enclosed in an evacuated glass tube called envelope.

* Base :

→ The base is provided to the CRT through which the connections are made to the various parts .

*Fluorescent Screen :

→ The light produced by the screen does not disappear immediately when bombardment by electrons ceases (i,e) when the signal becomes zero, the time period for which the trace remains on the screen after the signal becomes zero is known as " persistence".

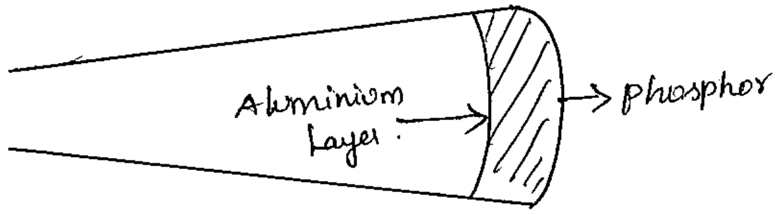
→ The screen is coated with a fluorescent material called phosphor which emits light when bombarded by electrons .

→ One of the common phosphor is Willemite, which is zinc, orthosilicate , $ZnO + SiO_2$, with traces of Manganese. This produces the familiar greenish trace . Other useful screen materials include compounds of zinc, cadmium, magnesium and silicon ..

→ The kinetic energy of the electron beam is converted into both light and heat energy when it hits the screen . The heat so produced gives rise to " phosphor burn" which is damaging & sometimes destructive .

→ This degrades the light output of phosphor and sometimes may cause complete phosphor destruction . Thus the phosphor must have high burn resistance to avoid accidental damage .

→ Similarly the phosphor screen is provided with an aluminium layer called aluminizing the cathode Ray tube .



→ Such a layer serves three functions.

* To avoid build up of charges on the phosphor which tend to slow down the electrons & limits the brightness.

* It serves as a light scatter. When the beam strikes the phosphor with aluminized layer, the light emitted back into the tube is reflected back towards the viewer which increases the brightness.

* The aluminium layer acts as a heat sink for the phosphor & thus reduces the chances of the phosphor burning.

*Phosphor Screen characteristics:

→ Many phosphor materials having different excitation times and colours as well as different phosphorescene times are available.

→ The type P_1, P_2, P_{11} (or) P_{31} are the short persistence phosphors and are used for the general purpose oscilloscopes.

→ Medical oscilloscopes require a longer phosphor decay.

TYPES OF INDICATING INSTRUMENTS :

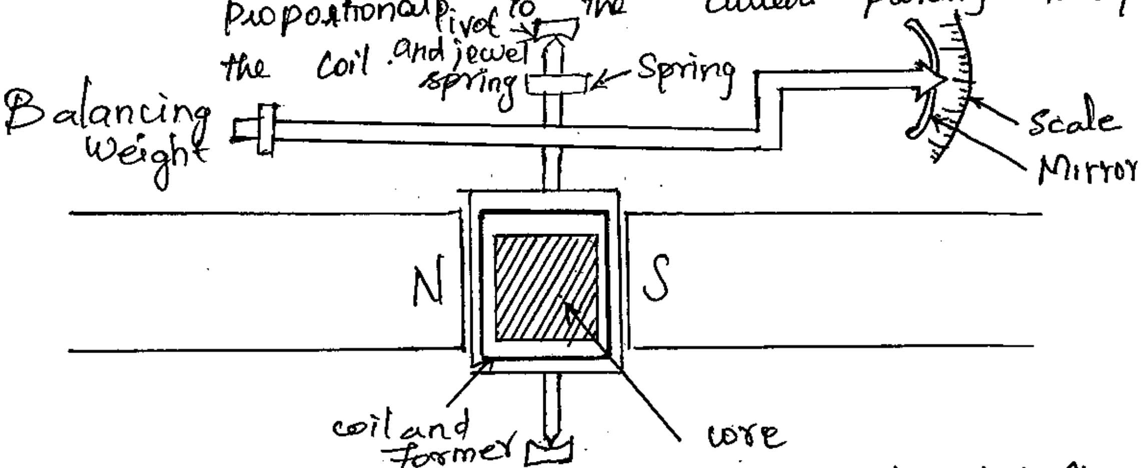
a) Permanent Magnet Moving Coil Instruments (PMMC) :

→ The PMMC are most accurate type for dc measurements. The action of these instruments is based on the Motoring principle.

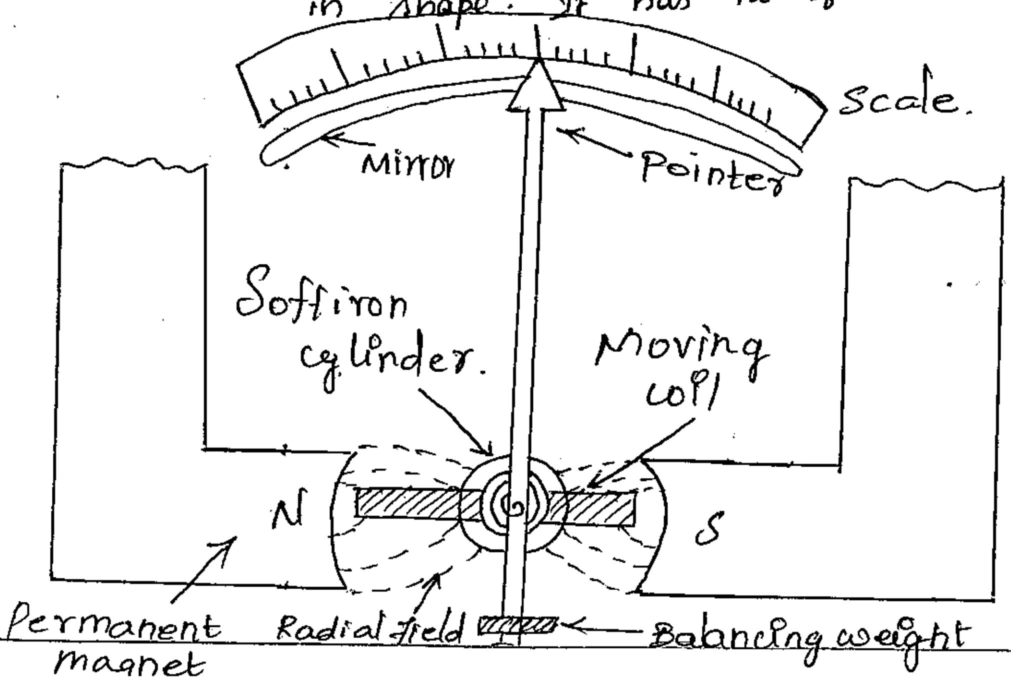
→ When a current carrying coil is placed in the Magnetic field produced by Permanent Magnet, the coil experiences a force and Moves.

→ As the coil is Moving and the Magnet is permanent, the instrument is called PMMC. This basic principle is called D' Arsonval principle.

→ The amount of force experienced by the coil is proportional to the current passing through the coil.



→ The Moving Coil is either rectangular (or) circular in shape. It has no. of turns of fine wire.



→ The coil is suspended so that it is free to turn about its vertical axis. The coil is placed in uniform, horizontal & radial magnetic field of a permanent magnet in the shape of a horse-shoe. The iron core is spherical if coil is circular and is cylindrical if the coil is rectangular. Due to the iron core, the deflecting torque increases, increasing the sensitivity of the instrument.

→ The controlling torque is provided by two phosphor bronze hair springs. The damper torque is provided by eddy current damping. It is obtained by movement of the aluminium former, moving in the magnetic field of the permanent magnet.

→ The pointer is carried by the spindle and it moves over a graduated scale. The pointer has light weight so that it can deflect rapidly. The mirror is placed below the pointer to get the accurate reading by removing the parallax.

→ The weight of the instrument is normally counter balanced by the weights situated diametrically opposite and connected to it. The scale markings of the basic dc PMMC instruments are usually linearly spaced as the deflecting torque and hence the pointer deflection are directly proportional to the current passing through the coil.

Torque Equation:

→ The equation for the developed torque can be obtained from the basic law of the electro magnetic torque.

→ The deflecting torque is given by,

$$T_d = NBAI$$

T_d - Deflecting torque in N-m

B - Flux density in air gap, Wb/m^2

N - No. of turns of the coil.

A - Effective coil area, m^2

I - Current in the Moving Coil.

$$T_d = GI$$

$$G = NBA = \text{Constant}.$$

→ The Controlling torque is provided by the springs and is proportional to the angular deflection of the pointer.

$$T_c = K\theta$$

T_c - Controlling torque

K - Spring Constant.

θ - Angular deflection.

→ For the final steady state position,

$$T_d = T_c$$

$$GI = K\theta$$

$$\theta = \left(\frac{G}{K}\right) I.$$

$$I = \left(\frac{K}{G}\right)\theta.$$

Advantages:

* It has uniform scale
* The sensitivity is high.
* It has high accuracy.
* Instrument is free from hysteresis error
* Extension of instrument range is possible.
* Not affected by external Magnetic fields called stray Magnetic fields.

Disadvantages :

* Suitable for dc measurements only.
* Ageing of permanent Magnet and the control springs introduces the errors.
* The cost is high due to delicate construction & accurate Machining.

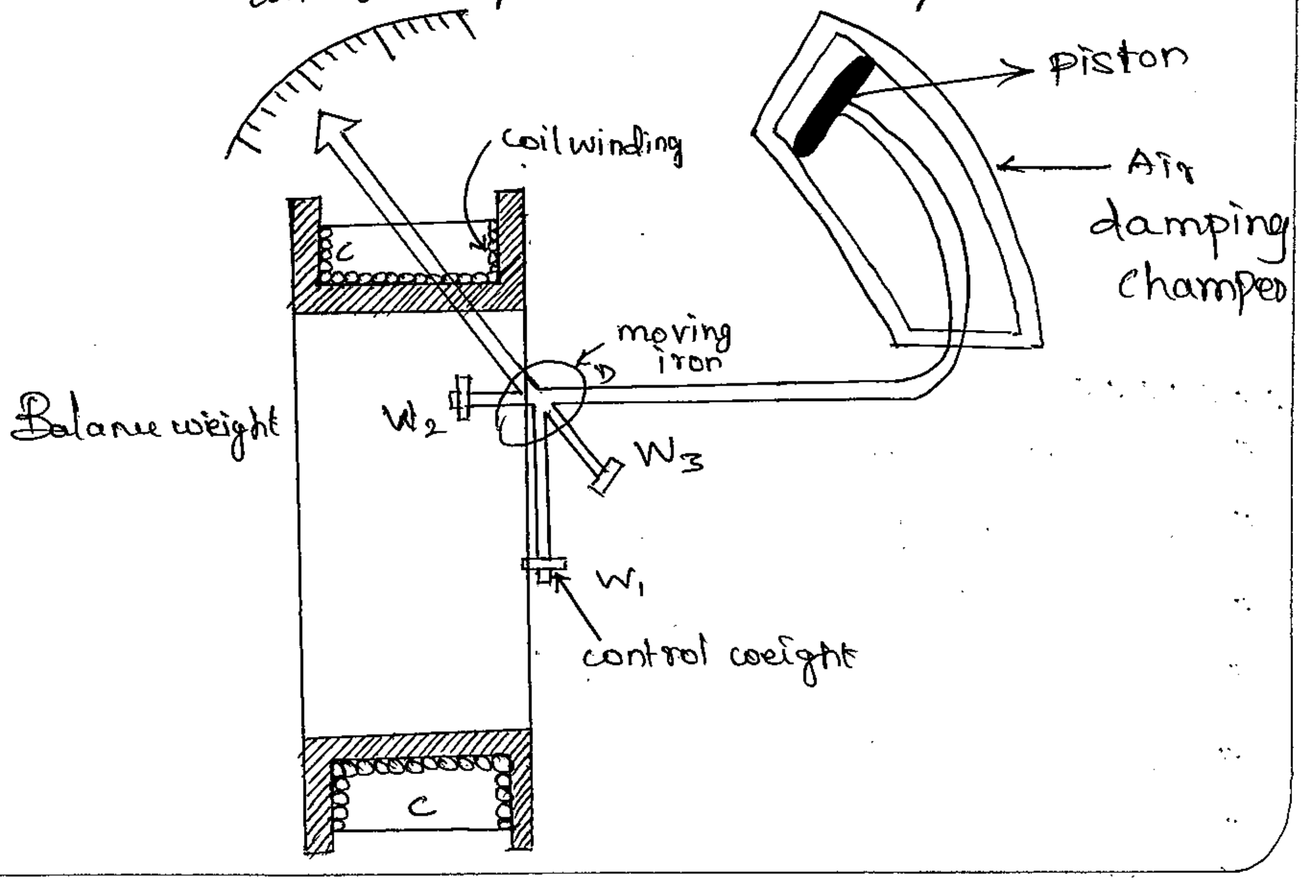
b) Moving Iron Instruments :

* Moving Iron attraction type
* Moving Iron Repulsion type.

i) Moving Iron Attraction Type Instrument :

→ It consists of a fixed coil C and Moving iron piece D. The coil is flat and has a narrow slot like opening. The Moving iron is a flat disc which is eccentrically mounted on the spindle.

→ The spindle is supported between the jewel bearings. the spindle carries a pointer which moves over a graduated scale. The no. of turns of the fixed coil are dependent on the range of the instrument.



→ The Controlling torque is Provided by the springs but gravity control may also be used for Vertically Mounted panel type instruments.

→ The damping torque is provided by the air friction. A light aluminium piston is attached to the moving system. It Moves in a fixed ~~change~~ Chamber. The Chamber is closed at one end. It can also be provided with the help of Vane attached to the Moving System.

→ The operating Magnetic field in Moving iron instruments is very Weak. Hence eddy Current damping is not used since it requires a permanent Magnet which would affect or distort the operating field.

ii) Moving Iron Repulsion Type Instrument:

→ These instruments have two vanes inside the coil, the one is fixed and other is Movable. When the Current flows in the Coil, both the vanes are magnetized with like polarities induced on the same side.

→ Hence due to the repulsion of like polarities, there is a force of repulsion between the two vanes Causing the Movement of the Moving Vane.

→ The two different designs of repulsion type instruments are:

* Radial vane type
* Co-axial Vane type.

Torque Equation:

Mechanical Work = $T_d \, d\theta$.

→ The Inductance is inversely proportional to the reluctance of the Magnetic circuit of Coil.

Let, I = Initial Current

L = Instrument Inductance

θ = Deflection

dI = Increase in Current

$d\theta$ = Change in deflection

dL = Change in Inductance

→ In order to effect an increment dI in the current, there must be an increase in the applied voltage given by,

$$e = \frac{d(LI)}{dt}$$

$$= I\frac{dL}{dt} + L\frac{dI}{dt}.$$

→ The electrical energy supplied is given by,

$$e.I\,dt = \left(I\frac{dL}{dt} + L\frac{dI}{dt}\right)I\,dt$$

$$= I^2\,dL + IL\,dI.$$

→ The stored energy increases from $\frac{1}{2}LI^2$ to $\frac{1}{2}(L+dL)(I+dI)^2$

→ Hence the change in the stored energy is given by,

$$= \frac{1}{2}(L+dL)(I+dI)^2 - \frac{1}{2}LI^2.$$

→ Neglecting higher order terms, this becomes

$$IL\,dI + \frac{1}{2}I^2\,dL.$$

→ The energy supplied is nothing but increase in stored energy plus the energy required for Mechanical work done.

$$I^2dL + IL\,dI = IL\,dI + \frac{1}{2}I^2dL + T_d\,d\theta.$$

$$T_d\,d\theta = \frac{1}{2}I^2dL$$

$$T_d = \frac{1}{2}I^2\frac{dL}{d\theta}.$$

→ While the Controlling torque is Given by,

$$T_c = K\theta .$$

$$K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

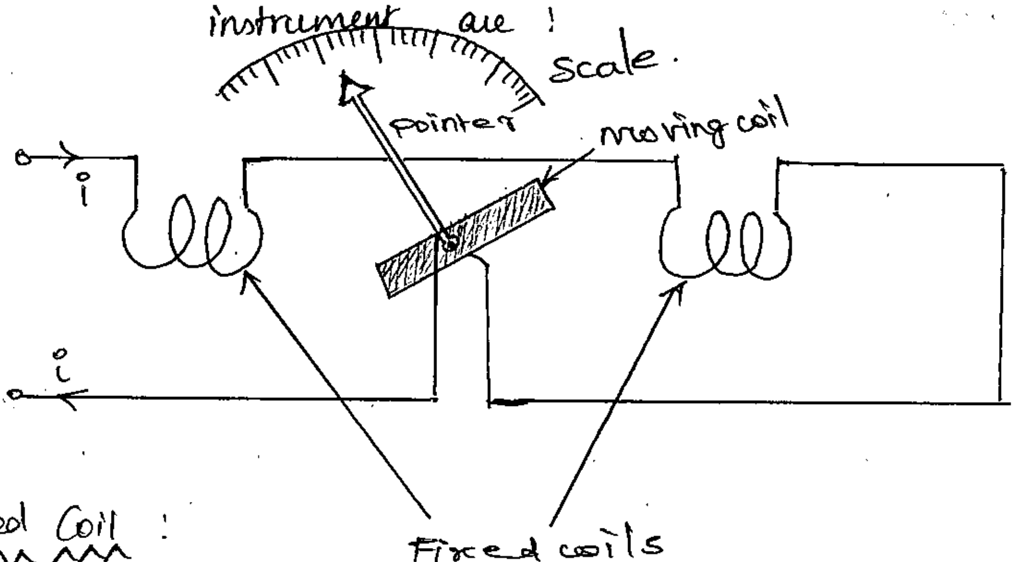
$$\theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta} .$$

→ Thus the deflection is proportional to the square of the current through the coil.

c) Electrodynamometer Type Instruments :

→ It is a transfer instrument. A transfer instrument is one which is Calibrated with a dc source and used without any Modifications for ac measurements.

→ The various parts of the electrodynamometer type instrument are :



Fixed Coil :

→ The necessary field required for the operation of the instrument is produced by the fixed coils. A uniform field is obtained near the Centre of coil due to division of coil in two sections. These Coils are air cored.

→ Fixed Coils are wound with fine wire for using as voltmeter, while for ammeters and wattmeters it is wound with heavy wire.

→ The Coils are usually Varnished. They are Clamped in place against the Coil supports.

→ Ceramic is usually used for Mounting Supports If Metal parts would have been used then it would weaken the field of the fixed coil.

Moving Coil:

→ It is wound either as a self - Sustaining coil or else on a non- Metallic former. If Metallic former is used, then it would induce eddy Currents in it.

Controlling:

→ The Controlling torque is provided by springs. These springs act as leads to the Moving coil.

Moving System:

→ The Moving Coil is mounted on an aluminium spindle. It Consists of Counter weights and pointer. Sometimes, a suspension May be used, in case a high accuracy is desired.

Damping:

→ The damping torque is provided by air friction, by a pair of aluminium Vanes which are attached to the spindle at the bottom. They move in sector shaped Chambers.

Shielding:

→ The field produced by these instruments is very weak. Even earth's Magnetic field affects the reading. So shielding is done to protect it from stray Magnetic fields. It is done by enclosing in a casing of high permeability alloy

→ For using electrodynamo meter as ammeter, fixed and moving coils are connected in series and carry the same current. A suitable shunt is connected to these coils to limit current through them upto desired limit.

→ The electrodynamo meter can be used as a voltmeter by connecting the fixed & moving coils in series with a high non-inductive resistance.

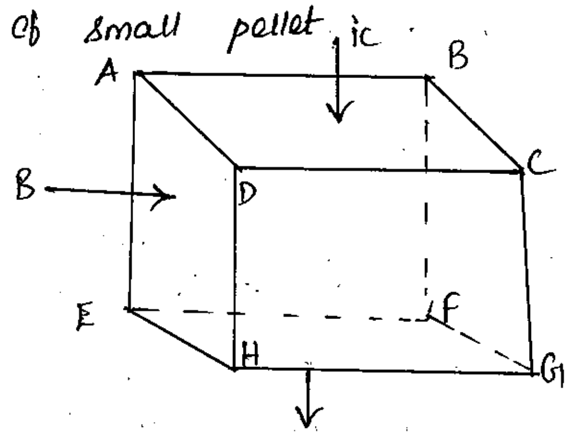
→ For using electrodynamo meter as a wattmeter to measure the power, the fixed coil acts as a current coil & must be connected in series with the load. The moving coil acts as a voltage coil (or) pressure coil & must be connected across the supply. The wattmeter indicates the supply power.

→ When current passes through the fixed & moving coil, both coils produce the magnetic fields. The field produced by fixed coil is proportional to the load current while the field produced by the moving coil is proportional to the voltage.

→ As the deflecting torque is produced due to the interaction of these two fields, the deflection is proportional to the power supplied to the load.

HALL EFFECT :

→ Consider a n-type semiconducting Material of small pellet.



→ A current of i_c is followed to pass from the surface ABCD to the surface EFGH. Let the surface ABEF be subjected to a north pole magnetic field of the flux density B.

→ As per Fleming's left hand rule, the +ve charges in the pellet gets concentrated near the surface ADHE and negative charges near the surface BCFG.

→ Since, ntype Material has free -ve charges, these electrons get concentrated near the surface BCGF. This change in distribution makes the surface ADHE more positive than the surface BCGF. Thus the potential difference between the surface ADHE & BCGF is known as 'Hall emf'.

→ It has been experimentally shown that the emf due to hall effect (V_H) is given by,

$$V_H = R_H \frac{i_c B}{d}$$

V_H = Hall emf.

i_c = Current through the pellet

B = Flux density

R_H = Constant.

UNIT V
MEASUREMENTS & INSTRUMENTATION

1. Define: Transducer
A transducer is defined as a device that receives energy from one system and transmits it to another, often is a different form.

2. Write the parameters of electrical transducer.
The parameters of electrical transducer are:
i. Linearity
ii. Sensitivity
iii. Dynamic range
iv. Repeatability
v. Physical size

3. List the advantages of electrical transducers.
The advantages of electrical transducers are:
i. Electrical amplification and attenuation can be easily done.
ii. Mass-interia effects are minimized.
iii. Effects of friction are minimized.
iv. Using very small power level.
v. Electrical output can be easily used, transmitted and processed for the purpose of measurement.
vi. The output can be indicated and recorded remotely at a distance from the sensing medium.

4. Give the limitations of thermistor.
Limitations of thermistor are:
i. Non-linearity in resistance Vs temperature characteristics.
ii. Unsuitable for wide temperature range.
iii. Very low excitation current to avoid self-heating.
iv. Need of shielded power lines, filters etc., due to high resistance.

5. In what principles,inductive transducer works?
i. Variation of self-inductance.
ii. Variation of mutual-inductance.

6. List out the features of piezo-electric accelerometer.
The features of piezo-electric accelerometer are:
i. Instrument is quite small in size and has a low weight.
ii. The natural frequency is very high.
iii. Useful for high input frequencies and the response is poor at low frequencies.
iv. The crystal is a source with a high output impedance and in order to avoid loading effect, a voltage monitoring source of a high input impedance should be used.

7. Define: Inductive Transducer

Inductive transducer is defined as a device that converts physical motion into a change in inductance. It may be either of active or passive type.

8. Give the principle of capacitive transducers.

Capacitive transducer principle is a linear change in capacitance with changes in the physical position of the moving element may be used to provide an electrical indication of the elements position.

$C=KA/d$

Where K= dielectric constant.

9. Mention the functions performed by the measurement system.

The functions performed by the measurement system are

i. Indicating function
ii. Recording function
iii. Controlling function

10 . List the functional elements of the measurement systems.

The three main functional elements of the measurement systems are:

i. Primary sensing element
ii. Variable conversion element
iii. Data presentation element

11. Write the characteristics of the measurement system.

Characteristics of measurement system is divided into two categories:

i. Static characteristics
ii. Dynamic characteristics

12. Write the main static characteristics?

The main static characteristics are:

i. Accuracy
ii. Sensitivity
iii. Reproducibility
iv. Drift
v. Static error
vi. Dead zone
vii. Resolution
viii. Precision
ix. Repeatability

13. Define static error

Static error is defined as the difference between the true value and the measured value of the quantity.

Static error = At – Am

where Am =measured value of quantity

At =true value of quantity.

14. Define resolution

Resolution is defined as the smallest increment of quantity being measured which canbedetected with certainty being measured which can be detected with certainty by an instrument.

15. Define threshold

Threshold is defined as the minimum value of the input at which the output startschanging/increasing from zero

16..Define linearity

The linearity is defined as the ability to reproduce the input characteristics symmetrically and linearly.

17..Define reproducibility

Reproducibility is defined as the degree of closeness with which a givenvalue may be repeatedly measured. It is specified in terms of scale readings over a given period of time.

18.Define drift

Drift is defined as slow variation of reading from a fixed value.

19.Mention the methods that are used for generating the two electron beams within theCRT.

The methods that are used for generating the two electron beams within the CRT are the double gun tube and split beam method.

20. Mention the two storage techniques used in oscilloscope CRTs.

The two storage techniques used in oscilloscope CRTs are mesh storage and phosphor storage.

21. CRO has become an universal tool in all kinds of electrical and electronic investigation.Why ?

CRO has become an universal tool in all kinds of electrical and electronic investigations because in CRO, the vertical input voltage is the voltage under investigation and it moves theluminous spot up and down in accordance with the instantaneous value of the voltage. When theinput voltage repeats itself at a fast rate, the trace (display) on the screen, appears stationary onthe screen.

22. Name the components of a CRO.

The Components of CRO are:

i. cathode ray tube (CRT) along with electron gun assembly
ii. deflection plate assembly
iii. fluorescent screen
iv. glass envelope and
v. base.

23. What is an electrongun ?

An electon gun is the source of focussed and accelerated electron beam is the electron gun. The electron gun which emits electrons and forms them into a beam consists of a heater, a cathode, a grid a pre-accelerating anode, a focussing anode and an accelerating anode.